BLACKWELL COMPANIONS TO THE ANCIENT WORLD

A COMPANION TO

SCIENCE, TECHNOLOGY, AND MEDICINE IN ANCIENT GREECE AND ROME

VOLUME I

EDITED BY
GEORGIA L. IRBY



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A COMPANION TO SCIENCE, TECHNOLOGY, AND MEDICINE IN ANCIENT GREECE AND ROME

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Volume I

Edited by

Georgia L. Irby

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Abbreviations

AA:	*Archäologischer Anzeiger*
ABSA:	*Annual of the British School at Athens*
ABull:	*The Art Bulletin*
AEA:	*Archivo Español de Arqueología*
AGPh:	*Archiv für Geschichte der Philosophie*
AHES:	*Archive for History of Exact Sciences*
AIHS:	*Archives internationales d'histoire des sciences*
AJA:	*American Journal of Archaeology*
AJPh:	*American Journal of Philology*
AncSoc:	*Ancient Society*
ANET:	Pritchard, J. B., ed. 1969. *Ancient Near Eastern Texts Relating to the Old Testament*. 3rd edition. Princeton: Princeton University Press
ANRW:	*Aufstieg und Niedergang der römischen Welt*. Berlin: de Gruyter. 1972–
AntCl:	*L'Antiquité classique*
AS:	*Anatolian Studies*
AW:	*Antike Welt*
BABesch:	*Bulletin Antieke Beschaving*
BAR:	*British Archaeological Reports*
BAR-IS:	*British Archaeological Reports–International Series*
BASP:	*Bulletin of the American Society of Papyrologists*
BCH:	*Bulletin de correspondance hellénique*
BCTH:	*Bulletin archéologique du Comité des travaux historique*
BHM:	*Bulletin of the History of Medicine*
BICS:	*Bulletin of the Institute of Classical Studies of the University of London*
BJ:	*Bonner Jahrbücher des Rheinischen Landesmuseums in Bonn und des Vereins von Altertumsfreunden im Rheinlande*
BNP:	*Brill's New Pauly* Leiden, edited by H. Cancik and H. Schneider. 2002–. Leiden: Brill
CAAG:	Berthelot, Marcelin, and Charles-Émile Ruelle. 1887–88. *Collection des anciens alchimistes grecs*. Paris: George Steinheil

CCAG: Catalogus Codicum Astrologorum Graecorum
CIL: *Corpus inscriptionum Latinarum*. Berlin 1862–
CJ: *The Classical Journal*
CMG: *Corpus Medicorum Graecorum* Berlin: Akademie-Verlag, 1908–
CML: *Corpus Medicorum Latinorum*. Leipzig: Teubner, 1915–
CP: Theophrastus, *De Causis Plantarum* (*On the Causes of Plants*)
CPh: *Classical Philology*
CQ: *Classical Quarterly*
CRAI: *Comptes rendus de l'Académie des inscriptions et belles-lettres*
CW: *The Classical World*
DHA: *Dialogues d'histoire ancienne*
DK: Diels, Hermann and Walther Kranz. 1951–52. *Die Fragmente der Vorsokratiker, griechisch und deutsch*. Berlin: Weidmann
EANS: *Keyser, Paul and Georgia L. Irby-Massie, eds. 2008. The Encyclopedia of Ancient Natural Scientists. London: Routledge*
EMC: *Échos du monde classique*
G&R: *Greece and Rome*
GA: Aristotle, *On the Generation of Animals*
GC: Aristotle, *On Generation and Corruption*
GeogrAnt: *Geographia Antiqua*
GRBS: *Greek, Roman, and Byzantine Studies*
HA: Aristotle, *De Historia Animalium* (*On the Enquiry into Animals*)
HP: Theophrastus, *De Historia Plantarum* (*On the Enquiry into Plants*)
HR: *History of Religions*
HSPh: *Harvard Studies in Classical Philology*
IEJ: *Israel Exploration Journal*
IEph: *Die Inschriften von Ephesos*. 1979–84. Bonn: Habelt
IG: *Inscriptiones Graecae*, 3rd ed. 1981–. Berlin
IGUR: Moretti, L., ed. 1968–. Inscriptiones Graecae Urbis Romae. Rome
IJNA: *International Journal of Nautical Archaeology*
IJPP: *International Journal of Paleopathology*
ILS: Dessau, Hermann. ed. *Inscriptiones Latinae Selectae*. 1892–1916. Berlin
JAS: *Journal of the Royal Asiatic Society of Great Britain and Ireland*
JDAI: *Jahrbuch des Deutschen Archäologischen Instituts*
JESHO: *Journal of the Economic and Social History of the Orient*
JGS: *Journal of Glass Studies*
JHB: *Journal of the History of Biology*
JHS: *Journal of Hellenic Studies*
JMA: *Journal of Mediterranean Archaeology*
JNES: *Journal of Near Eastern Studies*
JRA: *Journal of Roman Archaeology*
JRS: *Journal of Roman Studies*
JSAH: *Journal of the Society of Architectural Historians*
KJ: *Kölner Jahrbuch*
KRS: Kirk, G.S., J.E. Raven, and M. Schofield. 1984. *The Presocratic Philosophers: A Critical History with a Selection of Texts*, 2nd ed. Cambridge: Cambridge University Press

LIMC:	*Lexicon Iconographicum Mythologiae Classicae*. 1981–2009. Zurich: Artemis
LSCG:	Sokolowski, Franciszek. 1969. *Lois sacrées des cités grecques.* Paris: de Boccard
	LSJ: Liddell, H. G., R. Scott, and Jones, H.S., eds. 1996 (revised). A Greek–English Lexicon. Oxford: Clarendon. 9th edition
MDAI(A):	*Mitteilungen des Deutschen Archäologischen Instituts*
MEFRA:	*Mélanges d'Archéologie et d'Histoire de l'école Française de Rome, Antiquité*
MNIR:	*Mededelingen van het Nederlandsch historisch Instituut te Rome*
NH:	Pliny the Elder, *Naturalis Historia (Natural History)*
NQ:	Seneca the Younger, *Naturales Quaestiones* (*Natural Questions*)
OGIS:	*Orientis Graeci Inscriptiones Selectae*. 1903–1905. Leipzig: Hildesheim
OJA:	*Oxford Journal of Archaeology*
ORom:	*Opuscula Romana*
OSAPh:	*Oxford Studies in Ancient Philosophy*
PA:	Aristotle, *On the Parts of Animals*
PAA:	*Praktika tes Akademias Athenon*
PAS:	*Proceedings of the Aristotelian Society*
PBSR:	*Papers of the British School at Rome*
PCPhS:	*Proceedings of the Cambridge Philological Society*
PECS:	Stillwell, Richard. 1972. *Princeton Encyclopedia of Classical Sites.* Princeton, NJ: Princeton University Press
PhR:	*Philosophical Review*
POxy:	*The Oxyrhynchus Papyri*. 1898–. London: Egypt Exploration Fund
RA:	*Revue archéologique*
RBPh:	*Revue belge de philologie et d'histoire*
RCCM:	*Rivista di cultura classica e medioevale*
REA:	*Revue des études anciennes*
REL:	*Revue des études latines*
RUSCH:	*Rutgers University Studies in Classical Humanities*
SHPS:	*Studies in History and Philosophy of Science*
SIG:	Dittenberger, Wilhelm, ed. 1917–1920. *Sylloge Inscriptionum Graecarum*. Hildesheim: Olms
SMEA:	*Studi micenei ed egeo-anatolici*
SMSR:	*Studi e materiali di storia delle religioni*
SVF:	von Arnim, Hans. 1964. *Stoicorum Veterum Fragmenta*. Stuttgart: Teubner
TAPhA:	*Transactions and Proceedings of the American Philological Association*
TAPhS:	*Transactions of the American Philosophical Society*
TEGP:	Graham, Daniel W. 2010. *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics.* 2 vols. Cambridge: Cambridge University Press
TrGF:	Diggle, James et al., eds. 1998– . Tragicorum Graecorum Fragmenta. Oxford: Clarendon.
VT:	*Vetus Testamentum*
YCS:	*Yale Classical Studies*
ZPE:	*Zeitschrift für Papyrologie und Epigraphik*
ZWG:	*Sudhoffs Archiv: Zeitschrift für Wissenschaftsgeschichte*

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Introduction

Georgia L. Irby

1. "Science" in Antiquity

From Thales onward, Greek intellectuals sought to understand the world around them, and from this tradition we derive two very important scientific terms: *physics*, a Greek term for "the nature of things"; and *science*, the Latin word for "knowledge." Science, as the ancients envisioned it, can hardly be separated from other intellectual pursuits, including technology (broadly, the application of scientific principles) and medicine (drawing on mathematical and natural sciences, technology, as well as religion and magic, often nearly indistinguishable). Spheres of knowledge in antiquity were understood as having more fluid boundaries. Thus seeking or imposing modern disciplinary compartmentalization on ancient initiatives does violence to the ancient thinkers and trivializes their accomplishments. "Science" in the ancient world, moreover, never lost its sense of wonder nor its intimate connection with ethics and the divine: even in the Aristotelian corpus (among the most "scientific" collections in the ancient world) matters of theology are considered (Barnes 1995, 67, 106; cf. Nature and the Divine). "Scientist," furthermore, was not a recognized profession until the nineteenth century, and natural philosophers in the ancient world followed many paradigms: after the death of Alexander the Great (323 BCE), royal patronage enabled talented minds to pursue "science" full time (especially at Alexandria, whose Museum and Library attracted scholars from across the Greek-speaking world into the fifth century CE), but Pliny the Elder was a Roman statesman of broad learning and curiosity, like the nineteenth-century gentleman scholar. The notion of academic specialization, furthermore, would have been anathema to the ancients. For example, in addition to four-element theory to explain *physis* (nature), Empedocles proposed hypotheses on optics, evolution, and theology; Democritus' interests included mathematics, music, and ethics, as well as physics (atomic theory).

Scientific traditions cannot be separated from the culture which produced and employed them—any more than trends in literature or religion. And the methods and principles of Greek science were forged by the agonistic nature of Greek society, which

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prejudiced Greek investigations into the natural world and shaped the interrelationships between teacher and student as well as between competing schools. Greek science was an exercise in debate and persuasion. Given the state of the instrumentation, many scientific hypotheses were unprovable; thus, scholars aimed to persuade their audiences of the truth of a given theory. The Greeks also valued autonomy, and their philosophical schools were not so much "schools" in the modern sense as groups of like-minded thinkers. Many thinkers were autodidacts, and even those who studied under famous teachers were not altogether content to follow the direction of their predecessors, often carving out their own paths, citing predecessors' views or ignoring them—whichever proved more convenient. This attitude, of course, varied from one author to another: Pliny the Elder, although more polemical than Vitruvius, nonetheless still relied largely on his predecessors (see Fögen 2009).

The methods of Greek science were largely theoretical owing to the limitations of equipment and technology. Experimentation was not a virtue, and this attitude reflects the contention between "art" and "skill" (or "doing"—the prejudice was against those who worked with their hands, such as the dirty, sweaty craftsmen; Galen tackled the question of whether medicine is an art or a skill, and he also argued that the best physicians were likewise philosophers). In the context of natural philosophy, Aristotle recognized and recommended empirical data and observation, long valued by medical practitioners and theorists (Mithridates' notorious immunity to all known poisons and venoms was the result of a long program of research and development of antidotes by the toxicologists in his service combined with empirical trials on death-row prisoners). But theory almost always held sway, even in the light of empirical evidence (e.g., the rejection of Eratosthenes' remarkably accurate estimate of the earth's circumference, and the enduring theory of geocentrism: Astronomy, Geography).

Although most ancient Mediterranean science, technology, and medicine stems from the Greek intellectual praxis, the Romans fostered and advanced these conventions (Roman Responses to Greek Science and Scholarship as a Cultural and Political Phenomenon, Scientific Encyclopedias). Scholars living under the hegemony of the Roman Empire preserved and synthesized much of the Greek accomplishment in Latin (e.g., Pliny the Elder) and Greek (e.g., Athenaeus), new advances continued to be made on both sides of the Ionian Sea, and the Greco-Roman achievement was preserved and enhanced by later traditions (Translation and Transmission of Ancient Scientific Texts, The Reception of Greco-Roman Science in the Renaissance: Assimilation(s), Transformation(s), Rejection, Hybridization).

Preservation and transmission was a long process that began with the Greeks themselves. As thinkers distilled the work of their predecessors, usually in the interest of refuting them, original texts were lost, and much survives only in fragments, paraphrase, or redaction: for example, the Presocratic Natural Philosophers, culled by Aristotle and others, neatly collected, translated, and annotated in the *TEGP*; and the medical thinkers (third century BCE to second century CE), plundered by Galen who effectively silenced those voices with which he disagreed. Much of the surviving corpus is a distorted and often uncontextualized selection, but a selection nonetheless that was considered worthy to be copied numerous times over the span of 2500 years (and in many cases translated into Arabic and other languages, which thus accounts for their survival). Furthermore, ancient texts remain unedited and untranslated into modern languages (consequently, the works of Galen which survive only in Arabic transmission or translation still remain

largely inaccessible to most readers, in spite of encouraging developments), but the scholarly work progresses apace, and every year sees the publication of new editions and improved translations (e.g., Hine 2010; Roller 2014). The References appended to each chapter here usually omit editions and translations: editions are useful only to the specialist, and many of the canonical authors are available in translation online (e.g., the Perseus Project: http://www.perseus.tufts.edu/hopper/collection?collection=Perseus:collection:Greco-Roman; Internet Classics Archive: http://classics.mit.edu/) or through standard collections (such as the Loeb Classical Library, Cambridge, MA: Harvard University Press [in English]; the Collection Budé, Paris [in French]; the Tusculum Collection, Berlin: de Gruyter [in German]; and the invaluable *CMG* and *CML*). Translations are, ultimately, interpretations, and their reliability and utility vary greatly.

2. A Very Brief History of the "History of Greco-Roman Science"

More texts survive from antiquity that can be classified as "scientific" than of any other genre. Although these texts were considered interesting, relevant, or useful in antiquity, the modern Academy's engagement has been storied: the Greco-Roman scientific achievement was even dismissed out of hand in the nineteenth century (e.g., Schvarcz 1862). Our modern field of study has its genesis in the work of the Danish Classical philologist J. L. Heiberg (1854–1928), who produced scholarly editions of Archimedes, Apollonius of Perga, Euclid, Hero, and Ptolemy (among others) and the British mathematician T. L. Heath (1861–1940), who translated Apollonius of Perga, Diophantus, Aristarchus of Samos, and Euclid into English, and whose monographs on Greek mathematics and astronomy helped shape the early discourse.

The 1920s and 1930s saw fruitful advances in the history of science in general, and Greco-Roman science in particular. In 1927–1928, the first International Academy of the History of Science was founded on the initiative of Italian-born Aldo Mieli, formally trained in chemistry and subsequently earning a second doctorate in the history of science. In August 1928, the Academy sponsored the Sixth Congress of Historical Sciences in Oslo, and its official journal—*Archeion* (now *AIHS*), Mieli's brainchild—was the first international journal devoted to the history of Science. Mieli also collaborated with French scholar Pierre Brunet to produce a monograph on Greek science, envisioned as the first installment in a multivolume project (1935) that followed from Mieli's one-volume general treatment in 1925 (see further, Chimisso 2008, 100–104).

At nearly the same time, monographs appeared in English from the pens of the Classically trained Irish scholar, Benjamin Farrington (1936, 1953)—whose materialist bias may reflect his political leanings more than the realties of Greek scientific endeavors—and Cambridge-trained F. M. Cornford (1938, 1952), who investigated Greek philosophy in terms of its fundamental religious, social, and conceptual foundations. In 1936, at a lecture series arranged by the History of Science Committee at Cambridge, Cornford surveyed the methods and questions of Greek and Roman natural philosophers (Thales, Plato, Aristotle, Lucretius, Poseidonius, Seneca, and others). Soon following was Cohen and Drabkin's seminal sourcebook (1948), arranged according to broad modern disciplinary divisions (including the mathematical sciences, chemistry, biology, medicine, and even psychology).

In 1951, E. R. Dodds' groundbreaking *The Greeks and the Irrational* delved into questions about the nature of ideas and the interpretation of knowledge, which in turn opened up space for wider-reaching discussions into Greek natural philosophy and its place in Greek intellectual history. American-born Marshall Clagett explored the role of mathematics in natural philosophy, and his 1955 volume remains a standard. From the 1970s, the field has been dominated by Cambridge-educated G. E. R. Lloyd (1970, 1973), who continues to examine the nexus of culture and science with several approaches, including the methods of structural anthropology (e.g., of Claude Lévi-Strauss: 1979). From the late 1980s, Lloyd has also turned to comparative studies, especially between Chinese and Greek science (2006), in sustained efforts to dissolve disciplinary boundaries that hinder rather than further exploration, interpretation, and understanding. Lloyd's work underscores the variety and interdependence of co-existing ancient ideas about science.

Since the 1990s, the field is again burgeoning. Works that broadly treat the ancient world now include chapters or entries on scientific topics (McGeough 2004; Keyser and Irby-Massie 2006; Gagarin 2009). Surveys run the gamut from the popularizing (Bertman 2010) to the penetrating (Rihll 1999, 2006; Lehoux 2012). New sourcebooks introduce readers to neglected but important writers (Humphrey, Oleson, and Sherwood 1998; Irby-Massie and Keyser 2002). Recent publications cover all scientific genres from astronomy to zoology (Cuomo 2001; Evans 1998). Studies inquire into the sciences as they are rooted in philosophy and theory (Gregory 2000; Naddaf 2005; van der Eijk 2005). Monographs and edited volumes treat single authors: Hankinson 2008 (Galen) and Murphy 2004 (Pliny the Elder). Modern scholars are asking intriguing questions that explore diverse aspects of the broad field classified as "science" in antiquity. Historians of ancient science are producing studies on the influence of scientists and their thought (Jaeger 2008), on the analysis of the literary elements and narrative strategies of ancient technical writers (Netz 2009), and on the transmission of scientific knowledge (Gutas 1998).

3. The Wiley-Blackwell Companion to Greek and Roman Science, Medicine, and Technology

In these two volumes, we investigate the key disciplines, concepts, and movements in ancient science, technology, and medicine as rooted within the historical, cultural, and philosophical contexts of Greek and Roman society. Each of the sixty chapters offers a substantive, clear, and accessible introduction to the current state of knowledge and scholarly advances within its particular subfield, while also giving a sense of new approaches, directions, and debates. The discipline is broad and arborescent, and we do not aim to be comprehensive: suggestions for further reading are appended to each chapter for those who wish to dig more deeply. Our chronological scope is similarly broad, from Thales (circa 600 BCE) to the late Roman Empire (circa 600 CE), and some chapters look back to the ancient near eastern models that significantly shaped Greco-Roman approaches (i.e., ASTROLOGY). The ancients did not compartmentalize their approach to the world, and we do so here only for the ease of organizing so large a project. Many chapters are intended to complement each other, and where questions and points of knowledge overlap, cross-references are generously offered in SQUARE CAPITAL LETTERS.

Although there is no perfect arrangement of topics, for the sake of expediency one volume focuses on the mathematical and natural sciences as understood from the modern perspective. The second volume then examines cultural applications, where "pure science" intersects with other fields of study. Chapters investigating similar (or closely related) questions from different perspectives are grouped together.

Volume 1

In the first section, "Physics and Cosmogony," we set forth Greek explanations for and interpretations of how the world works, from Presocratic to Stoic physics to the role of the gods, what the world is made of, and how things are able to move within the *cosmos.* In the second section, "The Mathematical Sciences," we scrutinize traditional scientific disciplines founded on the methods and principles of mathematics (including Astronomy, Astrology, Ancient Optics: Theories and Problems of Vision, Hydrostatics and Pneumatics in Antiquity, and The Science of Harmonics and Music Theory in Ancient Greece). We then investigate the sciences of the earth (Part III: "Earth Sciences") including the material composition of the earth and bodies of water and the laws of physics that govern them (Classical Geology and the Mines of the Greeks and Romans, Hydrology: Oceans, Rivers, and Other Waterways), the measurement and layout of the earth (Geography), sub-lunar phenomena (Meteorology, "the study of things in the middle"), and the "chemical" manipulation of matter (Greco-Egyptian and Byzantine Alchemy). Part IV ("Life Sciences") examines the science of living things: plants (Greek and Roman Botany) and animals (Zoology), the reciprocal relationships between the environment and life-forms ("Ecology" in the Ancient Mediterranean), the generation of living creatures (Embryology), and how living creatures came into being and whether species can change or are eternal (The Failure of Evolutionary Thinking in Antiquity). In the fifth part ("Healing and the Human Body"), we explore several aspects of Greco-Roman approaches to the human body: its shape, construction, and functioning (Anatomy and Physiology; Gynecology; Regimen and Athletic Training); divergent approaches to the treatment of illness (Physicians and "Schools"; Pharmacy; Magic, Curses, and Healing; Healing Shrines); the study of disease (Epidemiology and Pathology), and the study of man (Psychology and Physiognomics; Anthropology: Knowledge of Man).

Volume II

Here we aim to understand the human applications of "science." Part VI ("Food Sciences") investigates questions pertaining to growing and raising food (Greek and Roman Agriculture; Animal Husbandry), its preparation (Oil and Wine Production; Cooking and Baking Technology), and storage (Food Storage Technology) as well as the nutritional and medicinal efficacy of common foodstuffs (Culinary and Medicinal Uses of Wine and Olive Oil; Nutrition). Part VII ("Technology of Human Life") focuses on the technology of human life, including the essential needs for shelter (Greek Public and Religious Architecture; Greek Domestic Architecture; Roman Domestic Architecture), clothing (Textile Technology), and defense (Siegeworks and Fortifications and Arms and Weapons), as well as

those technologies that enhance human life (Greek Interior Decoration: Materials and Technology in the Art of *Cosmesis* and Display; Roman Interior Design; Urban Infrastructure in the Roman World). Part VIII ("Travel") treats the technologies of travel, including mapping and navigation together with mechanisms of land and sea vehicles. In Part IX ("Telling Time"), we compare Greek and Roman approaches to marking and recording time, and examine instruments devised to advance this aim. In Part X ("Synthesis and Response"), we see how Greek and Roman scientific approaches fit within the broader worldview, including the cross-pollination of Greek and Indian science, Roman synthesis and response to earlier Greek science, and the transmission, translation, interpretation, and adaptation of the Greco-Roman scientific tradition by later scholars from the Muslim tradition and into the Italian Renaissance.

4. Transliterations and Translations

These volumes are intended for the inquisitive non-specialist, and every attempt has been made to translate and transliterate non-English texts. Very few exceptions have been made, and it is the hope of all the authors that these indulgences will not distract readers untrained in Greek, Latin, or German. Inexperience with these languages will not handicap the reader. A text of transliterated Greek (accompanied by translation or paraphrase) will make no sense to the Greekless reader, and it will look annoyingly odd to the reader with some knowledge of the ancient language.

The transliteration of Greek names is a subject that has become contentious: whether to retain the traditional Anglicized spellings or to Hellenize them with the view to fidelity to the original language. And though it might be desirable to have orthographic harmony with *EANS* (Keyser and Irby-Massie 2006: a useful compendium on ancient natural scientists), in the interest of accessibility, we employ "traditional" Anglicized orthography of Greek names. Although Sokrates (Socrates) and Empedokles (Empedocles) or Theophrastos (Theophrastus) should cause no problems, Aristoteles (Aristotle) and Epikouros (Epicurus) or Dioskourides (Dioscorides) may raise eyebrows, while Herakleitos (Heraclitus) may seem like a mystifying string of unpronounceable letters. And although conventions exist and every effort at consistency has been made, T. E. Lawrence's thoughts on the transliteration of Arabic names is as revealing as it is entertaining and very much applicable to the transliteration of Greek names:

> Arabic names won't go into English, exactly, for their consonants are not the same as ours, and their vowels, like ours, vary from district to district. There are some 'scientific systems' of transliteration, helpful to people who know enough Arabic not to need helping, but a wash-out for the world. (*Seven Pillars of Wisdom*. New York: Doubleday reprint 1991, 21)

5. Acknowledgments

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PART I

Physics and Cosmogony

CHAPTER 1

The Creation and Destruction of the World

Andrew D. Gregory

1. Introduction

The creation and destruction of the world were much discussed in antiquity, and the Presocratics, Plato, Aristotle, and Hellenistic thinkers all made distinctive contributions. The term "creation" could in some ways be a little misleading. None of the ancient Greeks believed anything to be created out of nothing, *ex nihilo*; instead, the world we know was generated from some prior, less organized state of the universe. Nor should "creation" here be taken necessarily to imply a creator, or even some entity which organizes. The Greek notion of *cosmos* is also important. A *cosmos* was not only a well ordered place, it was often also thought of as aesthetically and/or morally good. I will use "universe" for all that there is and "*cosmos*" for a well-ordered world within the universe. In general, a *cosmos* consisted of earth, sun, moon, five planets, and some surrounding stars. In some views, one *cosmos* exhausted the universe, in others there were many *cosmoi* (plural of *cosmos*) within a universe, with variations on earth, sun, moon, and five planets. In some views, there was one *cosmos*, eternal once generated; in others, *cosmoi* were subject to destruction and replacement. One can classify Greek ideas on the creation and destruction of the world into four broad types:

1) A single *cosmos* is generated, which then exists permanently, with no destruction.
2) There are a succession of *cosmoi*. Only one exists at a time, but when one is destroyed another is generated in its place.
3) There are multiple *cosmoi* which co-exist. These undergo destruction, but other *cosmoi* are generated which replace them.
4) There is no generation or destruction of the *cosmos*. It has always been here and will always be here.

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A different way of classifying theories of the creation and destruction of the world is in terms of whether *cosmoi* are generated by chance, with a multiplicity of accidents, or by design. The order of our *cosmos* might be explained by chance, with an infinite array of other accidental *cosmoi* of which our *cosmos* is one. Alternatively, someone or something may have guided the generation of our *cosmos* such that it has order. An interesting question is, then, whether all those who postulate chance have many different *cosmoi*, either co-existent or successive, and all those who postulate design have a unique *cosmos*. No ancient thinker held that a unique *cosmos* had come about by chance.

Two more questions relate to the sophistication of ancient thinking on the creation and destruction of the world. To what extent are ideas of space and time (finite, unlimited, infinite) coordinated with ideas on the creation and destruction of the world? Second, to what extent are parallel discussions of the origins of life coordinated with ideas on the creation and destruction of the world? On these questions hangs the answer to whether ancient discussions of the creation and destruction of the world were a loose collection of entertaining tales or a serious and coordinated philosophical investigation.

In terms of sources, from Plato onward, we have good evidence for what individuals and schools believed, both in relation to original texts and works by the commentators. In later antiquity, Neoplatonists and early Christians also theorized about the creation and destruction of the world. With the Presocratics, little original material has survived, and problematic are accounts preserved with the doxographers, who tend in some cases to assimilate differing views and elsewhere to see precursors to Christian views. Plato, as ever, has his own specific interpretive difficulties. His *Timaeus* gives a wonderful account of the generation of the world, but commentators have been split since antiquity on whether this is a literal or a metaphorical account.

2. Myth and Hesiod

Prior to the first philosophical accounts of the creation and destruction of the world, mythological and poetical explanations were given. Egyptian and Babylonian mythologies employed many gods to explain the origins of the world, and often the idea that land forms after water dries out, a notion probably derived from the seasonal flooding of the Nile, Tigris, and Euphrates rivers. Typical of these is this Babylonian account:

> When above the heavens had not yet been named
> And below the earth had not been called by a name
> When only Apsu primeval, their begetter existed
> And mother Ti'amat, who gave birth to them all
> When their water still mixed together
> And no dry land had been formed and not even a marsh could be seen
> When none of the gods had yet been brought into being
> When they had not yet been called by their names, and
> their destinies had not yet been fixed
> Then were the Gods created in the midst of them.
>
> (trans. Heidel 1942, 8)

Early Greek mythologies too, such as those of the Orphics, mixed creation in terms of the sexual couplings of the gods with idea of growth from a primeval egg. One issue here, on which there are a diverse range of positions, is how great the difference is (if any) between mythology and any philosophical account of the creation of the world. Some would say that there is no difference in structure, others that there is no difference in their function within society. One can argue for significant differences on the grounds that philosophical accounts are either parsimonious, invariantly reject the supernatural in contrast with myths, or are some combination of these premises. One can also argue that the key difference is process: philosophical theories need to be based on evidence and argument, and they need to be capable of justification relative to other theories in ways in which myths are not. Attempts to differentiate between myths and Greek philosophical theories of creation on the basis of the involvement of gods will not be successful, as many Greek theories invoke some form of god, though there are interesting comparisons to be made about the role of gods. A different approach is to differentiate between creation tales and cosmogony, where the end product of a cosmogony has the characteristics of a Greek *cosmos* but a creation tale does not.

Hesiod is often seen as an important bridge between creation myth and cosmogony.[1] His account in the *Theogony* gives a logical sequence of events leading to the world as we know it, and, in contrast to many myths, there is a strict and well-organized genealogy of the gods described in the *Theogony*:

> First a chasm was generated, then broad-breasted Gaia (earth), a safe seat for all forever. … From the chasm, Erebus and black night were generated. From night, aether and day were generated, who she bore after sex with Erebus. (116–125)

Hesiod is the first to make explicit that the world, once generated, will last forever. How sharp a division exists between Hesiod and the first philosophical accounts of the creation and destruction of the world is controversial. One view, championed by Cornford, Stokes, and West, argues that there is little difference, while others hold that philosophical cosmogony proper begins with the Milesians and that this is a different type of discourse from the myths of Hesiod. Most recently, Gregory (2013) suggests that Anaximander (*TEGP* 30), giving natural explanations for thunder, lightning, thunderbolts, whirlwinds, and typhoons, is a direct allusion to Hesiod's *Theogony* 845–846, in particular, where these phenomena are explained in terms of the actions and wills of the gods.

3. The Milesians

There is a general principle for the Milesian thinkers, Thales, Anaximander, and Anaximenes, that what we see around us is generated from some basic element (water, the unlimited, and air, respectively) and will ultimately be destroyed back into that basic element. Aristotle tells us:

> Most of the first philosophers thought of matter as the only principle of all things. That from which all things are, that from which a thing first comes to be, and into which it is ultimately destroyed, the substance persisting but changing in its qualities. This they say is the element and beginning of the things that are and because of this they say there is no absolute coming-to-be or destruction, but nature is always preserved. (*Metaphysics* 983b18–27)

We know little of Thales' ideas on the formation of the world, but we are somewhat better informed about Anaximander and Anaximenes, although there remains controversy about their views. Anaximander supposed there to be an *apeiron*, probably best translated as "unlimited," something without spatial or temporal limits or any distinction between its parts:

> He says this is not water, nor any of the other so-called elements, but some other unlimited nature, from which are generated all the heavens and the *cosmos* in them. The source of generation for extant things is that into which destruction occurs, **according to what is proper. They pay penalty and retribution to each other for injustices according to the order of time**, as he says in a poetic fashion. (*TEGP* 9)

The words in bold here are generally accepted as Anaximander's own (KRS 105–106, 117–121). We also hear:

> Anaximander says that which is productive out of the eternal hot and cold was separated at the genesis of this *cosmos*, and that a sphere of flame was formed around the air around the earth like the bark around a tree. When this was broken off and enclosed in certain circles, the sun, moon, and stars were formed. (*TEGP* 19)

So first the opposites of hot and cold are produced from the *apeiron*, followed by a process which generates the earth. Aristotle tells us something very interesting:

> The unlimited has no beginning … However, this seems to be the beginning of all other things, and it surrounds and steers (*kybernan*) all, as with all those who do not suppose other explanations, such as mind or love, beyond the unlimited. This is divine, for it is immortal and indestructible, as Anaximander and most of the physiologoi say. (*TEGP* 16)

Thus it would seem that the unlimited has some power to steer and may help to guide the *cosmos* into existence (*kybernan*: to steer, as in a boat, or more metaphorically, to guide or govern; Guthrie 1962–1981, 1.88 note 2). The latter may be important in suggesting some form of intelligent guidance. To what extent Anaximander considered the *apeiron* to be divine is not clear.

The controversy with Anaximander's view concerns how many worlds he believed in and what became of them. There are three positions here, that he believed in

1) an infinite number of co-existent worlds which were destroyed but then formed new worlds,
2) a single *cosmos* which was destroyed but then formed another *cosmos*, the cycle continuing in perpetuity, or
3) a single *cosmos* which did not undergo destruction.

The basic substance for Anaximenes was air:

> All things are generated by a certain condensation of air, and again by its rarefaction. Motion has existed for all time. He says that when the air felts, firstly the earth is generated, entirely flat, and because of this, it rides on the air. So too sun, moon, and the other stars have their origins in generation from earth. (*TEGP* 11)

We also hear:

> Anaximenes declared air to be the beginning of existing things. From it all things come to be and into it all things are dissolved. He says **as our soul, being air, holds us in order (*syngkratei*), so wind and air envelop the whole *cosmos*.** (*TEGP* 8)

There is debate about whether the words in bold are Anaximenes' own, but the sense is clear enough and should be compared with Anaximander's *kybernan* (steering). With Anaximenes there is a similar debate about the number of *cosmoi* and their fate. Possible interpretations include multiple co-existent *cosmoi*, a single recurring *cosmos*, and a unique everlasting *cosmos*.

4. Heraclitus

Interestingly, Heraclitus rejected cosmogony and destruction for the world:

> This *cosmos*, the same for all, was not made by Gods or men, but has always existed and will always exist. It is an ever living fire, kindling in measures and going out in measures. (*TEGP* 47)

If we take this at face value, then there is no creation and destruction of the world for Heraclitus. Some doxographers, perhaps influenced by the importance of fire in Heraclitus, assimilated him to the Stoics, who believed in successive *cosmoi*: the death of one *cosmos* in a fiery conflagration leading to the birth of the next. On the evidence we have, there is no reason to suppose Heraclitus believed in successive *cosmoi*. The doxographic tradition could be misleading and even simply wrong. Relative to the Milesians, there are two interesting points. First, there is also a sense of cosmic justice and fair exchange. Second, it is interesting to note that even though Heraclitus does not have a generation for the *cosmos*, he nevertheless believes there is steering. So *TEGP* 40 says that "all things are steered through all" (cf. *TEGP* 56: "The thunderbolt steers all things.")

5. The Hippocratics

The Presocratic medical writers too were interested in the origins and fate of the world, especially where they wished to place their account of the nature of human beings and how they should be treated medically in a broader philosophical context. The Hippocratic *On Regimen* 1.10 (circa 400 BCE) describes the body, how the parts are suitable for their functions, and the synergy of those parts according to a fiery triptych responding to the physical properties of dry, moist, cold, and hot:

> In this fire made for itself three circuits bounded by each other internally and externally. Those towards the hold of the moist have the power of the moon, while those towards the outer circuits, towards the surrounding mass, have the power of the stars and those in the middle are bound internally and externally. The hottest and strongest fire, which controls all things, manages everything according to nature, it is imperceptible to sight or touch. In this are soul, mind, understanding, growth, change, diminution, separation, sleep, waking. This steers all things though all both here and there and is never still.

Again we have the steering motif as part of the formation and control of the *cosmos*. Important here, too, is the correspondence of microcosm and macrocosm, the way in which the human body has structural similarities to the way in which the whole *cosmos* is put together.

6. Eleatics

Also significant is Parmenides' thinking on the creation and destruction of the world:

> It never was nor will be, as it is now, all alike,
> one and continuous. What birth will you seek for it?
> In what way, from what source did it grow? I will not allow you
> to think or say from not being, for it is not to be thought or said
> that it is not; and what warrant might have driven it
> later rather than sooner, beginning from nothing, to grow?
> (*TEGP* 17.5–10)

While the passage is quite general about any change whatsoever, it was also seen as denying creation *ex nihilo*. Whether this is original to Parmenides, or whether it codified something that was held generally, we do not find any other Greek thinker proposing that something comes from nothing. All Greek thinking on creation of the world involves organization from a previous, less organized state.

7. Empedocles

Empedocles' cosmic cycle has been the subject of much debate. I give the orthodox or "symmetrical" view of this cycle, though there are many variations, and more radical interpretations are possible. For Empedocles, there are four elements, earth, water, air, and fire, and two principles, Love and Strife. I am careful not to call Love and Strife "forces" as they do not act in a manner recognizable as any modern description of a force. Love is a principle of association, whereby all the elements are mixed together, while Strife is a principle of dissociation whereby all the elements are separated. On the orthodox view, there are two extremes to Empedocles' cosmic cycle. There is a state of complete association of the elements, where they are perfectly mixed together, under the dominance of Love. And there is a state of complete dissociation, where the elements form four disjoint groups, under the dominance of Strife.

On the orthodox view, there are two periods of world formation. When Love begins to associate the elements after the time of Strife's complete dominance, a world is formed. However, as Love moves the elements further toward complete association, there will be a destruction of our world as well. As Strife begins to dissociate the elements after the period of Love's complete dominance, a world is formed. Again though, as Strife moves the elements further toward complete dissociation, there will be a destruction of our world. So there is a cycle of the generation of a single world and its destruction in perpetuity. Aristotle comments:

> At the same time he says that the *cosmos* is in a similar condition now under the influence of strife to that which it was in under the influence of love. (*TEGP* 54)

Empedocles himself says:

> I will give a double account. At one time, they grew together to be one alone out of many, at another time they grew apart to become many out of one. In two ways are mortal things generated, and in two ways do they fail. They are born and perish through the coming together of all things, and they are nourished and vanish as they are drawn away once again. These things never cease their continual interchange. At one time all things were brought together through Love, at another each being drawn apart by Strife's hatred. In that they have learned to grow into one from many, and the one is again drawn apart into many. In this way they are generated and themselves have no stable life, in that they never cease their continual interchange, they are forever unchanged in the cycle. (*TEGP* 41.1–13)

What is remarkable here is that a *cosmos* is not seen as an end state of a process, but a by-product of the all-encompassing cosmic cycle. Two issues which are controversial in Empedocles' cosmogony are the role of chance and how different successive cycles are. Aristotle comments:

> Empedocles says that air is not always separated out upward but according to chance—He says in his cosmogony "Thus at one time it ran by chance, but many times it was otherwise"—and he says that the parts of animals are for the most part generated by chance. (*TEGP* 97)

One must always be cautious with Aristotle regarding chance, as he will call events chance in the absence of teleology, even if those events are determined. Here he seems to attribute genuine chance events in cosmogony to Empedocles. This would suggest that various cycles are quite different from each other, unlike the Stoic theory of universal recurrence (§13, below), yet this is contested. We also find chance in Empedocles' zoogony, where Aristotle describes the nightmare scenario whereby parts of animals wander freely until they join together by chance to make viable living creatures:

> On the earth there burst forth many faces without necks, arms wandered bare bereft of shoulders, and eyes wandered needing foreheads. (*TEGP* 118)
>
> Many sprang up two-faced and two-breasted, man-faced ox progeny, and conversely ox-headed man progeny. (*TEGP* 121)

Whether Empedocles envisaged any teleology on this process is again controversial. Some say yes, others say that the descriptions of the eye on which this view rests are simply descriptions of the structure and function of the eye without teleology. Studies of Empedocles are currently in a state of flux, with the relatively recent discovery of new material in the Strasbourg papyrus and radical reassessments of the relationship between science and religion in Empedocles in light of recent advances in historiography.

8. Anaxagoras

Anaxagoras was the first Presocratic to give a cosmic intelligence, *Nous*, an independent existence and a role in cosmogony, in contrast with the pantheism of Anaximander and Anaximenes. From an initial state of mixture, *Nous*—pure, unlimited, and

unmixed—controls a vortex which separates out the mixture and leads to the formation of the *cosmos*:

> *Nous* is the finest and purest of all things, it has all knowledge concerning everything and it has the greatest power. *Nous* controls all things that have life, both the greater and the smaller. *Nous* controlled the revolution of the whole, such that it revolved in the beginning. At first it revolved in a small region, but now it revolves in a greater, and will revolve in a greater still. The things which are mixed and separated and divided are all known by *Nous*. *Nous* ordered them all, this revolution in which the stars and the sun and the moon and the air and the aether which are being separated off. This revolution produced the separation. The dense is separated from the rare, and the hot from the cold, the bright from the dark and the dry from the moist. There are many parts of many things. Nothing is entirely separated or divided from anything else except *Nous*. *Nous* is entirely alike, both the greater and smaller parts of it. Nothing else is like anything else, but what is most in each single entity is most clearly what it is and was. (*TEGP* 31)

Anaxagoras also says:

> As these things rotated in this way they were separated out by the force and speed. It is the speed which generates the force. The speed is unlike any speed which now exists among mankind, being in every way many times more rapid. (*TEGP* 17)

More specifically:

> The dense, the moist, the cold and the dark came together here, where the earth now is, while the rare, the hot, the dry and the bright went out into the further reaches of the aether. (*TEGP* 35)

The general outline of an initial mixture, followed by a vortex initiated and controlled by *Nous* resulting in the *cosmos* we now know, is clear enough. There is no indication in any of the ancient evidence that Anaxagoras gave any role to chance in this. It is an interesting development in Greek thought that while *Nous* has many of the attributes of a deity (immortality, intelligence, etc.), at no point is it referred to as divine.

Sometimes Anaxagoras is credited with the first teleological account of the creation of the world. Whether that is accepted depends on what is thought of the earlier "steering" principle and also on what one makes of Plato's criticisms in the *Phaedo*, effectively that this is not a full teleological account. While there is nothing about the destruction of the *cosmos* or successive worlds in Anaxagoras, there has been debate about the possibility of co-existent worlds:

> If this is so, it is right to believe that there are many things of all types in all that has been separated, seeds of all things and all sorts of shapes, colors and tastes and men have been formed and animals have souls, and that men have lived in cities and established farms, as with us, and have sun and moon and the others as with us, and the earth grows for them a great amount of many sorts of things, of which they harvest the useful and take into their houses to consume. This then I have said concerning separation, that separation would occur not only with us, but elsewhere too. (DK 59B9)

There are ways of accommodating this passage within a one-*cosmos* framework, or this can be thought to suppose many *cosmoi* separated in space, as with the atomists (§9, below), or with variations of the idea that smaller *cosmoi* are embedded in larger *cosmoi*.

9. Leucippus and Democritus

Leucippus and Democritus (in common with many, I make no attempt to separate their views) held that there was an infinite void populated with an infinite number of atoms. There was no beginning to this infinite universe. Within this universe were an infinite number of co-existent *cosmoi*, coming into existence after the formation of a vortex in the void and then destroyed. The residual matter was then used in further vortices and *cosmoi*:

> Leucippus holds that the whole is infinite … part of it is full, and part void … from these innumerable *cosmoi* come to be and are dissolved into these again. The *cosmoi* are generated in this manner. By "cutting off from the infinite" many bodies of all shapes move into a great void, where they are crowded together and produce a single vortex, where colliding with each other and circulating in all manner of ways, they separate out like to like. When, because of their great number they are no longer capable of moving around in equilibrium, those that are fine spread out into the outside void, as if sifted, while the rest "hold together" and becoming entangled, they unite their motions and create the first spherical structure. This stands apart like a membrane, containing in itself all kinds of bodies. As they whirl around, due to the resistance of the middle, the surrounding membrane becomes thin, and the close packed atoms flow together due to touching the vortex. In this way the earth came into being, the atoms which had been borne in to the middle remaining there together. Again the surrounding membrane itself is increased, due to the influx of external bodies. As it moves around in the vortex, it takes in whatever it touches. Some of the bodies which become entangled form a structure which is firstly moist and muddy, but which dries out as it revolves with the vortex of the whole, and then ignites to produce the constitution of the stars. (*TEGP* 47)

These *cosmoi* are all different from one another. They grow, reach a peak, and then decline and are destroyed:

> In some of these (*cosmoi*) there is no sun or moon, in some they are larger than ours and in some more numerous. The spaces between *cosmoi* are not equal, in places there are more and in others less, some are growing, some are in their prime, some declining, some are coming to be and others failing. They are destroyed by falling into each other. There are *cosmoi* bereft of animals and vegetation and all moisture. In our *cosmos* the earth was generated prior to the stars, and the moon is the lowest, followed by the sun and then the stars. A *cosmos* is at its height until it can no longer accrete external material. (*TEGP* 53)

How original and radical Leucippus and Democritus are in their views here depends on what we attribute to Anaximander—did he (or anyone else) believe in an infinite number of co-existent *cosmoi* prior to Leucippus and Democritus? If not, then this is a radical departure. In any event, there are important differences in that Leucippus and Democritus attribute a significant role to chance and deny any form of intelligence, design, or purpose for the universe. Contentious issues are whether this can properly be

described as a fully mechanical view (biological analogues such as membranes are used, and the explanation of the like-to-like principle is biological and agricultural rather than mechanical), and whether this is in fact or in intention an atheist view (Leucippus and Democritus do have things to say about the gods).

10. Plato

Plato's *Timaeus* gives an extended account of the generation of the best possible *cosmos* by a craftsman god from a primordial chaos. This account was highly influential in antiquity. Opinion is still divided on whether this is a literal or metaphorical account, what actually happened or what the world would be like in the absence of a caring god. What is clear is Plato's thoroughgoing teleological intent. Early in the *Timaeus* (30a), we are told that:

> God desired that all things should be good, and nothing paltry as far as was possible, he took over all that was visible, which was not at rest but in discordant and disorderly motion, and led it into order out of disorder, judging the former to be entirely better than the latter.

This applies to the large-scale *cosmos*, and also the small-scale *cosmos*, the basic entities that constitute the *cosmos*, and the living entities which populate the *cosmos*:

> This we hypothesize as the principle of fire and of the other bodies … but the principles of these which are higher are known only to God and whoever is friendly to him. It is necessary to give an account of the nature of the four best bodies, different to each other, with some able to be produced out of the others by dissolution … We must be eager then to bring together the best four types of body, and to state that we have adequately grasped the nature of these bodies. Of the two triangles the isosceles has one nature, the scalene an unlimited number. Of this unlimited number we must select the best if we intend to begin in the proper manner. If someone has singled out anything better for the construction of these bodies, his victory will be that of a friend rather than an enemy. We shall pass over the many and postulate the best triangles. (*Timaeus* 53d4–54a6)

It is notable that, in contrast to Leucippus and Democritus, Plato has a non-progressive conception of the primordial state. So while for Leucippus and Democritus *cosmoi* will form without any intervention in the primordial state, Plato is specific in arguing they will not. It is often thought that Plato's objection to Leucippus and Democritus is theological, but the following passage from the *Laws* (889b; cf. Vlastos 1975, 29) indicates there may be other more subtle objections as well:

> Let me put it more clearly. Fire, water, earth, and air all exist due to nature and chance, they say, and none to skill, and the bodies which come after these, earth, sun, moon, and stars, came into being because of these entirely soulless entities. Each being moved by chance, according to the power each has, they somehow fell together in a fitting and harmonious manner, hot with cold or dry with moist or hard with soft, all of the forced blendings happening by the mixing of opposites according to chance. In this way and by these means the heavens and all that pertains to them have come into being and all of the animals and plants, all of the seasons having been created from these things, not by intelligence, they say, nor by some god nor some skill, but, as we say, through nature and chance.

This poses a key question for ancient cosmogony; is it plausible to suppose that our *cosmos* came about by chance? Plato is clear on the fate of the *cosmos*. The Demiurge says that:

> I am the craftsman and father of these works, and they are indissoluble except by my will. Although all that is bound can be dissolved, to will to dissolve that which has been beautifully and well constructed would be bad. (*Timaeus* 41a)

This is important in itself and may also be significant in the literal/metaphorical debate. In *On the Heavens* 1.12 (§12, below), Aristotle produced some highly influential arguments to show that something generated could not be eternal. Early attempts at a metaphorical interpretation may well have been motivated by a desire not to be susceptible to Aristotle's critique. The modern metaphorical view holds that if we take the cosmogony literally, there are too many evident inconsistencies in the account. The literal view argues that the inconsistencies are not so many or so problematic and, while not denying that there are inconsistencies, argues that these fall within the early warning in the *Timaeus* not to expect a fully consistent account.

11. Aristotle

Aristotle's position on the creation and destruction of the world is in essence very simple. The world is neither created nor destroyed but eternal. It always has existed and always will exist:

> The whole heaven is not generated nor can it be destroyed, as some have said, but is unique and eternal, not having beginning or end to its lifetime, having and embracing unlimited time in itself. (*On the Heavens* 283b26–29)

Aristotle has a complementary position on the origin of life and species. Life has always existed, and the species we see now have always existed. Aristotle has some interesting arguments for the eternity of the *cosmos*. One quite modern contention concerns the possibility of generation *ex nihilo*:

> In conclusion then, the basic principle is clear. There is always a ratio between changes, for they are in time, and between two determinate time periods there is always a ratio, but there is no ratio between fullness and the void. (*Physics* 216a8–11)

So if something were to be created from nothing, that would then involve us in infinities as nothing cannot be in ratio with something. In *On the Heavens* 1.12, Aristotle argues for the following conclusions:

1) Everything which always exists is absolutely ungenerable and indestructible.
2) Everything which is absolutely ungenerable and indestructible always exists.

Along with this goes the following assumption:

> Nothing can be indestructible or ungenerable through chance. Chance and luck are contrary to that which always or mostly happens. That which exists for an unlimited time, absolutely or from a certain time, exists either absolutely or for the most part. (*On the Heavens* 283a32)

So a *cosmos* which exists forever is incapable of not existing. Indeed, anything which exists forever exists of necessity. The precise nature of Aristotle's argument is controversial, and to the modern eye something has gone wrong here (see Judson 1983 for the nature of the supposed error). Whatever Aristotle's reason for holding this view, his target is clear enough. He wishes to oppose the Platonic view that the *cosmos* came into existence and will subsequently exist for all time. *On the Heavens* (283b17-21) concludes as follows:

> It is impossible for what was previously eternal to perish later, or what was previously not eternal to be eternal later. All generable and destructible things are subject to change. They change by means of contraries, and that from which natural things are constructed is the same as those by which they are destroyed.

Aristotle's influential view was one of the issues that later caused difficulties for the Christian church, which consequently had to rethink Aristotle's views in the generation of scholasticism, the fusion of Christian theology with Aristotelian thought.

12. Epicurus and Lucretius

The views of Epicurus and Lucretius are a development of the earlier atomism of Leucippus and Democritus. Epicurus says that

> There are an infinite number of *cosmoi* both like and unlike this one. As has already been demonstrated, there are an infinity of atoms, and they are carried far away. The atoms which are such that a *cosmos* could be generated or made from them, are not exhausted in the completion of one *cosmos* or many, nor all those that are alike or those that are unlike. (*Letter to Herodotus* 45.3–9; cf. Lucretius 1.232–233)

An important factor in cosmogony for Epicurus and Lucretius is the atomic swerve. Atoms are thought to fall in straight lines. Unless there is lateral motion, atoms would never interact. So atoms have the ability to move sideways on occasions, in an unpredictable manner. Epicurus describes the origins of *cosmoi*:

> *Cosmos* formation occurs when the appropriate seeds flow in from one *cosmos* or an inter-*cosmos* or from many. Gradually, by additions and joinings and migrations to another place, as may occur, and appropriate irrigations of this matter, a state of completion and permanence is reached, which lasts while the underlying foundations are capable of being added to. (*Letter to Pythocles*, 89.6–11)

Lucretius gives us some more specific details:

> Firstly, all of the pieces of earth, because of their weight and entanglement, gathered in the center and took the lowest place. The more tightly they became united and entangled, the more they expelled that which would form the sea, stars, sun, moon and the walls of the great world. The constituents of these bodies are smoother, rounder and of significantly smaller size than the elements of the earth. Firstly, fiery aether immediately passed through the loose interstices of earth and being light, elevated itself carrying with it much fire … light and aether then formed a coherent body curved in all places which spread widely in all directions to enclose all things in a greedy embrace. (5.449–471)

Behind this there is an important principle of cosmology:

> So many primordial particles, in a multitude of ways, have been propelled by their own weight and impacts for an infinite amount of time, and they have made trial of all things their union could produce. It is hardly surprising if they have come into arrangements and patterns of motion like those repeated by this world. (5.186–194)

This should be compared with the views of Leucippus and Democritus and contrasted with the views of Plato and the Stoics.

13. Stoics

The Stoics were believers in a process known as *ekpurōsis*, whereby a world was created out of a cosmic conflagration and later destroyed into a cosmic conflagration. So the beginning and the end of the world was in fire. There is only a single world at any one time, but the process of the generation and subsequent destruction goes on for eternity:

> The *cosmos* is generated when the substance is converted from fire through air into moisture. The thicker parts of this then condense to become earth, while the finer are thoroughly rarefied, and when they have been thinned a great deal, they become fire. After this, from mixture come plants, animals and other sorts of things. (*SVF* 1.102)

We are also told:

> Only matter and god survive *ekpurōsis*. (*SVF* 2.1047)

A key part of the Stoic view is that god guides the generation of the *cosmos* and that the *cosmos* has a providential ordering. An important Stoic argument against any non-teleological, non-providential *cosmos* is given by Cicero, through his speaker Balbus in *On the Nature of the Gods*:

> Should I not be amazed here that anyone might persuade themselves that certain solid and indivisible pieces of matter are carried by their own weight and from the fortunate combination of these bodies a world of the greatest splendor and beauty is generated? I fail to see why someone who thinks this can occur does not also believe that if innumerable copies of the twenty one letters, made of gold or anything else, were thrown together in some vessel then shaken out onto the ground, it is possible that they would form a readable *Annals* of Ennius. I doubt whether Fortune would give us even a single verse! (2.37)

And, according to those who believe in atomism:

> From bodies without any heat, or with any quality or any sense the world has emerged complete by chance, or rather innumerable worlds, some being born and some perishing at each moment. But if the coming together of atoms can produce a world, why can it not produce a colonnade, a temple, a dwelling, which are much less difficult things to produce? (2.37)

This should be contrasted with the views of the atomists and, in particular, that of Lucretius at the end of the previous section. One key issue for the Stoics, a subject of much debate, was whether the successive worlds would be identical or not:

> The *cosmos* is re-established in its original condition. The stars move again in a similar fashion, and each thing which happened in the first period is completed without any change. There will be again a Socrates and Plato and each of humanity with the same friends and citizens. They will suffer and meet the same things, and deal with the same things, and every city, village and field will similarly be reconstituted. This reconstitution of everything happens not once but many times, or rather, this reconstitution is accomplished an unlimited number of times. Those gods who are not subject to destruction, due to their knowledge of this one period, know from it all that will happen in future periods. There will be nothing foreign to what has happened previously, but all will be utterly without change of even the smallest detail. (*SVF* 2.625)

Simplicius discerned a problem:

> In saying that the same I is generated in the regeneration the Stoics rightly enquire whether the I now and the I at some other time are one in number, through being the same in substance, or are torn apart through being placed in different cosmogonies. (*SVF* 2.627)

Origen tells us:

> Those who were ashamed of this doctrine said there were few and very insignificant changes of things occurring in one period when compared to the preceding period. (*SVF* 2.626)

Here we learn more detail on what sort of changes we might expect from one cycle to another:

> The Stoics believe that after *ekpurõsis*, all things happen again in the *cosmos* according to number, such that the same idiosyncrasies in nature that existed before will occur again in this *cosmos*, as Chrysippus says in *On the Cosmos* … They say that the only discernible changes between later and prior idiosyncrasies of nature are due to certain external accidents, and these changes, for the same Dion continuing and living, do not alter him. He does not become someone else if formerly he had spots on his face, but subsequently he does not. Such changes, they say, do happen between the idiosyncrasies of nature in one *cosmos* and another. (*SVF* 2624)

This view on the relation of successive worlds should be contrasted with that of Empedocles.

14. Early Christians

With the rise of Christianity, we find the idea of creation *ex nihilo* being taken seriously and adopted for the first time. Creation *ex nihilo* cannot be found in any thinker prior to the rise of Christianity. Sorabji (1983, 246 note 65) lists some possible exceptions, but in each case the balance of evidence is against an *ex nihilo* view. There is no

definite position of creation *ex nihilo* outside the Greek and early Christian traditions. In the Jewish tradition, there are some inconclusive passages in the Syriac *Apocalypse of Baruch*:

> You who at the beginning of world called forth what previously was not. (21.4)
> By a word you called into life what was not there. (48.4)

One might possibly interpret these passages as entailing creation *ex nihilo*, but more plausible alternatives are available. For the first passage, it might be the organization of the world called forth into existence from chaotic pre-existing matter; in the second, life is called into existence from non-animate pre-existing matter. Some early Christians then, though not unanimously, perhaps as a way of demarcating themselves from the Greek philosophical tradition, originate serious contemplation of creation *ex nihilo*. There was a considerable divergence of opinion in response to a battery of arguments concerning creation in general and Christian creation in particular. I do not see any clear cut evidence for creation *ex nihilo* in the Bible. This may surprise some, but that is the view of many scholars. I would add, in symmetry, that I do not find clear-cut evidence in favor of creation from pre-existing matter either. It may well be that for the original authors of the Bible this was not a key question. So:

1) There are passages which refer to God's act of creation without referring to pre-existing matter, but none which state there was no pre-existing matter.
2) There are passages which refer to God ordering a *cosmos* out of pre-existing matter, but none which state that this matter has always existed and has not been earlier created *ex nihilo*.

What we do not find is the kind of explicit formulation that Augustine gives:

> All formed things were generated from matter, and this matter itself was made from absolutely nothing. (*On "Genesis" against the Manicheans* 1.6)

I would agree with Winston (1971–1972, 191; cf. May 1994, xi–xiii; Grant 1980, 137):

> The first explicit formulation of creation *ex nihilo* appeared in second-century Christian literature.

This only became an issue around the end of the first century CE in debates between Christian theologians and Neoplatonist philosophers. On balance, most passages lean towards creation from pre-existing matter without excluding creation *ex nihilo*.

15. Conclusion

There was much discussion of the creation and destruction of the world and much original and sophisticated thought on the topic. Ideas about the creation and destruction of the world were tied not only to theological beliefs, but also to views on the nature of explanation as well as space and time, and to views on the origins of humans and life in

general. In these ancient discussions, we can see the genesis of many modern debates on the origins of the universe and how we should go about explaining the order of the universe.

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FURTHER READING

For ancient theories of creation, see especially David Sedley (*Creationism and Its Critiques in Antiquity*. Berkeley: University of California Press, 2007), and Andrew Gregory (*Ancient Greek Cosmogony*. London: Duckworth, 2007).

NOTES

1 For considerable similarities between Hesiod and the Hittite account found on the Kumarbi stone (Gurney 1952, 194; KRS 45–46). Pherecydes (circa 550 BCE) is an interesting character, but Aristotle puts him in a different tradition from the philosophical thought of the Milesians (KRS 50–71). Alkman (circa 600 BCE) is possibly a bridge between myth and philosophy, but what little we know of him is badly corrupted by later commentators. See West 1971, 1–77, 206–208; KRS 47–49; Aristotle *Metaphysics* 1091b; Penwill 1974; West 1963, 154–156; West 1971; Vernant 1965.

CHAPTER 2

Matter

Daniel W. Graham

1. Introduction

Matter is one of the basic concepts of modern science. It played a large role in ancient philosophical theories in a time when philosophy and science were still connected. Aristotle made the most important contributions to the understanding of matter, but the concept had a history both before and after him. By seeing what problems the ancient concept of matter solved, we can appreciate the origins of the theory of matter.

2. Matter in the Presocratics

Aristotle tells us that the earliest philosophers identified a single material *archē* (starting point or principle) from which the *cosmos* came to be. For Thales this was water, for Anaximenes air, and for Heraclitus fire. Aristotle suggests an all-encompassing scheme that the several theories follow, which has come to be known as "material monism," the view that everything is really just one kind of matter in different forms or manifestations. There was a primeval state in which only the *archē*, whatever that was, existed. Then that original stuff was somehow acted upon to present different appearances. In Anaximenes' version, perhaps the best-articulated one, air turned into fire when it was rarefied; when it was compressed, it turned into wind first, then cloud, then water, then earth, and then stones, respectively, as it became more compact (*TEGP* 3, 6). Thus we get seven states of matter, which in its most natural manifestation appears to us as air. Its degree of density determines what phenomenal properties it has. But in material monism, there is only one kind of matter, however differently it may *appear* to us in its several states (Aristotle, *Metaphysics* 1.3–4). We might compare a modern scientific theory, according to which water is H_2O, but under the influence of temperature and pressure it may manifest itself as a solid (ice), a liquid, or a gas (water vapor).

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Almost all scholars follow Aristotle in this interpretation of the earliest philosophers. There are, however, serious problems for the interpretation. We know virtually nothing about Thales' actual theory; Anaximander, the philosopher after Thales, does not really fit into this picture—as Aristotle himself sometimes recognizes; and Heraclitus denies one key principle of material monism. This leaves only Anaximenes. And when Plato discusses Anaximenes' theory, he reads it in a radically different way from Aristotle. He sees the theory as saying that the several kinds of matter are not different manifestations of the same thing, but different substances that have changed their natures in being rarefied or compressed (*Timaeus* 49b–c). For instance, when air turns into fire by rarefaction, the air is gone; fire is not rarefied air, but a different substance from air, a successor substance with a different nature. Heraclitus takes a similar approach, saying that the birth of one substance is the death of another (*TEGP* 101). On this reading, Anaximenes, and perhaps his early Ionian compatriots, are pluralists who think that at one time (the origin of the world) there was only one kind of stuff, but now there are many. Incidentally, Xenophanes can also be read in this way, though Aristotle dismisses his physical theory as not worth discussing. On the new interpretation, the theories in question are versions of the "generating substance theory," whereby one kind of substance is generated from another without being identical with it (see Stokes 1971; Graham 2006).

The great watershed in Presocratic philosophy is Parmenides, who criticizes his philosophical predecessors in a philosophical poem. He proposes a problem that is sometimes called the Eleatic Challenge: "How can what-is come to be from what-is-not?" This sounds like the question, "How can something come from nothing?" although his own formulation is multiply ambiguous. According to Parmenides, only what-is is, whereas what-is-not is not, because what-is can be known or understood or talked about, whereas what-is-not is unknown and unexpressible (*TEGP* 11). But coming-to-be presupposes what-is-not (something would have to come to be from what-is-not), so it is impossible; and differentiation involves what-is-not (for what-is would be different from what-is-not), so it is impossible. Consequently, what-is must be without coming-to-be or perishing, as well as all alike, changeless, and complete (*TEGP* 17). Parmenides' argument seems to entail that there is only one thing in reality, namely what-is, which is completely homogeneous and unchanging. If this is so, then there can be no cosmogony or cosmology, only a kind of static ontology, or science of reality.

Curiously, however, Parmenides goes on in the latter part of his poem to produce his own original cosmology. He posits the existence of two *morphai* or forms, light and night, the former rare and light and bright, the latter dense and heavy and dark. He says that mortals make some mistake in positing these two forms, but he implies that the cosmology he develops is nonetheless superior to all other cosmological theories (*TEGP* 17.50-61). On his theory, one makes other substances by mixing the two forms together, presumably making different substances by using different proportions. Parmenides goes on to articulate a detailed cosmology that, in some respects, notably astronomy, is actually far superior to previous theories in its empirical implications.

Parmenides provides for the first time a tightly argued theory. Yet what exactly he is saying and what precisely is the relation between the main argument and the cosmology remain controversial. His argument against coming-to-be makes good sense as a refutation of the generating substance theory, but it is not effective against material monism. Most scholars think Parmenides' cosmology is meant as an argument to the effect that the best theory possible would look like Parmenides', but even it is false,

so all cosmologies are false. And they assume that after Parmenides most philosophers are desperately trying save cosmology from Parmenides' arguments. Yet his immediate successors always speak as if they agree with him and never seem to argue against him. And they all produce theories of matter that look like improved versions of Parmenides' mixture theory. Whatever Parmenides aims to do, his successors seem to take his cosmology as a model for, rather than refutation of, their projects.

The natural philosophers after Parmenides are predominantly and noncontroversially pluralists about matter in that they believe in a plurality of basic stuffs. These stuffs have a fixed nature that is invariable, like Parmenides' light and night, but they can mix with each other to produce different outcomes. Anaxagoras seems to posit an unlimited number of stuffs, including air, earth, and aether (identified with the contents of the upper atmosphere). He may also think of what we would call qualities, such as hot and cold, wet and dry, as being stuffs, though this is controversial (*TEGP* 11, 13). He holds that everything is in everything, meaning apparently that every sample of matter contains all the constituent stuffs in it (*TEGP* 19). What predominates in the mixture manifests itself, by giving its characteristics to the whole mixture (*TEGP* 31). But since everything else is found in the mixture, any other phenomenal characteristics can emerge, if conditions are right for a concentration of a different stuff to occur.

Empedocles uses a simpler model. He posits just four basic stuffs: earth, water, air, and fire, which he calls "roots" (*rhizōmata*) (*TEGP* 26). As these combine in different ratios, they can produce all other substances: blood, bone, wood, iron, and so on (*TEGP* 114, 115). Thus he, in effect, recognizes a distinction between elements and compounds. The elements are permanent features of the world, and the compounds are temporary arrangements of those features. Empedocles recognizes two forces that act on the elements, which he personifies as Love and Strife (*TEGP* 41.19–26). Strife keeps different elements separated, whereas Love acts to draw them together. Anaxagoras had said that Mind initiates the separation of the stuffs from an original chaotic mixture by starting a vortex motion that stratifies heavier and lighter stuffs (*TEGP* 31). Both Anaxagoras and Empedocles picture the basic stuffs as passive bodies, elements acted upon by forces external to them so as to mix or separate (see Schwabe 1980). Before Parmenides, natural philosophers seem to have conceived of stuffs, or some of them at least, as having their own active powers and even intelligence.

The most famous pluralist theory is that invented by Leucippus and elaborated by Democritus: the atomic theory. Leucippus may be seen as taking Parmenides' night and light, which are dense and rare, respectively, and developing them to the extremes that the former becomes completely full and the latter completely empty (*TEGP* 10). This leaves completely solid matter on the one hand and completely empty space on the other. Since nothing we experience is completely solid or indestructible, what is so must be tiny. There must be minimal pieces of matter, to stop an infinite regress of division as envisaged by Zeno of Elea (Simplicius, *Physics* 139.24–140.6). These are the *atoma* or indivisibles, which can combine to form macroscopic objects. Empty space, or void, provides a place for atoms to move so that they can be arranged and rearranged. When one macroscopic object dissolves, its component atoms do not go out of existence, but they are merely redistributed. Thus nothing (that really is) comes to be or perishes (at the microscopic level), as Parmenides says, but the appearance of coming-to-be and perishing (at the macroscopic level) is explained.

Presocratic theories made heavy use of material entities, which seem to count as the ultimate realities. Indeed, it is difficult to see that the Presocratics even had a place for forms or formed objects in their ontologies. For them, material realities constituted the building blocks of the *cosmos*. In one kind of theory, stuffs might be transformed into one another, so that each stuff is a kind of phase state of basic matter, like solid, liquid, gas, and plasma in modern physical theory. In another version, stuffs were permanent realities that mixed to produce different compounds or mixtures, as in the modern theory of elements or of mixtures. Furthermore, Presocratics differed in whether they thought matter was continuous (as did most theorists) or discrete (the atomists). Accordingly, early Greek philosophy explored many of the logically possible theories of matter and at least provided models and arguments for those theories. As yet there was no experimental basis for choosing among them, but proponents of the several theories could claim that their theories had advantages in solving some problem or other. And Parmenides could claim to have convinced everyone that *being* had to be prior to *becoming*.

3. Socrates and Plato

Contemporary with the latest "Presocratic" philosophers, Socrates turned philosophy away from cosmology toward ethics and human concerns, bringing philosophy down from heaven, as Cicero put it (*Tusculan Disputations* 5.4.10). According to Plato, Socrates did not criticize natural philosophy, but he had no time for it. Nor did Socrates have time for metaphysics with its potential interest in matter. Socrates' immediate followers mostly focused on ethical theory and practical applications, with one important exception: Plato.

In the *Phaedo*, Plato has the character Socrates, who had in earlier dialogues concerned himself almost exclusively with ethical problems (in accordance with what we know of the historical Socrates), make a foray into scientific explanation and metaphysics. One of the themes of this dialogue is that *if* one should study scientific and cosmological questions from the viewpoint of an assumption that the *cosmos* is ordered for the best, that is, that the order inherent in the *cosmos* presupposes moral values, then one could pursue science in a way that is consistent with the pursuit of ethics. In the *Phaedo*, Plato introduces his theory of Forms, according to which ideals such as Equality, Justice, and Goodness exist as ultimate realities and give to perceivable things their intelligibility and order. But what do they inhere in?

Plato has little to say about the material basis of existence, but he does eventually give an answer based on an early discussion of the dialogue. After introducing the Forms, Socrates observes that, for instance, not only Tallness itself, but the tallness "in us" will not allow shortness to co-exist with it, but will either flee or perish (102d–103a). Nevertheless, someone objects, did we not say earlier that opposites always come from opposites, referring to a previous proof of immortality from opposites (70d–71a)? "Then, my friend," Socrates replies, "we were talking of things that *have* opposite qualities, and naming these after them, but now we say that these opposites *themselves* … never can tolerate the coming to be from one another" (103b–c, trans. Grube, italics added). Here Plato finally makes a crucial distinction, more than thirty Stephanus pages after,[1] he speaks of opposites, between a property and the bearer of that property. After pausing only a moment over this distinction, however, he then explores the relations between lower-level and higher-level properties, such as three and odd. In principle, then, Plato recognizes a subject of properties, but he shows little interest in that subject.

Plato makes a systematic distinction between the Forms, which always are what they are, and sensible objects, which are changeable and unstable. He seems to include in his account of the shortcomings of sensible objects the facts that such an object now has a property F, now loses it; that at the same time it is F and not-F or the opposite of F. For instance, Simmias is tall in relation to Socrates and short in relation to Phaedo. And it may appear to different observers at the same time to be F and not-F. Consequently, sensible things are not objects of knowledge, but of opinion. Plato says that sensible things partake of or participate in or imitate Forms, but he does not explain this connection.

Finally, in his late work, the *Timaeus,* Plato gets around to saying something about the subject that partakes of the Forms. This work is Plato's only essay in natural philosophy, one which in a way fulfills a promissory note he issued in the *Phaedo* when he called for a science based on showing how the world is organized for the best. In the *Timaeus*, the eponymous main speaker sketches a world designed by a divine craftsman or engineer, the "Demiurge," so as to make the best use of the materials available to him. The account, Timaeus warns, will be at best a likely story, since in the realm of changing objects scientific knowledge is not possible. Faced with accounting for the role of necessity in the world, Timaeus posits, in addition to a changeless, perfect archetype and a changeable imitation of that archetype, a third entity, a "receptacle of all becoming," which in the same breath he calls a "nurse" (49a). He explains that, to all appearances, stuffs constantly change into one another; if we try to refer to some stuff, such as water, it changes even as we try to pick it out. The safest answer is to say the indexical term such as "this" refers to that *in* which the sensible stuff appears (49e–50a). He imagines someone molding gold into different shapes continually; if asked, "What is that?" the best answer would be "Gold." The receptacle takes on the form of the eternal realities. In the end, the Forms are like a father, the receptacle a mother, and the sensible object an offspring (50d).

Originally, the receptacle was filled with changing qualities, which it somehow sifted so that those of similar kinds group together in the same regions. The Demiurge imposed order on them by forming triangles of the appropriate shape and compounding them into regular solids to represent the several qualities. Now that they had mathematical characteristics they could behave in a more orderly fashion. In this way, the Demiurge created the physical basis for the four elements, three of which were interchangeable with each other (water, air, fire), one of which did not connect with them (earth) (52d–56b).

Plato's story is highly suggestive but also obscure. The receptacle seems to function as a kind of locus for appearances, or perhaps a medium (as the gold analogy suggests). It does not have any character of its own (unlike gold), but provides the potential (space?) for appearances. It is known neither by reason nor perception, but only by a kind of "bastard reasoning" (52b). Such an entity might qualify as providing extension, like Descartes' matter, but it can offer no mass or solidity. Further, this entity appears nowhere else in Plato and hence has no immediate application to the problem of change.

One other Platonic scheme has some connection with the theory of matter. In the late *Philebus*, Plato speaks of the "gift of Prometheus," who not only gave to man fire, but also a recognition that everything is one and many (16c–d). To understand anything, we must identify a single form, and apply it to an unlimited field of phenomena. For instance, there are an unlimited number of sounds, but we impose order by dividing the concept of sound into a finite number of articulate sounds, which constitute the letters.

With this we develop the science of literacy that allows us to represent all the sounds (of our language). Plato uses this model to suggest a general ontological scheme in which a limit is imposed on an unlimited domain to produce a mixture that represents a harmonious state of balance (23c–26d). He extends this notion into cosmology and notes that an agent is needed to create the mixture, a craftsman (*dēmiurgoun*) (26e–27c). This last step brings us close to the *Timaeus*. But in the *Philebus* scheme, the correlate of matter is not a receptacle, or space, or place, but an unlimited domain of phenomena such as fine weather, perhaps some indeterminate reality. This concept, too, has interesting implications, but Plato does not develop it further.

4. Aristotle

Aristotle brings matter to the forefront of philosophy, gives it a secure place in philosophical theory, and lays the foundation of all later studies and applications of the concept. Aristotle begins his metaphysical theorizing in the *Categories* by distinguishing between entities which are "said of" other entities and those which are not; and entities which are "in" other entities, and those which are not. Thus Man is said of Socrates, and Color is said of Paleness; Color is in Man, and Paleness is in Socrates. Aristotle's meaning emerges more clearly from his examples than from his misleading terminology. The entities that are said of other entities are what Aristotle later calls "universals"; those that are never said of others are called "individuals." Entities in other entities are called "accidents" or "attributes"; those not in others are called "substances." Aristotle distinguishes between universal (or "secondary") substances such as Man and individual (or "primary") substances such as Socrates. All other entities, he maintains, depend for their existence on primary substances, for if primary substances did not exist nothing else would either. The primary substance, moreover, is the "subject" or "substratum" (*hypokeimenon*) for all other things.

Aristotle thus produces a powerful ontology that distinguishes between universals and particulars, things (substances) and attributes. Whereas Plato had distinguished between Forms and sensible objects, he made no further distinctions and left the nature and status of sensible objects unclear. In his basic ontology, however, Aristotle does not have matter, nor any clear place for matter, since the primary substance is formally individual or indivisible (*atomon*). Aristotle's theory allows for a basic analysis of change: a primary substance stays the same even though its attributes change. Thus when pale Socrates gets a suntan, he remains Socrates, while one accident or attribute (paleness) is replaced by another (darkness) (*Categories* 4a17–20). Accidental change can be analyzed as an exchange of attributes in a continuing substance.

But there is a problem lurking in Aristotle's ontology. Aristotle wishes to support a commonsense view of the world that can account for natural changes. Yet Socrates is not everlasting but is born, lives, and then dies. How can we account for Socrates' coming-to-be or birth and his perishing or death? If Socrates is theoretically simple, then he either exists or not, without any antecedent or successor entities. Consequently, he seems to come to be out of nothing and perish into nothing, in violation of Parmenides' rejection of those possibilities.

In *Physics*, book I, Aristotle faces the general problem of change squarely, and draws on the theoretical presuppositions of his ontology to extend that ontology. He recognizes that change presupposes three principles: two contraries and a substratum (chapters

5–6). For instance, in the unproblematic example of the *Categories*, the two contraries are paleness and darkness, the substratum Socrates. What then of the case of Socrates' birth? Aristotle proposes an example that provides a suggestive case study. In making a bronze statue, the sculptor melts and forms metal into a statue. The substratum is the bronze, which goes from being unformed to being formed. In the example, he stretches the notion of contraries to that of opposites (a broader class that includes contradictories) and the notion of substratum to include non-substantial, or not fully determinate, entities. Generalizing, we have a "privation," not-formed, a "form," formed or shaped, and a "matter," bronze (1.7, cf. 1. 9). Applying this new scheme, we can now look for some biological stuff such as protoplasm, which goes from being nonhuman to being human. Thus Socrates does not come from nothing, but from some less-than-human matter that gets informed so as to become human.

On this scheme, we now have a substratum that is more fundamental than the primary substance, namely, matter. Moreover, the primary substance is no longer simple and indivisible, but it is at least theoretically divisible into matter and form. Now Aristotle can explain all change using the principles of the *Categories* in an expanded way: change is exchange of forms in a pre-existing substratum, either substance or matter. Further, he realizes that he now can answer the Eleatic Challenge: how can what-is come to be from what-is-not? The Presocratic pluralists had been able to explain change as rearrangement of pre-existing entities, but they had never actually allowed for coming-to-be and perishing; rather, they explained them away as mere appearances caused by aggregation and segregation. Aristotle, by contrast, seeks to vindicate coming-to-be and perishing. He says that "what-is-not" is ambiguous. In one sense, what-is comes to be from what-is-not in that the privation (not-F) is replaced by the possession of form (F); but in another sense, something is always there, namely, the matter, which *is* throughout the process. What-is does not come *from* nothing, but in place of what-is-not, where the "what-is-not" denotes absence, not nothingness (1. 8). Thus, by metaphysical inventiveness and semantic subtlety, Aristotle answers the Eleatic Challenge (Graham 1987, chapter 5).

Aristotle makes one more important advance: he invents a name for matter: *hylē*. The term, which comes from a word for "woods, wood, timber," Aristotle makes into a theoretical term for what underlies substance, and defines it: "My definition of matter is just this—the primary substratum of each thing, from which it comes to be without qualification, and which persists in the result" (*Physics* 192a31–32, trans. Hardie and Gaye). Surprisingly, the Presocratics, who made so much of stuffs, had no generic term to classify stuffs such as earth, water, and air. Aristotle uses the terms *eidos* and *morphē* to denote the form that contrasts with matter (the former of which Plato had used, along with *idea*, for his transcendent Forms). With an explicit theory of form, Aristotle can raise new questions, explore implications, and apply his concept to new domains.

One immediate application comes in Aristotle's theory of cause. He recognizes four causes (*aitia*) or explanatory factors, the efficient or moving, the final, the formal, and the material causes. For instance, in the making of a statue, a sculptor (efficient cause) fashions a statue for the sake of beautifying a courtyard (final cause), by imposing a shape (formal cause) on bronze (material cause). A complete account of a process ideally includes all four causes, and hence provides an essential role for matter in explaining events. In a paradigmatic situation, an agent or agency acts for an end by imposing order on a material.

Aristotle's theory that substances are composed of matter and form, known as hylomorphism, provides a scheme for explanation rather than a specific analysis, for hylomorphic analysis can be applied at different levels of composition. For instance, Socrates can be analyzed into his body (matter) and soul (form); his body can then be further analyzed into a structure (form) of "anhomoeomerous" or nonhomogeneous parts (matter), such as limbs and organs; these can in turn be analyzed into homoeomerous (homogeneous) parts, such as tissues (muscle, bone) and fluids (blood, bile); these homoeomerous parts can then be analyzed into the four elements (earth, water, air, and fire, those identified by Empedocles), which are the simple bodies. At each level, there is a form and matter, with the matter of one level becoming the composite of another.

The four elements themselves raise interesting problems of their own. For Aristotle, the four "so-called" elements are the most primitive stuffs found in the world. They are "so-called" because they are not really fixed elements, but undergo transformations into one another (similar to Plato's theory and the generating substance theory). Thus, when water is heated, it turns into air (as it evaporates), and if air is dried out, it then becomes fire. But since the "elements" change their natures in their transformations, they undergo substantial change or coming-to-be and perishing. They must have a substratum to persist through these changes; but this substratum itself must be characterless, for otherwise the substratum itself would turn out to be the ultimate material reality, and material monism would be true. Caught in a theoretical dilemma, Aristotle says the matter in question is never found by itself, but only in connection with the formal qualities that constitute it as an element, that is, hot or cold, wet or dry (Aristotle, *GC* 329a24–35). The matter in question is "prime matter" (*prōtē hylē*), the lowest possible level of matter (Aristotle, *Metaphysics* 1049a25–26, 1015a7–10; cf. "a single common matter" *On the Heavens* 312a31–32). But to what extent is Aristotle committed to it? This question remains highly controversial, but certainly Aristotle raises the issue of prime matter as a kind of ultimate substratum, and the notion plays an important role in later theoretical developments.

The opposition between form and matter leads Aristotle into other labyrinths. In the *Categories*, Aristotle seems to recognize several criteria of reality: (1) intelligibility: the real is what can be defined or understood; (2) particularity: the real is what can be pointed to, referred to, picked out as a "this"; and (3) subjecthood: the real is what underlies and grounds all else. Primary substance satisfies all three criteria and hence is unproblematically superior to all other entities. But once we divide substance into form and matter, we lose the unity. In Socrates, we find form, matter, and the composite (the union of form and matter). Form seems to satisfy the criterion of intelligibility, matter that of subjecthood, and the composite that of particularity (though Aristotle curiously attributes particularity to form). What then is the ultimate reality, that is, the ultimate substance? Aristotle struggles with this question in *Metaphysics* 7–8. At one point early in the discussion (7.3), he performs a thought experiment in which he removes every determinate character from a concrete substance (i.e., a person), for instance, Socrates: "When all else is stripped off, evidently nothing but matter remains … By matter I mean that which in itself is neither a particular thing nor of a certain quantity nor assigned to any other of the categories …" (1029a11–12, 20–21, trans. Ross). Here again, through a *via negativa*, we seem to approach a kind of prime matter which on the subjecthood criterion would be substance, but Aristotle rejects this as too indeterminate to be knowable.

One other important feature of matter in Aristotle is its connection with potentiality. Aristotle develops a theory of potentiality (*dynamis*) and actuality (*energeia*) or

realization (*entelecheia*) (see *Metaphysics* 9), which is the forerunner of similar modern theories. Aristotle associates matter with potentiality and form with actuality, and he seems to suggest that potentiality-actuality and matter-form are interchangeable theories (*Physics* 191b27–29; *Metaphysics* 1045a23–25; contrast 1048b4–9). While the two theories are closely connected, they are not interchangeable. Whereas matter either lacks or has the relevant form (privation vs. possession of an indivisible form), the scheme of actuality is a more-or-less scale that allows someone to be, for example "more a man" at one time than another (when the boy Socrates grows up, for instance—a possibility ruled out in the *Categories*), while an acorn becomes more an oak tree when it is mature than when it is a sapling (*Metaphysics* 1050a4–10; contrast *Categories* 3b33–39). In this sense, the theory of actuality fills in a gap in Aristotle's account of coming-to-be by providing a basis for gradual change: it allows a sliding scale of exemplification of form in matter.

According to Aristotle, then, matter is at least relatively indeterminate, a substratum for higher-level changes, a bearer of potentiality. In its most basic manifestation, it comprises the four so-called elements. Philosophically, it answers the Eleatic Challenge of Parmenides. Scientifically, it provides the material cause for explanations, the basic "chemistry" of the *cosmos*. Form is necessary to impart order to matter, but matter is necessary to provide a subject for form. Matter retains one of the marks of substantiality, subjecthood, and constitutes one pole of reality. Eventually, Aristotle's physical theory becomes the default theory for physics and cosmology in the ancient world. His interpretation of the four elements becomes standard: earth, water, air, and fire are found in the changeable region below the moon; they undergo transformations into each other but maintain a balance of quantity of the different elements. Of the four elements, earth and water have naturally tendencies to move downward to the center of the *cosmos*, which coincides with the center of the earth; fire and air have a natural tendency upward to the circumference. From the moon outward is found a fifth element, identified with aether, that naturally moves with a circular motion east to west along with the heavenly bodies, which are also composed of the fifth element. The fifth element does not undergo transformations like the four elements. The *cosmos* is a large but finite sphere, outside of which there is nothing—no void, no place, no space (Astronomy).

On Aristotle's theory, the elements are the most basic kinds of occurrent matter (prime matter is not found separate from the elements). They do not share any one property. Earth is dry and cold, water wet and cold, air wet and hot, and fire dry and hot. The four elements correspond to the great cosmic masses: earth (at the center), water around it (in the seas), air above the water, and fiery exhalations above that. The fifth element surrounds all the others. The four elements mix to form other stuffs, such as flesh, bone, wood, and iron.

5. Hellenistic Philosophy

Epicureanism

After Aristotle, there arose the new theories of Epicureanism and Stoicism. Epicureanism did not invent a new physical theory, but rather borrowed from the Presocratic atomism of Democritus, with some modifications, and aimed to apply its insights to

ethical and human problems. Democritus held that atoms had an unlimited number of shapes. All atoms have motion from time immemorial. They sometimes collide with each other, and, depending on their shapes, they may combine into conglomerates of atoms, for instance, if they hook on to each other. They seem to have something like mass, but no weight, since they move freely in an infinite void.

Epicurus, in contrast, ascribes weight to atoms. He envisages them as originally falling down together in a parallel track to each other. But at some point, one or more atoms swerve from a determined course, collide with other atoms, and begin a cosmic process whereby atoms could collect in some regions to form a world (Lucretius 2.216–224). Worlds come together as a result of chance interactions and eventually perish when the forces holding them together give way to stronger forces. What it means for atoms to fall down in an infinite void remains unclear, as does the need to posit a stage of parallel motions prior to the swerve. Epicureans use the swerve not only to account for cosmogony, but also to account for the individual's ability to act freely, without being determined by prior states of affairs: causal inputs into the mind do not determine a unique outcome, given the power of soul atoms to deviate in their paths (Lucretius 2.251–293). Whether replacing determinism with indeterminism solves the problem of free will and responsible action is questionable.

In any case, the Epicureans are materialists in a fairly modern sense, in holding that the ultimate reality is material, and reducing all phenomenal action to motions of material components (whether these motions are deterministic or not). The atoms have certain properties, including size (they are microscopic but not all of the same size), shape, and weight (Epicurus, *Letter to Herodotus* 54). They have Eleatic properties: they do not come into being or perish; they are completely full of being; they are changeless (in internal character) and complete (in themselves) (Lucretius 1.503–550). They are not, however, incapable of any change, for they do change positions in the void, that is, they move in place. Atoms do not of themselves have color or smell or taste; these sensations arise from interactions between outside stimuli and sensory organs. Thus we can make a distinction between something like primary and secondary qualities, where only the former are real, or have a counterpart in the real world, while the latter are mere appearances.

Unlike some other theorists, for whom matter is a merely passive and potential entity, for the Epicureans all action and reaction are found in atoms and, hence, in bodies. The void itself is completely incapable of action, only allowing the motion of atoms (Epicurus, *Letter to Herodotus* 67).

Epicureans can deal with the great world masses of earth, water, air, and fire without positing special elements. Rather, bodies of the same general size and shape tend to collect in the same areas because the forces acting on bodies sort them in a similar way. As for specific physical or astronomical theories, Epicureans tend to avoid committing themselves to any particular theory, as long as competing theories show how natural forces lead to the problematic phenomena. The object of theorizing is not to solve all problems, but to remove the fear of supernatural interventions, thus allowing one to live a tranquil life without superstitious fears.

Stoicism

Zeno of Citium founded the Stoa in Athens about the same time as Epicurus organized his Garden. Whereas Epicurus had borrowed his physical principles from Presocratic

atomism, Zeno borrowed his physical principles from Heraclitus. While atomism had been developed in a systematic way by Democritus and others, Heraclitus, to all appearances, offered insights rather than systematic constructions. Thus Zeno likely had to do a good deal of reconstruction and innovation. He developed his Heraclitean physics as a version of material monism, with fire, of course, as the fundamental form of matter.

The Stoics recognize the canonical four elements and, like Aristotle, consider them to be impermanent, undergoing transformations into one another. Nevertheless, fire occupies a special place in the set of elements as the element par excellence, the most active, and the one that at times makes up the totality of matter (*SVF* 2.413); for there is a cosmic cycle during which all the elements return to being fire, and no other element exists. Consequently, the world, with its different elements and heavenly bodies, burns up in a conflagration, after which the world as it was is reborn (*SVF* 2.625).

The Stoics distinguish between elements, which have form and are perishable (individually), and principles, which are without generation and destruction, and also without form. There are two principles: what acts and what is acted upon. The latter principle is matter. Being purely passive, it has no shape or motion and must be acted upon by an agent or active principle. The active principle is identified with reason and is recognized as God (*SVF* 2.299, 300; *SVF* 1.88).

In singling out two principles, and making them formless, the Stoics in a sense treat the principles as abstractions. In fact, matter and reason are never found separated from one another. We can distinguish them by an act of judgment, but we cannot locate them apart from one another. Thus the Stoics recognize prime matter as a principle but, like Aristotle, they declare that it never exists in a state devoid of some kind of form. There are four elements, each with its own character, and of these fire and air are the most active. These are capable of shaping and informing physical objects. But in the ultimate analysis, there is just prime matter and God, the passive and the active, with God imparting to matter whatever form and structure it needs to have to fulfill its role. God is purely immanent and ubiquitous. Matter is also ubiquitous within the world.

Matter, in a sense that is clearly indebted to Aristotle, serves as a fundamental principle of Stoicism, as the real basis of all change. Like Aristotle, the Stoics maintain that there is radical change of one element to another without violating the Eleatic Challenge. Something is always there as the substratum; it is never found as a pure potentiality, but it always persists through the change while new forms manifest themselves in it.

6. Neoplatonism

In the third century CE, Plotinus develops a spiritual kind of Platonism stressing a hierarchy of realities, or hypostases, starting from the One, which overflows to give rise to Mind, which in turn overflows to give rise to Soul. Yet Plotinus is deeply indebted to Aristotle for his metaphysics, and he sees that he can account for the world of change adequately only by positing matter. He does, accordingly, argue that matter exists, providing the substratum for forms (*Enneads* 2.4, "On Matter"). He identifies matter with the substratum, and also with Plato's receptacle. Forms exist; but where there are Forms, there must be something which is formed, and that is matter. For Plotinus, matter is what-is absolutely unqualified, deprived of all quantity, dimension, shape, quality, and so on. "And matter must not be composite, but simple and one thing in its own nature; for so it will be destitute of all qualities" (2.4.8, trans. Armstrong). Everything determinate

and intelligible about matter must come from form. We can understand matter only by thinking away all definite characterizations of things. Matter is in its own nature unlimited (2.4.15).

Plotinus also adds an ethical dimension to his discussion of matter. Matter, as the unlimited, is completely deprived of form, order, and intelligibility. Since these are the sources of good, matter is the source of evil. Plotinus devotes a treatise to arguing for the negative value of matter (1.8, "On What Are and Whence Come Evils"). Whereas the One is to be identified with Plato's Form of the Good, as a transcendent reality and value, if evil exists, it must belong to things that are not, though not to things absolutely non-existent. It must be something unlimited and without form and order. Souls become evil by looking to becoming, "and the principle of becoming is the nature of matter, which is so evil that it infects with its own evil that which … only directs its gaze to it. For since it is altogether without any share in good and is a privation of good and a pure lack of it, it makes everything which comes into contact with it in any way like itself" (1.8.4, trans. Armstrong). Since good is order and intelligibility, evil is the lack of these, a kind of ontological deprivation. Plotinus sees matter as playing a role in the world, but as occupying the lowest rung of existence, and accordingly providing the source of evil in the world.

Plotinus and his numerous followers added to Plato's ontology a theory of matter inspired by Aristotle, but in the process they managed to magnify Plato's other-worldly tendencies by making matter the source of evil.

7. Christian Thought

The rapid growth of Christianity eventually brought Christian intellectuals into confrontations with philosophical schools. The one radical change Christians introduced, on the basis of a (perhaps extreme) reading of the Hebrew creation story, was a claim that matter was created *ex nihilo*, by an all-powerful God (Tatian, *Address to the Greeks* 5, 12; Tertullian, *Against Hermogenes* 33, 45; Gregory 2007, chapter 13). Most Greek cosmogonies stressed natural processes that led to the ordering of the world, though Plato, for his part, posited a creator god, the Demiurge, who organized (but did not create out of nothing) pre-existent materials into the *cosmos* (see Sedley 2007). For the first time, Christians envisaged a beginning to time and all existence (except for the existence of God). On the new model, the creation of matter was the first stage of a teleological construction of the world.

Christian intellectuals tended to find Plato's theories, especially his moral position, congenial, and eventually combined their theology and cosmology with Platonic principles, specifically Middle- and Neoplatonic principles. But they faced the problem of reconciling the theory of matter with the goodness of God: how could a good God create something that was, in its nature, evil, as Platonists claimed matter was? God looked over his creation in the beginning, "and, behold, it was very good" (Genesis 1:31). Augustine (354–430 CE) points out that all created things are good insofar as they exist. He recognizes a hierarchy of beings, along with the Neoplatonists, by whom he is deeply influenced, but he insists that all things have goodness in a way appropriate to them. Evil is a privation of good. For Augustine, however, this kind of evil is not inherent in things but results from corruption or sin (see Augustine, *On the City of God* 12.2–5).

8. Summary

Matter plays an important role in Greek philosophy from the beginning to the end. Material principles provide the starting points of explanation in Presocratic philosophy. Parmenides criticizes what he perceives as incoherencies in the treatment of these material principles. As a result of his criticisms, post-Parmenidean philosophers posit the existence of a plurality of kinds of matter which are changeless in their natures, and which comprise the world. The most influential pluralist theory, that of Empedocles, posits four elements, which are taken up by most subsequent theorists in some version or other.

Plato attributes reality not to material but to ideal principles, the Forms, which seem to be instantiated in changeable material natures, though he rarely focuses on the latter. Aristotle, by contrast, develops a theory that makes use of both material and formal principles. Matter (which he names *hylē*) is the substratum for substance and, more generally the substratum for any change, which persists throughout that change. Coming-to-be is the replacement of a privation by a form in the matter. Thus Socrates' matter changes from being not-human to being human, perhaps at conception. Aristotle's scheme answers the Eleatic Challenge: How does what-is come from what-is-not? There is something there all along, namely, the matter; what-is-not, namely, the privation or lack of form, is replaced by the form. The final state of a coming-to-be is a substance, which can be analyzed as a form in a matter. Matter is the passive, unintelligible principle which grounds the substance's potentiality; form is the active, intelligible principle which actualizes the potentiality. Matter is a necessary principle in any change and a necessary component in any (or almost any) substance.

After Aristotle, the Epicureans have little to say about a general theory of matter, but through their atomism they make material principles the basis of all reality. The Stoics maintain something like prime matter as an abstract principle which, combined with God, comprises reality. The Neoplatonists also recognize matter as an abstract principle, which, as the lowest rung of their ontological hierarchy and the most indeterminate, is the source of evil. Christian theorists adopt much of Neoplatonic theory, but insist that matter is created by God *ex nihilo*, and as a necessary part of creation, is inherently good, not evil.

On all of these theories, matter forms the lowest level of "being" in the universe, the foundation of all reality. On all but the Christian theory, it is everlasting. On some theories, matter is changeless in its nature; on some, it can transform itself into other kinds of matter. But *some* kind of matter is always present. On some theories, formal principles shape matter into higher-level compounds and compositions. On some theories, the changes of matter occur by chance; on some, a divine craftsman or providence shapes its ends. In any case, matter becomes a starting point for all natural theory. In antiquity, matter never quite stands on its own two feet, but it is always correlated and contrasted with form, void, reason, or intelligibility. In modern philosophy and science, it will become increasingly disconnected from form, as well as from space, reason, agents, and purposes, to be a contender for the title of substance or ultimate reality, the one role Aristotle saw it as unfitted to fulfill.

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For a collection of essays on matter, McMullin 1963. For theories of matter in the Presocratics, see Graham 2006, criticizing the more traditional views of Jonathan Barnes, *The Presocratic Philosophers* (revised edition, London: Routledge & Kegan Paul, 1982). On Aristotle, see David Bostock, *Space, Time, Matter, and Form: Essays on Aristotle's Physics* (Oxford: Oxford University Press, 2006) and Graham, *Aristotle's Two Systems* 1987. Richard Sorabji 1988 studies a number of problems concerning matter.

NOTES

1 Henricus Stephanus' 1578 edition of the works of Plato provides the modern system of reference and organization; pages were further subdivided into five equal sections (a–e).

CHAPTER 3

Motion and Energy

Jean De Groot

1. Introduction

There were two sources for the treatment of motion in the fifth to third centuries BCE. One was a fluid set of mathematical descriptions of local motion that were called mechanics (*mēchanica*) by the mid-fourth century. Aristotle ranked *mēchanica* among the other mathematical sciences, like geometry, astronomy, and optics (*Posterior Analytics* 76a23–25, 78b35–39; *Metaphysics* 1078a9–21). The second source was philosophical discourse about natural things (*ta physica*), which considered what motion is and why it occurs. Both lines of investigation originated from experience, but, as the centuries passed, the concepts of the philosophy of motion became more allied with metaphysics than mechanics, while the province of mechanics became almost entirely the design of machines.

The ancient science of motion can hardly be said to have a beginning, since practical mechanics goes back to primordial experiences of parrying forces acting upon the human body, for example, moving a boulder from a field or prevailing in hand-to-hand combat. Ancient literary sources describe the experiences of handling force as routine or rule-based without making them mathematical (e.g., chariot-racing: Homer, *Iliad* 23.335–345; Plato, *Ion* 537a–d). Importantly, ancient mechanics never lost this empirical, experiential thread.

Two periods can be distinguished in the ancient study of movement. The first begins with the earliest investigators of motion, known to us primarily as astronomers. An important but still enigmatic figure of the early history of mechanics is the philosopher and mathematician, Archytas, ruler of Taras (Tarentum) in southern Italy in the late fifth century BCE. Archytas influenced Plato and Aristotle greatly, though Plato resisted Archytas' philosophy and methods (Huffman 2005, 34; Lloyd, 1990; Zhmud 2006, 93). A generation after Plato and Aristotle, in the *Mechanics* (circa 300–270 BCE) attributed to Aristotle's school, two key mathematical principles of movement are recorded:

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the tetragon of movements, similar to the modern parallelogram of forces; and the moving radius principle, a mathematical account of the power of the lever. This second principle had been stated already by Plato (*Laws* 893d1–5) and Aristotle (*On the Heavens* 289b15–35). At the Lyceum, Aristotle's school in Athens, the philosophical study of motion at first profited from mechanics. Aristotle sought to bring a mathematical style of thought, proportional reasoning, into the formulation of the basic concepts of natural philosophy in a kind of unified field theory of all types of change. This first period culminates with Archimedes, whose statement of the law of the lever in terms of equilibrium on a balance redirected analysis of the lever toward the notion of centers of gravity.

The second period is characterized by a separation of mechanics and natural philosophy. Aristotle's successors as scholarch of the Lyceum, Theophrastus and Strato, took his generalization of movement as largely sufficient for all types of change. Strato focused on philosophical puzzles still present in Aristotle's philosophy of motion. Epicureanism and Stoicism finally pushed aside Aristotle's naturalistic philosophy in a declining Athens (Grayeff 1974). Mathematical investigations shifted to Ptolemaic Alexandria. Later, as the dominant Platonism of the Hellenistic period became increasingly otherworldly (first to sixth centuries CE), Plato's interpretation of mathematics as ideal and immutable became an intellectual commonplace, never to be dislodged. In this environment, the kinship of mechanics with machine technology made mechanics an unlikely source for true and universal science. The subjects of mechanics were machines for war, building, or public works. The key mechanician of record from this period is Hero. Hero was interested in why machines work, so theoretical mechanics did not disappear. The underlying concepts of mechanics in this second period, though, had already been achieved and were in place by the death of Archimedes.

We will consider first the most ancient mathematical mechanics, then basic philosophical ideas about movement, returning by means of Archimedes to Hellenistic mechanics.

2. Mathematical Mechanics up to Archimedes

The geographical setting for the early history of mechanics was not Athens or even mainland Greece but the Greek colonies, situated both east in Asia Minor and its nearby islands, Samos, Chios, and Rhodes, and west in southern Italy and Sicily. We have only little information about the contribution to a general science of motion that might have been made by the earliest scientists from the colonies of Asia Minor. For the most part, later testimonies treat these thinkers as astronomers and mathematicians. Early on, however, mechanics and astronomy shared a mathematical principle. Despite the difficulties attendant upon the task (Netz 2002; Bodnár 2007), establishing the migrations and possible communication among the reported astronomers is of interest for reconstructing ancient mechanics.

Aristotle's student Eudemus was the Lyceum's preservationist of all things astronomical and mathematical. Eudemus reports that Anaximander was the first to concern himself with the "magnitudes and distances" of the planets, a report of note for mechanics too. Hippocrates of Chios (*fl.* 440-400 BCE) visited Athens, bringing with him the astronomical knowledge of his elder, Oenopides of Chios. Pursuing the mathematics of heavenly movement and active in the eastern colonies from the fifth to second centuries BCE are Callippus (Cyzicus), Autolycus (Pitane), Aristarchus (Samos), and Hipparchus (Rhodes).

There are no reports of any contribution to mechanics by Pythagoras. Indeed, whether Pythagoras made any specific mathematical discoveries is a question presently undergoing scholarly reassessment (Burkert 1972; Zhmud 2006; MATHEMATICS). Pythagoras migrated from Samos in Asia Minor to Croton in southern Italy around 532 BCE, where he established a religious cult that was also meant to foster mathematical research. At the least, his activities in southern Italy contributed to the mathematical style of thinking about the natural problems practiced there.

Eudoxus, a mathematician and astronomer from Cnidus, is reported to have studied geometry with Archytas in Taras in southern Italy (Diogenes Laërtius 8.8.86; Zhmud 2006, 96). Eudoxus, in Athens for at least a short time, was an important influence on Aristotle. By this time, astronomy and mechanics shared a fundamental kinematic principle with several mathematically equivalent versions:

1) Points on a line rotating about one stationary endpoint are all moving at different speeds.
2) Points on a rotating disk, being bound to one another, move faster or slower depending on their distance from the center of the disk.
3) Concentric circles rotating together move at different speeds. That is, in the same time the moving circles describe arcs that are smaller or larger in proportion to the length of their radii.

Placing this principle in the astronomy of "the mathematicians" Eudoxus and Callippus, Aristotle made it a centerpiece of his own conception of the heavens (*On the Heavens* 289b34–290a5, 291b6–10). For the sake of simplicity, we refer to the principle as *MR/CC*—moving radius/concentric circles.

MR/CC in formulation 1) is central to the explanation in the Aristotelian *Mechanics* of why a lever (*mochlos*) lifts a heavy weight with a smaller force than would be required by a direct application of force to the weight. The problem is overcoming impediments to human action, something made explicit at the beginning of the *Mechanics*. We should imagine different lengths along a common diameter of a circle but on opposite sides of a center **A**, a fulcrum (*hypomochlion*) (Figure 3.1). A lesser weight applied at the longer end of a beam will move a greater weight at the shorter end, the beam moving in a plane around the unmoved **A**. This conception—of either a lever or a balance of unequal beams—takes movement along opposite arcs as the indicator and measure of inclination (*rhopē*) to move.

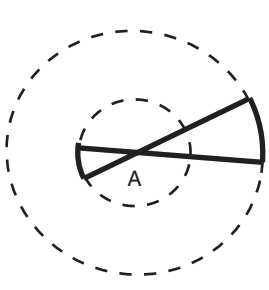


Figure 3.1 Action of leverage on a balance of unequal beams.

Mechanics was probably written after Aristotle's death (322 BCE) by someone in his school, but various passages in Aristotle show his familiarity with *MR/CC*. He

recognized the correlation of smaller to larger movements in leverage phenomena and sought to apply the underlying idea of mechanical advantage to animal movement and other natural powers, where a similar amplification of effect takes place (*Movement of Animals* 701b23–32; *GA* 2.1, 734b9–19).

In astronomy, the principle helped to set the order and relative speeds of the sun, moon, and wandering planets. In accordance with formulation 1), there is an outer collection of distant stars moving faster than other brighter and nearer objects in the sky. That the most distant circle or sphere moved fastest around a common center, the earth, accorded with astronomical observation of the pinpoint stars moving in concert relative to the other heavenly bodies. Movement of the stars manifests the greatest regularity and speed, and so, on *MR/CC*, the stars would be furthest away. Taking this as given, distances and base speeds of the planets could be determined *relative to* the most regular movement of stars. This was a theme of Eudoxus' astronomical treatise, *On Speeds*, only a small portion of which survives (Simplicius, *On "On the Heavens"* 492.31–497.8 Heiberg; Lasserre 1966). Even if the planets move more slowly, however, *MR/CC* should simply keep the interior bodies in the same position relative to the more distant stars from our perspective on earth. That the planets wander and move even more slowly gave ancient astronomers the problem set for planetary investigation, namely, to combine other movements of the planets with the movement they shared with the outermost sphere of stars (that Plato set the problem of astronomy as explaining all heavenly movements by uniform circular movement—concentric spheres—is disputed as myth-making of the early Academy: Zhmud 2006, chapter 3; see also Astronomy).

The author of *Mechanics* presents another mathematical principle of motion in close proximity to his extended account of the moving radius principle: the tetragon of movements (*Mechanics* 848b15–28). The beginning point and endpoint of a rectilinear movement (or any part of the movement) are taken to subtend a diagonal of the four-sided rectangular plane figure (Figure 3.2). Two different sides of the tetragon then represent movements the body is undergoing. For any distance covered along the diagonal of the tetragon, the ratio of two sides of the movement's complement tetragon is always the same. So, $\frac{EJ}{JG} \propto \frac{EZ}{ZD} \propto \frac{AB}{BH}$. There is a similar rule known in modern mechanics as the parallelogram of forces. (The ancient author does not use the word *parallelogramma*.) In the ancient account, the sides of the tetragon represent not forces but movements or distances covered in a time. In *Mechanics*, the author says that the body traveling along the diagonal moves "with two movements according to the ratio of the sides" (848b24). Even a body going in a straight line is construed as moving with two motions.

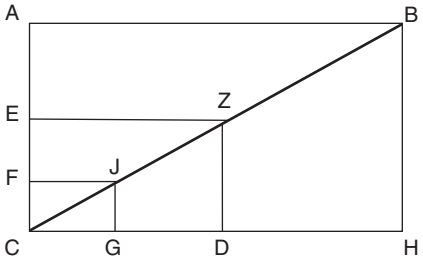


Figure 3.2 Tetragon of movements.

The first extant ancient treatise on this subject, *Mechanics*, is also the first text wherein the tetragon of movements appears in a clear mathematical formulation.[1] *MR/CC* appeared earlier in Plato and Aristotle, as we have seen. The tetragon of movements seems to us simpler, so one would expect it to be prior in conception to the moving radius. *MR/CC* may have been prior in ancient understanding, nonetheless, given its accessibility in leverage phenomena and its relevance to comparison of the speeds of heavenly bodies. The two principles for rectilinear and circular motion, respectively, must have had a fairly close relation historically, however, because both principles understand movement ongoing in terms of ratios of straight lines constructed around the locus of movement.

When the author of *Mechanics* says that the lever allows one to move large weights with a force (*rhopē*) much smaller than the force of the weight, he demonstrates this in terms of rectilinear elements of the circle. Similar arcs are those for which the following proportion holds: as in Figure 3.3, $\frac{BK}{KG} \propto \frac{XF}{FH}$, and arcs *BG* and *XH* are covered in the same time by the points carried along on a radius, *AB,* that are moving at different speeds. The author treats this correlation of arcs from different circles as part of the theory of the lever, but the solution would be relevant to how long a lever must be in order to move a given weight and where the fulcrum should be. It would also be relevant to complex machines combining leverage with a wheel and axle that transfers mechanical advantage into a different plane. From a theoretical standpoint, however, the proportion given in *Mechanics* 1 hardly seems superior to the simple rule given by Aristotle that arcs covered in the same time are those that share the same two radii (Figure 3.4; *On the Heavens* 290a2–5). That radii subtend concentric arcs covered in the same time is seen to be true by mere inspection of the geometry of the circle, and so one might wonder why *Mechanics* resorts to proportions of straight lines interior to the circle at all in the theory of mechanical advantage.

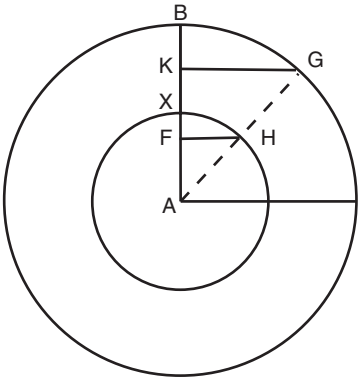


Figure 3.3 Proportion of straight-line movements contributing to circular motion in *Mechanics* 1.

The key to the otherwise superfluous cogency of the argument in *Mechanics* 1 is sameness of ratio. This is the link between the moving radius and the tetragon of movements—and, notably, between them and a report about Archytas. Let us then step backward a generation to consider one aspect of Archytas' expertise in ratios and proportions. This glance back to Archytas will show how circular movement and sameness of ratio were allied in the study of movement early on and also how broadly circular motion was construed.

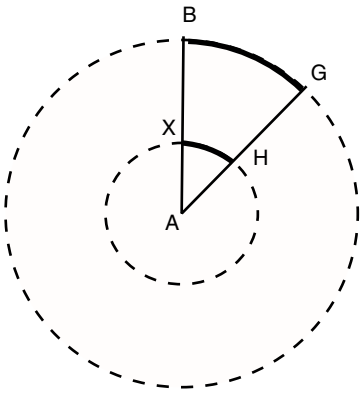


Figure 3.4 Arcs covered in the same time share radii. (Aristotle, *On the Heavens* 2).

Archytas of Taras, an older contemporary of Plato, is reported by Diogenes Laërtius to have first systematized mechanics (8.79–83; see Huffman 2005, 80–81). Archytas' mathematical ingenuity is well documented along with his use of moving mathematical objects in geometric constructions. Archytas was also interested in why unspecialized organic tissues—plant stems, animal limbs, the thorax—grow in a rounded shape (pseudo-Aristotle, *Problems* 915a26–32). He attributed the circular growth pattern of unspecialized organic tissue to a "proportion of equality" belonging to circular movement. Archytas says that every movement is characterized by a proportion of equality but that the proportion for circular motion is the only one that yields movement that "turns back on itself" so as to make curved shapes.

With some confidence we can understand Archytas' proportion of equality as being the sameness of ratio. Archytas is documented as an originator of the arithmetic, geometric, and harmonic means. The geometric mean is a pair of ratios that are the same and share one term, e.g., $\frac{a}{b} \propto \frac{b}{c}$, where b is the mean, or shared, term. Sameness of ratio may be more general, however, and not involve a mean term:[2] $\frac{a}{b} \propto \frac{c}{d}$. The simplest formulation of same ratios for the case of circular growth would be that a growth expansion is *circular* when ratios of the different distances from the center of a stem of earlier and later curved growth are the same as ratios of arcs of the curves having those radii.[3] We can imagine Aristotle's dual radii of Figure 3.4 transposed to a cross section of a stem or rings in a tree stump: in that case, $\frac{AB}{AX} \propto \frac{arc\ BG}{arc\ XH}$. A more precise and versatile formulation would involve the segments of radii and perpendiculars used in *Mechanics* 1. Whatever the exact character of Archytas' proportion of equality, it likely involved comparison of ratios of rectilinear elements of the circle.

What we have seen so far is that, early on, accounts of movement were given in terms of the trajectory or traces of movement. Geometry lent intelligibility to movement, by providing an underlying geometrical structure of element-movements that could combine and were represented by lines. Resultant movements could be either straight or curved. These ancient accounts are best described as *kinematic*. In contrast to dynamics, where forces or causes are part of an explanation, kinematics accounts for readily perceivable movements, using mathematical tools capable of tracking differences or changes in speeds. Kinematic reasoning can be quite powerful when it includes the idea of an

invariance present through a single change or across different changes. An invariance appears in change through a predictable mutual *covariance* of a finite number of factors contributing to change. This is basically an idea of equilibrium (*isorrhopia*) present in change itself. Covariance did figure in ancient mechanics.

3. Philosophical Ideas about Motion

Concepts of movement and power accompanied this beginning of mechanics. Archytas thought movement occurs because of something unequal or uneven in what undergoes movement or in the situation in which movement occurs (DK 47A23). The disordered, irregular, or unequal is the cause of movement. Movement itself, though, has the proportion of equality (A23a). For Archytas, movement is an ongoing dynamic reconciliation of what is in imbalance.

Plato is reported by Simplicius to have held the opposite of Archytas' view (DKA23a). Movement itself is disordered. Permanence and immutability are superior. In Plato's *Republic*, the very fact of change in material things makes them unsuitable objects for anything but opinion, which is unreliable (478a–c). In the *Sophist*, however, Plato considers whether movement, along with Difference and the Same, might have to be included in the realm of what is (248d6–249b6) because soul is the principle of life and intelligence. Since life is activity, soul must involve movement.

Aristotle knew the work of Archytas well, and he took up the idea of movement as orderly. A focus on the order in movement is reflected in Aristotle's answers to Zeno of Elea, who had said that movement either could not occur at all or could not be completed. Whether a body is resolvable to indivisibles (*atoma*, un-cut) or is infinitely divisible, movement is impossible, Zeno argued (*TEGP* 15–22). In his response (*Physics* 6.9–10), Aristotle said that movement and time follow the structure of magnitude (*megethos*, size of body), which can always be cut again however many cuts one takes. This is an idea of the infinite as potential, because the being of the infinite depends on a process of dividing an already limited magnitude over which the movement happens. The movement is divided into smaller and smaller portions like the magnitude over which movement occurs, so motion is never infinite in the sense of going on indefinitely. There is no *actual* infinite, in the sense of infinite addition, because the universe itself is finite. Aristotle's notion of infinite divisibility pertained to the structure of continuity in real things (*Physics* 3.4–8; 5.3; 6.1).

Aristotle also regarded the parts of movement as ordered in relation to the culmination of the movement. He said that, whenever a movement is orderly in the sense of having a direction and the parts of the movement serve the accomplishment of something intelligible and beneficial, then the order was for the sake of that end, or *telos*. This claim is argued in *Physics* 2.8 in terms of a contrast of the regular and the coincidental in natural change.

In his writings where living things are the starting point, change is understood in terms of a set of determinable causes (*Physics* 2.4; MATTER), which should be the objects of biological research. The *telos*, or natural culmination (final cause), of a biological change, is first of all an entity, a functional organism, but to an even greater extent the organism's actions in execution of its way of life and reproduction of itself. For this activity, Aristotle appropriated the word *energeia*, the origin of the English word

"energy," and he coined another word, *entelecheia*, which he understood as activity that executed an achieved *telos*. Both of these terms are translated as "actuality." Aristotle distinguished actuality from movement by whether or not the *telos* was present in the action itself. Movement occurs because it is tending toward some functional end, the achievement of which will substitute the actuality of the end for the movement that led up to it. Some activities can be viewed as either an actuality or a movement. A spider builds a web as part of its particular mode of life, so its building a web is an actuality, part of a healthy and well-ordered spider life. At the same time, building a web has a beginning, middle, and end, and to this extent it is a movement embedded within the spider's overall *telos*-activity (199a20–30).

This biologically inspired model of movement presented in Aristotle's *Physics* 2 complements his philosophical analysis of movement in terms of substratum and form in *Physics* 1. These two books were written relatively early in Aristotle's career, though he may have revised them later. *Physics* 2, in particular, answers inadequacies of Presocratic natural philosophy cited by Plato in his *Phaedo*. There, Socrates says that explanation by materials and random movement cannot account for why something exists, nor can it say why it is better that a natural entity be as it is or why its activities and movements are better because of being performed this way rather than some other (97c–98b6). Clearly, though, it is better for the spider to gain sustenance with a spider web than simply chasing down its food as a lion does. For Aristotle, *telos* is that "for-the-sake-of-which" movement occurs and is thus a reason for change that is rooted in the good of individual natural things. Finally, all things aim to share in the divine (*On the Soul* 415a26–b2; see also Nature and the Divine). Explanation of change in terms of a natural culmination that is in some way a reason or good is called teleology.

Aristotle's definition of movement linked a movement to its *telos* while acknowledging that movement is only on the way toward that *telos*. He said that movement is the actuality of what is potential insofar as it is potential (*Physics* 201a9–15, 227–29b5). Whatever is changing has with its contributing causes everything needed to reach an end, if nothing impedes it. This is what it means for something to be potential (*to dynamei on*). The potential is, for Aristotle, a way of existing, not a logical possibility, and potentiality indicates the presence of concrete natural materials and conditions that are necessary for the end to be accomplished. Under the influence of an agent cause (often understood as the cause of *existence*), a movement brings what is potential to actuality (*energeia*). So the potential involved in the definition of motion is the potential to be some actual thing which incorporates the *telos* proper to that thing. Movement actualizes that very potential (there is not a second potentiality just for movement). Motion is a mode of actuality but one that is by its nature an incomplete actuality (*Physics* 201b31–33). However elusive, Aristotle's definition of motion recognizes over against Parmenides and Zeno that movement cannot be denied as a reality.

A key concept of *Physics* 2 is the definition of nature to which motion is central. Aristotle defines nature (*physis*) as an inborn principle of movement within a thing (192b21–23). Natural things (*ta physica*) move under their own power, in contrast to crafted objects, which have no inborn power of movement (192b18). Nature is a term of contrast, then. Aristotle thinks we easily identify natural things. Referring to Parmenides, Aristotle says it is obvious that there are things that move naturally, so that the study of physical things is concerned with principles of exactly this sort of movement (185a5–14). Matter and form are both regarded as the nature of a thing, and

Aristotle's four causes further explicate these two natures responsible for movement and the identity of natural things.

The idea of an inborn principle of change applied to local motion led Aristotle to distinguish natural from forced motion. Force (*bia*) is a cause of motion acting from outside a natural body. Lifting a heavy object in the air is forced motion, as is an animal destroying its prey for food. Aristotle rejected the atomism of Leucippus and Democritus because it made all motion forced, he said. This is because the atoms all act on one another externally (*On the Heavens* 300b8–16). Aristotle countered that, to give a physical account, one must decide which movements are natural (300b13–14). Thus he saw Democritus' idea of a ceaseless undetermined movement of atoms as too feeble and spare to account for the variety and order of natural movements.

This evaluation of external movers did not prevent Aristotle from treating the forced movements in simple machines, like the lever, as clues to how powers (*dynameis*) are in natural things. The power of leverage, as even the construction of automatic puppets showed (Berryman 2003), generates much out of little. Something similar occurs in the growth of an animal from seed. "Artificial" living things, the *automata*, move by duplication and enhancement of an initial movement. Aristotle knew that the moving radius principle lay behind the effects of automatic puppetry. Similarly, natural powers are not nothing before they act, but they are little or not much (*GA* 734b10–12, 741b7–8). Furthermore, even the powers of the craftsman must be drawn from nature. If a ship were made by nature, it would be made in the same way it is built in the shipbuilding craft. Craft completes nature (*Physics* 199a15–17, b26–30).

Modern scientists for the most part limit their considerations of motion to what Aristotle called local motion (*phora*), or movement from place to place. Aristotle's account of local motion is not derived from his teleology but has different starting points. In *Physics* 4–6, Aristotle relies on Eudoxus' analytic tools of ratio and proportion for a model of change. He considers what will happen when presently acting forces increase or decrease, or how speeds will change when some fraction of the time or the weight is taken or when one factor is multiplied while others remain the same.

In many passages of *Physics* and *On the Heavens*, Aristotle uses letters—*A, B, Γ*—to stand for weights, times, speeds, or just "things" involved in a change. Because of this use of symbols in an argument about covariance, some have thought that there are extractable "laws of motion" in Aristotle's physics (Drabkin 1938). The claim is strained and relies too much on a modern idea of physical law. An appropriate notion for thinking about mechanics in Aristotle is the idea of "background knowledge." Knowledge (*gnōsis*) that could become science (*epistemē*) is first held in experience as memory and then in intellect as fragmentary and rudimentary concepts. This knowledge is brought to bear in explaining new situations. Aristotle drew upon background knowledge and used a universalizing mathematical style of reasoning to extend knowledge, moving between what he himself defined as levels of experience and knowledge (*Metaphysics* 1, *Posterior Analytics* 2.19).

Let us consider some of the concepts that emerged from the philosophical development around mechanics. A key concept in Aristotle and the Aristotelian *Mechanics* is *rhopē*, a term that can be translated as force but which has a connotation of power sufficient to initiate movement or to alter movement under way. For example, *Mechanics* 8 considers a weight at the top of a vertical diameter of a circle, poised so as to be motionless. If this body receives a slight impulse:

> … As soon as it is set in motion, there is more weight on the side to which it is moved, as though it had an inclination (*rhepon*) in that direction. Hence, it is easier for one who pushes it forward to move it; for it is easier to move any body in a direction to which it inclines, just as it is difficult to move it contrary to its inclination (*rheopē*). (851b26–33)

This passage shows why a line wrapped around a winch is easier to move in hauling a load against its weight than simply pulling on the line hand over hand. In this case, *rhopē*, inclination or advantage in movement, comes from a combination of shape, position, and weight. Aristotle himself uses the term *rhopē* similarly in *Physics* 4.8:

> We see that [bodies] having a greater impulse (*rhopē*) either of weight or of lightness, if they are alike in other respects, move faster over an equal space, and in the ratio which their magnitudes bear to each other. (216a13–16)

Here, we catch a glimpse of Aristotle's conceptualization of faster and slower in terms of variables in proportion. Higher speed is described in terms of inclination (*rhopē*), in effect superior active weight. Aristotle uses this insight to explain projectile motion. The force of throw adds *rhopē* to a movement-situation. The throw puts the projectile in motion but also agitates the air around it. The air around the projectile pushes on the traveling body, because the air is moving faster. By its greater *rhopē* due to speed, the air counters the downward tendency of the weight. Even the projectile's shape may contribute to its *rhopē* in cleaving the air at a faster rate than it would without that shape (216a19). Aristotle says that in a void all things would move at the same speed (a20).

Aristotle's treatment of projectile movement in *Physics* 4.8 relies on implicit notions of balance, excess, and advantage in force or weight. This is a kinematic type of account. Aristotle is often said to conceptualize a case like projectile motion entirely in terms of something having the status of a local unmoved mover imprinting its form upon a moved thing. The air is unmoved insofar as it possesses a form, in this case a form of distance-to-be-covered. In contrast to this more metaphysical interpretation, *Physics* 4.8, among other passages, shows that Aristotle thought in terms of the energy of movement, either in balance or in what amounts to opposition. He treats projectile motion in terms of excess or deficit of competing movement states.

Compared to *rhopē*, two other Greek words used in mechanics, *dynamis* and *ischus*, have simpler meanings in relation to movement. As already noted, Aristotle uses *dynamis* to mean a mode of existence for materials that can be a more complex being. Organs of a particular sort have the potential to become a mammal body, for instance. Tissues have the potential to become those organs, and so on down the scale of complexity of contributing material causes. Potentiality exists on many levels. In the later *Mechanics*, however, *dynamis* is active power, a push or blow that initiates a movement. On this meaning, *dynamis* is nearly interchangeable with *ischus*, "force." The most obvious type of force is weight. On the Aristotelian theory of the *cosmos*, there was a cohort force of lightness. Aristotle preferred to describe each as a power, *dynamis*, the actuality of which has no name unless it is *rhopē* (*On the Heavens* 307b28–33).

The *Mechanics* overlays some interesting notions of force upon its kinematic account of the lever. The author says that the natural (*kata physin*) trajectory of a point on a circumference that receives a push or blow is a straight line tangent to the circle. When the push is exerted at the end of a beam fixed about a fulcrum or axis, however, there

comes into play a constraint (*ekkrousis*, 849a7) pulling the point inward (849a11–13). This makes the point on the circumference move away from the tangent and assume a curved motion around the stationary fulcrum. The constraint is greater for a point on a smaller circle nearer the center.

In the modern era, energy is associated with powers of attraction, such as gravity, magnetism, and electricity. "Electron" comes from the Greek word for amber, *ēlectron*, a fossil resin noted for its power of attraction (*to helkein*). Theophrastus classes it with other materials possessing attractive powers, among which "some say are not only hay and leaves, but also bronze and iron if light …" (*On Stones* 28.3–4). The phenomenon of static electricity is being described. The similarity to magnetism was noticed, but magnetism was not taken to be the same phenomenon. Democritus had attributed the attractive power of the lodestone to three contributing causes: effluvia (*aporroiai*) emitted from the stone, like-to-like attraction, and the fact that materials rush in to fill up a void. The idea, made clearer later by Lucretius (6.906–1089), is that effluvia emitted by the stone push away what is around the natural magnet, creating a void into which follow the material attracted by being like the lodestone (Alexander of Aphrodisias, *Problems and Solutions* 72.28–29). The effluvia enter the pores of the attracted iron. Pores play a role in accounts of magnetism from Empedocles through Aristotle's successors, Theophrastus and Strato (Berryman 1996, 88–91). Common measure and superposition were also involved in the ability of an effluvium to bear particles into pores (*Problems and Solutions* 72.15–17). Alexander of Aphrodisias raises a number of problems for accounts by effluvia and pores, including why iron is attracted but not other metals like silver or lead. Alexander notes that the stone seems attracted to the iron filings as much as the iron is attracted to the magnetic stone. He also asks how one explains the attractive qualities of amber and chaff with these presuppositions (*Problems and Solutions* 72.12–26; 73.8, 26–27).

Lightning (*astrapē*) was associated with attraction phenomena only to the extent that both involved a contrast of dry and moist (Meteorology). Amber, Aristotle held, was earth from which all moisture has been extruded, making the earthy material more solid. Lightning was also defined by its dryness. Dry wind extruded from condensing clouds produced thunder as that dry wind hit other clouds. Hot wind is briefly inflamed as it hits the clouds, producing lightning (*Meteorology* 369a14–b11). Strato placed even more emphasis on dry air being forced out (*ekbiasthen*) by moisture to produce both thunder and lightning (Desclos and Fortenbaugh 2011, §52). Lightning thus involves more of an idea of violent forcefulness—extrusion or pushing—than the account of drawing or attracting given in the case of the amber, hay, or the lodestone.

In general, it seems that thinkers after Aristotle were uncomfortable with the basic notion of simple attraction either of likes or unlikes, and they sought to explain apparent attraction in terms of structure, local movement, and contact. This strategy led away from the simplicity of kinematics toward a multiplicity of explanations wherein Aristotelian concepts of form and matter lent structure to accounts of the interaction of materials.

4. Archimedes on Motion

The best-known piece of ancient mechanics is undoubtedly Archimedes' law of the lever in *On Planes in Equilibrium or Centers of Gravity of Planes*. Archimedes' law of the lever is simple as he presents it:

> Magnitudes are of like measure (commensurate, *summetra*) by their unequal weights balancing (*issorhopein*) at distances having the same ratio inversely as the weights.

That is, if a larger weight W is at distance D from the fulcrum, and the lesser weight w is at distance d, then $\frac{W}{w} \propto \frac{d}{D}$ (Propositions 6–7) (Figure 3.5; Heiberg 1910–1915, 2.133–138; Heath 2002, 192–193). A description of the absence of movement on a balance of unequal beams, this proposition is demonstrated from assumptions, the first of which is that equal weights balance at equal distances and that equal weights at unequal distances incline (*rhepein*) in the direction of the greater distance. Archimedes' second assumption is that the equilibrium of weights at a given distance from one another will be disturbed by an addition to one of the weights, and the inclination of movement will be in the direction of the addition made. This assumption shows why his proportion governing equilibrium is called a law of the lever: it supports conclusions about both equilibrium and movement on a balance of unequal beams. It is not only a change in weight that may affect balance; distance affects it too. A kinship between the dynamic formulation of the lever is found in Aristotle, the Aristotelian *Mechanics* and Archimedes' law of the lever. According to Pappus of Alexandria (*Collections* 8, 1068.19–20), Archimedes wrote a treatise on balances proving that greater circles overpower (*katakratousi*) lesser circles with the same center. This is the idiom of the Aristotelian *Mechanics* and earlier references to leverage in Plato and Aristotle. Archimedes, however, makes an important departure from the earlier tradition.

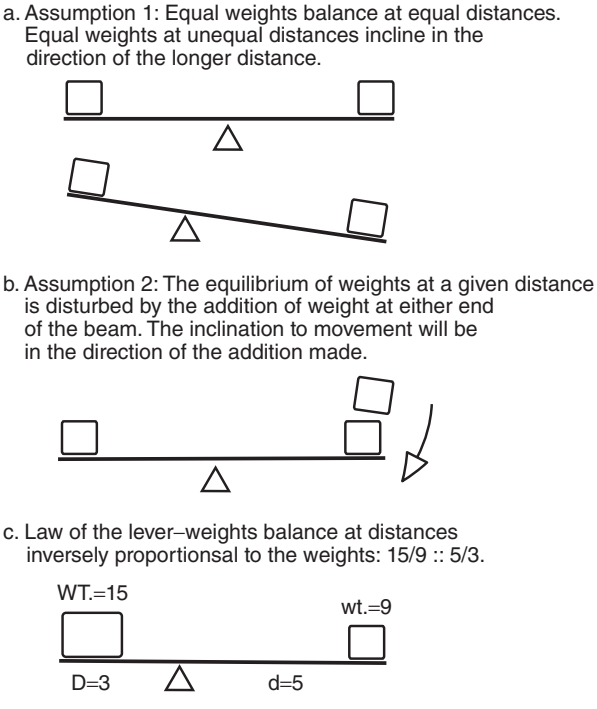


Figure 3.5 Archimedes' law of the lever.

Archimedes' law is not dependent on the geometry of concentric circles. Indeed, the treatise takes a different path toward a proportion governing movement. The inverse proportion of weight and distance for magnitudes (propositions 6–7) follows upon Proposition 4, Archimedes' introduction of centers of gravity (*centra tōn bareōn*, i.e., centers of weights). A center of gravity is a point within a body where, if the body could be suspended from a thread attached there, the body would not rotate but would remain still. Archimedes said that the center of gravity of *two* bodies, which themselves have different centers of gravity (let us imagine an oblong shell and a clam shell at ends of a mobile), is the mid-point of their respective centers of gravity. From this proposition onward, Archimedes is able to formulate his law of the lever, dividing magnitudes and multiplying centers of gravity in a way productive of theorems advancing the geometry of parallelograms and triangles (Propositions 9–13). Accordingly, the movement of the balance is placed in a new setting, given a different rationale. What is of great interest in *Equilibriums* is Archimedes' use of principles of motion governing weight as if they belong in a purely geometrical setting.

Dijksterhuis (1987, 294–295) says that Archimedes treats centers of gravity as if they were "a perfectly familiar thing," thereby suggesting a prehistory of the concept. There is evidence of this prehistory in several cases of *Physical Problems* 16, attributed to Aristotle and his school (concerning the dating of *Physical Problems* 16 and analysis of the relevant problems: De Groot 2013, chapter 7). The most telling passage asks why an unbalanced body, when thrown, rotates in its forward motion. The answer is that opposite points within the body, constraining one another as they tend to move at different speeds, naturally fall into a circular rotation around the middle (*meson*) of the body, which is as if unmoved (*Problems* 913a38–b5). The passage points out how readily circularity can result from a combination of movements. Its conception of an unmoved middle in a moving body may be part of the prehistory of Archimedes' centers of gravity. The passage shows that thinkers before Archimedes applied the principles of balance to broader physical problems.

The Method of Mechanical Theorems is a work of Archimedes discovered in the early twentieth century as part of the now-famous Archimedes palimpsest (Netz and Noel 2008). In it, Archimedes discovers theorems about the volumes of solids by a method that involved balancing solids as if they were weights, using the mathematical feint of centers of gravity. The solids are taken as composed of slices infinitely thin but still having magnitude (infinitesimals). A common axis of the two solids is the beam of the lever. Although the results of the method belong to stereometry, the *Method* deserves mention as part of mechanics for several reasons. One is the presumption of movement lying behind the notion of centers of weight. Mechanics is the *mathēma* wherein mathematical objects move. Another is the productive notion of covariance among contributing factors in a system of change. The role in *Equilibriums* and *Method* of a fulcrum and opposed distances grounds covariance in movement due to weight. Natural change and mathematical analysis are involved with one another as making up the subject of mechanics.

Plutarch recounts that Archimedes made catapults that kept the Roman forces from overrunning Syracuse, forcing upon them a siege tactic (Archimedes, incidentally, was killed in the Roman invasion of Syracuse in 212 BCE). Although Archimedes made these machines, Plutarch says that he regarded engineering as vulgar (*agennē kai banausan*) and left no treatises on the subject, preferring geometry which was unmixed with worldly

necessity (*Marcellus* 17.4). This is a model Platonic description of the higher status of geometry over mechanics. Recent scholarship offers constructive skepticism that Plutarch's testimony reflects Archimedes' genuine views (Burkert 1972; Cambiano 1998).[4] Plutarch's comment shows, though, how theoretical mechanics was hemmed in by the dominant Platonic philosophy of mathematics in the Hellenistic world. Mechanics was associated with machines, and its mathematical objects moved.

5. Mechanics in the Hellenistic Period

The mechanics of which we have knowledge after Archimedes concerns construction of machines, and thus falls strictly speaking into the history of technology. Even during Archimedes' lifetime, scientific activity had come to revolve around Alexandria under the Ptolemies. Greatly admired in Alexandria, the axiomatic approach of Euclid's *Elements* was associated with the Platonic school (Fraser 1972, 1, 387–388). This perhaps explains the slightly deprecatory tone of Archimedes' letter introducing his own mechanical method of theorems to Eratosthenes, a prominent scientist in Alexandria (*Method* 2.426.6–7). Important names in Alexandrian mechanics are Ctesibius, known only by report, and Philo and Hero, both flourishing in Roman Alexandria. Although Philo and Hero wrote about machines, it is possible to distinguish their works from practical manuals. They dealt with general principles of how machines work, while practical manuals would focus on details of construction, how to make parts function, and ways to compensate for weaknesses in a structure (Schiefsky 2008; Russo 2004; Berryman 2009).

Only parts of Philo's *Mechanicē Syntaxis* survive. Missing are Philo's more theoretical sections. Philo wished to place his work on ballistics in the tradition of theoretical mechanics, and he referred to the Aristotelian *Mechanics*. In describing catapult designs, he also had to introduce new notions relevant to the elastic materials involved, like sinews and springs (Berryman 2009, 125–126). A classic problem of design dwelt upon in this period was scale. Scaling up to a useful full-size machine from a small model involved the problem of the limits of function at larger sizes for both design and materials.

Like Philo, Hero wrote about machines but with a concern for how they work. Hero published treatises on pneumatics, mirrors, war machines, *automata*, and on mechanics proper (his *Mechanics* survives complete only in Arabic). He was the first to treat together the five simple machines, which he calls powers (*dynameis*), identifying one nature (*physis*) behind them all (fragment 2.2, 14–15). Distinguishing a rational (*logicon*) and manual (*cheirourgicon*) part of mechanics (Pappus 1022.13–1024.2), Hero took both the Aristotelian *Mechanics* and Archimedes' law of the lever as reference points for reducing the other simple machines to the lever.

Hero provides an account of dividing work by multiplying the number of machines—for example, pulleys—between a load and the laborer exerting force. The load can be moved by this means but not without an increase in the time taken. Walking the pull-rope along at a slower speed, the laborer is able to move the opposing weight (Schiefsky 2008). Hero still used the older concentric circles account of the lever as an explanatory principle. In his *Automatopoetica* (7–8; Hero 1.362–365), he invoked the rolling cone as a trope, or short-hand version, of the principle. Hero ascribed puppeteering effects to the ancients, and the rolling cone is certainly one he has in mind (De Groot 2008). The rolling cone as a trope for amplification of movement encodes information about leverage. With its stiff surface, the cone exemplifies the even distribution of force throughout

a body and the consequent fact that the same force produces different speeds in different locations of a continuous body. The cone also transfers its movement to a plane surface on which it describes circles. It is thus a pithy illustration of the ability of machines to transfer movement into different planes.

The idea that runs through all of the kinematic texts and machine designs of the ancient period is equilibrium (for the Hellenistic period, see Schiefsky 2008). Equilibrium does not, however, mean stasis, or deprivation of movement. It means there is similarity or equality (*iso-*) of force or inclination (*-rhopē*) in movement itself.

6. Conclusion

Here we have considered the study of motion as a theoretical enterprise involving both a mathematical approach and a wide range of concepts. Our account holds, as I believe practitioners of ancient mechanics believed, that the movement of mathematical objects is sometimes natural and acceptable. This reflects the grounding of basic mathematical principles in experience. Historians of early modern science often insist on the importance of the Platonizing influence in seventeenth-century theories of motion for achieving a mathematical mechanics. So it may seem surprising that the Platonic view of mathematics as immutable may have been an impediment to ancient theoretical mechanics. On the other hand, Aristotle's very success in extending proportional reasoning from local motion to many types of change made his commentators view movement more and more within a philosophical, not a mechanical, frame of reference. What is remarkable about the long history of ancient mechanics is that a few basic principles—the tetragon of movements, the *MR/CC*, Archimedes' law of the lever, and his practice of multiplying centers of gravity—remained central even as mechanics moved away from theoretical formulations. There is something basic about kinematic principles that keeps them freshly appearing in the history of science. Others have documented the influence of Archimedes, Hero, Pappus, and Vitruvius on medieval and early modern mechanics (Knorr 1982; Russo 2004). We have shown that mechanics had a longer prehistory than has heretofore been discerned.

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to Archimedes especially useful to a science or mathematics student is Sherman Stein, *Archimedes: What Did He Do Besides Cry Eureka?* (Washington, DC: Mathematical Association of America, 1999). A valuable overview of Hellenistic mathematical science is Serafina Cuomo, *Pappus of Alexandria and the Mathematics of Late Antiquity* (Cambridge: Cambridge University Press, 2000).

NOTES

1 Aristotle may have the combination of movements in mind in *Meteorology* 342a22–28, where he presents oblique motion as a result of upward and downward tendencies. Hussey affirms the connection (1991, 221), whereas Berryman disputes it (2009, 100).

2 It should be noted that the proportion sign ($\propto$) means that the *ratios* are the same ratio, e.g., $\frac{1}{6} \propto \frac{27}{162}$, not that corresponding elements in the ratios are the same.

3 That the relation of the diameter of a circle to its circumference is a constant was well known in the fifth century but was expressed by means of ratios: $\frac{D}{d} \propto \frac{C}{c}$, where uppercase and lowercase letters indicate longer and shorter diameters and larger and smaller circles, respectively.

4 In addition, it is now doubted that Eudoxus, the greatest influence on Archimedes and his method, was ever closely allied with Plato (Zhmud 2006).

CHAPTER 4

Nature and the Divine

Svetla Slaveva-Griffin

1. Introduction

Aristotle opens the *Metaphysics* with the famous summation that "all men by nature (*physis*) desire to know" (980a.1). The concepts of nature and the divine are coeval with the history of the human yearning to learn. *Physis*, the Greek word for "nature," derives from the verb *phuō* denoting "to grow, beget," related to proto-Indo-European *bhū, "can," "create," "develop" (cf. Chantraine 1999). Its Latin equivalent *natura* derives from the verb *nascor*, "to be born, be begotten." In both languages, "growth" and "becoming" educe the conceptual core of the term. On the other hand, the etymology of *theos* ("god") and its substantivized impersonal form *to theon* ("the divine") in Greek is uncertain (perhaps from *θ*f*εσος, "spirit" or τίθημι, "to place:" Chantraine 1999). Their Latin equivalents, *deus* and *div(in)um*, are traced back to the root **dyew-/diw-* referring to the main proto-Indo-European deity of the diurnal sky.[1] The etymology of the two concepts adumbrates the twists and turns of their history at the heart of which lies the premise that nature represents the physical world and what is beyond, the hyper-natural, represents the divine.

Nature and the divine are the two pillars of the Greco-Roman understanding of the universe. A comprehensive definition of the divine is found in Clarian Apollo's oracle from Oinoanda (third century CE): "self-engendered, untaught, without mother, unshakeable / admitting of no name, with many names, dwelling in fire—this is god" (Henrichs 2010, 19–20; Herodotus 2.53.2). In the Greek expression "this is god," the neuter form of the demonstrative pronoun "this" predicates the word "god" and linguistically re-enacts the intrinsic tendency of ancient thought to depersonalize the meaning of the concept from "god" to "the divine"—a tendency best formulated in Cicero: "You ask me what or of what kind god is" (*On the Nature of the Gods* 1.22.60; Henrichs 2010, 20, note 4). The abstract concept of the divine then denotes everything beyond the physical, the human,

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and the discursive. The negation of these concrete qualities, however, first depends on our understanding of this physical world and this human condition. The knowledge of the divine starts with the knowledge of nature.

The definition of nature, more difficult to grasp in comparison to the divine, can be narrowed down to three main aspects (see Vlastos 1975; Lloyd 1991; Nadaff 2005):

1) The power of becoming, growing, and changing, personified in the concept of "Goddess Nature"/"Mother Earth" or depersonified in the abstract notion of Nature;
2) the spatio-temporal materiality of a class of things, for example, stars, trees, birds, men, and computers;
3) a particular essence, such as Socrates or a box of chocolates.

The three aspects converge in the ancient view of the universe as nature (*physis*), testified by the title "On Nature" (*Peri physeōs*) traditionally given to texts about the physical, such as those ascribed to Anaximander, Heraclitus, Parmenides, and Epicurus.

The ancient disciplines dealing with nature and the divine, respectively *physiologia* and *theologia*, constitute c*osmologia*, the study of the universe (*cosmos*). In the pursuit of knowledge about what our senses perceive as physical reality, the alliance of nature and the divine seems alien, if not contrary, to the modern construct of "science." The latter comprises the systematic analysis of phenomena and their underlying causes and effects barring any notion of the divine, whereas the speculation of what is above or beyond nature we have altogether delegated to another field of knowledge specifically characterized as "non-scientific." The sharp division between the study of nature and the divine is so well entrenched in our understanding of science that we have almost completely forgotten that the term "scientist" was not invented and put into circulation until 1833 when, at the third annual meeting of the *British Association of the Advancement of Science*, William Whewell ironically agreed with Samuel Taylor Coleridge's objection that members of the Association should not call themselves "natural philosophers" but "scientists" (Snyder 2011). He did so not to appease Coleridge but formally to acknowledge the empirical tide in the study of nature.

The full implications of this turn of events are extraneous to our subject. Of importance is that the term "natural philosophers" and the discipline of "natural philosophy," which convey the notion of a combined study of nature and the divine, characterized and dominated the field of natural sciences only 180 years ago. Coleridge's objection to the newly fledging empiricism is not against its experimental side but rather against the professed neglect of metaphysical questions. In other words, Coleridge laments the loss of—or the threat of losing—the authentic relation between the two, inherited from antiquity.

It is the job of the historian of (natural) philosophy to keep alive the memory of the shared beginnings of physics and theology. That the study of the divine pertains to physical science can be proved by a quick glance at any period of the Platonic tradition, but the most telling evidence is found in the Aristotelian corpus—one of the most "scientific" (from a modern perspective) collections—where matters of theology are primarily, albeit still indirectly, addressed in the last two books of the *Physics*, Aristotle's treatise on nature (Barnes 1995, 67, 106). The divine then, even for a scientifically oriented mind as Aristotle's, is nothing but the blueprint of the physical.

To study nature in antiquity means to study the universe as an organic whole defined and structured by the relation between its physical and hyper-physical elements. The beginning of this relation is naturally, no pun intended, found in myth.

2. Myth and the Birth of "Gods and Earth"

The narrative mode of myth presents significant obstacles for unraveling the scientific origins of the two concepts. It lacks the ratiocinative induction or deduction of what nature or the divine is (for current integrative trends in the understanding of *mythos* and *logos*: Nelson 1998; Brisson 2000; Buxton 2001; Morgan 2004; Boys-Stones and Haubold 2010). Instead, myth describes the origin of the physical world, that is, cosmogony. It is not coincidental that the most complete mythological account of the beginning of the universe is found in a poem devoted to the "birth of gods." Hesiod's *Theogony* (circa 750–650 BCE: Most 2006, xxiv–xxv) introduces nature and the divine as congenital twins (116–133):[2]

> In truth, first of all Chasm came to be, and then broad-breasted Earth, the ever immovable seat of all the immortals who possess snowy Olympus' peak and murky Tartarus in the depths of the broad-pathed earth, and Eros who is the most beautiful among the immortal gods … From Chasm, Erebos and black Night came to be; and then Aether and Day came forth from Night, who conceived and bore them after mingling in love with Erebos. Earth first of all bore starry Sky, equal to herself, to cover her on every side, so that she would be the ever immovable seat for the blessed gods; and she bore the high mountains. And she also bore the barren sea seething with its swell, Pontus, without delightful love; and then, having bedded with Sky, she bore deep-eddying Ocean… (trans. Most 2006)

Nature here emerges as the construct of the physical environment. Its origin lies in a sequence of finite spatio-temporal acts in which Chasm (a primordial substrate denoting "a gapping yawn:" cf. *Theogony* 700, 814; Pender 2010, 229; Sedley 2010, 250), Earth (*Gaia*), the Underworld (*Tartarus*), and Love (*Eros*) become. The reason for this "becoming," however, is not clear, but its omission allows the possibility for an external agent instigating the cosmogonical process. The grounding (pun intended this time) of this cosmogonical process is Earth, the first identifiable physical element which also plants the first kernel of verticality in this process by designating the Underworld as spatially inferior to Earth.

In regard to the divine, it should be noted that the first two elements in the universe, Chasm and Earth, are not introduced from the start as divine beings, but as physical entities. Despite this anthropocentric orientation, Earth is first described as "the ever immovable seat of all the immortals" (*Theogony* 117–118), counterbalanced by the Underworld. Next comes into existence the abstract force of attraction between things, personified by Eros, "the most beautiful among the immortal gods" (120). His absolute power is asserted by the first sexual cosmogonical act: Night, "mingling in love with Erebos" gives birth to Aether and Day (124–125). Their example is followed by Earth who for the lack of a consort—first parthenogenetically ("without delightful love," 132)—creates, in this order, the Heavens "the ever immovable seat for the blessed gods" (128), the mountains, and the Sea. After a sexual union with her first-born, she gives birth to Ocean, the river that encircles and delimits her. This generative process finalizes the spatial vertical axis in the organization of the universe in which both Earth

and Heavens are identified as "immovable seat" of the gods (*Theogony* 17, 128), that is, the centers of divine activity. The spatial verticality creates a divine hierarchy from the Dodekatheon of the main Olympian gods to the minor deities gracing the lowest physical strata (Burkert 1985; Larson 2007) and unfolds the physical landscape which horizontally maps the terrain as perceived by men's senses. The number of divine beings even defeats enumeration in Roman religion, the animistic nature of which envisions supernatural powers in every material object (Beard, North, and Price 1998).

In Hesiod's account, both gods and nature are created at the same time, and the concept of Earth as the goddess Gaia symbolizes their congenital fusion. She is both a super-power begetting the gods as well as the physical firmament of men. The innate relation between the two, however, makes the interpretation of myth as allegory overly simplistic. It has forced scholars of Greco-Roman religion to shift their attention to interpreting myth as a repository of rituals that regulate and enact the interaction between men and gods.[3] The *Homeric Hymn to Demeter* is a case in point.

Written down in its extant form between 650 and 550 BCE, the *Hymn* offers a new perspective on the relation between nature and the divine wherein nature is the plane of communication between men and gods. Structuralist studies have sought to uncover the social context of every detail of the narrative (Foley 1994). Their analysis interprets the text as a directive for the Eleusinian initiation rites. But the myth also reveals nature as a stage of social and gender issues, power struggles, life, and death. Nature is the physical ground of operation in the narrative. In its wild form, nature is the crime scene of Hades' abduction of Kore, the daughter of the Goddess of Grains, Demeter. Struck by insurmountable grief for the loss of her child, Demeter enters the mortal world to inflict famine and exact justice from the highest divine power, Zeus. In its tamed form, nature is the battlefield of the gods. By withdrawing from her divine duties, Demeter disturbs the established relation between men and gods. Men can no longer offer sacrifices to the gods, and thereby the powerful goddess forces Zeus to find a compromise, which allows her daughter annually to spend time with her on Olympus. Nature is the physical expression of Demeter and, as such, it thrives, grieves, starves, and rejoices with its patron goddess. In other words, Nature is the cross-point of the vertical and horizontal axes in the structure of the universe.

As in Hesiod's *Theogony*, the *Hymn* begins on earth, tracing the vertical and horizontal planes of the *cosmos*. The narrative commences with a description of Kore as a young maiden playing with her friends in a beautiful but dangerous meadow in the wilderness, away from civilization and thus susceptible to violence. At the end of the *Hymn*, Kore's annual journey unifies the lowest and the highest strata of the universe, the Underworld and Olympus. But the most serious impact of these divine events is felt on earth, in the cycle of vegetation attuned to a mother's grief for her daughter. Nature is the medium through which the gods enact their power. This enactment, however, does not close but rather widens the gap between men and gods. The programmatic message of this separation is stamped in Demeter's failed attempt to bestow immortality upon young Demophoön as a gift for his parents' hospitality. Gods occupy the heavens, men the earth, and nature brings them together and keeps them apart.

Myth defines nature and the divine as fusion of concrete characteristics and abstract notions. Both concepts try to draw the fine line between the phenomena and that which underlies them. This intrinsic duality attracts the attention of the first philosophers, the Presocratics, who put forth different explanatory models.

3. Presocratics

Aristotle calls the first thinkers (circa 640–546 BCE)—active when the *Homeric Hymn of Demeter* was recorded—"natural" philosophers (*physikoi*) on the grounds that they postulate different material substances as the originating principles of the universe (*Metaphysics* 1067a6): water in Thales (*hydōr*), the "indefinite" (*apeiron*) in Anaximander, and air (*aēr*) in Anaximenes (*Metaphysics* 983b6–984a6; Guthrie 1962). Each of these elements equates nature with a physically specific substance, which is individually considered as a universal originating principle (*archē*, Aristotle's term: *Metaphysics* 983b3. On Anaximander's use of it: KRS 107–108; Guthrie 1962, 76–77). The life-giving importance of water and air does not require empirical sophistication, and its constitutive role can be easily surmised. Even Anaximander's *apeiron*, abstract at first sight, carries the materialistic connotations of "spatially infinite" and "indefinite in kind" (KRS 108–110). These first "natural" philosophers equate nature with physical appearance. Among them, Anaximander is even credited with writing a treatise entitled "On Nature" (*Peri physeōs*; see KRS 101).

We lack reliable evidence for the Milesians' views on the divine but, in light of their successors' persistent interest, we can suppose with some confidence that the idea is not foreign to them. While Thales' alleged saying that "everything is full of gods" (*TEGP* 35) is indicative of this interest, at the forefront of the Presocratic concept of the divine stands Xenophanes with his pronouncement that "if cattle, horses and lions had hands/… then they would draw images of gods …/each of them exactly as their own bodies,/horses gods like horses and cattle gods like cattle" (*TEGP* 32) as one of the hallmarks of Greek rationalism (KRS 163–181).[4] There is more to his impetus than a sheer call for rationalism, however. The anthropomorphism of the Greek gods is not as deleterious to the formation of more abstract ideas about the universe as their anthropocentrism, which bestows upon them all kinds of moral depravation. The gods of Greek mythology do not only look like men, they wrong like men. Xenophanes finds this preposterous and rejects it in full favor of the abstract concept of "one god, greatest among men and gods/in no way similar to mortals either in body or thought" (*TEGP* 35; Henrichs 2010, 32; Trépanier 2010, 276–281). This god is omniscient and omnipresent (*TEGP* 36), does not move (*TEGP* 38), but "without effort he stirs all things with the thought of his mind" (*TEGP* 37). The monotheistic overtones here have tempted scholars to see kernels of opposition to traditional Greek polytheism, but such tension seems artificial in light of Xenophanes' ubiquitous references to gods in the plural (*TEGP* 29–33, 35, 74, 77; cf. Trépanier 2010, 279). This dichotomy is later solved by Plato's concept of the Demiurge.

The Presocratic concept of a "unified" divine, although gender specific, makes a major conceptual leap from mythological personification of the divine to abstract unification of the universe. Per Aristotle's report, Xenophanes is "the first of those who declare all (*panta*) is one (*hen*)" and "the One (*to hen*) is the god" (*ton theon*: *Metaphysics* 986b.21–25). Unclear are the relationship between Xenophanes' single god and the "one-over-many" universe (*hen-panta*), however, and the relation between the universe as a whole and the particulars of the physical world in the foundation of which Xenophanes postulates earth and water (*TEGP* 50, 55). The only clear element in his view is the notion of vertical subordination.

The first clear articulation of the vertical relation between nature and the divine is found in Heraclitus (Guthrie 1962; KRS 182–215). According to him, the universe is a dynamic whole, cyclically created and extinguished, governed by fire. All primary elements participate in a hierarchically interlocked system of transformations: "Fire lives the death of earth, and air lives the death of fire, water the death of air, earth the death of water" (*TEGP* 53). In this sequence, fire is the most metamorphous; it is both a physical element and a supervening essence connected with soul, cognition, life, and the divine; it is also "intelligence" (*logos*), which governs the universe (*TEGP* 40), steers all like "a thunderbolt" (*TEGP* 56), and is related to the name of Zeus (*TEGP* 147). In addition to this singular overseeing god, Heraclitus recognizes a multitude of lesser gods who, against the traditional understanding of divinity, participate in nature's cycle of life-and-death in that "immortals are mortals, mortals immortals, living the others' death, dying the other's life" (*TEGP* 112). Heraclitus' conception of the divine distinguishes between one god, who is "wise, separate from all other things" (*TEGP* 39), and a plurality of gods, who are subjects of human temporality. His view keeps the universe in the balance between mortality and immortality, which makes nature and the divine inseparable: "God is day and night, winter and summer, war and peace, satiety and famine" (*TEGP* 148). Both nature and the divine are "in flux" (Plato, *Cratylus* 402a; Aristotle, *Metaphysics* 987a32).

The Presocratics' growing interest in distinguishing the physical aspect of nature from its governing principles makes a decisive turn with Parmenides (Guthrie 1962; KRS 239–262; Cordero 2012). He envisions two possible ways of thinking about the universe: the Way of Truth and the Way of Opinion (*TEGP* 11, 16). The Way of Truth teaches the concept of Being (*to eon*), which defines absolute existence as *that which is* (*TEGP* 17). Without any notion of plurality, Being is ungenerated, indestructible, whole, homogeneous, unmoved, and perfect (17.3–4). Its absoluteness is contrasted in the dualist/pluralist cosmogony, offered by the Way of Opinion. Following earlier Presocratic cosmogonies, Parmenides posits Fire and Night as the originative elements of the physical world (*TEGP* 17, 20, 24–26).

It is difficult to reconstruct Parmenides' understanding of the relation between nature and the divine aside from the rejection of the physical characteristics of nature as "deceitful" (*TEGP* 17.52). The concept of the divine, on the other hand, is not present in the Way of Truth, but in the Way of Opinion, as if a human construct which is invalid outside the context of physicality. The Way of Opinion envisions, in the center of the celestial rings, a goddess (*daimõn*) who "governs all" and "rules over hateful begetting and mixture" (*TEGP* 26.3–5), while the Way of Truth never refers to Being as god, a god, nor as divine (Trépanier 2010, 293–297). But, despite this omission, Parmenides' Being has a strong divine resonance: its indestructibility alludes to the immortality of the gods as a whole, its lack of origin speaks of Heraclitus' singular god; its completeness, perfection, and immovability recall Xenophanes' supreme thinking god. One conclusion we can draw about the relation between nature and the divine in Parmenides is the complete conceptual polarization between the plurality of nature and the singularity of Being. To reconcile the two is the glove he threw to his successors.

And indeed they took it. Empedocles, Anaxagoras, and the atomists counteracted Parmenides' monism by postulating an ever-increasing plurality in the foundation of the universe. This development, in its turn, faces its own challenges for formulating the relation between nature and the divine. In Empedocles, we find a complete fusion in

which the four primary elements (*stoicheia*: earth, water, air, and fire) are named after the Olympian gods (Zeus, Hera, Hades, and Nestis; *TEGP* 26). As such, the elements are immortal and eternal, but they are also considered to be the physical "roots" (*rizōmata*) of the material world (*TEGP* 46.3). This cosmogonical dynamic is regulated by the two opposing forces of Love (elemental attraction creating physical bodies) and Strife (elemental repulsion destroying physical bodies). The primary elements originally co-exist in harmony in a cosmic entity figuratively called *Sphairos* ("sphere"; *TEGP* 55) but in time Strife prevails, forcing the primary elements to create the physical world. The materiality and non-transcendence of *Sphairos* as supervening deity has nothing in common with any earlier concept of divinity (Primavesi 2008). This anti-Parmenidean view puts the relation between nature and the divine on starkly materialistic terms.

Anaxagoras, approximately Empedocles' contemporary, even more radically "corrects" Parmenides' anti-pluralism (KRS 362–394; Curd 2007). He posits an indefinite number of constituents, "seeds" (*spermata*), in the formation of the universe (*TEGP* 13). Originally these seeds are disordered and commingled until a higher intelligence, Mind (*Nous*) separates, in a cosmic rotation, those that are alike from those that are different (*TEGP* 18, 20, 21, 24). For Empedocles (*TEGP* 41), the physical world is a series of temporary manifestations of certain constituents which predominate in a given place and time. Anaxagoras' Mind (*TEGP* 31), on the other hand, stands in the place of a supervening principle although we note here again, as in Parmenides earlier, that nowhere in Anaxagoras' extant fragments is Mind described as god, a god, nor as divine. Mind therefore acts as a supreme universal deity, but its presence is depersonalized to the level of a physical force (rather differently from Heraclitus' understanding of a cosmic god who directly participates even in the social affairs of the universe; cf. Trépanier 2010, 301). Anaxagoras perceives the relation between nature and the divine as one between impure mixed disorderly matter and pure Mind. While the characteristics of Mind as "unlimited and autonomous and mixed with no other thing" (*TEGP* 31) remind us of Parmenides' Being, Anaxagoras' view of the physical world redeems the Empedoclean value of cosmological change.

The materialistic interpretation of the relation between the two concepts culminates in the atomic theory of Leucippus and Democritus (KRS 400–426; Taylor 1999; Matter). According to their theory, an infinite number of atoms ("un-cuttables") randomly fills in the void in the universe with temporary configurations of matter. According to this model, the physical world is a fleeting instantiation, a freeze frame of constantly reconfiguring atoms on the horizontal axis of time (see The Creation and Destruction of the World for multiple/infinite universes). Consequently, the impermanence and randomness of the natural world preclude the presence of any hyper-physical governing divine force or entity.

The concept of divinity in itself presupposes the idea of a finite universe as an object of organization and control. The atomists' mechanistic understanding of thought as a result of atomic interaction, which creates images (*eidōla*) that imperceptibly penetrate the organs of sense and impress their content on the mind, annihilates the need for any form of supra-natural intelligence. But we should not rush to the conclusion that the absence of a cosmic god makes the atomists atheists. There is ample doxographical evidence that Democritus conceived of the gods as physical emissions—in miscellaneous proportions—of the aforementioned images (*TEGP* 182, 183). Democritus' concept of gods, however, is rather problematic. It is not clear of what the gods are images, whether they

are their own entities, and so on (see Trépanier 2010, 314). Regardless how sparsely understood, his famous statement that "the divine is *Nous* in fiery spherical atoms" (DK A74; Aëtius 1.7.16) acknowledges the presence of the divine, in whatever conspicuous form. But it also contains elements of more traditional views, which associate the divine with some kind of intelligence, with one of the primary elements, with the sphere as a symbol of completeness, and with an underlying material substrate (the plurality of atoms). The skeptical notion toward the gods, however, reaches full fruition later in the Epicurean philosophical school, which considers the gods too happy and content with their blessedness to be bothered with the physical world.

By the fifth century BCE, the Presocratic natural philosophers disassemble the mythological understanding of the relation between nature and the divine. For them, the divine provides—with varying degrees of abstraction—intelligence, structure, and organization to the material substrate of nature. It is always in the fore- or background of the Presocratic understanding of nature. In its center lies the question of the relation between unity and multiplicity in the universe. The Presocratics chart two ways of going about it. The early Milesians and Heraclitus explain the organization of the universe with a singular omnipresent material: water, the *apeiron*, air, or fire. In this sequence, the explicit progression from materiality to immateriality culminates in Parmenides' rejection of plurality.

On the other side of the camp are Empedocles, Anaxagoras, and the atomists, who derive their cosmological views from the multiplicity and diversity of the physical world. This pluralism redefines the relation between nature and the divine. For Empedocles, it results in populating the universe with an overabundance of deities commensurate with its physical multiplicity. For Anaxagoras and the atomists, it results in loosening, if not diminishing, the overseeing presence of the divine. The two courses of thought take parallel, non-converging, tracks. Anaxagoras' rarified divine and the atomists' randomized nature open the door for other solutions.

4. Plato

The *Timaeus* is Plato's dialogue on physics and, although it does not articulate a clear definition of nature—nor does any of his other works—it imparts the most information about Plato's view on the relation between nature and the divine. The importance of this relation for Plato and the ensuing Platonic tradition is properly weighted by the penultimate place of the dialogue in the later Platonic curriculum, second only to the *Parmenides*, Plato's text on ontology and metaphysics (Tarrant 2000; Reydams-Schils 2003; Sedley 2007, 2010).

The *Timaeus* contains Plato's systemic solution to the monistic–pluralistic divide of the Presocratic cosmologies *pace* their growing materialistic trend. Its task is to retain the monism of Parmenides' Being by subordinating to it the pluralism of Empedocles, Anaxagoras, and the atomists. Therefore, the dialogue introduces the opposite Presocratic views as two possible models for the structure of the universe (respectively Being and Becoming, *Timaeus* 28a–29a). The two models are related by an external causal agent, the Demiurge, who orders physical plurality (Becoming) as an image of the eternal paradigms of existence (Being, i.e., the Forms). A complete rejection of the world of Becoming, along Parmenidean lines, is not an option for Plato—regardless of its appeal—because its rejection would also entail abolishing the idea of Being as a paradigm of Becoming. Without postulating an external noble cause, it is not clear how

and why these two models would relate. Therefore, Plato enthusiastically endorses the causal presence between the two models: "Now surely it's clear to all that it was the eternal model he looked at, for, of all the things that have come to be, our world is the most beautiful, and of causes the craftsman is the most excellent" (*Timaeus* 29a2–7, hereinafter Zeyl's trans.; Broadie 2012, 7–12).

Plato's concept of the Demiurge combines the notion of governing divine intelligence found in Xenophanes, Heraclitus, and Anaxagoras. The etymology of "Demiurge" ("one who fashions") casts him as a "maker" or "father" of the universe (especially *Timaeus* 29a3, 37c7, 40c2, 41a7, 69c3; Cornford 1935, 34–39; Zeyl 2000, 14, n.15). But his craftsman's activity is more cosmological than cosmogonical. He did not create the universe *ex nihilo*, like the God in the Abrahamic tradition, but "he took over all that was visible—not at rest but in discordant and disorderly motion—and brought it from disorder into order, because he believed that order was in every way better than disorder" (*Timaeus* 30a3–6). The Demiurge's innate intelligence orders the primordial material mass into a finite universe; for "in the realm of things naturally visible, no unintelligent thing could as a whole be better than anything that does possess intelligence as a whole" (*Timaeus* 30b1–3).

Plato consistently refers to the Demiurge as "god," and the two most distinct characteristics of his divine nature effect the two most essential characteristics of the physical world: goodness and orderliness. The Demiurge on his own accord, unlike the power-hungry divine progenies in Hesiod's *Theogony*, passes his goodness onto the universe "as far as it is possible" (*Timaeus* 30a3) and uses his own intelligence to endow the universe with intelligence and soul (30b8–c1). Goodness, intelligence, and soul, in this order, are in the foundation of the physical world which unfolds in a chain of four cosmological events: first, the Demiurge fashions the body of the universe from the four primary elements (31b–34b); second, he makes the soul from a proportional mixture of Being, the Same, and the Different (34c–37c); third, he devises time as the image of eternity and bestows it upon the model of the universe (37c–39e); fourth, he crafts the divine race (40a–41a). This sequential order induces the notion of ontological verticality.

The divine itself is hierarchically organized in Plato. On one level, as father of the gods, the Demiurge supersedes the divine and the universe by remaining external to it. On another level, the intra-mundane divine unfolds its own distinction between the visible and the invisible gods. Since the *Timaeus* is devoted to physics, Plato is more confident in describing how the Demiurge first makes, "mostly out of fire," the visible gods (the fixed stars) among whom Earth "ranks as the foremost, the one with greatest seniority" (40b8–c3). But he is less certain about the Demiurge's second divine creation: the invisible gods—for which Plato resorts to the account in Hesiod's *Theogony* (Pender 2010; Sedley 2010):

> Earth and Heaven gave birth to Ocean and Tethys, who in turn gave birth to Phorkys, Cronus, and Rhea and all the gods in that generation. Cronus and Rhea gave birth to Zeus and Hera, as well as all those siblings who are called by names we know. These, in turn, gave birth to yet another generation. (*Timaeus* 40e4–41a3)

Unlike Hesiod, Plato begins the divine succession not with Chasm but with Earth and Heaven, the upper part of Hesiod's spatially vertical axis. The Demiurge is the external agent, absent in Hesiod, who causes the "becoming" of Earth not by creating but by

ordering an already existing primordial mass (30a3–6). As the last link in this cosmogonical chain, the invisible gods are inferior to their creator even to the extent that Plato makes the Demiurge explicitly grant them their divinity. Hesiod's gods serve a higher philosophical purpose in the *Timaeus*: to prevent the supervening divine cause from direct contact with humanity. Therefore, the Demiurge imparts this task to the lesser gods: "Weave what is mortal to what is immortal, fashion and beget living things. Give them food, cause them to grow, and when they perish, receive them back again" (41d1–3). The human race then is a divine creation, albeit not of the first order, and partakes in nature at the horizontal axis of motion and change.

Plato's treatment of the divine in the *Timaeus* reveals an orderly structure of visible and invisible deities overseen by an external power of goodness, intelligence, and causation. His treatment of nature, however, is not so straightforward. Although the primary causes are described as having "intelligent nature" (*emphrōn physis*: 46d8), this description does not equate nature with intelligence but only makes intelligence its most essential feature. If we tease out a working definition of nature in the *Timaeus*, it would be something along the lines that nature is the orderly horizontal expansion of the world of becoming. More precisely, nature does not produce spontaneously but "by a cause that works by reason and divine knowledge derived from a god" (*Sophist* 265c8–9, trans. White [1993]). Thus, by ordering the universe, the Demiurge creates a blessed god (*Timaeus* 34b8) and "a shrine for the everlasting gods" (37c6–7). The true divine nature of the universe (*pantos physin*) is also the last sight the Demiurge reveals to the individual souls before they "fall into" their embodied lives (41e2). Nature in the *Timaeus* is created by and for the divine.

5. Stoics

The Stoics, in Hellenistic and Roman times, give new meaning to Plato's basic tenet that the universe is good and ordered because it is created by a divine intelligent cause. They postulate one active divine principle (God or *logos*) and one passive material principle (*hylē*). Contrary to Plato, the former itself is also a body (a combination of matter and form) and thus acts upon matter from within (Diogenes Laërtius 7.134). The Stoic god is breath (*pneuma*), which animates the universe from one cycle of conflagration to another. This breath is a mixture of air and fire, the two active primary elements as opposed to water and earth, the two passive. As *pneuma*, God is a physical compound of the first two and acts as a cause upon the second two (Seneca, *Letter* 65.2). This extreme materialism leads the Stoics to equate God with nature and, in turn, to define nature as "a fire proceeding methodically to generation" (Sandbach 1975). The cosmogonical fire is the active agent which brings to fruition God's design of the universe. The Stoics conceive of the divine as an internal cosmic force directly responsible for the existence of the physical world. Their view of nature and the divine revives the Heraclitean idea of divine fire and physical change in opposition to Plato and in defense of materialism (Meijer 2007).

6. Aristotle

Aristotle's understanding of nature and the divine brings together the major strengths and constraints of his physics and metaphysics. The scientific acumen he displays in the *Physics* and the biological works, especially *Generation of Animals* and *History of*

Animals, makes his discussion of god and the divine bleak. If we are to look for some substantial treatment of the topic in his *Metaphysics*, aside from the cameo discussion of the "unmoved mover" in book Λ, we will be disappointed (Fuller 1907; Barnes 1995). In fact, his lenghtiest elaboration is found in the last two books of the *Physics*, and even there it is still in the background (Barnes 1995, 103, 106). The upshot of this anomaly, as far as our survey is concerned, is the affirmation that, for Aristotle as for Plato, the understanding of the divine goes hand in hand with the understanding of nature.

Aristotle's alternative to Plato's solution of the Presocratics' monistic–pluralistic divide of reality is his hylomorphism, according to which everything is a combination of matter (*hylē*) and form (*morphē*). The relation between the two is further explained by his four-cause model (MATTER), especially with regard to the final cause, which identifies the function and purpose of the material, determined by its form. The effectiveness of the four causes is further justified by teleological considerations, the most important of which is Aristotle's famous dictum that "nature does not make anything in vain" (*On the Heavens* 271a33; *Parts of Animals* 658a9; *Generation of Animals* 741b13; Barnes 1995, 129). According to him, nature is "an irreducible part of the explanatory system of the world" (Hankinson 1995, 159) and "a principle (*archē*) and causes of change (*aitiai*) and its cessation in those things in which it is present primarily, *per se* and not *per accidens*" (*Physics* 192b21–23). Since motion and change underlay the existence of everything including nature, then nature just as everything else must always have a cause of motion. If we trace the chain of causation in the universe from the tree outside our window to the five concentric spheres that keep the universe in motion, we will ultimately arrive, with Aristotle, at "unexplainable explanations" of the first causes of things (*Posterior Analytics* 85b27–86a3; for concentric spheres, see ASTRONOMY). Although Aristotle's causes are separated from the divine, when it comes to the ultimate cause of the eternal celestial movements, he is pressed to introduce the concept of the unmoved mover:

> There *is* something which is always moving with an unceasing motion, which is motion in a circle—this is clear not only to reason but also to observation. Hence the first heavens must be eternal. There is therefore something which moves them. And since what both moves and is moved has an intermediate status, there must be a mover which moves them without being moved, eternal and a substance and actual. (*Metaphysics* 1072a21–26, trans. Barnes 1995)

These unmoved movers (55 or 49 in number: *Metaphysics* 1074a15–16) are themselves first causes, immovable substances, and traditionally considered as "gods":

> Our remote ancestors have handed down remnants to posterity in the form of myths, to the effect that the heavenly bodies are gods and that the divine encompasses the whole of nature. But the rest has been added by way of myth to persuade the vulgar and for the use of the laws and of expediency. For they say that the gods are anthropomorphic and like some of the other animals … But if you distinguish among what they say and accept only the first part—that they thought the primary substances to be gods—, then you would think that they were divinely inspired. (*Metaphysics* 1074b1–10)

Aristotle's attitude to myths is more skeptical than Plato's concession to Hesiod's cosmogony in the *Timaeus*. Aristotle's unmoved movers have nothing in common with

the conventional gods; they are instead substances, incorporeal, homogeneous, and indivisible. They do not cause movement by physical contact but as objects of desire (*Metaphysics* 1072a26–32). They think constantly and, because of their good nature, they are somehow responsible for overseeing the universe "for the sake of the good." Their intelligence and goodness bring them closer to Plato's Demiurge but, unlike the Demiurge, they are not artisans of the physical world (Cornford 1935, 39; Barnes 1995, 127–129).

The notion of the divine itself presents for Aristotle a roadblock to his empirically oriented line of research (Barnes 1995, 127–135). It is both impossible and unthinkable for him to ignore it. The divine causation represented by the concept of the unmoved movers transforms Aristotle's physics into metaphysics.

7. Neoplatonists

Aristotle's definition of nature as an active principle culminates in the long-gestating notion that nature entails not only a spatio-temporal disposition of an individual thing but also the essence underlying the existence of a particular class of things. This notion is a small step from the broader view of nature *qua* nature, that is, an overarching principle of the physical world. The last premise finds propitious grounds in the Neoplatonic view of the universe as a dynamic system of underlying causalities. The philosophers, who perceive of themselves as Plato's followers in late antiquity, understand nature closely to the modern conception of it, as a growing power, complexity, and self-organization. For them, the divine is synonymous with that which is beyond the physical and is omnipresent.

Until recently, if we were to say that nature is also important for the understanding of Neoplatonic metaphysics, we would have been met with heavy skepticism. The concept of nature, however, has been rediscovered, in the last decade, as one of the rapidly growing topics in Neoplatonic studies (e.g., Sorabji 2005, volume 2; Chiaradonna and Trabattoni 2009; Wilberding and Horn 2012). This floruit is a result of our improved understanding of the relation of Neoplatonic metaphysics with the material world, and its particulars, physics and biology. When it comes to the place of nature in this interdependent view, we can rephrase Chiaradonna's and Trabattoni's quip that "physics is but a part of metaphysics" to "physics is nothing but instantiated metaphysics," that is, the material expression of higher principles (Chiaradonna and Trabattoni 2009, 14). In this vein, the concept of nature has a high profile in Neoplatonism.

It is not an exaggeration to consider Plato's cosmology in the *Timaeus* as the foundation of the Neoplatonic understanding of the universe. Macrocosmically, this understanding offers an expanded, and later over-expanded, model of the Demiurge's creation. Broadly sketched, it views the universe as an organic whole of three causally successive underlying principles (*hypostaseis*): the One, the transcendent source of every thing that *there is*; Intellect, the intelligible image of the One, containing all intelligible beings in one-in-many unity; and Soul, the image of Intellect and the intermediary between the intelligible realm and the physical world (for an outline of Plotinus' three hypostases, see *Enneads* 5.1). Because of its proximity to corporeality, Soul is amphibious in that a part of it always remains in Intellect, its ontological antecedent, and another descends to the material world, its ontological descendent.

There are two possibilities for nature to be included in this ontological chain. One is somehow to relate nature to Soul, the intermediary principle enmattering the higher ontological principles (*logoi*) in the physical world. The other is for nature to be an independent,

fourth, principle, ontologically posterior and thus inferior to Soul. Both possibilities face serious difficulties and offer partial solutions (Martijn 2010; Gerson 2012).

The first possibility is taken up by Plotinus, commonly known as the founder of the school. He vertically defines nature as "an image of intelligence," "the last and lowest part of soul (*psychēs eschaton*)," and "the last ray of the rational principle" (*Enneads* 4.4.13.3–5; hereafter Armstrong's translations 1966–1988 with adaptations). This definition continues the long philosophical project to associate nature with higher governing intelligence. Looking at the universal structure from top to bottom, Plotinus makes reality commensurable with ontology, and ontology commensurable with intelligence and the rational principles ordering the universe. Since it has only an image of intelligence, nature does not think, it only creates (4.4.13.8) by passing its properties onto matter spontaneously, without reasoning: "Nature has no grasp or consciousness of anything" (4.4.13.14). The puck of intelligence, for Plotinus, stops with nature, and nature is the physical, thus lowest, expression of Soul, indirectly of Intellect, and ultimately of the One. Nature is the most remote product of these underlying principles (3.2.16.13–17). He explains the non-intelligence of nature with its inability to contemplate as he anthropomorphizes nature to speak with its own words: "What comes into being is what **I** see in my silence, an object of contemplation (*theōria*) which comes to be naturally (*physis*)" (3.8.4.6–7). This silent self-revelation—that nature, unlike the hypostases, does not revert back to its source—determines that nature is not a hypostasis but "an offspring of a prior soul with a stronger life" (3.8.4.14–15; on the difficulties of Plotinus' multilayered concept of soul: Blumenthal 1971a, 1971b).

The second possibility in the Neoplatonic vertical cosmology—that nature is an independent underlying principle—is pursued by the scholarch of Plato's Academy in Athens, Proclus, in his *Commentary on the Timaeus* (*in Ti.*). For Proclus, Nature (capitalized according to the Neoplatonic convention of denoting a hypostasis) is an independent underlying principle, which plays a transitional role between Soul and the physical world (Martijn 2010, 30):

> It is inferior to [soul] due to being divided over bodies and by not reverting upon itself but rising above everything that comes after it by possessing their rational principles and producing everything and giving it life. (*in Ti.* 1.10.16–21, trans. Martijn 2010)

Proclus maintains Plotinus' position that nature is inseparable from corporeality, but he also disagrees with him on the same grounds. If nature is inseparable from corporeality, nature cannot be a part of soul (because soul is separable from the physical world), and therefore it is an independent entity (1.10.24–11.5).

Proclus' concept of Nature is closely related to the *Timaeus'* concept of Becoming. It is the life the Demiurge inserts in the universe in preparation to receive soul (*in Ti.* 1.401.25ff, Martijn 2010, 34). This association of Nature with the physical world supports Plotinus' view of Nature as irrational, divisible, and non-contemplative, but it also adds a horizontal depth to this vertical ontological structure by making Nature the last link in Proclus' great chain of ontological procession and reversion (Martijn 2010).

Proclus' inclusion of Nature in the hypostatic hierarchy of the universe has a transformative impact on the relation between nature and the divine. His interest in the intersection of polytheism with ontology allows him to embody to a full extent Thales' vision that "all things are full of gods" (*TEGP* 35; Proclus, *Platonic Theology* 3.27,

98.23; *Elements of Theology* 145.20). The divinization of the physical world is a result of a network of divine channels, in Proclus' words "chains," which ensures open and direct communication between nature and the divine (*Elements of Theology* 145; *Platonic Theology* 6.4; Chlup 2012, 127–136). This emboldens a late Platonist like himself to reach the Hesiod-esque conclusion that "All things that exist are begotten by the gods and have their foundation in them, being brought into existence by them without intermediation" (*in Ti.*1.209.13–25, trans. Runia and Share 2009; on the relation of Proclus' theology with the traditional Olympian pantheon, Chlup 2012, 112–136). Proclus' main message is that nature makes the invisible gods of Plato's *Timaeus* visible and has a share, however miniscule, of the divine.

8. Conclusion

Wilamowitz begins his study of Greek religion with the summation that "the gods are present" (Wilamowitz-Moellendorf 1931–1932, 17–19; Bremmer and Erskine 2010, 8). By this he means that the gods' anthropomorphism in myth makes the divine a part of the physical world. Nearly two millennia earlier, Plotinus insists that before we were born "some of us [were] even gods, pure souls and intellect united with the whole of reality" (*Enneads* 6.4.14.18–19). The two statements witness, from opposite ontological ends, the principal tenet that nature is an expression of the divine. As we have seen, the answer to the question "how so" has written the history of ancient philosophy and science.

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NOTES

1 Valpy 1828 relates *deus* to the Greek *theos*; Cf. Pokorny 1959. Bremmer and Erskine 2010, 1 discuss the common origin of *theos* and *deus.*
2 Among the alternatives are the Orphic cosmogonies deriving the universe from Night or from a cosmic egg and Pherecydes' account (sixth century BCE) positing three divine principles (Zas, Chthoniē, and Chronos) in the origin of the universe. For a survey of ancient cosmogonies, KRS 8–72. For more recent appraisals, Pender 2010; Sedley 2007, 2010.
3 On allegory and personification, Shapiro 1993; Stafford 2000; Borg 2002; On ritual, Burkert 1985; on structuralism, Vernant 1974; Vernant and Detienne 1974; Frazer 1994; on the history of interpretation of religion, Bremmer 2010; Henrichs 2010, 23–27.
4 Aristotle, *On the Soul* 1.5.411a8. Henrichs 2010, 22. Translations of the Presocratics come from Trépanier 2010, with adaptations.

PART II

The Mathematical Sciences

CHAPTER 5

Mathematics

Reviel Netz

1. Defining Ancient Greek Mathematics

At least the following extant ancient authors (see Table 5.1) should be counted as mathematicians (defined as those from whom any works in pure mathematics are extant).

Twelve authors, with about a million extant words, represent a small, but significant fraction of extant literature in Classical Greek. (The *Thesaurus Linguae Graecae* [*TLG*] counts about 60 million words from antiquity, total, which includes Christian texts; and I count a total of about 270 extant ancient Greek authors.) I shall return to discuss the significance of such numbers later on. Further, in this genre, more than perhaps any other from antiquity, the direct transmission in Greek is to be augmented through the evidence of translations: at least two more authors should be mentioned, then: Diocles (perhaps from Megalopolis, 200 BCE?) and Menelaus (Alexandria, 100 CE), both extant now, each with a fairly short work ("On Burning Mirrors" and "Spherics", respectively), in Arabic translation. The Arab transmission also augments the surviving works for about half of the authors in the foregoing list.

The core of this genre is easy to identify in formal terms. The search "@3" on *TLG* brings out the positions where the *TLG* encoders encountered a diagram in the original. This captures all the authors from the foregoing list: so, the authors in the list are characterized, to begin with, by the use of diagrams. Further, these authors use language, in at least a part of their writing, in a specific technical way, relying on a small selection of a few hundred Greek words that are employed in formulaic ways. The formulaic rules extend across all linguistic levels, beginning with the single elliptic phrase ("the <angle contained> by the <lines> AB, BG") all the up way to the level of the passage as a whole ("All X are Y. Take an X. I say it is Y. For let … therefore … therefore … therefore it is Y. Therefore all X are Y, QED"). Thus, even though Diophantus' major work (if

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Table 5.1

Name	Date (main period of activity, estimated and rounded to nearest multiple of 50)	Extant *TLG* word count of entire extant corpus (rounded to nearest 10,000, sometimes extending beyond pure mathematics, but always within the exact sciences)	Notes
Euclid of Alexandria	300 BCE	230,000	The traditional dating is questioned (Schneider 1979, 104, note 105) and little documented. Attributions of authorship are also vague. The word count provides a sense of an important ancient mathematical corpus.
Archimedes of Syracuse	250 BCE	110,000	
Apollonius of Perga	200 BCE	60,000	
Theodosius of Bithynia	200 BCE?	50,000	
Hypsicles of Alexandria	150 BCE? (or before 150 CE)	<10,000	The dating—based on an identification of a Basilides and a Protarchus, mentioned in Hypsicles' introduction, with two eponymous Epicurean philosophers—is now questioned (see Tepedino 1980).
Hero of Alexandria	50 CE?	150,000	This dating is uncertain: Sidoli 2011.
Nicomachus of Gerasa[1]	100 CE	30,000	
Diophantus of Alexandria	200 CE?	50,000	Diophantus' date is almost completely open (Knorr 1993). Since we have no Roman era references to him, it is reasonable to claim that the distribution of probabilities peaks late in the Roman era.
Serenus of Antinoeia	200 CE	30,000	
Pappus of Alexandria	300 CE	210,000	
Eutocius of Ascalon	500 CE	60,000	
Anthemius of Tralles	550 CE	<10,000	

indeed more than one authentic work by him survives at all), the *Arithmetics*, does not employ diagrams, it uses a formulaic language which is a clear adaptation of the Greek mathematical formulaic language. One author in the foregoing list does not employ, in general, this formulaic language: Nicomachus, who is in this list for his *Introduction to Arithmetic*. We are driven to consider, then, not only form but also subject matter.

Diophantus and Nicomachus stand out in our list because they deal primarily with arithmetic; all the other authors deal primarily with geometry. There are discussions of arithmetic in Euclid's *Elements* 7–9, as well as Pappus' *Collection* 2, but otherwise there are no other extant works primarily about arithmetic. Significantly, both Euclid and Pappus, in the arithmetical discussions cited here, rely on diagrams and employ a language closely modeled on that of Greek geometry. The core of the extant genre, then, is that of a specific formulaic language based on the diagram and discussing that which is most directly modeled by diagrams—geometry. This, however, may be partly a construct of the pattern of survival (see §2 below).

We may limit the genre inward, by emphasizing the core subject matter of geometry, or expand it outward, by adding in other subject matter of the exact sciences, above all astronomy (also, to a lesser extent, mechanics and music; the few works of optics in the extant literature, with important exceptions, are difficult to distinguish from pure geometry). Such fields are considered elsewhere in this volume, but it bears repeating that the border between geometry, on the one hand, and its scientific applications, on the other hand, is not easy to draw. Many Greek studies of the heavens proceed via a radical abstraction, where stars are considered as points or spheres whose position and trajectory are to be determined. This calls for a treatment which does not differ materially from that of pure geometry: thus, for instance, Aristarchus' *On the Sizes and Distances of the Sun and the Moon* (roughly 300 BCE; about 7,000 words) can be read as a contribution to cosmology, but it can also equally be read as the solution to the problem of bounding geometrical values given certain parameters, via the application of trigonometry. Nothing depends on the sun or the moon being anything other than geometrical spheres. It is true, however, that many discussions of astronomy do bring in more empirical considerations. (So, famously, Ptolemy begins his *Almagest* with a purely physical discussion of the immobility of the earth.) In terms of genre, what is most typical of sciences such as astronomy is that the purely formulaic discussion of objects set out in the diagram is interspersed within a "normal" prose discourse: technical, but no longer formulaic. To some extent, the same combination of formulaic-mathematical and more reflective prose is typical of later commentaries as a whole (and so one can find more discursive prose preceding and following mathematical arguments in Pappus and, to a lesser extent, in Eutocius). Also, several philosophical commentators (especially Proclus, who devotes an entire book to a commentary on Euclid's *Elements* 1; but also Simplicius, who provides our best evidence for the earliest Greek mathematics: see below), insert formulaic passages with geometrical content within their philosophical discussion. Thus, "Geometry" is not entirely isolated from more discursive passages, but on the whole, the presence of a more discursive prose seems to be related to a more "real-world" subject matter such as astronomy.

The distinction between geometry and arithmetic, on the one hand, and the "mixed sciences," on the other hand, has an ancient pedigree: it is suggested already by a mysterious testimony on Philolaus, who may have referred to geometry as the "mother-city" of the other sciences (*TEGP* 45; see Huffman 1993, 193–199), and is already a detailed,

sophisticated piece of Aristotle's philosophy of science (McKirahan 2010). It should be remembered, however, that the Greek word *mathēmata* (when it did not refer to "learning" in general) certainly referred to what we call "exact sciences," and never to what we call "mathematics." More generally, while authors in antiquity kept themselves within clearly fixed generic bounds, it is rare to find significant authors who contributed only to pure or only to mixed mathematical sciences. Apollonius—from whom only pure geometry or arithmetic is now securely attested—is said also to have contributed significantly to ancient astronomical theory (a study of the key devices of mature Greek planetary theory, the eccentrics and epicycles: Neugebauer 1951). Ptolemy—from whom we have extant an entire series of studies across the range of the mixed sciences, none in pure geometry and arithmetic—is reported by Proclus to have studied the parallels' postulate (*Commentary on Euclid* 191.21–24). It thus seems reasonable to conclude that the relevant ancient generic boundary was that of "exact sciences," not of mathematics. In this survey, I concentrate on what we now call "mathematics," not because this correlates well with a major ancient distinction, but because I was asked to do so by my editor.

2. In Lieu of Historical Narrative: Questions of Chronology, Geography, Demography

When Did Greek Mathematics Begin and How Did It Progress?

Allow me to change the subject. General surveys still sometimes tell the linear narrative where individuals pick up, in sequence, impersonal continuities: "The History of Greek Philosophy," "The History of Greek Mathematics"… In the case of Greek mathematics, this Hegelian image of the relay race is uniquely inept. Impersonal continuity makes sense, up to a point, in the description of social institutions—those that stay when people don't. Greek mathematics never acquired such institutional hold (unlike, say, philosophy in the Hellenistic Athenian schools; grammar in the Alexandrian library; medicine in a handful of cases from the family school at Cos onward; and, of course, the many Greek institutions of performance, such as Athenian drama). Rather, Greek mathematics—as well as most other ancient cultural endeavors—seems to have been pursued primarily by a handful of small networks of individuals, networks that did not survive beyond two generations or so.

This is a survey article in a general handbook: one is supposed to be cautious. I cast away caution and assert, instead, an original, and certain-to-be-controversial claim: that *nearly the entirety of the Greek creative achievement in pure mathematics may be assigned to two distinct networks.* The first is the one described in Proclus' summary of the history of early Greek mathematics (Proclus, *Commentary on Euclid* 1.66–68, conventionally understood to derive from Eudemus' history of Greek geometry). The best introduction to Eudemus is Zhmud 2002, who dates the work circa 330 BCE. It is therefore debatable whether the appearance of the first network is not a construct of our evidence. I have argued in Netz 2014 that it is not, and I refer readers to details there, but the main argument is comparative: Greek cultural practices overwhelmingly tend to cluster in such generational groups. This first network can be dated to around the mid-fourth century BCE. The second network is that of Archimedes, his correspondents, and the

authors in the following generation, reacting to Archimedes' achievement, at around the end of the third century BCE.

Proclus knows 13 individuals who were mathematically active around Plato's life, and our knowledge of early Greek mathematics is dominated by such individuals, above all these three: Archytas, Theaetetus, and Eudoxus.

Starting with Archimedes' correspondence with Conon, Dositheus, and Eratosthenes, we may follow a similar concentration of contributions to pure mathematics; several authors are evidently responding to Archimedes' challenge, for instance in completing apparent lacunae in his works or in general in producing work which evidently aims at a similar type of brilliance, of whom the most important is clearly Apollonius. Knorr 1986—intended as a survey of a major aspect of Greek mathematics as a whole—is, in fact, primarily a study of the authors of this network.

Hippocrates of Chios (as well as Oenopides) surely preceded the first network and must have made a seminal contribution (Netz 2004; for Oenopides: Bodnár 2007); it is hard to judge what similar contribution might have been made by other early figures. In general, current scholars tend either to avoid speculation on earlier Greek mathematics or to suspect that we know so little because there is little to know: the earliest evidence we have for Greek mathematics (from the last third of the fifth century BCE) coincides with a wider cultural shift, the rise of prose as a significant vehicle. It seems quite possible that it was only then that mathematical authorship even emerged.

This historical background is also useful to answer the question of why Greek mathematics declined, a question sometimes raised concerning the trajectory of Greek mathematics in the generations following Archimedes. Such a question is meaningful only in the context of the Hegelian relay race. In reality, Greek mathematics never declined, it always progressed brilliantly—in the two episodes in which it was pursued.

And so: two networks, around Athens, around Alexandria. In between the two networks, we find Euclid's efforts of compilation, as well as a group of astronomers. Later than Archimedes' network, we find sporadic responses as well as efforts of collection and commentary—and, of course, a more creative work in the mixed sciences and, in particular, in astronomy. I return to discuss the contrast between the two networks below.

I resist the suggestion that Greek mathematics experience a "decline" following the immediate post-Archimedean generation. It is, however, accurate to note that there was no third network of pure mathematicians. The more isolated, later authors are indeed less ambitious. Many later works are reformulations of an earlier tradition or even, explicitly, commentaries on it: Menelaus, however brilliantly, essentially revised an earlier *Spherics* (for Menelaus' use of his sources: Sidoli 2006), Pappus compiled and commented on a vast range of works from the second network, Proclus wrote a commentary on Euclid's *Elements* 1… Even then it is hard to detect a meaningful clustering of authors around a particular project. Many individuals, from Nicomachus to Eutocius, tried—with a level of success we cannot now judge—to establish themselves as mathematical teachers in an environment where philosophical education was well established, typically led by individual masters, and of a Platonist variety open to mathematics. But none seems to have founded a school to survive his own teaching.

Perhaps we would have presented a different picture had our survey been of "the exact sciences," rather than of pure mathematics. Ptolemy alone presents a clear pinnacle of achievement in the mixed sciences, and it is likely that his immediate generation showed more activity (Menelaus, also an astronomer, was a somewhat older contempo-

rary). And yet this has to be put in the context of the trajectory of Greek cultural practice as a whole. The Roman era is marked by a large expansion of medical authorship, for instance, leading up to Galen, a major innovative author and member of an expansive—if competitive—network of practitioners. There is nothing like this in the exact sciences. What can certainly be said is that the exact sciences, and in particular pure mathematics, had a much weaker impact on Roman civilization itself. Here, Greece failed to conqueror its rude conqueror.

Especially in late antiquity, it was not just that mathematics was no longer pursued with an eye to original new breakthroughs. Rather, it was specifically pursued with an eye on the past; authors were especially interested in commenting upon and collecting the works of a past now made canonical. This, indeed, is typical of late ancient culture as a whole. The significance of this turn toward "Deuteronomic Texts" is that a mathematics focused on the reviewing of past achievements may naturally aim to homogenize and consolidate. The image of mathematics as a "system" may to some extent be a legacy of this period.

However dispersed, mathematical efforts in the period after Archimedes share a geographical location: Alexandria. The hub of the second network never lost its central location for the exact sciences, with authors such as Hero, Ptolemy, and Pappus. No other location ever emerges (unlike medicine or grammar, also associated with Alexandria but, in this case, sometimes evolving a presence elsewhere, for instance, in Asia Minor or Rome). More than other disciplines, perhaps, mathematics attracts its scattering of practitioners from the new lands of the Eastern Mediterranean. (So, for instance, Nicomachus was from Gerasa; Eutocius from Ascalon.) In a sense, then, it was not just the Romans who did not take to Greek mathematics. During the entirety of the post-Classical era, interest in mathematics was always far from the old Aegean core of Greek civilization. Perhaps related to this is the following: while to us the Greek contribution to the exact sciences is seen as seminal, the Greeks themselves hardly integrated it into their cultural identity, which was based, instead, on maintaining the literary canon. The Greek mathematical text—focused on the actual written document with its non-performative visual emphasis—was extremely remote from canonical literature. In late antiquity and into early Byzantium, however, perhaps with the changing cultural understanding of literature and its role, mathematics may have become more central. Integrated in some fashion into a Platonist philosophy, works of mathematics were re-read and, most crucially, maintained—resulting in the respectable extant corpus of roughly one million words.

And yet Greek mathematicians were not many, a fact obscured, if anything, by the more favorable reception in early Byzantium. About 5% of all extant ancient Greek authors are mathematicians, even if we confine ourselves to pure mathematics (with a more generous—and more accurate—definition, including authors in the exact sciences as a whole, the percentage jumps to about 10%). Almost certainly, the percentage of mathematicians among ancient authors was much smaller: it was a genre especially fitted for survival into Byzantium.

There are about 150 mathematical authors attested from antiquity.[2] I once estimated—taking into consideration the further evidence for the visibility of mathematicians in our record—that the order of magnitude for mathematical authors active in antiquity was about a thousand individuals (Netz 1999, 283–284). I would now revise this estimate as follows. When making it, I acknowledged the wide fluctuations

in the numbers of mathematicians, but did not yet conceive of Greek mathematical authorship as primarily concentrated in the two networks mentioned earlier. This tends to further cap our estimate of active mathematicians. It would be difficult to argue that less than 20%, say, of all ancient mathematicians were active in the Archimedean network, of which more than half had to be active simultaneously at the peak. So, a call for more than a thousand mathematicians in antiquity is also a call for over a hundred mathematical authors active simultaneously with Archimedes, which—given the internal evidence of Archimedes' own network of correspondence—begins to stretch credulity. It begins to seem likely, then, that "a thousand mathematicians" is on the higher end of the probable range. But then again, a number in the lower hundreds would imply that a very substantial fraction of all authors—however obscure—are now attested, which also stretches credulity. We are driven to conclude that the number of mathematical authors in antiquity was likely in the high hundreds. Of these, many dozens could be active simultaneously in the two peak periods, but no more than a handful in any other time.

The great bulk of authors would have composed no more than a few works, and the average production would have to be in the low range of the extant authors: say, in the range of a few tens of thousands of words (while this seems high in terms of Table 5.1, bear in mind that the entire corpus of no extant author is anywhere near complete). If we had all of ancient mathematics intact, we would probably find a corpus in the low tens of millions of words. It seems plausible that we have attested something like 20% of ancient mathematical authors, and have extant something like 3%–5% of ancient mathematical texts. Our knowledge is far from complete, but it is probably a good reflection of the more important trends. Let us now move to review them.

3. Themes of Greek Mathematics

The main theme of Greek mathematics is proof. One must read an entire proposition to get the flavor (Euclid, *Elements* 1.20). In my translation, words elided in the Greek original (other than for "point" and "line") are within pointed brackets; numerals and letters are added, standing for steps in the proof and the construction, respectively (Figure 5.1):

> The two sides of every triangle are greater than remaining <side>, taken together in every way.
>
> For let there be a triangle, ABG. I say that the two sides of the triangle ABG are greater than the remaining <side>, taken together in every way, BA, AG <greater> than BG; AB, BG <greater> than AG; and BG, GA <greater> than AB.

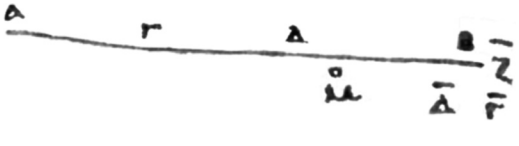


Figure 5.1 Euclid, *Elements* 1.20. (Florence, The Biblioteca Medicea Laurenziana, Ms. Laurenziana 28.3, f. 89 r. Reproduced with permission of MiBACT.)

(a) For let AB be drawn through to the point D, (b) and let AD be set equal to GA, (c) and let DG be joined.

(1) Now, since DA is equal to AG, (2) the angle, too, is equal, that <contained> by ADG to the <angle contained> by AGD; (3) Therefore the <angle contained> by BGD is greater than the <angle contained> by ADG; (4) and since DGB is a triangle having the angle <contained> by BGD greater, (5) while the greater side is subtended by the greater angle, (6) therefore DB is greater than BG; (7) therefore BA, AG are greater than BG; (8) so, similarly, we shall prove that AB, BG are greater than GA, and BG, GA <are greater> than AB.

Therefore two sides of every triangle are greater than the remaining <side>, taken together in every way; which it was required to prove.

The starting points of the proof (steps not argued for, but taken for granted within the context of the proof) are 1 and 5. The arguments are: 1→2, 2→3, 3→4, 4&5→6, 6→7. Step 8 asks us to revisit steps 1–7 as a whole and admit their transferability to the two remaining cases.

The proof crucially relies on two identifications:

The line segment DB is nothing other than the two line segments DA, AB, taken together; (required for the final argument 6→7 to go through), and

The angle contained by BGD is nothing other than the two angles contained by AGD, AGB, taken together. (Required for the argument 2→3).

Both identifications involve the decomposition and re-composition of a geometrical component—a line, an angle—by its constituents. I emphasize immediately: while it is conceivable to find a series of statements that recovers verbally the validity of such identifications, no such series of statements is offered in this proposition. Instead, it is clear that the reader is expected to inspect directly, that is visually, this validity. This then is a visual, diagrammatic move.

The argument 3→4 is a richer case of re-identification: having asserted that a certain angle is greater than another, it is then asserted that a certain triangle is a triangle possessing a certain angle as greater. Nothing new is asserted, other than (i) the identification of a certain triangle as the one containing the angles in question and (ii) a *verbal* reformulation. The verbal reformulation is the important one: Euclid has basically restated the claim of Step 3, so that it would fit the general language of Step 5. And where does the general language of Step 5 arise from? It is, in fact, a direct citation of the immediately preceding proposition 19. Note, however, that Euclid does not explicitly say "based on the previous proposition" or "see 1.19." Instead, he relies on a verbal repetition. This is indeed the favorite technique of Greek mathematical cross-references, where a proposition marks its reliance on a previous one through verbal echoes. In this case, then, the move is more verbal, mediated and enabled by the sharply outlined, formulaic language of Greek mathematics.

In general, the proposition relies on two previous results that establish how the metrics of sides map into the metrics of angles: equality breeds equality (*Elements* 1.5, and the basis for 1→2 here), and inequality breeds inequality (*Elements* 1.19, cited as Step 5, and the basis for argument 4&5→6 here). We have now covered all starting points and arguments other than Step 1, which is true by hypothesis, directly restating the construction of Step b (that such a construction is possible is vouched by *Elements* 1.2).

In sum, then, proofs rely on previous propositions, mediated via verbal echoes, and otherwise, for its immediate argument, they rely on a combination of visual and verbal cues. In this elementary example, from the beginning of Euclid's *Elements*, the reliance on verbal formulaic relations is limited to reference to previous results. Later on, especially as proportion theory is introduced, we find arguments where the logic itself is verbally and formulaically mediated ("Line A is to line B as line C is to line D, while line C is to line D as line E is to line F, therefore line A is to line B as line E is to line F"). The generic determinants of Greek mathematics—diagram and a formulaic language—are the two components that make it a deductive mechanism. It is a genre predicated on the primacy of proof. It is likely enough, then, that the very emergence of the genre might be related to the central role of argument and persuasion in Greek culture (Lloyd 1990, Chapters 3–4).

It might be the very centrality of those tools—verbal and visual identifications—that made Greek mathematics focus so much on geometry. In geometry, after all, diagrams are especially useful. Still, the strong emphasis on geometry alone is not characteristic of Greek mathematics as a whole, and the exception is important: namely, what I earlier called the first network of Greek mathematics. I would now argue that its very flavor of doing mathematics could have been distinct.

In truth, this is a difficult claim to make on methodological grounds. The second network is well represented in our extant corpus, better reported in our testimonies, and better served by the Arabic transmission. For the earlier network, on the other hand, all that we have are, at best, a couple of fragments that we may trace back to Archytas, as well as some mediated claims about the contributions of individual members in the network. If anything, we have slightly more on the even earlier Hippocrates of Chios. Fortunately, it is a likely enough assumption that the knowledge contained in Euclid's *Elements* (or perhaps in his corpus in general) is due to the first network. This allows us to note certain qualitative contrasts between the two networks. To be clear: historians of Greek mathematics have tended to mine the evidence of Euclid—our earliest substantial survival—to reconstruct the even earlier origins of Greek mathematics in the fifth century or even before, and only recently has it become clear that such reconstructions are unsound (for which see, in particular, Saito 1998). Using Euclid to reconstruct the *fourth* century, however, is difficult in practice but certainly warranted in principle.

So, we may start with a scholion to Euclid's *Elements* 5, stating—for whatever it is worth—that the results of this book are due to Eudoxus (Heiberg 1886, 5.280). Pappus' commentary to Euclid's *Elements* 10 ascribes a key development of this book to Theaetetus.[3] Furthermore, there is substantial evidence that Archytas developed a system of classification of *means* between numbers, and that he also contributed to the theory of the division of the musical octave: most importantly, we have a report of a proof equivalent to Euclid's *Sectio Canonis* 3.[4] There is no reliable evidence for the historical origins of the arithmetical books of Euclid's *Elements* (7–9)—the standard attribution of these books to "Pythagorean" sources is not well founded (see below). It is remarkable just how much they engage with the classification of numbers and their ratios through categories such as "prime," "square," and "cube" numbers and "continuous" ratios (7–9.20), and "odd," "even," and "perfect" numbers (11.21–36).

We end up with roughly half of Euclid's *Elements.* The half not taken, Books 5, 7–9, and 10, are characterized by an interest in the classification of non-configurational systems: numbers, ratios, and irrationals. This may be seen as the most characteristic interest of the first network.

The second network of Greek mathematicians already shows little attention to non-configurational classification. There is some interest in complicated calculations, but these often have spatial motivations (the clearest example: the calculations of the value of π by Archimedes in the *Measurement of Circle* and by Apollonius in his "fast delivery" [Eutocius, *On the Dimension of the Circle*, Heiberg 1915, 258.16–18]). There is little contribution to number theory between Euclid and Diophantus. *On Polygonal Numbers*, attributed to Diophantus, does make a reference to arithmetical definitions by Hypsicles (Tannery 1893, 470.27, 472.20), explicitly quoted as definitions rather than theorems; the implication is that Hypsicles made certain arithmetical assumptions in the course of a different (astronomical?) investigation. The scientific revolution would quickly find the routes to spectacular, original developments of number theory, based on tools that require no more than the elementary number theory known to Euclid. Number theory was neglected in the centuries following Euclid not because it was in any sense "exhausted," but because of a certain cultural preference.

With a handful of exceptions, the great bulk of the known work of the second network is dedicated to the description and simplification of curvilinear objects: their many measurements by Archimedes, followed by his many epigones; Apollonius' theories of conic curves; even the physical studies of Archimedes (the most original feature of the second network) aim at finding the center of gravity of a parabolic segment (Archimedes' *Planes in Equilibrium*) or the conditions of stability of a paraboloid of revolution (Archimedes' *Floating Bodies*). We may also note many further contributions to geometry, for instance, in Apollonius' systematic surveys of geometrical problems or in the various traditions of the special problems of cube duplication or angle trisection.

The contrast with the mathematics of the first network is stark. There one could indeed note an interest in geometrical problems, for instance, in Archytas' solution to the problem of the duplication of the cube, or in the construction of the five regular solids. However, in the context of Archytas' other projects, it appears quite possible that his interest in the problem could have been motivated by his wider interests in the classification of means and ratios (the duplication of the cube is essentially the problem, given two unequal lines, of finding two lines that form continuous proportions with them: we recall the interest in "continuous" proportion in *Elements* 8); while the construction of the regular solids is, in the context in which we know it—Euclid's *Elements* 13—presented as an application of the classification of irrationals.

We are left with one extant, advanced result of the first network clearly focused on configurational geometry, namely, the measurement of the volumes of pyramids, cylinders, and cones, in *Elements* 12. It is this result which Archimedes singles out for praise, twice, in both the introduction to *Sphere and Cylinder 1* as well as the introduction to *The Method*, as due to Eudoxus. The impression therefore is that the work of the first network was typically motivated by questions of the classification of non-configurational objects, the most significant exception being Eudoxus' measurement of several solid volumes; and that Archimedes made this exceptional result paradigmatic for his own mathematical project. Within this new mathematical project, the earlier interest in non-configurational classification did not entirely disappear, but it was now marginal. Rule and exception, foreground and background, became flipped. And yet—however fragmentary our evidence—it bears mentioning that Hippocrates of Chios' *Quadrature of Lunules* is a diagrammatic, visual proof of a geometrical set of equalities. Our evidence for Greek mathematics emerges first as geometrical, diagrammatic proof.

The contrast may yet appear somewhat abstract: let us now try to put more flesh on these descriptions of the first and second networks. What is this mathematics of non-configurational classification?

The simplest example of a non-configurational classification is familiar enough: the odd and the even. Euclid dedicates 14 propositions (9.21–34) to a brief, self-contained theory of this classification. It should be stressed immediately that the discussion is structured in proofs analogous to the one given earlier. Indeed, the Euclidean practice is to represent numbers by line segments, and, when they are to be added or subtracted, the line segments are positioned along a single line, as in the following figure for 9.26 (Figure 5.2). AB and BC are odd numbers, and BD is the unit, and we can quickly prove, looking at this diagram, that (in our terms) (odd – odd) = even, based on the previous proposition 9.25 that (even – even) = even. We have exactly the same components of proof as in the earlier geometrical argument.

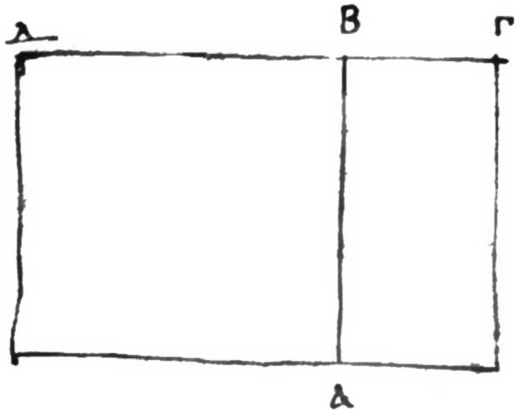


Figure 5.2 Odd and even numbers represented by line segments. (Florence, The Biblioteca Medicea Laurenziana, Ms. Laurenziana 28.3, f. 98 r. Reproduced with permission of MiBACT.)

The subject matter, in this case, is the manner in which elements of the classification, combined together, give rise to others. Often, such classifications become more complex and allow for a richer set of combinations. Euclid has numbers that are "even times even" (in our terms, they have the form 2n*2m); others are "odd times even" ((2n+1)*2m). He can thus prove, for instance, that, in our terms, 2^n can only be even times even (9.32). The reader might wonder why Euclid does not speak in the more general language of factors. Indeed, *Elements* 7.30 nearly asserts—yet does not—the fundamental theorem of arithmetic (the claim of 7.30 is that if mn = p, and q, a prime, measures mn, it must also measure either m or n). Perhaps the project of classifying numbers according to categories such as "odd," "even," "square," and "prime" is not the same as the modern project of number theory: what is fundamental to the latter was less fundamental to the Greeks.

"Odd," "even," and indeed "square" or "prime," are fairly straightforward classifications. *Elements* 10 engaged in much more complex classification of a much more complex object: irrationals. We take two lines. Is there a line segment which measures them both? If not, then they are incommensurable. Or we may look at the squares on the two lines: is there a square area that measures both squares? If not, the lines are

incommensurable in square. An interesting category is that of lines commensurable in square only (so, for instance, are the side and diagonal in a square). Now, we take a given line as starting point and begin to distinguish the universe of lines that are or are not commensurable with it in square: those that are, are called "rational," those that are not are called "irrational." So, for example (Figure 5.3), take two rational straight lines that are, between them, commensurable in square only (if the length of the original line segment is 1, these may be 1 and $\sqrt{2}$). Consider the area of the rectangle contained by them and then take the square equal to that rectangle. Ready to find its side? Fine! Euclid proves, in 10.21, that this side is irrational, and that it defines a special class of irrationals, called "medials." Following that, through the grueling 115 propositions of *Elements* 10, Euclid defines and puts in relation an entire sequence of classes of irrationals. The final proposition 115 points out that the sequence of classifications may be extended indefinitely. This is possibly a later scholion, aware of Apollonius' contribution to the theory of irrationals. If so, we find that the main contribution of the second network to non-configurational classification was a *critique* of the most ambitious classification of the first.

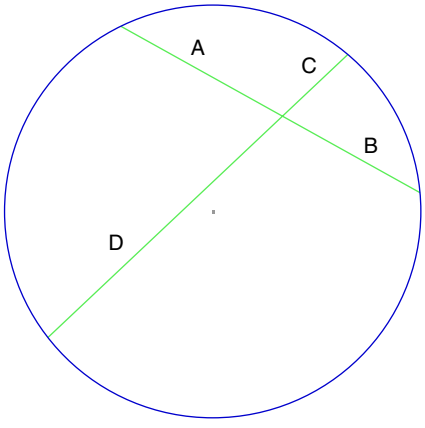


Figure 5.3 Two rational straight lines, commensurable in square only.

The classifications of irrationals are the most ambitious in Greek mathematics, but the Greek interest in such classifications likely does not arise from an interest in irrationality or, literally, "lack-of-ratio." Instead, the main interest of Greek mathematics was in the classification of ratio itself. *Elements* 5 presents a sophisticated derivation of the main properties of ratio and proportion and, at an even more elementary level, it is likely that the mathematicians of the first network could have been impressed by the motivation—lying outside pure mathematics—of classifying ratios between integers. A fundamental, early result of Greek music theory was that musical harmonies are associated with simple numerical ratios (The Science of Harmonics and Music Theory in Ancient Greece). Early on, such ratios were classified as "epimoric," or the ratio n+1:n. A classification of integer ratios and the study of the conditions for deriving epimoric ratios became, then, a central concern for a certain group of Greek mathematicians. Archytas was surely among them, besides being also in some sense a "Pythagorean." To the extent—likely enough—that Archytas had a significant impact on the work of the first network of Greek mathematics, we may argue that a Pythagorean fascination with

the mathematization of the natural world was crucial to the mathematics of the fourth century. Late Ancient Platonists who grafted their philosophy onto the achievement of Greek mathematics were right, then, to focus on the two fields of arithmetic and music and, essentially, on a revival of first-network mathematics.

But this was already not the dominant form of mathematics available in circulation: the second network changed all that. Let us move on to consider this, much more modern-looking achievement.

Greek mathematical proofs gain their power through the combination of visual and verbal identities. This is clearest with geometrical proportions: when it is argued that four geometrical objects stand in a fixed proportion, we can manipulate them as spatial elements, or as purely symbolic elements within the proportion formula. It is always interesting when we find that certain proportions naturally inhere in a geometrical configuration: so, for instance, early on it was realized that when two chords in a circle cut each other, the resulting four segments are in proportion (Figure 5.4):

A:B::C:D

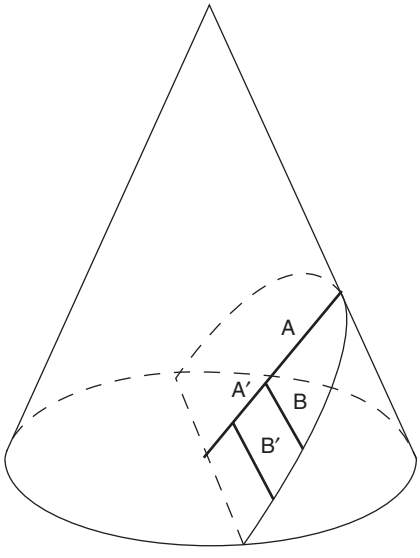


Figure 5.4 Two chords in a circle cutting each other.

A thought suggests itself: what happens when the circle is tilted in space? Imagine it, more concretely, tilted within a cone (Figure 5.5):

This particular configuration—what we now call a parabola—is especially interesting: we find that the proportion of the chords of the aforementioned circle can now be transformed into the following proportion:

$A:A'::B^2:B'^2$

The ratio between certain segments is the same as the ratio between the *squares* on other segments. (To us, of course, this would simply mean that the parabola is a quadratic curve.)

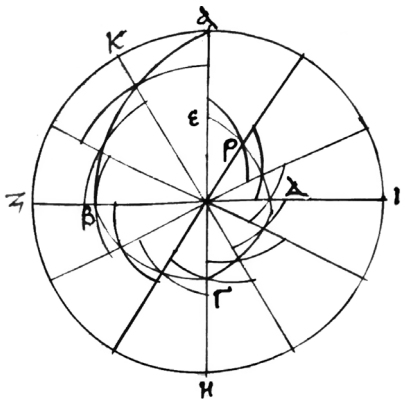


Figure 5.5 Circle tilted within a cone. (Bioblioteca Medicea Laurenziana, Ms. Laurenziana 28.4, f. 85 r. Reproduced with permission of MiBACT.)

The three conic sections—what we now call parabola, ellipse, and hyperbola—all give rise to this type of proportion. In a sense, such results are interesting from the point of view of the classifications of segments, proportions, and means. Perhaps for this reason, it was the mathematicians active late in the first network (perhaps Aristaeus?) who discovered the conic sections.

A century later, Archimedes, and the authors following him, looked at the conic sections, not as tools for the classification of means but as spatial objects in their own right. With hindsight, we can say that this program is effective because the curves are quadratic, giving rise to simple ratios. Indeed, Archimedes considers not only the plane curves but also the solids to which they give rise: for instance, a conoid is a parabolic or hyperbolic segment rotated around its axis; a spheroid is an ellipse rotated around its axis. Thus in *On Conoids and Spheroids*, Archimedes finds that a paraboloid is 3:2 an inscribed cone; a hemispheroid 2:1 an inscribed cone. In *The Quadrature of the Parabola*, the parabolic segment is found to be 4:3 an inscribed triangle. In *Planes in Equilibrium*, we learn that the center of gravity of a parabolic segment cuts its axis in the ratio 3:2. In *Floating Bodies*, we learn that the conditions governing the stability of a paraboloid immersed in liquid depend on the linear ratios defined by the axis, with tipping points—literally—at the following ratios: 3:2, 15:4. All of this is almost too good to be true, and yet the results just keep coming. Apollonius dedicated an entire massive treatise—in its original form, eight books—to conics. Here, the emphasis is on striking equalities and limiting cases that are obtained when lines are drawn through the conic sections. Similar to this is Diocles' observation concerning the focal property of the parabola, making possible the theoretical construction of a burning mirror (Optics). In general, curves with predetermined geometrical proportions can be used to solve geometrical problems such as the so-called trisection of an angle, or the duplication of a cube: this program can once again be seen as an extension of the program of studying conic sections (looking, in this case, for other sections, rather than for other applications of the conics). This field, in particular, is surveyed by Knorr (1986).

In the foregoing examples, we note the fascination with simple measurements—and in this respect, Archimedes, as noted earlier, emulated Eudoxus' finding of the 1:3 ratio of the cone and the cylinder enclosing it. Sometimes, such simple measurements could

be found even without the conic sections. The closest Archimedes ever came to Eudoxus was in the finding of the ratio 2:3 between a sphere and the cylinder enclosing it: *Sphere and Cylinder*; one may also add the ratio 1:3 between a spiral segment and a circle enclosing it: *Spiral Lines*. Throughout, we are most impressed by Archimedes' technique, once again a continuation of Eudoxus. In considering the properties of a curved magnitude, Archimedes constructs a linear magnitude that can be made to differ from the curved magnitude by less than any given amount: thus, for instance, it can be shown that the sequence of circle sectors inscribed inside a spiral area may be made to differ from the spiral area by less than any given difference, simply by making the number of sectors suitably large. It can thus be shown that the assumption that the spiral area is more or less than a third of the circle gives rise to the paradoxical result that it is either smaller than an area it encloses, or greater than an area that encloses it (Figure 5.5).

This technique is suggestive of the modern calculus, and indeed it was Archimedes' example that prompted the mathematicians of the scientific revolution to develop their own, more general tools of integration.

No such general tool is to be found in Archimedes, and indeed one is struck by the rich brilliance of individual results—and by the emphasis on their individuality. Instead of aiming for generalization and systematization, the authors of the second network aim at isolated tours-de-force. Perhaps they seek to surprise their readers: I have suggested in Netz 2009 that this emphasis on the surprising combination may strike a chord with a Hellenistic audience, trained in the generically innovative poetics of contemporary literature.

The scientific revolution took Archimedes and made a general system out of him. In this, however, they followed the lead of late antiquity. In the culture of commentary, the individual brilliance of the individual result mattered less. What mattered now was the foundation of all established results in the text now taken as canonical, that of Euclid's *Elements*. In late antiquity, little of deep mathematical significance was added other than that new orientation, but the immediate heirs of Greek mathematics—Islamic mathematicians active from the ninth century onward (see Translation and Transmission of Ancient Scientific Texts)—did change mathematics itself. The isolated problems of Archimedes and Apollonius become, in a work such as Khayyam's algebra, particular cases within a system of equations to be solved through a given set of techniques. It would be left to the scientific revolution to codify and simplify such techniques, so that eventually one would have the mathematics of the generalized curve or the generalized equation, and the conics would become, finally, our quadratics (to summarize the controversial claim of Netz [2004]; cf. Acerbi [2005]).

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FURTHER READING AND GUIDES FOR RESEARCH

The first three articles collected in Sidoli, Van Brummelen, and Berggren 2014 are bibliographic studies of research in Greek mathematics from the 1960s to 1984; from 1984 to 1998; and from 1998 to 2014, respectively. Anyone studying Greek mathematics should have this volume to hand.

The bulk of the editions we now use for Greek mathematics still antedate the 1960s. We are lucky that Johan Ludvig Heiberg, a philologist of genius, edited many of those extant million words of Greek mathematics (most important, the three great Hellenistic authors: Archimedes, Apollonius, and Euclid). Much early scholarship into the

history of Greek mathematics is marred by anachronism—where the peculiar concerns of ancient mathematicians are ignored. Also, a significant amount of early scholarship was dedicated to speculative (and idle) reconstructions of the earliest Greek mathematics (Saito 1998/2014). An early plea against anachronism in the scholarship of Greek mathematics—Klein 1934–1936/1968—remains an important influence on contemporary scholarship. All recent scholarship begins from Unguru 1975, an article that made a claim once controversial, now universally shared: ancient mathematics must be read on its own rather than our own modern terms. The Greek conic sections were geometrical figures, and not algebraic curves. Forty years ago, this was not yet evident.

Whom should you read today? Sidoli, Van Brummelen, and Berggren 2014 single out three works as typical of research in the years 1998–2014: Acerbi 2010, Cuomo 2001, and Netz 1999. In the two decades preceding, one would surely single out Fowler 1998 (first edition: 1987), Knorr 1986, and Mueller 1981. Many names could be added, but two authors, especially, made their mark through a series of articles rather than in any single book: Ken Saito and Bernard Vitrac.

During his brief life as a scholar, Knorr dominated and reinvigorated the study of Greek mathematics. His first book (based on his dissertation) from 1975 squarely belongs to the old tradition of speculations concerning early Greek mathematics; a constant stream of articles since, culminating in his 1986 book, refocused scholarship on the study of the firmly attested achievements of Greek mathematics: in practice, what I call the second network. Fowler's book is speculative and yet rich in detail about the evidence for Greek mathematical practice. Mueller's book is explicitly about Euclid's *Elements* alone, but Mueller opened up the field to consider the logic of Greek mathematics on its own terms. Together, such works prepared the way for current scholarship, where the emphasis is often on putting Greek mathematical texts within the literary and historical context of Greek culture as a whole. The tendency is to consider Greek mathematics as a genre, that form of Greek writing which is based diagrams and a formulaic language. This new turn in the study of Greek mathematics coincides with a new emphasis, within Greek cultural studies, on incorporating the evidence from texts outside the literary canon. The result is a new synthesis of the study of Greek science into the study of Greek civilization as a whole.

NOTES

1 One could also mention here Theon of Smyrna (100 CE), whose contemporary contribution to Platonic pedagogy does include a fair amount of mathematical discussion.
2 I generated a list of 144 authors in 1997, corrected and expanded to 164 in *EANS*: this, however, even if clearly an improvement on mine, is intended to be charitable in its definition of a "mathematician."
3 While Book 10, strictly speaking, is a study of the ratios between lines, such lines are typically taken only within minimal configuration, and so what matters is not their spatial networking but rather just their relations as quantities. In practical terms, what distinguishes non-configurational studies in Greek mathematics is the emphasis on diagrams constituted by separate, nonintersecting lines.
4 The general theory of means is fragment 2 (Huffman 2005, 162–181); the contribution to music theory is fragment 1 (103–161, but especially part three, 4.402–482). The explicit musical proof is A19 (451–470), from Boëthius' *On Music* 3.2.

CHAPTER 6

Astronomy

Andrew D. Gregory

1. Some Historiographical Issues

The models of the heavens of some Greek thinkers, particularly the earlier ones, can be reconstructed in many ways. We do not have enough evidence to state categorically exactly how these models were put together. If we are generous and allow the best possible reconstruction, it is possible to generate some quite sophisticated models. The limits of what a model can do should, of course, be explored, but with caution and the caveat that this is our best reconstruction. There can also be a tension between astronomy and cosmology in such reconstructions. So, as we will see for Anaximander, attributing a sophisticated astronomy to him compromises his account of the stability of the earth, while attributing a sophisticated astronomy to Plato compromises the idea of perfectly regular circular motion. There is then a choice to be made between attributing sophisticated astronomy or strong cosmological principle. One aspect of that choice is whether the thinker in question should be considered primarily an astronomer or a cosmologist.

An important related issue is whether we should credit that all ancient thinkers believed that the model of the heavens they devised could account for all the phenomena of which they were aware. Simplicius, the sixth-century commentator, tells us:

> The unrolling spheres of Eudoxus' school do not save the phenomena, not only those that were found later, but also those known before and recognized by them. (*On "On the Heavens"* 504.17–20)

It is thus clear that Eudoxus and his followers at least did not have a model that accounted for all of the phenomena of which he was aware. Simplicius then proceeds to give evidence concerning variations in planetary distance and refers to annular eclipses

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(occurring when the moon is at such a distance from the earth that it does not cover the entire sun). He also tells us that it is evident to the naked eye that the moon does not always lie at the same distance from us, as it does not have the same size even when observed under seemingly similar conditions. We cannot then assume that all Greek thinkers thought their models could account for all of the phenomena they were aware of, let alone all of the phenomena we are aware of.

Nor can we suppose a linear progression in terms of sophistication in Greek astronomy. That is, if we have good evidence that one thinker postdates another, we cannot assume that in some way the later model is also more sophisticated.

That the Greeks believed themselves to live in a *cosmos* (plural, *cosmoi*) is significant. The root verb, *cosmeō*, had a sense not only of order but of good order (our words *cosmology* and even *cosmetic* derive from it) and could also have a sense of an aesthetically good or morally good order (see The Creation and Destruction of the World). Depending on the author, these senses can be more or less marked. I will use the word *cosmos* to retain this original sense, rather than the modern term *universe*.

The great majority of Greek and Roman astronomy was geocentric, earth centered. There were good reasons for the Greeks and Romans to believe this, the form of the argument being: if the earth were in motion, or not in the center of the *cosmos*, there would be perceptible consequences. We do not perceive these consequences. Therefore, the earth is not in motion. There is an important consequence of believing the earth to be central and stable. Nowadays, we explain some of what we see in the night sky in terms of the motion of the earth as apparent motion. For geocentrism, though, there are no apparent motions, and all the motions in the night sky are real. There were a wide range of predicted effects, from winds counter to the earth's spin or direction of motion to stellar parallax. This is the source of some of the complexity of Greek astronomy.

A final, yet enormously important, consideration can be put very bluntly: the ancient Greeks and Romans had no conception of gravity. Of course, they knew that heavy objects drop to earth and that the heavenly bodies move in a regular manner. They did not explain these phenomena in terms of gravity, though, and so needed other sorts of explanations for the regular motion of heavenly bodies. Sometimes that was done in a manner we might loosely describe as mechanical (i.e., using vortices), but often the heavenly bodies were seen as intelligent, choosing the correct motions and obeying something closer to civil law than our modern conception of mathematical law. It has not always been evident that the modern approach is correct, and we should allow the ancients some leeway in pursuing what to them were quite rational possibilities. The intelligence/civil law model gave a strong basis for regularities in the heavens.

2. Pre-Greek Astronomy

How much the Greeks knew of pre-Greek astronomy has always been an issue of considerable contention. It is clear that both Plato and Aristotle were at least aware of and praised Babylonian astronomical records. It has now been proved beyond doubt that later astronomers knew of and used these records. Whether the Presocratic Greeks were aware of Babylonian records and methods is still a matter of debate. The Babylonian records, accurate and extensive, were used to make predictions of selected phenomena in the heavens as deemed important for the calendar and for Babylonian astrology (e.g.,

the gods were thought to send messages to humans via the heavens). The means of prediction was to look for patterns in the data and then to select and refine algorithms. The Babylonians posited a flat earth and a hemispherical heaven across which the celestial bodies passed.

An assortment of contrasts can be drawn between Babylonian and early Greek astronomy. And while none on their own capture the full nature of the contrast, and none are correct in their simplest forms, all contribute something to the discussion. There is sometimes a philosophy of science agenda behind these contrasts, wishing to show that either the Babylonians or the Greeks were the first real scientific astronomers. That debate has generated rather more heat than light. And it may be best to consider science (and disciplines within science such as astronomy) to have multiple rather than singular origins, all making an interesting contribution. First, there is the contrast of arithmetical and geometrical models of the heavens. In relation to the heavens, the Babylonians used numbers, whereas the early Greeks used shapes, in particular, the circle. Although true to a certain extent, this masks other differences, especially in terms of goals and explanations in astronomy. Nor is the contrast absolute. This contrast can also be put in terms of differences between prediction and explanation. The Babylonian emphasis was on prediction, whereas the early Greeks were more interested in generating explanations of celestial motions. Recent work has shown how the Babylonians understood and explained the heavens, albeit in different ways from the early Greeks. Finally, one can rather crudely contrast Babylonian observational methods with the supposed philosophical speculation of the early Greeks. Although the early Greeks were more speculative than the Babylonians, that speculation still at least attempted to produce models which conformed to the motions of the heavens.

Thales

Although we find no technical astronomy as such in Homer and Hesiod, there is some knowledge of the heavens and some sense of a cosmology, albeit with a heaven above the earth and an underworld below. Thales, the first person in the Greek tradition of natural science/philosophy, is famed for predicting an eclipse (*TEGP* 5), but there are problems with the evidence. We are not sure if he did predict a solar eclipse, nor of the degree of accuracy of the prediction, nor of his methods. Since the Babylonians were able to predict eclipses, it is tempting to suppose that Thales had access to their records and methods, or perhaps even just their results. However, we have no concrete evidence of this. Other than supposing a central and stable earth, supported by water, we know little of Thales' picture of the heavens.

Anaximander

With Anaximander we have more information, and there has been considerable debate about the sophistication of his model of the heavens. Let us begin with the earth (*TEGP* 19–20). In shape, it is likened to a section of a stone column, so it is round with two flat surfaces. We are told that its depth is one third of its width (or three times its width, according to a minority view). It is probable that the surfaces were in fact slightly concave. The earth is in the center and does not move. On the standard view, the earth is unsupported. It does not move as it has no reason to move in any specific direction. That

is a remarkable departure in cosmology from any previous conception. Also remarkable are the facts that Anaximander is the first to have the heavenly bodies make full orbits under the earth and to give depth to the heavens (*TEGP* 22–23, 25, 28).

Anaximander divided the heavens into rings around the earth: the stars (closest), the moon, and sun (furthest). The heavenly bodies are, in fact, rings of fire for Anaximander. A ring is surrounded by condensed air that makes the fiery core invisible, except for a small hole. What we see as the heavenly bodies are then not separate entities, such as stars and moons as we understand them, but glimpses of the fiery core observed through a small mouth in the compressed air. One advantage of these rings is that they are continuous such that they do not upset the indifference argument for the earth, as would be the case with planets. The rings are also spaced equally from each other, giving them no preferred direction of movement. The usual reconstruction of the spacing is 9 (stars) 18 (moon) 27 (sun), the numbers here being proportions, probably in relation to the radius of the earth (Figure 6.1).

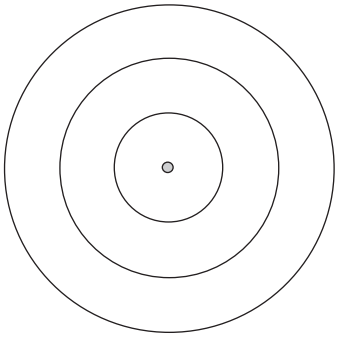


Figure 6.1 Anaximander's solar system.

How were these rings arranged? We do not know for certain. One possibility we can reasonably reject is that the rings are arranged concentrically in the same plane as the faces of the earth. If this were so, the stars, moon, and sun would only be visible near the horizon (Figure 6.2).

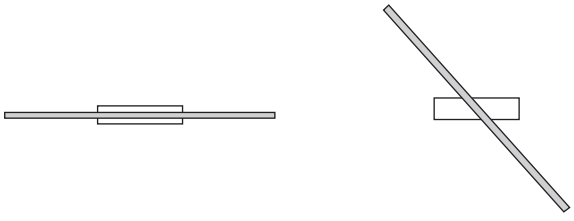


Figure 6.2 Stars viewed from the horizon.

The problem with this arrangement is that sun and moon would have the same paths across the sky each day, when in fact there are significant variations. We do have evidence for this arrangement. For Anaximander, the rings are said to lie "aslant" (*TEGP* 25), but we have no values for their slanting.

Some scholars have proposed a more complex scheme, whereby the sun and moon rings move up and down the axis of the *cosmos*. The summer solstice occurs when the sun is

furthest "up" and winter solstice when the sun is furthest "down." This is highly ingenious, but we have no textual evidence for this motion. It is also problematic in that if the sun and moon did move like this, then the earth would no longer be at the center of their orbits and so would have reason to move, compromising the argument for the stability of the earth.

This brings us to the type of difficulty in reconstructing models outlined earlier. We can give Anaximander a more sophisticated astronomy, allowing him to account for more phenomena, but this comes at the cost of cosmological principle in ruining the argument for the stability of the earth. There is no absolute answer to this issue, though my personal sense is that Anaximander pays a great deal of attention to the symmetry and stability of the *cosmos* and is unlikely to have compromised that.

Philolaus and the Pythagoreans

Aristotle gives us a good description of Philolaus' system (*TEGP* 24). At the center of the *cosmos* we have the central fire, with the earth, sun, moon, stars, and planets all orbiting around it. Between the earth and the central fire is the counter-earth, presumably in synchronous orbit with the earth such that we are unable to see the central fire. We then have the moon, sun, the five planets, and the sphere of the stars (Figure 6.3).

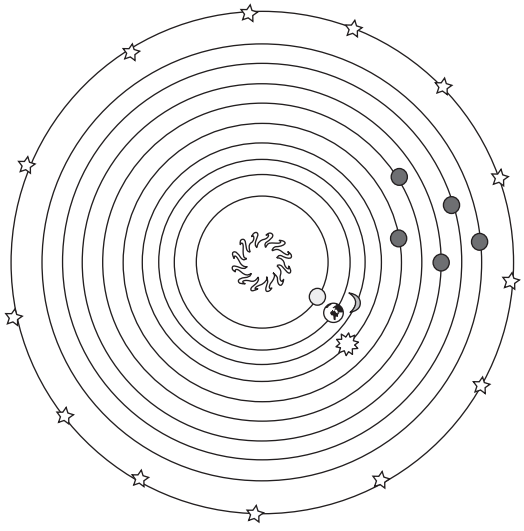


Figure 6.3 Philolaus' system.

While the description of Philolaus' system is reasonably clear, the purpose of this model is not. It is remarkable that the earth is in motion, though it is orbiting round the central fire, not the sun, and the sun is orbiting the central fire as well.

If the model is set up to accord with Pythagorean eschatology, rather than cosmological principle or astronomical observation, it is not clear how the model and any proposed eschatology fit together. It may be that, as Aristotle says, ten bodies were supposed in order to match with the Pythagorean perfect number, ten. That, of course, depends on how one counts the bodies. Some sources attribute the origins of the idea of regular circular motion to the Pythagoreans. That too is possible, though the sources on the Pythagoreans are notoriously corrupt, tending to aggrandize Pythagoras in particular by attributing ideas which were in fact formulated later.

Other Presocratics

The later Presocratic thinkers added little to technical astronomy, but there are some interesting discoveries and new ideas in cosmology. One important idea is that of the vortex, whereby the heavenly bodies are propelled round the earth. In Anaxagoras, the heavenly bodies are specifically heavy entities which need to be held aloft (*TEGP* 31). Parmenides was the first to speak of the moon as shining by reflected light (*TEGP* 35). The idea that the earth was spherical also dates from this period, though it is more difficult to pin down to any one person.

3. Euctemon and Meton

Euctemon and Meton are credited with an important discovery, that of the inequality of the seasons. The year can be divided into four parts by the two solstices and two equinoxes. The equinoxes are days of equal day and night, the solstices the days of maximum and minimum night and day. One might think that there would be equal numbers of days between equinoxes and solstices and between solstices and equinoxes. In fact, there are not, as Euctemon and Meton discovered. The reason for this is that the earth's orbit around the sun is elliptical (Figure 6.4).

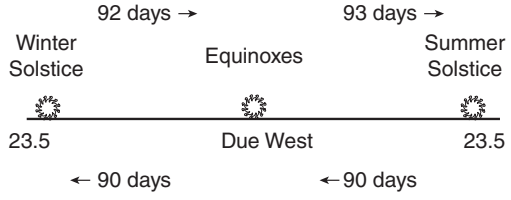


Figure 6.4 Inequality of equinoxes and solstices.

Meton is also credited with introducing the Metonic cycle, that nineteen solar years are very nearly equivalent to 223 lunar months, an important discovery in relation to generating a stable calendar (Diodorus Siculus 12.36.2).

4. Plato

Let us here concentrate on the model put forward in Plato's *Timaeus*, with, of course, reference to the *Republic*. The key idea is that the motions of the sun, moon, and planets can be analyzed in terms of combinations of regular circular motions. The *Timaeus* may mark a departure from the views of the *Republic* in two important ways. First, there is the *Republic's* attitude to the regularity of celestial motion:

> Concerning the proportion of night to day, and of these to the month, of month to year, and of the other stars to these and to each other, wouldn't he consider it absurd to think that these things always come to be the same manner and never undergo any deviation, as they are both physical and visible. (530a3–7)

Second, there is the *Republic* VII passage where Plato has Socrates say the following:

> It is by means of problems, then, that we shall proceed with astronomy as we do geometry, and we shall leave the things in the heavens alone, if by really taking part in astronomy we propose to make useful instead of useless the understanding that is by nature in the soul. (530b6–c1)

Timaeus 47a on the other hand tells us that

> God devised and gave to us vision in order that we might observe the rational revolutions of the heavens and use them against the revolutions of thought that are in us, which are like them, though those are clear and ours confused, and by learning thoroughly and partaking in calculations correct according to nature, by imitation of the entirely unwandering revolutions of God we might stabilize the wandering revolutions in ourselves.

The "unwandering revolutions of God" here are the motions of the heavens, and there is ample evidence elsewhere in the *Timaeus* that the motions of the heavens are regular. *Timaeus* 34a and 40b tell us that the motions of the *cosmos* as a whole, and those of the fixed stars, are unwandering. There cannot then be a metaphysical problem with the regular motions of the heavens (i.e., that which is visible and bodily *can* move in a regular manner; cf. *Republic* 529d–530d). If the "wanderings" of the planets constitute time (39c), and the planets, sun, and moon are the "guardians of time" (38c), then, unless Plato envisages a non-uniform passage of time, the motions of the heavenly bodies are regular. For there to be a contrast between time and eternity, all that is required is that time moves while eternity does not. This is similar to the position of the *Laws* (822a) and *Epinomis*, but different from the *Republic* and the *Statesman*, where the *cosmos* is degenerating toward chaos, and so the heavenly motions become chaotic. It is interesting to note that while both the *Republic* (616b) and the *Statesman* (270a9) have the *cosmos* rotating on a pivot, the *Timaeus* (34a; cf. 33d) has the *cosmos* free floating. It is also arguable that Plato moves from a degenerating to a stable *cosmos* (see Gregory 2001, 101–113).

Some commentators have detected a rejection or denigration of the phenomena or of observational astronomy in the second *Republic* passage (Heath 1913, 135–140; cf. Mittelstraß 1963, 117; Neugebauer 1951, 157). There are alternatives here, based on the conditional nature of the passage (*if* we use astronomy for this purpose, then … other purposes may have other protases), and much depends on what is thought to be the epistemological import of the middle books of the *Republic* (for further details: Gregory 2001, chapter 2). In the *Timaeus* passage, observation of the heavens is encouraged.

In the *Timaeus'* model of the heavens, there is a sphere of fixed stars which rotates once a day. The sun, moon, and planets share in this motion, but they also have a second circular motion, with the axis offset to that of the stars. The sun, moon, and planets will then be seen in successively slightly different positions relative to the fixed stars owing to this second motion. We are not given any specific angle here. Plato merely says this is like the Greek letter θ, with the model working best if we use the angle of the ecliptic, around 23.5 degrees (Figure 6.5).

Plato says that the moon completes its second motion in a month, the sun in a year, and Mercury and Venus in about a year. But he omits values for the other planets. There

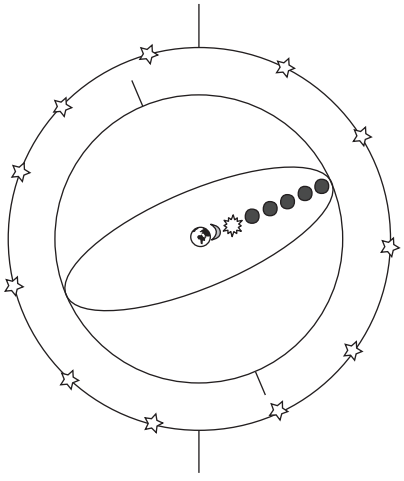


Figure 6.5 Plato's two-sphere model.

are several advantages of this model, which gives reasonable approximations for the motions of the sun, moon, and planets using only two regular circular motions. There are also significant problems. The sun, moon, and earth are all permanently in the same plane so there will be full solar and lunar eclipses roughly every month, and there will be no variation in the type of eclipse. The planets are also in the same plane and so will occlude each other every time they pass (which is rare) rather than passing each other in the zodiac. Plato is also aware that Mercury, Venus, and the sun "overtake and are overtaken by each other" (38d), which occurs because Mercury and Venus are inferior planets; that is, their orbit around the sun is smaller than that of the earth. Plato then says that Mercury and Venus have a contrary power (38d4) to the sun. We do not know the nature of this "contrary power."

Plato is another example where we have a conflict between a simple and strong cosmological principle and astronomical sophistication. There can be no doubt that Plato is aware of more phenomena than any model using two regular circular motions for sun, moon, and planets can reproduce. The most interesting passage in this respect is 40c:

> (1) The dances of these stars and their juxtapositions with one another, (2) the circling backs and advances of their own cycles, (3) which of the gods come into contact with each other and which into opposition, (4) which cover each other relative to us, and (5) for what periods they each disappear and again re-appear.

When planets pass each other in the zodiac, they can be close to one another (1), be so close that they appear to merge into one large object (3), or occlude one another (4). Planets can undergo retrograde motion (2), and Mercury and Venus disappear as they come close to the sun and then reappear on the other side of the sun, a phenomenon much studied by the Babylonians. None of these phenomena can be accounted for by the *Timaeus* model. As Vlastos (1975, 50) has commented, "Plato's language here is saturated with the terms of observational astronomy" (Figure 6.6).

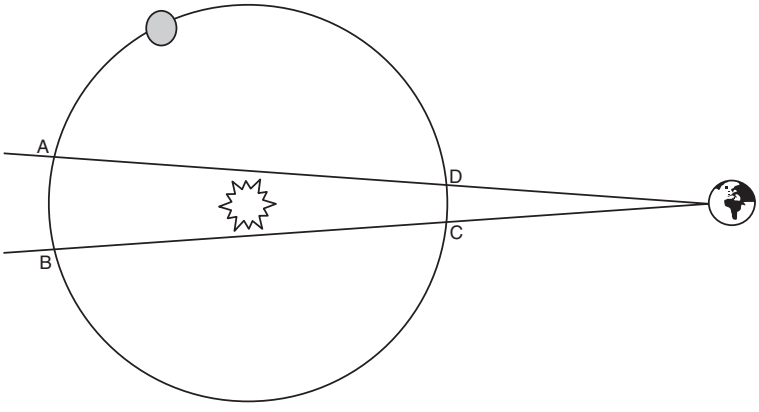


Figure 6.6 Venus, Mercury, and the Sun.

It has been argued that the contrary power can apply more widely than just to the overtaking/overtaken phenomenon of Mercury, Venus, and the sun. The text does not justify this, and there is a question of which phenomena we apply it to, if we do not apply it to all the phenomena of which Plato was aware. It should be evident that the more we allow the application of some form of contrary power, the more regular circular motion will be compromised.

The alternative here is to treat the *Timaeus* model as a prototype, strong on cosmological principle (regular circular motion only) but weaker on astronomical detail. The "contrary power" merely notes there is a difficulty with Mercury, Venus, and the sun without giving an answer, and it does not apply to other phenomena. If we take this view, then the evidence of Simplicius makes good sense:

> Plato assigned circular, regular and ordered motions to the heavens, and offered this problem to the mathematicians: which hypotheses of regular, circular and ordered motion are capable of saving the phenomena of the planets, and first Eudoxus of Knidos produced the hypothesis of the so-called unrolling spheres. (*On "On the Heavens"* 492.31–493.5; cf. 488.18–24)

Plato was not able to do this himself with combinations of two circular notions, but keeping to the program of analyzing the motions of the heavens in terms of regular circular motions, he challenges others to provide solutions within that framework.

5. Eudoxus

Eudoxus, noted also for producing a star catalog, put forward a view which was more complex than that of Plato's *Timaeus*, and that could also account for a good deal more of the phenomena. Instead of proposing two motions for the sun, moon, and planets, Eudoxus proposed three for the sun and the moon and four for the planets. These were all regular circular motions with a common center (homocentric/concentric sphere model). Two of the motions were the same as those proposed by Plato in the *Timaeus*, one taking the body round in a full circle in one day, the other generating motion along the ecliptic (Figure 6.7).

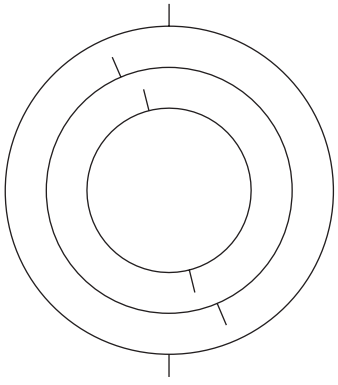


Figure 6.7 Third sphere for the sun and the moon.

Eudoxus, though, proposed a third motion for the sun and moon. This works reasonably well for the moon if we suppose that the third motion is offset for the motion that drives the moon along the ecliptic by about five degrees. This will give the moon a deviation from the ecliptic of five degrees on each side, which is correct. It is interesting that Eudoxus proposes a third motion for the sun. We think of the ecliptic as the path followed by the sun. The ancient Greeks thought in terms of the line through the middle of the zodiac, with the possibility that the sun might deviate from that. While we think of the sun as something special in astronomical terms, it is clear that the Greeks did not, not privileging it in any way and generating similar models for the sun as for other heavenly objects. It may be that, given the difficulty of measuring the precise point of the solstices, Eudoxus had a small third motion for the sun to account for data which appeared to give a variable point for the solstices. It is also possible that Eudoxus gave the sun a small motion in order to improve his model for eclipses (Figure 6.8).

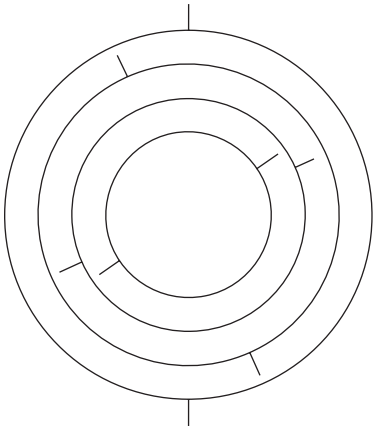


Figure 6.8 Eudoxus' four spheres.

Eudoxus proposed a four motion model for the planets. Again, two of the motions take care of the daily motion and motion along the ecliptic, respectively. The other two motions were used to give a representation of retrograde motion. If we take these two motions on their own, they make a shape known as a hippopede (Figure 6.9).

If we combine them with the first two motions, then we get something like retrograde motion (Figure 6.10).

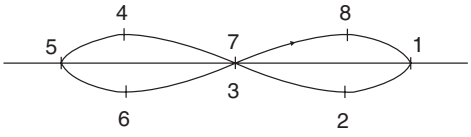


Figure 6.9 A hippopede.

With the benefit of modern mathematics and computer modeling, we have a better appreciation of what Eudoxus' model could and could not do. One of the problems is that we have little in terms of figures to apply to the spheres. We do not know much about the angles they were set at relative to each other, nor about their speeds.

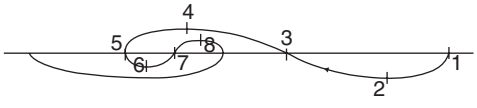


Figure 6.10 Motion resulting from daily motion and motion along the ecliptic.

6. Callippus

Callippus further developed Eudoxus' work and moved to a five motion concentric sphere model for most celestial bodies. Where Eudoxus used a total of 27 spheres, Callippus used 34. This is likely to have produced greater accuracy in modeling the celestial motions, but we have no quantitative assessment of by how much. Callippus produced a system of 5 spheres for the sun and the moon. The standard explanation is that the extra spheres for the sun give an approximation of the inequality of the seasons, and those for the moon give a similar approximation of differences in the moon's orbital velocity, neither effect being explicable on Eudoxus' model. Callippus also produced 5 sphere models for Mercury, Venus, and Mars, staying with 4 sphere models for Jupiter and Saturn. While tolerable approximations of the retrograde motion of Jupiter and Saturn are possible on Eudoxus' model, they are not possible for Mercury, Venus, and Mars (see Yavetz 1998; Mendell 1998).

There are inherent problems with the concentric sphere model. The first is intrinsic to the nature of the model: all the entities must of necessity be at a constant distance from the middle. But there are some quite noticeable variations in the apparent size/brightness of the moon and the planets, well known to the ancients and indeed mentioned by Simplicius. While Eudoxus' solution to retrograde motion was ingenious, its application was difficult. While concentric sphere astronomy could, just about, produce retrograde motion, it could not produce the actual shapes of retrograde motion seen in the night sky. Finally, although Callippus' work produced some improvement, concentric sphere astronomy, it had difficulty in modeling the changes in angular motion actually made by the celestial bodies.

There has been some debate about the nature of the motions proposed by Eudoxus and Callippus. Were they simply means of calculating and predicting the celestial motions? Or were the circles conceived as actual circles, in some way mechanically driving the heavenly bodies? Concentric sphere astronomy has been characterized in this manner

by those seeing it as an early example of instrumentalism or of realism. It is important to note here that Plato thought that heavenly bodies were intelligent and selected their best path—consistently choosing the best path being the mark of intelligence, thus giving a strong underpinning to the regularity of the heavens. If Eudoxus and Callippus worked in this tradition, then neither instrumentalism or full realism seems appropriate. This illustrates the futility of imposing modern debates in the philosophy of science on ancient thinkers.

7. Aristotle

There is a sense that Aristotle adds little to Greek astronomy. His system of concentric spheres is essentially Callippus', and the predictive power of Aristotle's system is certainly no greater than Callippus'. What Aristotle did was to make the spheres in some sense concrete, as being composed out of aether, Aristotle's fifth element whose natural motion was circular (*On the Cosmos* 392a6–10). So the motion of each of the spheres was entirely natural and eternal, as that motion was circular. Aristotle believed that the *cosmos* had always existed in its current form and always would, and that there was never any change in the heavens. The aether is neither heavy nor light, so in Aristotle's scheme it has no natural motion either toward or away from the earth. Any change that might appear to occur in the heavens, in fact, happened in the terrestrial realm. For Aristotle, the terrestrial realm—consisting of earth, water, air, and fire, in roughly that order going outward—encompassed everything from the center of the earth, which was also the center of the *cosmos*, out to the moon. Fire in the heavens was transparent unless inflamed by something.

The arrangement of the spheres for Aristotle was complex. The sphere of the fixed stars, the outermost sphere, is simple enough. However, for each of the other celestial bodies, there is a set of spheres whose combined motion drives that heavenly body. As the spheres are arranged like a huge onion, or Russian doll, with no empty space between the spheres, each sphere drives the next one in. So Saturn, the outermost planet for Aristotle, has a set of driving spheres, but to prevent Saturn's motion from influencing Jupiter's motion, the next planet in, there is also a set of retroactive spheres that cancel the transfer of Saturn's motion before Jupiter's driving spheres can engage. This process proceeds inward, ultimately until we come to the moon, where there are no retroactive spheres since the moon is the nearest body to the earth. There is debate on exactly how many spheres this system requires and whether Aristotle counts them properly!

Celestial motions had to have an effect on what happens in the terrestrial realm, according to Aristotle. Aristotle's theory of motion had earth and water moving naturally toward the center of the *cosmos* (the earth). Earth was heavier than water, and hence water is placed around the earth. Air and fire, on the other hand, were positively light, moving away from the center with the orbit of the moon that formed a barrier to how far they could move. Fire was lighter than air, so it constituted the outermost layer of the terrestrial realm. As Aristotle believed, the *cosmos* had always been in existence, and there had been sufficient time for the natural motions of each element to sort the elements into perfect concentric shells with no mixing of the elements unless some other influence opposed this. The motions of the heavens provided this, their motions affecting the terrestrial realm and preventing the full separation of the elements.

Aristotle's account of what we see when we look at the heavens is interesting. We do not see the celestial bodies directly. Rather, the motion of each of the celestial bodies inflames a patch of the fiery area of the terrestrial realm directly below it. And this is what we see. One implication of this view is that each of the celestial bodies shines by its own light, rather than by any reflected light, which is problematic for the phases of the moon. Nor is it clear what happens at eclipses, especially lunar eclipses, when the moon should continue shining. In other places, Aristotle quite clearly knows the explanation of eclipses, but he does not seem to have thought through the implications of how we see celestial bodies.

There are also some well-known problems with the interface of the terrestrial and celestial realms. Aristotle's account of the motion of celestial objects affecting the fiery part of the terrestrial realm is a possibility for the moon, where the moon is the nearest body to earth, and there are no retroactive spheres. However, the sun has retroactive spheres, so it is by no means clear how the sun's motion could influence what is going on in the fiery part of the terrestrial realm, or indeed any of the celestial bodies farther out than the sun (Figure 6.11).

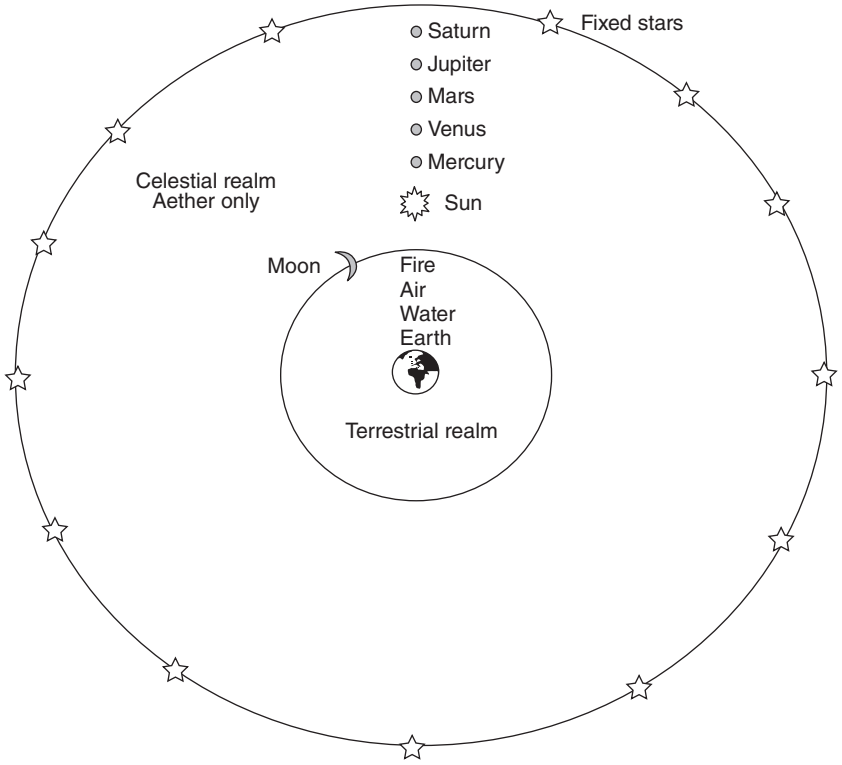


Figure 6.11 The celestial and terrestrial realms.

It is important to note here that all the stars are equidistant, so there is no depth to the star field, and that the distance from Jupiter to Saturn is on the same order of magnitude as the distance from Saturn to the fixed stars.

8. Aristarchus

Aristarchus needs to be mentioned in any history of Greek astronomy, if only to dispel some of the misconceptions which have surrounded him. In older historiographies, Aristarchus was given a prominent place in histories of Greek astronomy for his proposal of heliocentricism (Heath's 1913 history of Greek astronomy is simply called *Aristarchus of Samos: The Ancient Copernicus*). Aristarchus was seen to have had the correct idea and to have anticipated Copernicus. The question, then, was why the Greeks had not adopted this correct idea. This was put down to religious reasons, with the following passage from Plutarch often cited:

> Cleanthes thought that the Greeks ought to indict Aristarchus of Samos on a charge of impiety for putting in motion the hearth of the universe (that is the earth). (*On the Face in the Disc of the Moon* 922f–23a)

Some older histories of science, pursuing a strong agenda in terms of a perceived conflict between religion and science, saw this as prima facie evidence of the religious suppression of Aristarchus' theory. Often overlooked, however, is that there were good astronomical and physical reasons to reject heliocentricism. If the earth were in motion, then a good deal of Greek physics would have had to be wrong, but we have no trace of any replacement physics from Aristarchus. The observable effects for a mobile earth predicted by Greek physics were not seen. If the earth were in motion, that should have been detectable against the background of the stars in a small *cosmos* (an effect known as parallax), but it was not. The alternative, of a massive expansion of the *cosmos*, was not seen as necessary. This was an issue for Copernicus, Kepler, and Galileo, as well. If the earth were in regular circular motion around the sun, then there would be a perfect equality of the seasons and no precession of the equinoxes. The inequality of the seasons was known, and the precession of the equinoxes was soon discovered, a slow change in the orientation of the earth due to a small wobble in its axis of rotation which results in a small change in how the stars are observed. Both effects were explained within the geocentric system without recourse to a mobile earth. In contrast, the geocentric programmed had no physical or conceptual problems, parallax was not an issue, and geocentrism could account for the inequality of the seasons and the precession of the equinoxes.

9. Hipparchus

Hipparchus was possibly the greatest observational astronomer in antiquity. Although Ptolemy achieved more in terms of a fundamental theoretical synthesis for the heavens, Hipparchus possibly made the greatest advances in generating reliable astronomical data.

Of particular importance is Hipparchus' star catalog, detailing the positions of the stars with considerable accuracy, by far the best star catalog to this point in antiquity.

Hipparchus also introduced distinctions between the apparent brightness of the stars, introducing a six-point scale which is the basis for the scale used today. An important part of Hipparchus' work was comparing his star catalog with previous work, and attempting to improve on accuracy. Hipparchus found small but systematic differences, due not to error but to a small change in the apparent positions of the stars relative to the earth. This was the discovery of the precession of the equinoxes, caused by a systematic change in the inclination of the earth's axis of spin. This was a remarkable discovery: the change is quite subtle and requires a great deal of accurate and diligent observation to be detected. It is also clear from Hipparchus' work that he knew a good deal about the Babylonian data and their methods in astronomy. Much of Hipparchus' work involved small but important improvements on technical issues. He worked on producing better values for many of the cycles of the heavens, attempting to produce models for phenomena such as the inequality of the seasons.

10. Ptolemy

The work of Claudius Ptolemy is generally recognized as the pinnacle of ancient work on astronomy. His model of the heavens was comprehensive, systematic, and highly accurate by the standards of the time. In many ways it was a typical Hellenistic synthesis, bringing together existing knowledge of astronomy with Ptolemy's own research and innovations and forging a comprehensive system that would last at least until the Renaissance, parallel to Galen with anatomy and physiology and Euclid with geometry. Ptolemy's great text in astronomy was the *Syntaxis*, the "gathering together," commonly known by its Arabic name, the *Almagest*, the "greatest." Also of significance is Ptolemy's *Planetary Hypotheses*. Often ignored or marginalized is the *Tetrabiblos*, a work on astrology. It should be noted that Ptolemy considered his work on astrology to be a valid part of his work on the heavens more generally—ancient astrology was concerned with the broader effects of the heaven on the earth, and Ptolemy considered these influence to be entirely natural (see also Astrology). Ptolemy also wrote works on music, geography, and optics.

Ptolemaic astronomy produced accurate representations of the motions of the heavens even if the models could be quite complex. There are three basic devices within Ptolemaic astronomy: epicycle, eccentric, and equant. Here we have the basic epicycle device (Figure 6.12).

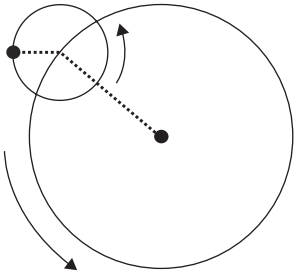


Figure 6.12 The basic epicycle.

The planet rotates in a circle, the epicyclic circle, which has its center on the larger circle, the deferent circle. The center of the epicyclic circle also moves with regular

circular motion around the deferent circle. These motions can be made to produce loops like retrograde motion with appropriate choice of the sizes and speeds of the circles. It is possible to use circles of radically different sizes and to compound further circles in order to generate the motions of the heavens. The second device is the eccentric (Figure 6.13).

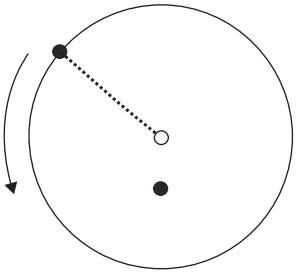


Figure 6.13 Eccentric circle.

This is the eccentric in its simplest form. The planet revolves around a center, with regular circular motion, but the earth is no longer at the rotational center, but is slightly offset. Here the earth is significantly offset to make the effect evident. The eccentric helps to model variations in distance from the earth. It is evident that the planet will be nearer the earth when it is at the bottom of its circle than when it is at the top. One can also add an epicyclic circle to the eccentric.

One consequence of the eccentric is that the earth is not at the center of the deferent circle. Technically then, Ptolemy's theory was geostatic but not geocentric. As Copernicus adopted this device but with the places of the earth and sun reversed, his system was technically heliostatic rather than heliocentric. It was not until 1609 and Kepler's recognition that the planetary orbits were ellipses that a truly heliocentric system emerged (Figure 6.14).

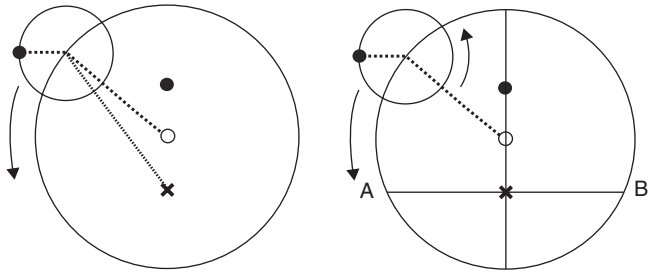


Figure 6.14 The equant.

When observed from the earth, the planets do not move with uniform angular motion across the sky even when they are not undergoing retrograde motion. This is no great surprise, as the planetary orbits are not in fact centered on the earth. The equant helps to model variations in the motions of the planets as seen from earth. And it builds in the eccentric idea, so once again there is a center to the deferent circle with the earth offset from this. There is a further important point though, the equant point, marked x. The planet has regular angular motion around x, but not around the center or around the earth. Consider the second diagram here (Figure 6.14). Ignoring the effect of the

epicycle, the planet will move from A to B in the same time as it moves from B to A, as there is regular angular motion around the equant point. Now consider this phenomenon as seen from the earth. A to B is around 90 degrees, B to A is around 270 degrees, and both are completed in the same time. Again, the offset of the earth and the equant point is greatly exaggerated in the diagram to make their effect evident. The equant has an interesting subsequent history, as Copernicus commented that

> The planetary theories of Ptolemy and most other astronomers, although consistent with the numerical data, seemed likewise to present no small difficulty. For these theories were not adequate unless certain equants were also conceived; it then appeared that a planet moved with uniform velocity neither on its deferent nor about the center of its epicycle. Hence a system of this sort seemed neither sufficiently absolute nor sufficiently pleasing to the mind. (*Commentariolus*)

In terms of cosmology, the earth was central, even if it was no longer the center of rotation. Then followed the moon, Mercury and Venus, the sun, Mars, Jupiter, and Saturn, and then the sphere of the fixed stars. The orbits were spaced on the principle that, while they could not overlap, there could be no empty space between the orbits either. One issue with Ptolemaic astronomy was that it was difficult to interpret in a realistic manner, especially as the earth was no longer the center of rotation. Another was that the system of circles used for the motion of each heavenly body was arbitrary. They were put together simply to generate the motion rather than in accord with any schematic plan. Both criticisms, incidentally, apply to Copernicus as well. When Copernicus introduced heliocentrism in 1543, his "Revolutions of the Celestial Orbs" swaps the places of the earth/moon with the sun and then recalculates the orbits using Ptolemaic devices in a Ptolemaic style. Tycho Brahe's system, the earth in the center with the planets orbiting the sun, while significantly different from Ptolemy's, still borrows many devices and explanations from Ptolemy. It was not until the work of Kepler, when each orbit was considered to be an ellipse around the sun, with the sun at the focus of the ellipse, that there was a coherent, unitary scheme for each planet, and there could be a conception of a force emanating from the central body controlling the motions of the planets. Kepler wrongly guessed magnetism, but others soon supposed it to be gravity.

11. Conclusion

Ptolemy's *Syntaxis* undoubtedly is the greatest work in astronomy in the ancient world. It forms the basis for all astronomy, both in Western Europe and in the Arabic/Islamic culture through to the sixteenth century. There was a tension between the relatively simple Aristotelian cosmology based on concentric spheres and the more sophisticated Ptolemaic astronomy based on the epicycle, and there were also questions about how, physically, the mathematical constructions of epicycle, eccentric, and equant were to be interpreted. These questions were more prominent within the Islamic tradition. Ptolemaic astronomy is sometimes seen as something of a dead end, and a rather moribund research program. At the time of Ptolemy, and immediately succeeding him, this is certainly not so. The Ptolemaic system improved considerably on the system of homocentric spheres, and it could model quite subtle and recently detected phenomena in the heavens such as the precession of the equinoxes. In a sense, its own success became its problem. Sufficiently accurate for all practical purposes, fitting reasonably well with the dominant Aristotelian philosophy and

cosmology, there was little pressure for radical change. The Ptolemaic system was remarkably long lasting. Even when challenged it continued to have a significant effect, influencing both Copernicus and Tycho Brahe by its methods well into the sixteenth century.

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CHAPTER 7

Astrology

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1. Astrology as the "Science of the Stars"

Speaking very generally, *astrology* (Greek for "the study of the stars") asks questions about the connection between heavenly phenomena and events on earth. Until recently, research into such connections was not separated in any way from that of the mathematical study of the stars—what today we call *astronomy*—even though in antiquity people already generally agreed that astronomy and astrology described two different ways of looking at heavenly phenomena (Hübner 1989). These ways of looking were not conceptually differentiated, however, and authors often simply referred to "mathematics" (*ars mathematica*) or "astronomy" (*astronomia*) when they actually meant astrology. The mathematical study of the stars provided the tools for gathering data for interpretative astrology. For our purposes, "astrology" usually refers to that interpretive branch of the study of the stars.

Since astrology asks about the *meaning* of heavenly phenomena for the earthly sphere, it is particularly interested in the *quality* of time (that is, how a specific point in time "feels" like or which "energy" is attached to it), as opposed to the pure *quantity* of time (that is, the measurement of duration and the calculation of planetary points of reference). In order to investigate the meaning of astral events, astrology postulates *correspondences* between planetary levels and earthly levels, correspondences that are basically established through symbolic analogies. *How* the correspondences came to exist—whether there is a secret synchronicity, a net of correspondences of everything that exists, or whether the stars act causally on the earth—was not uniformly assessed by astrologers. But even those astrologers who assumed causal links usually developed their analysis on the basis of symbolic interpretations and thus in a framework of correspondences.

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2. Formation of Tradition: Mesopotamian Astrology

Mesopotamia has long retained its image as the "cradle of astrology." While Egypt figured prominently among Roman authors as the homeland of magic, *Chaldean* developed into a code for astrologically skilled Babylonians. The calculating and interpretative science of the stars had reached a high level of quality in Mesopotamia early on. However, it was only in the second millennium BCE—mainly through the unification process under Hammurapi (Hammurabi)—that there took place a systematization of astrological knowledge which first enabled a differentiated research into the ways of the planets.

In order to understand why the Babylonians were so interested in astrological issues, we have to bear in mind that Babylonian religion is based on a dynamic polytheistic system that is utterly dependent on the *communication* between deities and human beings. Believers turn to divine powers by means of prayers, rituals, or sacrifice in order to receive support and protection; conversely, the gods reveal their will and their activities by means of *signs*. Such signs were read and interpreted by religious specialists in various ways: extraordinary events in nature—storms, thunder, bad harvest—were interpreted; priests looked at the innards of sacrificed animals; and they observed the movements of the stars, whose regularity was recognized and calculated over time, thus helping to prognosticate divine influences in the future (Oppenheim 1977, 206–227). However, a complete understanding of divine will was never achieved; too large was the spectrum of possible interpretations of planetary movements.

It is clear from this that the *priests* were responsible for the development of astronomy and astrology. And it is apparent why astronomy as a calculating branch of the science of the stars emerged to provide interpreting astrology with reliable data. Structuring and understanding the planetary movements meant to understand better the world of goddesses and gods. The planets—including sun and moon—functioned as the representatives of the divinities. Quite against a common misunderstanding, the Babylonians did not venerate the planets as gods, but as the stars of those gods (Aveni 1992, 115). Mesopotamian astrology was a complex and dynamic system with profound religious, public, and political implications. The astrological specialists who had the power of interpretation enjoyed high esteem and influence in public affairs; at the same time, they often found themselves in difficult situations when they had to adjust their interpretations to the will of a ruler in order to remain in his grace.

Consolidation in the Second Millennium

Although it is fair to assume that a certain astronomical knowledge and tradition regarding the interpretation of heavenly and earthly signs had been available earlier, documentary evidence leaves no doubt that it was only in the second millennium that an increased systematization and extension of Mesopotamian astrology occurred (on presumed older traditions: Koch-Westenholz 1995, 32–36). And the fact that in the seventh and sixth centuries BCE it was still extremely difficult to come to an exact calculation of calendars and planetary positions further illuminates the inconsistency of contemporary astrological systems.

An important caesura for the history of astrology was the dynasty of *Hammurapi* (reigned 1728–1689 BCE), founder of the Old Babylonian Empire. Hammurapi united

the numerous city-states of Sumer and Akkad into one kingdom and subsequently centralized his empire in many ways. He introduced a calendar reform and ensured that the names of the twelve Babylonian months were used in the whole empire. This calendar reform also called for the (irregular) insertion of an intercalating month to align the lunar calendar with the spring and autumn equinoxes (the intercalations became regular only after 527 BCE; GREEK CALENDARS; ROMAN CALENDARS).

When the enormous library of Asurbanipal was discovered in Nineveh in the nineteenth century, a collection of clay tablets with cuneiform texts was unearthed that scholars today regard as the first large work of astrological history. This work is referred to as *Enuma Anu Enlil* ("When Anu [and] Enlil," EAE) after its opening words. These texts functioned as the major reference work for professional astrologers at the royal court (Rochberg-Halton 1988, 8). Thousands of omens, divided among 70 "books" (i.e., tables), are listed, providing pretty easily accessible information about what earthly events to expect if certain heavenly events were observed. For example: "When in the month of Abatu on the 15th day Venus disappeared in the west, was invisible for three days, and reappeared on the 18th day of Abatu, [there will be] catastrophes of kings; Adad will bring rain, Ea subterranean water; kings will send greetings to kings" (van der Waerden 1968, 35; author's translation). This prognostication is taken from the famous and much-studied tablet 63 of the EAE series; many scholars argue that this tablet proves the existence of Venus prognostications and their collection already for the Old Babylonian period. From reconstructions of various copies of this tablet, we know that it originally must have contained a complete list of all heliacal risings and settings of Venus within a one year period. And since the text explicitly refers to the eighth year of Ammizaduga's reign, bringing us to the middle of the seventeenth century BCE, this tablet is called the "Venus tablet of Ammizaduga." We can also conclude that the Babylonians in this early period already knew the identity of the morning and evening star—Venus sets in the west in the evening and reappears in the east in the morning—a knowledge that Greek authors later regarded as a discovery of Parmenides or Pythagoras. Both appearances of Venus had the same divine name ^{d}NIN.DAR.AN.NA, which means something like "colorful lady of the heaven."

Compiled in the second half of the second millennium BCE, the omen series EAE rapidly developed into an almost canonical reference for astrological specialists. The complete series must have been available as early as around 1000 BCE, when Assyrian scholars systematically reorganized the omens. Whereas at the royal courts more or less complete copies were available, evidence indicates that wealthy private scholars could order their own copies as well. Sometimes these were comprehensive compilations that made possible a quick and practicable consultation of data. Most Assyrian and Babylonian astrologers may have had their small personal collection of EAE. Besides this canonical series, there existed alternative traditions of interpretation (Parpola 1993, 9).

The Search for Reliable Calculations

The systematizations of omen traditions responded to the political and religious necessity to gather information as reliable as possible about future events and the signs of the gods. However, the Venus Tablet of Ammizaduga, as well as other prognostications transmitted in EAE, was still to a large degree dependent on the observation of the

planetary movements. Only *after* the heliacal rising or the disappearance of a star had been observed could the specialist identify the meaning of the respective phenomenon in the tables. In the long run, this was not satisfactory. Therefore, the Babylonians searched for methods of calculation that could predict the risings, settings, and turning points of planetary movements.

Resulting from this endeavor were the so-called astrolabes introduced at the end of the second millennium. These were cyclic representations of the stars that rise heliacally during the year. The cycle was divided into twelve sectors (representing the twelve months) that in turn were divided into three zones by concentric circles. This led to 36 sectors. Each sector was marked by a star name and a number, and was ordered in three groups. The stars of Ea were in the outer ring, the stars of Anu in the middle, and the stars of Enlil in the inner ring.

In addition to the cyclic astrolabes, later textual ones were also in use. Here, too, the times are given at which the stars are first visible in the morning (their heliacal rising). But these texts also provide, for the first time, a basis for calculating planetary visibility, the lengths of day and night, as well as the risings and settings of the moon. By so doing, these astrolabes improved in several respects the ultimately simple prognostication of the Venus phases that had been practiced in the second millennium. Hence, by using the astrolabes, the experts could follow the movements of the planets during the year and could even prognosticate them into the future.

While the astrolabes represent a quite primitive form of scientific calculation, it was with the series *Mul.Apin* that Babylonian astronomy experienced its breakthrough. This series—named after its first letters—consists of two tables, the first extant copy of which dates from 686 BCE. Some scholars have tried to find "predecessors" of *Mul.Apin* already in the third millennium, but most assume that the series was compiled between 800 and 686 BCE. Regarding the underlying theories of planetary movement that were later elaborated, it seems probable that these originated in the second millennium, perhaps even already in Old Babylonian times (Brown 2000, 113–122).

What is the content of *Mul.Apin*? The first of the two tables deals mainly with the fixed stars that are ordered in the "three ways" in the sky, starting with the so-called "middle way" that corresponds to the equatorial strip of 30 degrees. We can easily combine the three ways/paths with the astrolabes mentioned earlier because they show a similar division of the sky. Furthermore, the table has a list of 33 stars of Enlil, 23 stars of Anu, and 15 stars of Ea, accompanied by a list of 14 so-called *ziqpu* stars. Actually, these "stars" are star positions, namely, the culmination (i.e., the highest position) of the respective stars. Finally, the table lists stars on the moon's path.

The second table concerns the planets, the sun and moon, Sirius, the equinoxes and solstices, risings and settings of planets, the four so-called "corner points" of the sky, the astronomical seasons, the Babylonian practice of intercalation, *gnōmōn* tables (a *gnōmōn* is a vertical staff that allows the measuring of time by its shadow), as well as omens from fixed stars and comets. Hence, this table—the most complete copy of which was found at Assur—is a huge compendium of astronomical and calendrical knowledge, as it had developed at the beginning of the first millennium BCE. The existence of at least seven copies (three in Assur, three from Asurbanipal's library, and one from New Babylonian times) clearly indicates the spread and the importance of *Mul.Apin*.

The development of a serious astrological discipline was dependent on the systematization of older knowledge and improved calculation skills. During the seventh

century BCE, scholars developed new methods of intercalation and calculated the risings and settings of planets. That *Mul.Apin* must be regarded as an important precursor of these developments is apparent when we look at the so-called *zodiacal scheme*, that is, the division of the sky into twelve areas of equal size. These twelve pieces or zones formed the basis of what later became the zodiac, and a close look at the tables reveals that *Mul.Apin* must represent the latest stage before the introduction of the zodiac (not mentioned in the text). We can also see that the zodiacal signs were named very simply: that is, by choosing one of the constellations close to the moon's orbit and designating the whole sequence accordingly. In the beginning, however, the practices of naming were not standardized.

Mul.Apin refers to the astronomical seasons that divide the solar year into twelve equally sized parts (months). What is more, the Babylonians in the eighth century BCE knew the obliquity of the ecliptic from which they derived the zodiacal scheme (van der Waerden 1968, 78–79). Earlier generations of scholars had argued that this knowledge was developed by Greeks of the seventh and sixth centuries BCE, for example, Cleostratus of Tenedos (circa 530–470 BCE), the first to mention the complete zodiac (without Libra). Thus, the prerequisite of the zodiac had already been formulated in the astronomy of *Mul.Apin*. Furthermore, these early first millennium BCE sources clearly indicate that the introduction of the zodiac was completely unrelated to mythical speculation but rather ensued from a simple pragmatic consideration. In Otto Neugebauer's words: "Indeed, the zodiac was hardly ever more than a mathematical idealization needed and used for computing purposes" (Neugebauer 1951, 97–98; author's translation).

From Astral Omens to Astrology

During the first millennium BCE, important changes occurred that had their impact on the further development of astrology. One of these changes relates to the role of the king: although the omens of the second millennium also concerned the person of the king in their prognoses, it was mainly the fortune of the country as a whole that was at stake. In Neo-Assyrian and Neo-Babylonian times—particularly under Asarhaddon and Asurbanipal—the king was moved entirely to the center of scrutiny. He was the main addressee of divine signs; all messages of the gods were related to him, and everything that happened to him was scrutinized minutely, since the fate of the whole country depended on his fortune. This change would have enormous influence on the interpretations of horoscopes in later times.

Another change relates to the history of astrology in its stricter sense. During the first millennium BCE, there occurred a process that extricated itself from the mere interpretation of omens and established a prognostic astrology based on calculation. David Brown even calls this a shift of paradigm. According to him, since around 2000, the "EAE paradigm" had been characterized by simple interpretation of signs ex post (i.e., retrospectively); in the eighth and seventh centuries BCE, this model was replaced by the "PCP paradigm" (*Prediction of Celestial Phenomena*). During this time, a central hypothesis, linked to astronomical predictions, was added to the repertoire of divinatory wisdom tradition. This new axiom of a prognostic paradigm remained valid until the end of cuneiform literature (Brown 2000, 211; cf. Pingree 1997).

Even if the notion of a paradigm shift might be a bit too strong, there can be no doubt that only between the Neo-Assyrian and the Seleucid periods, a discipline was developed

that we today refer to as "Classical astrology." We must keep in mind that the external conditions for scientific and cultural prosperity had been very good, as there were almost no repressive measures against religion and astronomy. Quite the contrary. After the collapse of Assyrian power, Babylonian culture experienced an enormous renaissance. Parallel with the military success of Nabopolassar (626 BCE) and Nebuchadnezzar II (605 BCE), both the economy and science flourished. When Cyrus conquered Babylonia in 539, cultural life profited from the religious tolerance of the Persian kings. Hence, we can assume a more or less undisturbed development. The reign of the Seleucids can be regarded as the heyday of astrological research in Mesopotamia. This period saw the introduction of horoscopic astrology and advanced astronomical methods of calculation, a development that was further enhanced by the fruitful exchange with Hellenistic culture.

An interesting question for the history of ancient astrology is the relation between *observation* and *calculation* of astronomical phenomena. Engaging the world of the stars in a scientific way is inseparable from empirical analysis of the phenomena under scrutiny and the search for general, standardized laws. As mentioned earlier, the Mesopotamian documents of the second millennium focused on observation and the application of older phenomena on contemporary or future events, while only from the sixth century BCE onward did a calculating astronomy provide the means necessary for prognostication. However, the systematic and diligent collection of data over a long period of time is a *conditio sine qua non* for any empirical science. The accomplishment of calculating planetary movements would have been unthinkable without the assiduous documentation of important as well as of seemingly insignificant events.

The so-called "astrological diaries" exemplify in a very concrete way how one can apply an empirical method based on the thinking in correspondences. These diaries belong to a larger group of observation texts in which scholars assiduously noted down everything that happened during the year. Stored in the archives of the royal palaces, these diaries document meteorological and astronomical observations, water levels, natural catastrophes, and other events. Extant are texts from the years 654, 568, 454, 441, 419, and 418 BCE. For 385 BCE onward, we still have the diaries of almost every second year until the first century CE—a vast amount of data for the search of regularities, repetitions, and general principles (Sachs and Hunger 1988–2006). Analysis of these texts renders a clear picture of the Babylonian observational practice that was continued later in an analogous way and formed the basis for Seleucid astrology as well. In this practice, the following aspects were of special importance: lunar movement was studied meticulously, particularly the dates of the new moon, full moon, its last visibility determined between the moon's rise and sunrise, and the moon's path through the ecliptic. While in the sixth century BCE astronomers still determined the positions with reference to the *constellations*, under the Seleucids the alternative system of providing positions with reference to the zodiacal *signs* (i.e., a division of the ecliptic into twelve pieces of equal size) prevailed. Furthermore, astronomers noted down the observations of lunar eclipses and their development, the positions of other planets with reference to the moon, and other data. Documentation of equinoxes and solstices completed the records.

Another important part of these diaries concerned the planets Mercury, Venus, Mars, Jupiter, and Saturn, of which the astronomers recorded all important "key dates," such as risings, settings, and dates of the planets' culminations. We also find descriptions of conjunctions of planets with planets or with zodiacal stars. These data were of an astonishing

precision, so that even Ptolemy, the famous astronomer of the second century CE, could work with them (ASTRONOMY). As the point of departure for his investigations, Ptolemy chose the year 748 BCE, because "from this time on all the old observations have been preserved more or less until this very day" (*Syntaxis* 3.7).

In their search for a scientifically based astrology, the ancient Mesopotamians were confronted with the problem that under the traditional system it was extremely difficult to define, unambiguously, the position of a planet in the sky. When someone says that Jupiter stands at the foot of Aries or at the head of Hydra, what does that mean? Where does a constellation begin and where does it end? This was an important question not only for astrology, but also for navigation, likewise dependent on exact information (see NAVIGATION). In the fifth century BCE, astronomers began to divide the ecliptic into twelve pieces of equal length; thus, every piece measured 30 degrees, resulting in a full circle of 360 degrees. Although the *constellations* located along the path of the sun vary considerably in extent, people used these constellations to give names to the twelve zodiacal *signs*. Starting with the vernal equinox point, the first 30 degrees were called "Aries," the degrees 30 to 59 were called "Taurus," etc., independent from the actual extent of those constellations. The difference between constellations and zodiacal signs must be emphasized because it has caused confusion since ancient times. Since the fifth century BCE, astrologers have worked not with the constellations but rather with the fictive signs of the zodiac, equal segments of the ecliptic.

In 1984, Francesca Rochberg edited a cuneiform tablet representing an intermediate state between EAE and Classical astrology. BM 36746 deals with lunar eclipses that occur in specific zodiacal signs. In the subsequent interpretation, this phenomenon is combined with the wind during the eclipse, which relates to the countries of the known world. An analysis of the text reveals that it owes much to the tradition of EAE and *Mul. Apin*; but at the same time, it contains elements of later (Hellenistic) astrology. Before Rochberg's publication, sources like this one had been known from the Seleucid period only. The new text closes a gap in this regard.

The eclipse omens from EAE are also the basis of BM 36746, but with the major difference that the text now explicitly names the twelve zodiacal signs. Making use of a uniform scheme of interpretation, all possible positions of the lunar eclipse are noted, with the addition of the planets Jupiter, Venus, Saturn, and Mars. Furthermore, the text includes the wind direction at the end of the nocturnal watch in the interpretation. This text, dated by Rochberg under the Achaemenides, is important in two respects:

> The importance of BM 36746 for the history of astrology lies in the fact that it exhibits for the first time in cuneiform literature forerunners to a number of astrological theories known before only from Hellenistic Greek sources, and further paralleled in third century Indian astrology. This text, therefore, serves as a connecting link between the omens of EAE and later Greek astrology. … Despite close parallels with Greek astrology, the content of this tablet can be traced back to older Babylonian literature and scholarly tradition. (Rochberg-Halton 1984, 118)

The second area in which this source throws a new light is the theory of aspects. The text divides the zodiacal signs schematically into four groups with three signs each, corresponding to the later Greek division. From this, a rudimentary doctrine of aspects is developed, with a special emphasis on what later would be called the trigon aspect.

While scholars had earlier attributed the introduction of the theory of aspects to the Greek *Isagoge* (*Introduction to the Phaenomena*) of Geminus (first century CE), we can now track an older Babylonian tradition. The Greeks added two things to this theory: the geometrical scrutiny of all possible divisions of the circle—in Babylonian mathematics and astronomy, geometry played a much less important role—and the doctrine of polarities and temperaments of the zodiacal signs.

All considerations underlying BM 36746 have the complete zodiac as their point of departure. Hence, it is very likely that the zodiac was introduced in Mesopotamia.

Under the Seleucids, astronomical competence had reached a significant level. Now, detailed calculations of the daily movements of moon, sun, and planets, the so-called "ephemerides," were recorded. The goal of these calculations was not only the demonstration of the regular orbits of a heavenly body, but also the prediction of new moons, eclipses, and conjunctions. With his edition of the *Astronomical Cuneiform Texts* in 1955, Otto Neugebauer contributed significantly to a better understanding of the mathematical basis of ephemerides. About one hundred texts in this collection stem from an archive in Uruk, the remaining approximately two hundred texts are of Babylonian origin, as Neugebauer presumes. The date of writing, given in the marginal colophons of the ephemerides, is often damaged. This uncertainty notwithstanding, we can be sure that the majority of the Uruk texts were recorded between the years 90 and 150 of the Seleucid Era (222–162 BCE), while almost all of the Babylonian ephemerides, after a brief period in the first century of the Seleucids (i.e., 312–212 BCE), date from 140–300 Seleucid Era (172–12 BCE).

The calculation of ephemerides was a peak moment of Babylonian astronomy. It had a direct influence on the further development of astrology and the substitution of older omen techniques. Now it was possible to calculate planetary positions for a concrete moment, both in the future and in the past. This ability is a prerequisite for casting horoscopes and for setting up prognoses concerning individual or mundane events, which later became the main interest of astrology.

When we talk of "horoscopes," we usually mean the graphic representation of planetary positions at a given moment, most commonly at the birth of a child (this branch of astrological inquiry is also called "genethlialogy"). The oldest known horoscopes from Babylonia belong exactly to this astrological genre, but such a classification should not be assumed for ancient literature in general. The Greeks, when they talk of *hōroskopos* (Latin *horoscopus*), "the view of the hour," often refer not to the birth chart as a whole, but only to the ascendant, the zodiacal sign rising in the east (Ptolemy, *Tetrabiblos* 3.2). With regard to technique and interpretation, too, the Babylonian horoscopes differ significantly from the Greek ones, even if we have to assume that under the Seleucids an intensive exchange of knowledge had taken place. In any case, the Babylonian horoscopes are older than the Greek or Egyptian ones. The oldest example of this genre dates to 410 BCE, the last extant cuneiform horoscope to 69 BCE; the Greek horoscopes are all from the first century BCE. An interesting horoscope, representative of the Babylonian interpretational technique, is the horoscope for Anu-Bēlšunu, cast on the date X.2 of the year 63 Seleucid Era (29 December 249 BCE: Rochberg 1998, 79–81). During the Seleucid period, horoscopes were cast not only for the king, but also for individuals of higher social ranks. In many cases, the references are limited to the planetary positions or to rudimentary interpretation of the respective constellations. In addition, several horoscopes contain further pieces of interpretation based on "signs" that occur during the

time of birth. Generally it is apparent that Babylonian astrologers read their horoscopes in the same way as they had interpreted birth omens in the large omen series. The intention was similar, but now the technique for providing the information was much more precise (Rochberg 1998, 16).

In conclusion, the opinion of older generations of scholars that elaborate astronomy and astrology is the product of Greek "science," while Mesopotamia only contributed some diffuse astral cult and a mytho-religious charging of the stars, is untenable. This, however, does not allow a return to a "pan-Babylonian" interpretation of history, so prominent—and controversial—at the beginning of the twentieth century with its ultimately failed attempt to derive all ancient religion and culture from Mesopotamia. But the fact remains that Greek and Roman astrologers stood, so to say, on the shoulders of their Assyrian and Babylonian colleagues, developing older material further in their own ways. During this process, Hellenistic philosophy, mythology, and geometry were included in what was to become "Classical astrology," now forming an inseparable unity.

3. Classical Astrology

When we talk of "Classical astrology," we usually refer to the continuation and further development of Babylonian astrology in Hellenistic and Roman times, which in the first centuries of the Christian era became the main discipline for interpreting the world and the future. Not only was that astrology integrated into the Roman canon of sciences, as one of the seven *artes*; the "language of the stars" became a kind of lingua franca, in which various cultural areas and religious traditions could easily communicate. The reasons for this astonishing rise of astrology have to do with a combination of social, political, religious, and scientific conditions. Let us take a look at astrology in Greek culture first.

Greek Astrology up to Hipparchus

It is difficult to answer the question as to when the Greeks began to engage astral or astrological ideas seriously. As late as the fourth century BCE, basic concepts regarding astral interpretations were developed. Older evidence, sometimes referred to as early forms of Greek astrology, can be neglected here as irrelevant. Indispensable, however, is a brief consideration of the speculative foundations established by Plato and his colleagues. Although they did not develop a proper astrology, those thinkers provided the mythological and philosophical material without which the formation of fully developed ancient astrology would have been impossible.

As far as we know, Plato is the first Greek who brought the composition of the starry sky into a mythological correlation with the earthly fate of human beings. In his late *Timaeus*, he talks of the fixed stars as "living beings of divine form and imperishable" (40b). The planets themselves Plato links directly to time, which god—the Demiurge—had created in collaboration with them (38e). This cosmology makes clear why Plato is often considered the founder of European esoteric traditions; the conception of the *cosmos* as a living being, with all parts linked to one another, has been an unshaken conviction in many systems of natural philosophy and astrology following Plato.

In the *Timaeus*, the Demiurge assigns the stars the responsibility to join the other gods in their task to create living beings by combining mortal with immortal matter, and to lead the living beings according to their qualities (41e–42e). This astral mythology is certainly not a proper Classical astrology; the same is true for the important theory of the "Great Year" (as it is called by Aristotle), which Plato knows already and which later became influential. Behind that theory lies the idea that the revolutions of the planets, those "living beings," can be related to one another (*Timaeus* 39c–e). When such a Great Year has come to an end and all planets have reached their original position again, an "extermination of everything on earth by an enormous fire" will occur (*Timaeus* 22d). This myth of the earth's renewal by a global fire was widely known in Greece, and the doctrine was perhaps imported from Persia and then transmitted to the west by the Babylonian calculations of planetary periods.

The first evidence of a rudimentary doctrine of aspects can also be gathered from the *Timaeus*. In a highly mythological way, Plato speaks of the "round dance" of the gods, during which some gods can form a conjunction when they meet or enter into a counter position (40c). Mastering the mathematical dimension of this "dance" was not Plato's interest; in fact, Greeks of the fifth century were not able to calculate the planetary circles. The same can be said of the zodiac. Of course, Plato repeatedly refers to the "twelve gods" (e.g., *Phaedrus* 246e–247a) and to the division of the empire into twelve regions (*Laws* 745b), but connecting this to the ecliptic would be exaggerated and artificial. If Plato had heard of the zodiac, he apparently could have known only a preliminary form of that Babylonian doctrine.

But already with Plato's student Eudoxus, things look quite different. From many ancient sources, we know that Eudoxus probably spent some time in Egypt, presumably in the years 381 and 380. It is difficult to tell, of course, what precisely he learned from his contacts with Egyptian priests. But in the first century CE, Plutarch ascribed to Eudoxus a significant number of astrological doctrines—from acquaintance with the Egyptian doctrine of aspects (*On Isis and Osiris* 30) and the names of some constellations (22) to the correlation between sun and moon on the one hand and on the other the secret meaning of the scarab, a constellation in the so-called twelve-hour-circle and the zodiacal sign of Cancer (74–75). Cicero (*On Divination* 2.87) notes that Eudoxus rejected the prediction of one's life from the day of birth (*dies natali*). But he seems to have approved an elementary form of universal astrology that included, for instance, yearly prognoses based on the position of the moon in the night of the New Year.

We should not exaggerate the knowledge that Eudoxus may have learned from the Egyptians. His significance rather should be seen in the fact that he demonstrates the increased engagement of Greek scholars with eastern astrology. Furthermore, he wielded a decisive influence on later astronomy, geometry, and mathematics (North 1994, 67–77). Thus, he stands on the threshold to rational, scientific interpretations of astrology, the most important early representative of which was Aristotle.

As we have said, Plato's main influence on ancient astrology was his mystical element that prepared ancient discourse for the adaptation of astral thinking. Plato's most important student, Aristotle, contributed significantly to the introduction of scientific astrology into ancient Greece with his own cosmological and physical models of explanation. He regarded the earth as the center of the *cosmos*, surrounded by the circles of the planets and beyond that the sky with the fixed stars. Aether is the fifth element, eternal and unchangeable. All spheres below the constellations are directly connected and subject to

the movement and change that ultimately follow a single drive. Those movements are conceptualized in an opposite direction: while the sphere of the fixed stars as the first movement represents the principle of permanence and duration, the second movement of the planetary sphere against the "oblique circle" (that is, the zodiacal belt) expresses the dynamic of earthly life. Life conditions and life-span on earth are determined by those opposing movements. This philosophical-metaphysical thought was fundamental for Classical astrology.

Aristotle's importance is apparent in yet another area of theorization, namely, in the combination of the four elements with the four "basic qualities" and states of aggregation, an influential theory in subsequent astrology. Aristotle distinguished the following correspondences:

Quality	*State of Aggregation*	*Element*
Warm	Dry	Fire
Warm	Humid/Fluid	Air
Cold	Humid/Fluid	Water
Cold	Dry	Earth

To be sure, the search for uniform basic elements or *Ur*-qualities is much older, attested in Greece already in the late sixth century BCE. The Pythagoreans, in particular, who gave special significance to the number four and who assumed an isomorphic relation between mathematics and all other levels of being, must be acknowledged as Aristotle's predecessors. But it was Aristotle who paved the way that subsequent astrologers would follow, with his derivation of the primary qualities and the application of their effects to the substances of planets and stars. An important influence was seen in medicine, because the fourfold scheme and the doctrine of the four humors could easily be transferred to the human body and was used by physicians to systematize and cure illnesses (Anatomy and Physiology; Epidemiology; Physicians and Schools). Aristotle, who otherwise was skeptical of Pythagorean philosophy, at this point supported their position.

Aristotle also established among philosophical circles the discipline that Ptolemy would later called mundane astrology. In his *Meteorology*, Aristotle attributes springtides, earthquakes, storms, and droughts to the appearance of comets (Book 1; Meteorology). In addition, the influence of important stars such as Sirius or Orion on weather conditions is explicitly acknowledged (Book 2).

Given these few steps of Greek philosophy up to the fourth century BCE, I do not want to postulate a developed form of Greek astrology. Franz Boll's words are still valid: it is "wrong to believe that astral interpretation had played any role in Greek culture until that time; neither Plato nor Aristotle nor even the Pythagoreans themselves cared about the activities of the 'Chaldeans'" (1950, 67; author's translation). However, considering Classical Greek philosophy in this context is important because it shows how the astrological traditions from the east found a well-prepared cultural milieu in which to be adopted. And not only astrologers of late antiquity, but also those of the Middle Ages and the early modern period, elaborated in many ways the concepts and models that Plato and Aristotle had provided.

The Transmission of Babylonian Astrology: Berossus

Historians are able to reconstruct with considerable detail how Babylonian thought entered the Hellenistic cultural setting, transmitted mainly by Greek-speaking Babylonian scholars. Of particular importance was Berossus, a priest of Bel (Marduk). Vitruvius (9.6.2) tells us that Berossus had founded a school of astrologers on the island of Cos, probably circa 281 BCE. Berossus' reputation—and the influence of his school in general—was considerable. Pliny the Elder (*NH* 7.123) reports that Berossus, "because of his divine predictions," was so highly honored in the Imperial period that a statue with a gold-plated tongue was erected in his memory.

We can be quite sure that Berossus is the author of the *Babyloniaka*, that is, the "Babylonian History," covering the beginnings of Babylonian history up to Alexander the Great, and making eastern knowledge available to a Greek-speaking public. Although the original is lost, fragments of Greek and Roman translations allow for the reconstruction of some content. Berossus also wrote on theories of comets and general astronomical doctrines as well as on the Great Year or World Year. Seneca (*NQ* 3.29) writes:

> Berossus […] claims that the ways of the stars determine the time of a fiery catastrophe and a flood. A fire will rage on earth when all stars that are now in different orbits are coming together in Cancer […]; a flood will happen when the group of the same stars is coming together in Capricorn. The first is caused by the summer solstice, the latter by the winter solstice.

This passage emphasizes that the attribution of doctrines to Babylonia is in fact not so easy, because, as we have seen with Eudoxus, the doctrine of the destruction of the world by a global fire had been long known in Greece. Consequently, some fragments combine this doctrine of Berossus with the Egyptian doctrines of Hermes Trismegistus. However, it can be demonstrated that we indeed see here the transmission of Babylonian material. According to Eusebius and Synkellus, in the second book of his *Babyloniaka*, Berossus gave a list of the "Kings of the Assyrians," from Alorus, the first king of Babylonia, to Xisuthrus, who reigned when the first flood occurred according to this tradition (Burstein 1978, 18–19). The kings' periods of rule come down to 120 *saroi* or 432,000 years (one Akkadian *sar* comprises 3,600 years). Those 120 *saroi*, however, cover only one fifth of the world's age, exactly 2,160,000 years or 600 *saroi* according to the fragment preserved by Eusebius and Synkellus where Berossus speaks of "notes that have been diligently kept in Babylonia and that cover a period of roughly 2,150,000 years." It can be assumed that according to this doctrine a "final age" of 12,000 years has to be added to the exact period of 2,148,000 years; Berossus started the final age with Alexander, and presumably ended it with a global catastrophe. Since these systems of calculation were only used in Babylonia, there can be no doubt about the origin of such a doctrine. The Babylonian background is further attested by the fact that 2,160,000 is divisible by 60^3, a mathematical system which spread from Babylonia to India but was clearly distinguished from the Greek one (see van der Waerden 1968, 116–119).

We can conclude that with Berossus we see for the first time an explicit astronomical calculation of the end of days based on planetary cycles (and not on astral myths as with

Plato). The figure of 432,000 years is derived from the revolutions of the two outer planets, Jupiter and Saturn—432,000 years correspond both to 14,400 cycles of Saturn and to 36,000 cycles of Jupiter.

The theory of the Great Year was subsequently spread and transformed, and finally it influenced the politics of Roman emperors. The history of Berossus' school of astrologers on Cos illuminates the further development of astrology, not only through application of transmitted knowledge but particularly through observation and research conducted by those scholars. Famous astrologers were affiliated with the Cos school, from Callippus of the school's first generation to the celebrated Hipparchus of Nicaea to whom we turn now.

Hipparchus Calculates the Precession of the Equinoxes

When one notes down the position of the sun in relation to the constellations every year on the day of the spring equinox, after a few years one will notice that this position has changed. This phenomenon occurs because the earth's equatorial bulge and the obliquity of the ecliptic allow the sun and moon to exert forces on the earth that produce a torque about its center of mass. This torque causes the earth's axis to precess with respect to the celestial sphere. The radius of this circle subtends an arc equal to 23.45 degrees (the obliquity of the ecliptic), and the precessional period is approximately 26,000 years. The corresponding oscillation of the celestial equator causes the Vernal Point (0 Aries) to move slowly westward at roughly 50 arc seconds per year.

During the first millennium BCE, the Vernal Point was in the zodiacal sign *and* the constellation of Aries. Later on, however, it slowly moved into the sign of Pisces and roughly 2,160 years later into the sign of Aquarius. This cycle, describable as a "Great Year," is also open to infinite mythological charging (until the "Age of Aquarius" propagated in the twentieth century). Since the Mesopotamian astrologers had observed the sky for such a long time, it may be assumed that a general knowledge about the precession did emerge quite early. However, there is no evidence that experts in Mesopotamia were able to calculate the exact *figure* of the precession. Credited with this important new step is Hipparchus, who intensively engaged both Babylonian astronomy and Greek geometry and arithmetic (North 1994, 92–104). In addition to many other astronomical calculations, for instance, the creation of a star catalog that later formed the basis of Ptolemy's studies, Hipparchus suggested a figure for the precession of the equinoxes of at least one degree in a century, which comes quite close to the actual figure of a little over 50 inches per year. This assumption was supported by Ptolemy.

Considering the great interest of ancient cultures in calculating and interpreting periods, "Great Years," and planetary cycles, one would expect that a discovery such as Hipparchus' would lead to excited responses. After all, it fell into a period in which the Vernal Point was moving from Aries to Pisces, a change that could have triggered many expectations. Unfortunately, we can only speculate here because the ancient sources do not refer explicitly to the ingress of the Vernal Point into Pisces. But there are scholars who assume a massive impact of Hipparchus' discovery on the religions of his time; some even suggest that the cult of Mithras in fact was born out of the astronomical determination of a new epoch (Beck 2006; cf. von Stuckrad 2000, 163–168).

4. Astrology in the Roman Empire

Let us take a brief look at the reception of Mesopotamian and Greek astrology in the Roman Empire. Roman culture assimilated astrological traditions from outside and integrated them into its own system. If we may believe the sparse sources, astrology was highly unpopular in Italy before the Roman expansion throughout the Mediterranean, if it was known at all. The first proof of the term *astrologi* in the sense of "star gazers" is found in Ennius (230–169 BCE), who also mentions the zodiacal signs (Cicero, *Republic* 1.18.30), but an elaborated astrology can hardly be concluded from this. In the second century BCE, there are hints at astrological activities, but, interestingly enough, only in elite circles; around 31 BCE, for instance, the Roman historian Valerius Maximus (1.3.3) reports that astrologers, along with followers of the foreign cult of Zeus Sabazios, were expelled from Rome and Italy. Such action was always taken in times of social and political unrest, because the leadership feared that astrologers might incite the population with their predictions (Cramer 1954, 233–248). Cato, a conservative aristocrat, reveals a similar attitude when, in 160 BCE, he mandated that under no circumstances should farm overseers (themselves slaves) look for advice from the "Chaldeans," that is, astrologers (*On Agriculture* 1.5.4). This fear was not strictly theoretical, as became clear circa 100 BCE, when one of these overseers, a certain Athenio, predicted the success of a slave revolt and his own ascension as the King of Sicily. After some short success, Athenio, an "expert of astrology," was sentenced to death (Diodorus Siculus 36.5.1–4).

A century later, Cicero witnessed the lingering popularity of astrology among the underprivileged when (referring back to Ennius) he allowed his brother Quintus to deride those who know little but exploit those who know even less (*On Divination* 1.132). Here speaks the experienced philosopher and priest—Cicero himself worked as augur, that is, as an interpreter of signs—who wants to protect the high art of interpreting divine signs from the clutches of charlatans. Apparently, in Cicero's lifetime there were astrologers among the many soothsayers who tried to make a living on the bustling markets around the Circus Maximus. Sometimes the elite sought advice there too; Horace (circa 35 BCE) admits that he himself visited them (see *Ode* 2.17), while Juvenal (circa 112 CE) was sure that only women of the lower classes did so (6.582–591; see Barton 1994, 33).

The presence of such an undifferentiated and pragmatic form of astrology is attested in many documents for the subsequent centuries, as well. That astrology became more and more accepted in highly educated circles of the Roman Empire, however, can only be explained when we take the influence of Greek scholars into account. From the third century BCE onward, in the process of Hellenization, a number of Roman intellectuals developed an interest in Greek philosophy and literature. After the Romans had conquered Greece (between 229 and 146 BCE), they assimilated Greek culture in their characteristic way. Romans began to learn from the Greeks. Aristocrats were educated by Greeks who often founded schools of their own, and, as "ambassadors," they brought their philosophy to Rome. With regard to astrology, the Stoa played a significant role. The stoic philosophy of Panaetius of Rhodes (circa 185–109 BCE) and his successor as head of the school, Poseidonius, helped establish astrology in Roman culture. Poseidonius settled in Rhodes and traveled repeatedly to Rome. In 78, Cicero himself listened to one of his lectures, and Poseidonius became a close friend to Pompey, whose politics he

emphatically supported. This relationship is only one example of how philosophically infused astrology increasingly captured the interest of Roman scholars and politicians, until it became fully established as a scientific discipline in the Roman Imperial period (Cramer 1954). The Roman philosophical schools that later generated whole dynasties of astrologers were indebted to their Greek predecessors, combining that knowledge with other traditions from the Roman Empire.

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CHAPTER 8

Ancient Optics: Theories and Problems of Vision

Philip Thibodeau

1. Introduction

When ancient thinkers set out to explain how our five senses work, they saw it as their first task to identify how each sense organ and object of sensation connect. In the case of touch and taste, since sense organ and object make direct contact, the task was easy, but for the other senses, identifying an appropriate physical intermediary posed a greater challenge. The ancients knew that vapors drifting into the interior of the nose were the agents of smell; hearing was likewise thought to occur thanks to motion from a noise-making object which traveled through the air to the ear. But the intermediary for vision was far more elusive. Vision is effective over vast distances—in the case of celestial bodies, distances comparable in scale to the entire universe—and can bridge those spaces almost instantaneously. Nevertheless, it operates in a strangely effortless fashion: while objects must exert themselves to make noise before they can be heard, they need make no effort to be seen, so long as they are properly lit and stand in an observer's field of view. Accounting for as commonplace a phenomenon as the visibility of stars at night thus taxed the ingenuity of ancient physicists, and helped trigger an intense and long-lasting debate. To this day, a full explanation of many important features of visual perception remains wanting.

For modern scientists, the task of explaining how we see falls into two parts. Specialists in optics study the behavior of light (as well as other forms of electromagnetic radiation) in its interaction with transparent or reflective materials; their field encompasses everything that happens to photons as they pass from, say, a green leaf on a tree to our eyes. But once that light reaches our cornea, a different set of researchers take over, neuroscientists and cognitive psychologists chief among them. It is their job to study how visible light is converted into nerve signals, how those signals are routed through

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our brains, and how processing within the brain correlates to our perception of features like color, size, shape, distance, and motion. The first science is a subfield of physics, whereas the second lies at the intersection of biology and psychology (Goldstein 1999; McIlwain 1996).

Greek and Roman investigators took an entirely different approach to the problem of sight, one that lacks this modern division. The field which the ancients called *optica* was dedicated to the investigation of *opsis*—a Greek term which could mean either (1) the eye, or (2) vision, or (3) rays or lines of sight. The field did not treat the behavior of light in and of itself. Authors of treatises on *optica* formulated theories designed to bridge the gap between eye and object and to explain how various visual phenomena such as color and shape are perceived. They devoted most of their attention to the cornea, air, and surfaces of objects. Far less thought was given to the interior of the eye, or what role the organ of intellection (the brain or, as many ancient philosophers saw it, the heart) might play in basic visual perception. From their point of view, the "processing" of basic data about the visual world was handled outside the eye. The eye's job was to put together a report on the visible realm and forward it to the soul within.

There was an important division of labor in ancient *optica*, one, however, that separated natural philosophers from geometers. Both were interested in explaining how we see, but each only used methods specific to their particular fields. Thus, Aristotle's account of vision in *On the Soul* and *Sense and Sensibilia* forms part of his broader theory of the nature of the soul and presupposes some understanding of his theories of matter and physical change, especially the key distinction between potential and actual forms of existence. His discussion of vision occasionally mentions geometric features of sight such as straight lines, but he does not employ geometrical methods. (Only in his investigation of the rainbow in *Meteorology* 3.5 do we find geometry and optics being combined.) Conversely, treatises on *optica* written by geometers like Euclid employ geometrical reasoning, but they have little to say about the physical or mechanical basis of vision. These two ancient approaches mostly complemented each other but occasionally clashed.

This division of methods led to a corresponding division of failures and successes. The geometers' lack of attention to physical theory left them exposed to pertinent criticisms, yet they made a number of indispensable contributions to optics, including a detailed account of perspective and sophisticated analyses of the geometry of reflection and refraction. Philosophers were divided over such basic matters as whether vision involved something entering or leaving the eye. Nevertheless, they developed simple and robust explanations for a number of features of visual perception and optical illusions which even today lack a decisive explanation. The only author who attempted a serious synthesis of both approaches was Ptolemy, whose five-book *Optica* constitutes a fitting and impressive capstone to the ancient optical tradition.

2. Four Kinds of Visual Theory

Four basic kinds of theories were proposed by ancient scientists, three of which involved material transport between eye and object and one which did not. One popular hypothesis held that we see thanks to a substance which was released from the eye in the direction of the visual object. Most of the proponents of this view, who today are termed extramissionists, were geometers; the earliest exponents were Pythagoreans from the fifth and fourth centuries BCE, including Archytas of Tarentum and Hippocrates of

Chios. The first surviving work in this vein is Euclid's *Optics* (circa 300 BCE), which opens with the following extramissionist premise:

> Let us posit that straight lines *leading from the eye travel over very great distances*, and that the shape encompassed by these lines of sight is a cone with its vertex in the eye and its base at the limits of the thing seen.

Notice how spare the physical theory is here—Euclid leaves unsaid what the material of the rays might be. Nevertheless, it is clear from this and other passages that we are to imagine something traveling away from the eye. Later astronomers like Aristarchus, Archimedes, and Hipparchus made casual use of extramissionist language, and Hero observed regarding the visual ray's velocity:

> That the rays released by our eyes travel away from us at an infinite speed can be learned from the following: if, after closing our eyes, we look again at the sky, it does not happen that any time passes before our sight reaches the sky. We see the stars as soon as we look, even though their distance is for all intents and purpose infinite. (*Catoptrica* 2)

Extramissionist conceptions of vision were not just the preserve of scientists: the "folk" theory of vision for most people in the Greco-Roman world involved some form of ocular ray (Mugler 1964, 64). Another source of the idea's persistence and popularity lay in its ability to explain a basic fact about the phenomenology of sight. As Galen notes (*On the Doctrines of Hippocrates and Plato* 7.5.39–40), when we see objects they do not appear to be in our heads or in our eyes but out in the world. The extramissive hypothesis dovetails nicely with this feeling that our vision goes out to objects and sees them where they are. As for the substance of the beam, it was variously held to be composed of some species of fire or light:

> What is projected from us is light. The flicker which shines forth from our eyes, and the fact that some persons can even see at night without the aid of external illuminations, like nocturnal animals, make this evident—take a man like Tiberius who was emperor of Rome. The eyes of some nocturnal animals even appear to shine brightly at night like fire. (Damianus, *Optical Hypotheses* 2)

For critics, this theory's chief shortcoming lay in the quantity of material needed to account for our ability to see remote objects. The simple act of looking at the starry sky could only be explained if the eyes were to emit enough fire or visual light to fill the universe—and, from the fourth century BCE onward, philosophers understood that the *cosmos* was many times bigger than the earth. Some extramissionists took to stressing the fineness and tenuousness of this substance, but this line of reasoning only created more problems. The Peripatetic commentator Alexander of Aphrodisias posed the following questions:

> If what the eye gives off is material, then how does it happen that it is not used up when the viewed object is as far from the viewer as, for example, the sky? Even if the material is extra-fine, the distance is so great that it will more than use up all the material that a living being might possess … Furthermore, if what is emitted is so fine that it can stretch out to a great distance without using up the supply of the creature that sent it, how could it fail to be easily damaged by any stray object? Obviously it wouldn't require a very strong wind to divert it from its straight line. (*On Aristotle's On Sensation*, 28 Wendland)

Other thinkers held that a stream of material travels in the other direction, from the surface of each visible object toward the eye. Proponents of this theory are called intromissionists, and most ancient intromissionists were atomists. This conception of the mechanism of sight corresponds rather closely to the truth about vision as we now understand it, but it is important to note that making a correct guess did not provide them with any serious advantage in ancient debates, for reasons that will be outlined later. We are best informed about the intromissive theory of the philosopher Epicurus, thanks to a short outline of it in his *Letter to Herodotus* (Diogenes Laërtius 10.46–51) and a longer exposition in the work of the Epicurean poet Lucretius (4.1–468). According to Epicurus, thin films called *eidola* pass through the air from objects to the eye:

> There exist certain outlines which have the same shape as solid bodies, but which are far more fine than any visible object. For it is quite possible that there should be structures like this in the air around us, suitable for rendering contours and degrees of fineness, and streams made up of these that preserve (sc. atoms) in the same position and order which they had on the solid bodies; we call these outlines *eidola* … We need to accept that we see and think when such things from the environment reach us. (*Letter to Herodotus* 10.46, 49)

A lack of primary sources hinders our understanding of earlier versions of intromissionism. This doctrine is ascribed to the founder of atomism, Leucippus, but without elaboration. Numerous authorities also attribute to Democritus a theory which at first glance seems close to Epicurus'. However, some of our oldest and most reliable sources suggest a rather different account. Aristotle says that Democritus' *eidola* reach the eye, but only in the absence of air to obstruct their progress (*On the Soul* 419a). Theophrastus reports that *eidola* from an object enable vision by pressing upon the intervening column of air and creating an imprint on it which gets reflected in the eye (*On the Senses* 50). The exact form of Democritus' theory remains a subject of a lively scholarly debate (cf. Rudolf 2011).

One of the advantages of intromissionism is that it places vision in the same category as the other remote senses, hearing and smell, which likewise involve the reception of something from the outside world (Lucretius 4.54–64). Intromissionism also posits that ordinary objects behave rather like fires, which obviously give off something that renders them visible; the difference between the white of a candle and the gleam of its flame is, in a sense, one of degree rather than kind, since both emit materials. As evidence for the emission of *eidola*, the atomists cited the way that brightly colored objects could tint their immediate environment. Lucretius offered a famous illustration based on Roman canopied theaters:

> Obviously, we see many things that throw off materials generously, not just from their deep interiors, as stated before, but from their surfaces; color is an example. This is what orange, red, and purple awnings do when they are stretched out above great theaters, spread out over the spars and beams, rippling and billowing; they stain all the stands and all the stage and make them ripple with their distinctive colors, and the more completely the theater-walls are enclosed, the more thoroughly drenched in beauty everything is, in the absence of direct light from the sun. Since canvasses release this "dye" from their material surface, all other things ought to release thin images, and in the same way, from their outermost surface. (4.72–86)

Mirrors were also said to offer evidence for the existence of *eidola*, since they serve as a kind of *eidola*-trap, catching and reflecting the stream of films which travel through the air and thus making them visible (Lucretius 4.98–109).

It is important to note that the atomists never spoke of individual atoms traveling from objects to the eye; the agents of vision were always the *eidola* themselves, whose atoms were thought to retain a fragile coherence as they moved. According to Epicurus, the *eidola* came in an unbroken succession, one film after another, so that the stream of films formed, in effect, a tenuous three-dimensional body. This focus on *eidola* caused many problems for the intromissionist theory, especially when it came to the perception of large objects. When a man looks at a mountain, *eidola* from that mountain must travel to the man; if that is the case, then how, critics asked, could they possibly fit into his eye?:

> How could someone turn their eyes so as to see sky, sea, shore, fields, ships, flocks, and countless other things, and see them in a single glance, when the pupil, which has the power of vision, is so small? How can a whole army be seen? Do images come off of individual soldiers, join together, and in this assemblage penetrate the eyes of thousands of onlookers? (Macrobius, *Saturnalia* 7.14.11)

Some evidence suggests that the eye was supposed to scan large *eidola*, taking in one eye-sized piece from them at a time until it imaged the complete whole; however, this explanation creates more problems than it solves (Avotins 1980). The Epicureans seem also to have argued that each *eidolon* loses atoms through attrition during its journey through the air, but while this process makes intelligible our inability to see details in remote objects, it still does not adequately explain how large films shrink small enough to fit into the eye. The problem of size would be the Achilles heel of intromissionist theories until circa 1000 CE, when the Arab philosopher Alhazen finally dispensed with the *eidolon* hypothesis altogether and instead demonstrated that the eye could piece together a coherent image on its own if light rays are reflected in every direction from every point on the surface of a given object (Lindberg 1976, 58–86).

A third kind of theory which combined features of intromissionism and extramissionism invoked streams of matter flowing from both visible objects and the eye. Plato, the chief exponent of this view, in fact postulated three different streams of "fire:" one coming from the eye, one from a source of illumination, and one from the seen object. He wrote in the *Timaeus* that it is a precondition for sight that the first two streams fuse: "whenever there is daylight round about, the visual current issues forth, like to like, and coalesces with it and is formed into a single homogenous body in a direct line with the eyes" (45c). Next, fiery particles from a colored object impinge on this fused body, causing the observer to see white or brightness if the atoms are smaller than those in the body, and black or darkness if the atoms are bigger (45b–46c, 67c–e).

Plato's reasons for proposing this theory are not entirely clear. He seems to have believed that it offered the best explanation of how mirrors work, since he cited the images formed on mirrors as evidence for the fusion of two currents (*Timaeus* 46a–c, *Sophist* 266b–c). The late Platonic commentator Calcidius felt that his master's theory had the virtue of completeness in comparison to simpler forms of extramissionism or intromissionism:

> The ancients … in my view founded their own doctrines by exploiting opportunities given to them by Plato. For while he formulated a complete system, explaining not only the cause

> of vision but also what that cause entails and what facilitates it and what the necessary conditions for vision are, later thinkers adopted views which derive from portions of the complete theory and treated the parts as if they were wholes. And thus their proposals possess merit, since what they are saying is true; yet, because a part lacks completeness, each succeeds only to a certain extent. (*On Plato's Timaeus* 243.5–6)

Conservatism vis-à-vis prior tradition may also have been a consideration. Disparate sets of *testiminonia* have the Presocratic philosopher Empedocles maintaining either that currents flow from the eye or that they flow from objects; one plausible way of reconciling this discrepancy is to assume that he postulated two such streams combining in midair (Long 1966). Plato's theory would then reproduce Empedocles', but with the addition of a third stream representing ambient light. Whatever its genesis, the fusion theory presented critics with an easy target, since it possessed all of the weaknesses of unidirectional theories and no obvious advantages. Aristotle found the basic notion of fusion implausible: "What is meant by the coalescence of light with light? Or how is it even possible? Coalescence does not occur between any two things taken at random" (*Sense and Sensibilia* 438b).

Theories of vision which required the movement of some form of matter through the air were problematic enough to make an alternative theory—involving no movement of material—quite attractive. The first to attempt such an explanation was Aristotle. Aristotle noted that four things need to be present together for vision to occur: the eye, a medium, a body, and some form of illumination. In addition, the eye must be a potentially seeing eye (that is, one belonging to a living creature and not a corpse), the medium must be a potentially transparent one (either air or water), and the object must be potentially visible (that is, it must possess color). Absent any of these conditions, there is no sight; but if all four are present together, vision becomes effective automatically, as the eye becomes an actually seeing eye, the medium becomes transparent, and the color of the object becomes actually seen (*On the Soul* 418a–419a). Since no movement of material is involved, this activity can take place instantaneously—as Aristotle puts it, like a lake freezing over all at once (*Sense and Sensibilia* 447a).

Taking a similar approach, the Stoics, led by the philosopher Chrysippus, devised a theory of vision which was in effect the ray theory of the geometers minus the premise of material transport. A crucial role was played in this theory by *pneuma*, an intelligent, mobile, and all-pervading substance which was said to govern all physical activity in the world, and of which each individual soul was composed. A portion of this soul-*pneuma* located in the eye was said to "prick" and "tense" a section of the surrounding air which was shaped like a cone, with its apex at the eye and its base on the surface of the visible object. The air within this cone united with the soul-*pneuma* in such a way that it became a sensitive extension of the soul into the environment. The Stoics famously compared this cone of air to a walking stick:

> There are some [i.e., the Stoics] who say that we see through the tension of the air. For when the air, which is in contact with the pupil, is stimulated by vision it is shaped into a cone, and once this cone has had its base stamped, as it were, by visible objects, sensation is produced—just as if by touch, through a walking stick. (*SVF* 864)

Galen later articulated a theory of vision which bore a close resemblance to the Stoic conception, but with a comparison of the air to a nerve:

> So it is plausible that the *pneuma* in the eyes, on first making contact with the surrounding air, unites with it and alters it completely to its own peculiar nature, without extending to any great distance … The air then becomes for the eye the kind of instrument for the discernment of sense objects that a nerve always is for the brain. (*On the Doctrines of Hippocrates and Plato* 7.4.25, 7.5.5)

Theories like these, involving an activated medium, avoided the problems of material intromissionism and extramissionism, and nicely respected the effortless character of ordinary vision. However, Aristotle's theory relies so much on abstract relations that—unless one accepts the meaningfulness of his distinction between potential and actual states of being—it may seem more like an articulation of the grammar of visual perception than a theory of physical process. Likewise, the Stoic or Galenic theory of vision would only convince someone already prepared to grant the existence of a *pneuma* that possessed all the powers claimed for it. In general, ancient explanations of the physics of vision were not freestanding theories, but they drew on broader accounts of matter and change for their concepts, terminology—and plausibility.

3. Theories of Color

Since the one power possessed by the eye alone is the ability to perceive color, ancient philosophers believed that any theory of vision worth its salt ought to be able to explain how color is sensed; but to do so successfully—to develop an accurate understanding of what color itself is—that is, a theory of color—would be advantageous. Ancient theories of color, like theories of vision, drew their premises from pre-existing accounts of matter and change. Most tackle the nature of primary colors, and then explain how the seemingly infinite number of intermediate hues arises from them.

Democritus famously described the character of reality thus: "By convention sweet, by convention bitter, by convention hot, by convention cold, by convention color; but in reality, atoms and the void" (*TEGP* 136). Consistent with this reductionist premise, his theory sought to explain the varieties of color by relating them to different kinds of atomic shape and size. Theophrastus reported his account in some detail:

> The primary colors are four in number, Democritus says. What is smooth is white; for if something is not rough, casts no shadow, and is not hard to penetrate, it is in every case bright … Black is made from the opposite, from [sc. atomic] shapes which are rough, unequal, and dissimilar … Things made of larger shapes will be more red; examples are flame and charcoal made from fresh rather than dry wood … Yellow-green is composed of both solid and void, its hue varying with the order and position of its particles. (*On the Senses* 73–75)

Democritus went on to describe how a host of secondary colors—gold, copper, crimson, woad blue, leek green, blue, sulfur, and nut brown—are generated from mixtures of the primaries (*On the Senses* 76–78). The listed mixtures do not reflect the

conventions of pigment blending familiar to painters, but they appear to derive from the observation of color changes in nature, especially in plants and animals (Struycken 2003).

In his *Timaeus*, Plato gave an account of structure and change in the material world which, like Democritus', postulates the existence of atoms. However, Plato has only five kinds of atomic shape, four of which are associated with specific elements: cubes with earth, icosohedra with water, octohedra with air, and tetrahedra with fire. Since all of the currents involved in vision are forms of fire, all of their constituent atoms must be tetrahedra. For this reason, Plato's discussion of colors, which otherwise strongly resembles Democritus', does not appeal to atomic shape. Instead, it links the differences in the primary colors to atomic size and force. Plato, like most ancient color theorists, has two primary colors: white, produced when smaller fire atoms "dilate" the visual current, and black, caused by larger atoms which "contract" it. "Brilliance" and red are pseudo-primaries, produced by powerful tetrahedra which force the eye to water. The secondary colors—light yellow, purple, dark violet, ruddy, gray, ochre, blue, light blue, and leek green—are then explained as mixtures of these four (*Timaeus* 67c–68d; Struycken 2003).

Aristotle was opposed in principle to the reductionist accounts of atomists; he thought it absurd to claim that a perceptible feature such as color could be derived from imperceptible features such as the profiles of atoms. Hence, his explanation of color, which starts by accounting for the two primaries white and black, makes the former essentially an aspect of ordinary brightness and the second an aspect of darkness. Aristotle then argued that the blending of white and black substances in various proportions produces further colors; he added the interesting suggestion that some colors (those with names?) might be associated with mixtures of white and black in integer proportions such as 2:3 or 3:5, while intermediate hues would derive from mixtures of incommensurable quantities (*On Sense and Sensibilia* 3; cf. Sorabji 1972). We do not possess a full elaboration of this theory; however, the pseudo-Aristotelian *On Colors* more than makes up for this absence with a highly detailed and at times brilliantly observed account of colors and color changes in the atmosphere and in flora and fauna.

For the Stoics, finally, color was a kind of body—or, to be more precise, the visual aspect of *pneuma*, the material that holds each object together. When the visual cone comes into contact with an object, the object's *pneuma* assimilates the air of the cone to itself; this qualitative change then propagates backward until it passes into the eye and eventually the soul:

> For when [the visual cone] becomes tight and clear, as it were, it reports that the object seen is white, and when confused and muddied it indicates that it is dark and shadowy. The experience is like that of men who are paralyzed by contact with certain marine fish, the "poison" which seeps through fishing line, pole, and hands, and reaches the interior sense. (*SVF* 863)

The simile here refers to the shock from an electric eel, which, like color, propagates through a series of connected bodies until it reaches the percipient's soul.

It is worth noting that modern physics, having done away with the ancient diversity of opinions about the nature of color, merely substitutes its own: thanks to quantum physics, the carriers of color (photons) can now be interpreted, depending on context,

as particles, packets of energy, intertwined electric and magnetic waves, or propagating sets of statistical probabilities.

4. Perception of Size, Shape, Contour, and Distance

Early speculations about the cause of vision seem to have focused mainly on identifying a mechanism for visual transmission and on accounting for different types of color. Starting around 300 BCE, however, theorists began to work in earnest on the question of how we recognize such *visibilia* as size, shape, contour, and distance. Epicurus and the Stoics offered physical explanations, and Euclid gave geometrical explanations, for both the perception and the misperception of spatial form.

The Epicurean explanation for visual shape perception was simple, effectively reducing sight to a form of touch: since each *eidolon* was in effect a two-dimensional mold of the surface it originated from, it could communicate the shape, size, and contour of its object simply by making contact with the eye. This explanation leaves the perception of distance unaccounted for, so Epicurus added another element to the visual process, a current of air driven along by *eidola*:

> The *eidolon* makes it possible for us to see how far each object is from us, and makes sure we know it: for as soon as it is emitted, it moves and pushes the air which lies between the object and our eyes, and in this way all the air streams through our eye and washes through our pupils as it passes through them. That is how it happens that we see how far away each thing is: and the more air that is pushed along, and the longer it takes to wash through our eyes, the more remote each object seems to be. (Lucretius 4.244–253)

The eye does not perceive distance directly then, but uses the amount of air which passes through it as a proxy for distance.

To account for optical illusions, the Epicureans seem to have invoked physical damage inflicted on individual *eidola* by atoms in the air. Lucretius offered the following explanation for an often-cited visual illusion, the case of a square tower whose profile appears rounded when viewed from a distance:

> When we observe a city's square towers from afar, it often happens that they appear round. This is because from a distance each angle appears dull—or more accurately, is not seen: its impact is lost, and its blow does not slip into our eyes. Because when *eidola* pass through a great quantity of air, the air produces collisions which force their impact to become weak. When for this reason all the angles escape our notice, it is as if the stone structures had been ground down on a lathe—although not like things that are truly round right in front of us; instead they resemble representations, like things in a sketch drawing. (4.353–363)

The process, then, is entirely mechanical: the corners of the square *eidola*, their weakest spots from a structural point of view, are knocked off by intervening air atoms as they travel, leaving them with smoothed-off outlines which the eye perceives.

The Stoic explanation for spatial-feature perception was both more economical than Epicurus' and less mechanical. Central to their account was the assumption that the cone of tensed air which mediates vision is self-sensing, and thus allows us to feel its shape and orientation in the same way that we can feel our own arms or legs. Accordingly, since the

base of the visual cone molds itself to the face of the object, the cone's perception of the shape of its base is at the same time a perception of the size, shape, and contour of the visible object. The same holds true of distance: because the cone's length is identical to the object's distance, the cone, in perceiving its own length, also perceives the distance to the object (*SVF* 863–864). On this account, all the spatial features of the visual world are perceived directly and in the place where they actually subsist.

The Stoics went on to account for illusions and cases of misperception by invoking a qualitative degradation of the cone, caused either by the "weakness" of the *pneuma* within the eye, or the dissipation of its "strength" as it attempted to reach objects which lay too far off:

> A cargo ship seen from afar will appear small when the power of vision fails and the *pneuma* is unable to spread out over all the ship's parts. Similarly a square tower will mimic the circular form of a cylinder, and a portico seen edge-on will shrink until it appears small, due to the weakness of the eyes. In the same way too the fire of the stars appears small, and even the sun, although it is many times larger than the earth, is seen within a circle two feet in diameter. (*SVF* 863)

Blaming errors of perception on the weakness of an overtaxed visual flux was, in fact, an ancient commonplace. In an extramissionist mood, Aristotle told the story of a sick man who constantly saw an image of himself reflected in the air in front of him as he walked; this, Aristotle claimed, was due to his visual power being so weak that it could only pass a few feet before doubling back (*Meteorology* 373b). Theophrastus blamed dizziness caused by heights on the wavering of the power of sight as it extended itself too far (*On Dizziness* 8). The Roman architect Vitruvius wrote that temple architraves must in some cases be made extra-large to compensate for the apparent diminution caused by vision's loss of "strength" as it cuts upward through the air (3.5.9). The Stoics then in citing vision's qualitative degradation were not innovating but appealing to a common intuition about the behavior of sight.

Euclid also had much to say about spatial perception in his *Optics*. For him, the key feature is the size of the object, which, he claimed, appears to an observer to be in direct proportion to the size of the angle formed at his eye by the visual cone:

> And let us posit … that things seen by a larger angle appear larger, that things seen by a smaller angle appear smaller, and that things seen under equal angles appear equal. (Definition 4)

Unlike the Stoics and Epicureans, Euclid's account only considers the perception of apparent, not true, size. Yet this simple premise, along with a few other trivial assumptions, enables him to account for a wide range of important visual phenomena: diminution, foreshortening, the apparent convergence of parallel lines, and various occlusion relations—all of the features that are involved in, say, making a perspective drawing of a temple or stage set. In fact, the range of phenomena considered by Euclid were all being represented in the works of Greek painters by the late fifth century BCE, as part of a movement to develop more "realistic" artistic techniques (Richter 1970; Hyman 1989; Thibodeau 2003; Greek Interior Design; Roman Interior Design). Euclid's studies would in turn help lay the foundation for the study and use of linear perspective during the Renaissance (Brownson 1981; Tobin 1990; Knorr 1991; Christensen 1999).

Euclid also tackled the degradation of image quality in objects seen from a distance by laying down the following premise about vision: "Let us posit … that things seen by more angles appear sharper" (Definition 7). Arguments based on this premise allowed him to show that, for every feature with visual magnitude, there is a distance at which it can no longer be seen—namely, the distance at which the angle it spans is smaller than the minimal angle separating two adjacent lines of sight (Propositions 1–3). Euclid then used this result to explain the aforementioned tower illusion: from a sufficient distance the sides of the tower will be visible but the corners will not; the resulting impression will thus be indistinguishable from one produced by a tower with rounded corners (Proposition 9; Berryman 1998; Thibodeau 2003, 143–146).

5. The Science of Mirrors

One of the most important inquiries of ancient optics was the study of mirrors and reflection, "*catoptrica,*" after the Greek word for "mirror," *katoptron*. Natural philosophers, as we have seen, speculated about the physics of image formation on mirrors; however, the serious investigation of the phenomena of reflection requires a geometric approach. The most significant discovery made by ancient geometers was the equal-angles law of reflection, which holds that the angle of reflection and the angle of incidence of a reflected ray must be equal. This principle is alluded to in an anonymous Peripatetic treatise (*Problems* 9.23, 901b, 16.13, 915b; Boyer 1946), but is clearly stated for the first time in the preface to Euclid's *Catoptrica*. The *Catoptrica* also articulates a second fundamental principle of reflection: that objects reflected in mirrors appear to lie at a point which is defined geometrically as the intersection of the line of sight with a line drawn perpendicular from the object to the mirror (Proposition 16). These two principles together provided ancient catoptrics with a true "paradigm," in Thomas Kuhn's sense of the term, since it allowed investigators to pursue a research program that involved applying the wealth of Greek geometrical insights to the study of mirrors and mirror images (Kuhn 1962; cf. Smith 1981). Euclid's treatise set this project in motion, explaining why certain mirrors reverse left and right or up and down, why objects appear diminished and warped in convex mirrors, and under what conditions objects can be seen in concave mirrors.

About a century after Euclid, the first work to treat optical science in the modern sense appeared, one that dealt exclusively with rays of light rather than visual rays. This work, surviving only in an Arabic translation, is a short treatise on burning mirrors by Diocles (about 200–175 BCE; Toomer 1975). The use of crude burning lenses and mirrors is attested earlier in Greece and Rome (Haas 1920), but Diocles' achievement was to use Hellenistic developments in the theory of conic sections to propose improved designs. Among other results, Diocles proved that burning mirrors with spherical surfaces concentrate light but do not bring it to a true focus (Propositions 2–3). He also demonstrated that parabolic reflectors do possess a true focus, a feature which makes them better at concentrating light and heat, and even more effective as the mirror is increased in size (Proposition 1).

Diocles' treatise is of additional interest for what it suggests about his famous contemporary Archimedes, reported to have composed a long but, unfortunately, lost work on catoptrics (Knorr 1983, 1985). This work seems to have played a key role in the development of the famous legend which had Archimedes deploying a burning mirror to great effect against the Roman fleet that lay siege to his native city of Syracuse in 215–212 BCE. Scholars now consider the story of the mirror a piece of historical fiction:

certainly it is suspicious that the anecdote appears in later sources, but not in the Greek historian Polybius who interviewed eyewitnesses to the siege and wrote at length about Archimedes' role in the resistance. In any event, only a large parabolic mirror of the kind Diocles described could have had any chance of setting distant ships on fire, but it is reasonable to suppose that Archimedes wrote about their construction.

Research in catoptrics produced practical results besides burning mirrors. The *Catoptrica* of Hero is a hybrid treatise, in part theoretical study of reflection phenomena and in part compilation of plans for constructing mirrors with useful or entertaining applications. Thus, the first half of the treatise demonstrates geometrically how to derive the equal-angle law of reflection from the assumption that rays of vision follow the shortest possible route in traveling from eye to mirror to seen object (4, 5). Its second half, by contrast, offers designs for funhouse-style mirrors that create wild distortions of images (13), devices for tracking foot-traffic on a street from within a closed building (16; compare Lucretius 4.304–307), and a temple mirror that would project an image of a goddess where an observer would expect to see his own reflection (18). These designs were not just idle fancies: Hero's contemporary Seneca reported that a Roman aristocrat named Hostius Quadra had mirrors of this sort installed in his bedroom to magnify and produce multiple images of his sexual acts (*NQ* 16.1–6).

6. A Grand Synthesis: Ptolemy's *Optics*

Not widely known in late antiquity, Ptolemy's five-book treatise on optics played at best a minor role in later developments in the field. The text exists today only in a Latin translation of an Arabic rendering of the Greek original; its fifth book survives incomplete, and its first is entirely lost. Nevertheless, it is clearly a work with no ancient rival in terms of the depth and sophistication of its analysis of sight. It combines physical and geometrical approaches to optics and represents the same kind of grand synthesis of prior optical studies that Ptolemy's *Syntaxis* was for Classical and Hellenistic Greek astronomy (Smith 1996, 1998; Lejeune 1956).

Ptolemy spelled out his theory of the physics of vision in his lost first book. Nevertheless, summaries in the other books and references in later sources make it possible for us to reconstruct it in outline. Ptolemy was an extramissionist who identified the substance of the visual ray with the fifth element from which, according to the Peripatetics, objects in the celestial realm are composed. He described the visual flux outside the eye as conical in shape and, like the Stoics, gave this cone a certain degree of self-sensitivity, which allowed it to perceive features such as distance. Ptolemy's cone was also characterized by dynamic variability, possessing peak "power" along its axis and weakening toward its circumference—a feature designed to account for the superior visual acuity the eye has when viewing objects at the center of our visual field (2.20).

Ptolemy began his list of visual perceptibles by defining what we truly see as "luminous compactness": that is, for an object to be seen, it must be both bright and dense. He identified color as the primary visual feature and included among secondary perceptibles size (both real and apparent), place, shape, contour, distance, motion, and rest (1.4–12). Following a detailed discussion of *sensibilia*, he presented an analytic catalog of several dozen optical illusions, divided into those caused by the visual objects themselves, those due to defects in the visual apparatus, and those that result from false cognitive judgments (1.83–142).

One of the most significant innovations in Ptolemy's work is the use of simple rules or algorithms to account for how we resolve situations where we are presented with conflicting perceptual clues. To take a simple example, let us suppose that two remote objects span the same angle at the eye. According to the angle postulate of Euclid's *Optics*, this should always cause them to appear indistinguishable in size. Ptolemy, however, believed that the visual flux is sensitive to distance. This enables him to formulate the following rule: if two objects span the same angle at the eye, and appear to lie at the same distance, then they are perceived to have the same true size; but if one of the objects is perceived to be more distant, then it will also be perceived to be truly larger than the other (1.56). This use of rules to articulate the character of visual space perception continues to be a mainstay in the work of cognitive scientists (Hoffman 1998; Hershenson 1999).

Ptolemy's two books on mirrors and reflection (3 and 4) indicate how sophisticated this area of study had become during the Hellenistic era. These books cover the same basic territory as Euclid (plane, convex, and concave mirrors) but in much greater detail and with much more analytic rigor. Perhaps the most impressive part of Ptolemy's work is that involving reflection in concave mirrors, especially where both object and eye lie within the sphere of which the mirror's surface forms part. Here, the number of distinct cases of reflection is potentially infinite, and Ptolemy gave a classification of these cases, noting for each one how images are magnified and what the apparent location of the viewed object is.

Finally, in his fifth book, Ptolemy offered the first geometrical account of the phenomenon of refraction between media of differing densities. Prior to Ptolemy, there was a general appreciation of the distorting effect that viewing objects through water could have on their appearances. Most often cited is the illusion of the straight oar which appears bent when in water (Thibodeau 2003, 149–150). However, there was no understanding of the principle governing the specific degree of deflection to which the visual ray was subject when passing from one medium to another. Ptolemy's initial approach to this problem was empirical: he set up an apparatus which would allow him to measure accurately the angles of the incident ray and of the reflected ray. He then used this device to measure the refraction of the ray as it passed from air into water, from air into glass, and from water into glass (5.8–21). Ptolemy was not able to deduce Snell's sine law from these measurements; nevertheless, he came up with a step function which could accommodate his results to a first approximation. His values for refraction from air into water illustrate how this function works:

Angle of Incidence	Angle of Refraction
10	8.0
20	15.5
30	22.5
40	29.0
50	35.0
60	40.5
70	45.5
80	50.0

Notice the constantly decreasing difference between successive angles of refraction: 7.5, 7, 6.5, 6, 5.5, 5, and 4.5. A similar pattern shows up in his measurements for other media. The observed values are "fudged" somewhat to fit his step function, and the principle is not as simple as the equal-angle law, yet Ptolemy has demonstrated that refraction too follows a law, one that can be given mathematical expression.

7. Postscript

A complete modern account of the causes of vision would have to touch on such matters as the speed of light, the particle–wave duality of photons, cognitive neuroscience, and the mind–body problem. That the ancients were able to achieve as much as they did with their premodern methods is nothing short of remarkable.

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FURTHER READING

The first chapter of Lindberg (1976) is the best general account in English of ancient debates about the nature and cause of vision; Simon (1988) relates the same history with a more detailed account of philosophical context. Smith (1981) gives a useful anthology of primary texts on ancient mathematical optics. Early Greek theories of vision are well treated by G. M. Stratton (*Theophrastus and the Greek Physiological Psychology before Aristotle*. London: Allen & Unwin, 1917) and J. I. Beare (*Greek Theories of Elementary Cognition from Alcmaeon to Aristotle*. Oxford: Clarendon, 1906); D. Hahm ("Early Hellenistic Theories of Vision and the Perception of Color." In *Studies in Perception*, edited by P. K. Machamer, 60–95. Columbus: Ohio State University Press, 1978) delves into the mechanics of Stoic and Epicurean optics. Smith (1996) is an essential guide to the most sophisticated ancient text on vision. Villard (2002) and Struycken (2003) have recently helped to answer some long-standing questions regarding ancient accounts of color vision. Thibodeau (2003) traces the development of ancient discussions of optical illusions.

CHAPTER 9

Hydrostatics and Pneumatics in Antiquity

Matteo Valleriani

1. Introduction

Ancient hydrostatics and the theoretical components of ancient pneumatics are explicitly formulated to explain a certain set of natural phenomena. These sciences belong to the general framework of mechanics, which implies that the emergence and establishment of such sciences occurs only once mechanical experience and studies are epistemologically capable of investigating nature and its phenomena. One of the oldest sources suggesting such a heuristic approach is Empedocles, who describes the phenomenon of breathing by analogy with the clepsydra (*TEGP* 127; Worthen 1970).

Within the general framework of the ancient theory of elements, pneumatics is a science that helps analyze all the phenomena that involve the movements of at least one of the following four elements: fire, air, water, and earth. Usually, pneumatics is associated with trick vessels, whereby technically manipulating the movement of a certain volume of one element controls and predetermines the movement of a second one. Theoretically, ancient pneumatics implies the study of the nature and behavior of elements, which in turn means the investigation of the nature and constitution of matter.

At first glance, hydrostatics (the study of fluids at rest or under pressure) appears to have only weak links to technological achievements. The entire framework of hydromechanics (the study of forces acting on and within fluids) is, instead, usually associated with technological enterprises, such as shipbuilding, water supply systems, or irrigation structures. Hydrostatics, therefore, seems to emerge only when investigating an isolated moment of a hydrodynamic process: for instance, a ship's displacement in water when its load is situated in a particular location on board. Thus, hydrostatics might appear to result from a particularly complex process of theoretical abstraction as it presupposes the condition of being able to mentally subdivide a hydrodynamic process into a finite

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number of stages of which the process is constituted. Hydrostatics, however, is also concerned with many common, everyday occurrences, especially in *polis* (city/public) life. Each time a water cistern was built, for instance, hydrostatic forces had to be controlled, whether consciously or not. All events that involve floating and/or immersion occur within the framework of hydrostatics.

Here, we consider the scientific and technological aspects of hydrostatics and pneumatics from the sixth century BCE to the sixth CE within the Mediterranean region. We shall show that the theoretical knowledge of hydrostatics and pneumatics emerges especially during periods when the practical activities related to these disciplines were particularly intensive. We aim to demonstrate that this theoretical knowledge emerges as a consequence of accumulating practical knowledge. Accumulation, finally, is investigated also from the perspective of diffusion and exchange within a Mediterranean network of intellectual centers.

First, we survey technological artifacts within the frame of both hydrostatics and pneumatics as corroborated by literary and archeological evidence. Second, we consider theoretical developments against the background of the fundamental traditions of thought.

2. Technology

Toward the end of the 1980s, there emerged a new historiographical approach to the ancient economy (see also LAND VEHICLES). Although still intensely debated, the idea that Mediterranean antiquity is characterized by economic stagnation was no longer dominant. Instead, some scholars applied to Classical history and technology an entrepreneurial investment-profit approach on the model seen in historical studies of other Western epochs and regions (for the link between ancient science and technology: Lewis 1997). On this vision, a panorama emerges according to which the history of the ancient economy experienced great expansion interwoven with periods of less intensive investment. The density of technological achievements clearly indicates the links between the ancient economy and technological innovations. From this perspective, we can map the development of technological innovations starting in Samos in the fifth century BCE and ending in the Iberian peninsula in the second century CE. Within this frame, the library and Museum of Alexandria, the fundamental hub of a technological and scientific revolution (Russo 2004) and where mechanics as such became an autonomous discipline, is interpreted as the natural result of the long accrual of knowledge that was transferred and transformed over space and time from one Mediterranean intellectual and cultural center to another. Besides Samos and Alexandria, other great centers of intensive technological developments included, for instance, Rhodes, Pergamon, and Syracuse. This not only testifies to the economic relevance of technology, but it also seems to indicate a slight shift of technological leadership over time from east to west.

Practical Knowledge in the Frame of Hydrostatics

Among the technical achievements that contributed more than any other to practical knowledge in hydrostatics are cisterns and dams. As components of water supply systems, hydraulic networks were used for irrigation and industrial plants. Cisterns were built for water supplies both continuous and discontinuous, as in the case of rainwater

storage. Beyond storage, cisterns could also be utilized as nodes where the water supply system branched off, for example, at the end of an aqueduct before entering the urban supply system (URBAN INFRASTRUCTURE IN THE ROMAN WORLD).

It is well known that cisterns grew in number and dimensions during antiquity. Cisterns were built by taking advantage of natural features as well as by using masonry or concrete (Forbes 1964–1971, 1.152). Particularly remarkable from a practical hydrostatics perspective are the ancient "bottle" cisterns (Hodge 2000). Several meters tall and narrow at the top, they were potentially capable of specifying, for instance, the relationship between the depth of water and the vertical and horizontal thrust. Besides bottle cisterns, great or colossal cisterns and dams were engineering feats that symbolized a significant accumulation of knowledge: great storage reservoirs were common in the Hellenistic and Roman periods, especially for industry (for example, textile production and mining) and agriculture. However, findings such as the *piscina mirabilis* ("the marvelous fishpond," fourth century CE) at Misenum (Figure 9.1) and the Cistern of the 1001 Columns in Istanbul (fifth century CE) show that colossal water storage projects were also conceived in the framework of urban water supply systems. Particularly relevant is the irrigation system constructed in the Faiyum region during the Ptolemaic dynasty of the third century BCE, to which the El-Lâhûn dam belongs. Five kilometers (3.1 miles) long and made of dry Nile mud, it has a section that decreases from 25 m (82′) at its base to 8 m (26′) at the top (Garbrecht 1995, 21–32; di Pasquale 2012,

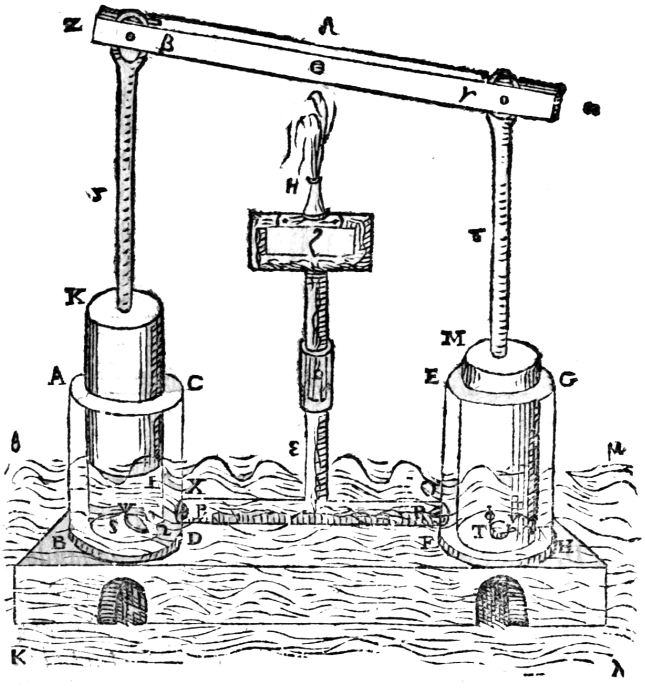


Figure 9.1 The force pump whose design was attributed to Ctesibius, in an early modern representation from a 16th century edition of the pneumatics of Hero of Alexandria (Giorgi 1592, 35v). (*Source:* Max Planck Institute for the History of Science, Library.)

82–83). It represents an impressive example of the management of vertically exerted pressure in concomitance with the use of a locally abundant material. Almost five centuries later, the Roman-built Alcantarilla dam, supplying water to Toledo (Toletum), was made from *opus caementicium* (Roman concrete, a much more resistant material: see also Roman Monumental and Public Architecture). The engineers were therefore able to reach a height of 12 m (39.3′) by means of a base of only 6 m (19.7′) and a top of 3.2 m (10.5′) (Cech 2010, 95). The selection and preparation of building materials for cisterns and dams was, of course, particularly relevant and implicitly embedded in the knowledge of controlling hydrostatic pressure. Such procedures had, in fact, already been codified by Vitruvius (8.6) and Pliny (*NH* 36.173; see also Humphrey, Oleson, and Sherwood 1997, 288–89).

Hydrostatic phenomena that required close management were also known in antiquity in the context of shipbuilding (Ships and Boats). For ships of considerable size, the hull was first constructed on land. The ship was then finished on water with the addition of further components such as benches, masts, and towers. Such operations were based on prerequisite knowledge of how to achieve a draft and how to position the center of gravity along the keel so that the ship could be navigated properly, either empty or loaded: for example, the famous *Syrakousia*, whose construction was supervised by Archimedes. According to Athenaeus (*Deipnosophists* 5.206–209), first the hull was built, then it was at least partially covered by tiling lead, after which it was finally launched to be completed on water. The ship had twenty benches with four oars per bench and three gangway levels. In addition to the usual components, the *Syrakousia* had a gymnasium, library, stalls for horses, a garden with pneumatic devices, and many other impressive features, all built on the water (Simms 1995).

Water was the most common mode of transportation for every sort of material exchange in the Mediterranean (Land Transport and Vehicles; Ships and Boats). In many cases, engineers had to manage the draft and positioning of the center of gravity correctly while, for instance, loading heavy weights (such as shaped stones for the construction of monuments). Moreover, the loaded ship had also to be navigated.

Knowledge related to hydrostatics was, finally, accumulated in the context of hydraulic mining, in particular, at the Roman gold mines on the Iberian peninsula during the second century ce, for example, Las Medulas. Roman engineers developed a method called *ruina montium* ("collapse of mountains"), whereby large cavities were built so that at least one side was relatively close to the mountain's external surface. A series of narrow tunnels connected the cavity to a large artificial reservoir of water at the top and filled by aqueducts. Thanks to the principle now known as "Pascal's barrel," water ran into the cavity from a height that caused the hydraulic pressure in the cavity to supersede the resistance of the wall of the cavity itself, therefore provoking an explosive effect. Gold was then extracted from the disintegrated stones (Pliny, *NH* 33.21; Rossi, Russo, and Russo 2009, 135–40; for a study of the relevance of such activities, through an analysis of environmental impact: Wilson 2002; see also Classical Geology and the Mines of the Greeks and Romans).

Because every phenomenon concerned with floating and immersion represents a hydrostatic phenomenon in practice, we note that practical knowledge of this kind was continuously accumulated through a myriad of everyday experiences and, though less frequent, underwater activities (scuba diving, diving bell: Rossi, Russo, and Russo 2009, 143).

Practical Knowledge in the Frame of Pneumatics

Ancient pneumatics is often associated with small and mostly recreational devices, as described by Hero of Alexandria. On the contrary, the construction of artifacts functioning on pneumatic principles was likewise extremely relevant in the context of water supply and irrigation systems.

The most impressive pneumatic achievements are represented by siphons, that is, pressurized pipes used to transfer water from one place to another, usually across valleys. In literature, siphons are often confused with gravity tunnels and pipes. One example of the latter is the famous tunnel built by Eupalinus at Samos during the sixth century BCE (Herodotus 3.60; URBAN INFRASTRUCTURE IN THE ROMAN WORLD). To be precise, "siphons" are actually inverted siphons. Long known and used on a small scale to mix or pour liquids, siphon technology developed to the point that siphons were already supplying water over long distances during the Hellenistic period. The most impressive example is certainly the pressurized pipe that supplied Pergamon from the beginning of the second century BCE and remained in use for at least four centuries (Garbrecht 1995, 65–86). Integrated into a city supply system of ten different conduits, the siphon, constituted of lead, covered over 3 km (about 2 miles) at a height of about 175 m (about 575′).

Siphon technology was then transferred successfully to the Roman world, where inverted siphons were built whenever a valley was so deep that the characteristic Roman arches, which sustained aqueducts, would have been unstable (Hodge 1983; Vitruvius 8.6, 1–11; Pliny, *NH* 31.57–58; Humphrey, Oleson, and Sherwood 1997, 294–97; URBAN INFRASTRUCTURE IN THE ROMAN WORLD). Numerous archeological findings testify to the vast spread of this technology.

Another pneumatic artifact, usually attributed to Ctesibius, is the force pump. Functioning more elaborately than a siphon, this type of pump, conceived and designed in advance, is assembled from prefabricated components. Force pumps are water-lifting devices comprising cylinders, pistons, valves, and pipes (Figure 9.2). While water is released from one cylinder by a piston, a valve allows a second cylinder to fill with water, whose piston in turn executes an alternating movement. Force pumps were already known in the third century BCE, and written descriptions of their construction and functioning go back (probably) to Ctesibius and Philo (Carra de Vaux 1902, 192–94). Vitruvius almost certainly had Philo's work at hand when he described this device at 10.7.1–4. Hero 1.28 provides a clear and detailed description. Through a geo-temporal analysis of the archeological findings, however, it might be circumstantially inferred that force pumps used for water lifting were much more widely distributed during the Roman Empire, as in the case of the inverted siphon. Initially used in small-scale systems such as for irrigating gardens, the force pump evolved in complexity and efficiency to deal with new challenges. Findings demonstrate that pumps were often of bronze, but new materials entered into use over time. A second-century CE pump for mine drainage in Sierra de Cartagena (southeastern Spain), for instance, was of lead. Most of the sources—both literary and material—testify to a standard use of such devices as fire extinguishers (Oleson 1984, 301–25; Oleson 2000, 272–85; Landels 2000, 75–83 for the force pump). Finally, the pump was also used to activate hydraulic organs whose conception and design are again attributed to Ctesibius. Either activated by force pumps or air pumps (bellows), water was used because its higher viscosity stabilized the pressure as air exited through the pipes, therefore producing the sound (Markovits 2003).

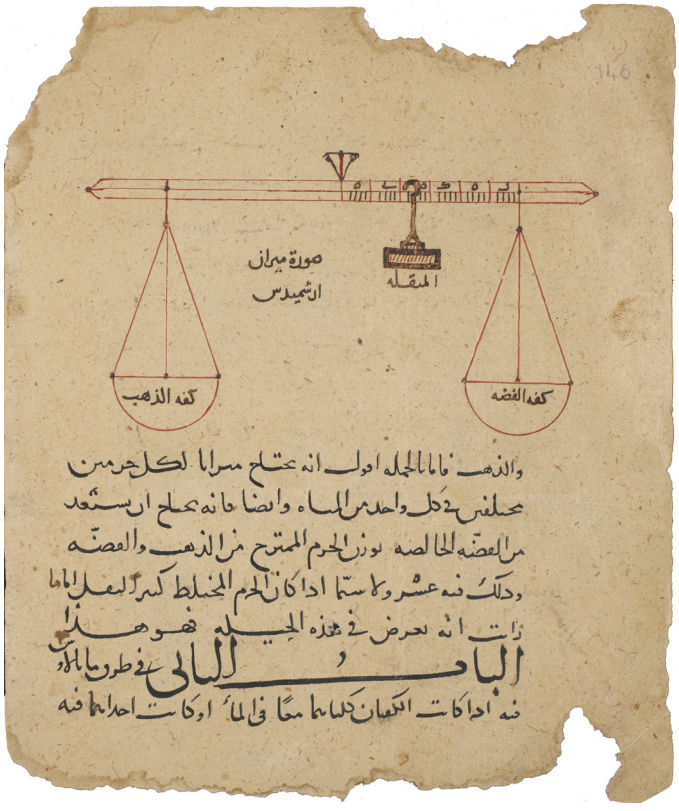


Figure 9.2 A hydrostatic balance corresponding to Remmius' description in his *Carmen de ponderibus et mensuris* and transferred into Arabic culture as a hydrostatic balance of Archimedes. (From 'Abd al-Rahmān al-Khāzinī, *Kitāb mīzān al-ḥikma*, Marv; MS Philadelphia, University of Pennsylvania, Lawrence J. Schieneberg Collection, 386, p. 146, circa 1270. *Source:* Lawrence J. Schoenberg Collection, Kislak Center for Special Collections, Rare Books and Manuscripts, University of Pennsylvania.)

Practical pneumatics, furthermore, played a significant role in measuring time. Water clocks such as the clepsydra have been in use since time immemorial. However, when clocks are meant to measure not only an interval of time but also the time of day, a problem occurs because of the unequal division of the day's twelve hours across the seasons (Greek Calendars; Roman Calendars; Time-Telling Devices). Water clocks were therefore conceived to have a variable, but controllable, flow of water as an internal mechanism that could be adapted to the changing lengths of days (Drachmann 1932). Sources mentioning alarm clocks that worked on the basis of pneumatic principles, moreover, have shown that such devices were known from at least the fourth century BCE. The famous alarm clock of Plato's Academy, for instance, was built to release a great quantity of water into a container that in turn released the contained air through a whistle (Athenaeus, *Deipnosophists* 4.171c; Diels 1965, 199–202).

Apart from clocks, small-scale pneumatic devices were widely diffused at the turn of the millennium, though many had already been conceived, built, and used for centuries. Hero's treatise contains a long series of descriptions of such devices, ranging from trick

vessels and fountains to organs and other objects to re-create natural sounds—for example, birdsongs—for gardens (n.b., the pneumatic garden installed on the *Syrakousia*, above). Numerous findings, however, show that such devices were common in Roman houses, too, in the spirit of Roman conviviality. By observing their distribution, we assume that trick vessels were fairly common over the entire region (Schürmann 1991, 1992 for the social meaning of small-scale ancient pneumatic devices).

As Lewis convincingly demonstrates, Philo's work on pneumatics needs to be contextualized within the framework of contemporary irrigation, industry, and water supply systems. Hero's work testifies to the interest in devices that were, strictly speaking, not essential but were nevertheless widespread. Hero's work can therefore be seen as the result of a particularly dynamic Mediterranean economy which embraced luxury goods on a scale never experienced before.

3. Science

The general system of natural philosophy in which theoretical hydrostatics and pneumatics emerged is specified in Aristotle's *Physics* and the fourth book of his *De Caelo* ("On the Heavens"). In the context of a spherical universe, wherein the world's center coincides with the earth's center, Aristotle conceived of the sublunar world as constituted of four elements, found either in their homogeneous state or mixed together to form all possible physical bodies (for Aristotle's physics, see MATTER).

Aristotle's world is a *plenum*: void cannot exist extensively or within individual bodies and elements. Fire and air are characterized by lightness, whereas water and earth are characterized by heaviness (heaviness and lightness are intended as absolute and not as specific weight[s]). All the elements tend to their "natural" places: air and fire tend to move upward, water and earth downward. Within this framework, the phenomenon of floating is explained through the composition of the mixed body. Floating on water is therefore explained by a quantity of the element "air" mixed within a floating body, for example, wood.

An alternative to this conception, which played a fundamental role in the development of theoretical pneumatics, was formulated by Democritus (*TEGP* 10–13) but rejected by Aristotle (*GC* 313a21–b5; Taylor 1999, 134; MATTER). The Democritean world is constituted of atoms of all possible shapes and absolute weights that move in the void. Democritus discussed the different behavior in water of objects made of the same material but with different shapes, for instance, metal: whereas a metal plate floats, a lighter object shaped like a nail sinks. Democritus' explanation was that the thinner nail-shaped object could penetrate and divide the atoms of the water more efficiently than the plate-shaped object.

These were the fundamental conceptions at a time when a theoretical science of hydrostatics and pneumatics began to emerge in the third century BCE.

Hydrostatics

The Greek mathematician Archimedes is our most important source for investigating ancient hydrostatics. Archimedes lived mostly in Syracuse, apart from one extended stay in Alexandria between 250 and 240, but he remained in contact with the scholars of the Alexandrian Museum for the rest of his life.[1] Archimedes formulated his theory of

hydrostatics and buoyancy in *On Floating Bodies*, divided into two books. In the first book, he presents the general principles of buoyancy and the rules for determining the stability of an object in a liquid. In the second, he investigates floating paraboloids and their positions of stable equilibrium. In spite of the exceptional level of mathematical abstraction displayed in this treatise, the second book is certainly rooted in the experience accumulated by the shipwright while building in water (Nowacki 2002, 2009).

Although Archimedes used the model of concentric spheres of liquid, he nevertheless departed from the Aristotelian conception, instead understanding liquid as comprising parts or particles. Archimedes' first postulate asserts that it is impossible for a fluid to be in a state of rest, as different thrusts act on different parts of the same fluid. He began his investigation by making explicit the intuitive, universal, and experiential knowledge related to the mobility of fluids. Within this same postulate, Archimedes abandoned intuitive physics to explain this knowledge in the form of a mechanical principle—closely connected to practical mechanics. He stated that particles subjected to more thrust move those subjected to less thrust, so that the fluid above acts perpendicularly on the one below. Finally, he determined the weight of the fluid as the cause of the thrust. This principle in turn allows for the formulation of a quantitative, mathematical approach to a series of cases related to the phenomenon of floating. Propositions 3–9, with which the first book concludes, deal with the following cases: a) a solid immersed in liquid has the same specific weight as the liquid itself; b) its specific weight is smaller; and c) its specific weight is greater. With these propositions, Archimedes also enunciated his eponymous principle: the energy exerted on a solid forcibly immersed in a liquid is equal to the weight of the liquid which is forced to move by the immersed solid (propositions 6, 7), a principle that governs all phenomena of immersion, such as the draft of a ship.

Although Archimedes' *On Floating Bodies* is the first theoretical work on hydrostatics in antiquity, it also represents the highest achievement in Classical Greek hydrostatics. Archimedes' results were transferred to Roman engineering, but in a different cultural framework. Fundamental for the reception history of Archimedes' theory of buoyancy is the famous legend of Hiero II's crown, described by Vitruvius (9.3): while Archimedes was at the baths and speculating on his own immersion in water, he apparently realized how to resolve the complicated problem posed by the tyrant to discover the exact quantity of gold and silver that were used to manufacture his crown. Instead of making use of the ratio between the different specific weights of solids and fluids, he suggested the method of volumetric comparison between solids of different specific weights. In practice, he suggested observing the rise of fluid levels in the container where the two solids are immersed. This would allow a determination of the quantity and, therefore, weights of the two solids. Although the method described by Vitruvius cannot possibly yield a precise measurement, its advantage lies in its less mathematical and more practical approach, a method that could be easily grasped by anyone.

Another Roman, Seneca the Younger, was also well aware of many of Archimedes' conclusions. Seneca describes, in particular, the differing buoyancy phenomena where there are different ratios between the specific weights of immersed solid and fluid (*NQ* 3.25.1–11). Although this knowledge seems to lead naturally to Archimedes' principle, Seneca, however, fails to mention that the motion of a body forcibly immersed depends upon the ratio between its specific weight and the fluid's. The same can be inferred

from the work of Menelaus of Alexandria (*fl.* 90–100 CE), a generation after Seneca, but whose text survives only in an Arabic translation by al-Khāzinī (Bancel 2008, 199; TRANSMISSION OF ANCIENT SCIENCE).

The Archimedean tradition of hydrostatic knowledge survived over centuries thanks to the legend of Hiero's crown. The Vitruvian volumetric solution, however, was not the only one known. Remmius Favinus reports Archimedes' method in a poem (now dated to the second half of the fourth century). With detail and great accuracy (Geus 2007), the poem describes an equal arm balance fitted with a sliding weight, as rendered in the works of al-Khāzinī (Figure 9.3). The same text describes an instrument that measures the weight of liquids, further testimony to the practical application (and inspiration) of Archimedes' theory. The instrument comprised a cylinder equipped with a scale for reading the level of the liquid. The cylinder, with a cone on one of the two bases for stability in liquid, is immersed so that the liquid's level can be read on the scale. The heaviness of liquids could yield information concerning, for instance, salinity or purity. Such information was important for a variety of objectives, ranging from industrial use, such as textile production, to medicine and hygiene. The same instrument is also described in a letter, dated 402 CE, by Synesius of Cyrene to the Greek mathematician Hypatia (Hercher 1873, 619).

Pneumatics

Although several pneumatic arrangements had already been described in the Homeric epics (gardens irrigated with underground ducts: *Odyssey* 7.129–131, smith's bellows: *Iliad* 18.470–471, water channeling: *Iliad* 21.257–259), early scientific approaches to pneumatics correspond to the first (Presocratic) theories of elements and matter in the sixth century BCE. At this time, practical knowledge in the same framework also began to accrue (di Pasquale 2012), and Empedocles, in particular, seems to have contributed greatly to this trajectory: some of his formulations sound very much like descriptions of the effects of atmospheric pressure. Consider a vessel filled with water and perforated both at its top and bottom (*TEGP* 127). If the hole at the top is kept closed, for instance by a finger, the water does not flow out from the bottom because, Empedocles explains, it reacts to the "air outside" the device. This could possibly mean that the air exerts its (atmospheric) pressure on the water and around the device. Empedocles' intuition concerning atmospheric pressure, however, was not perceived until the beginning of the twentieth century (Prager 1974, Chapter 1).

After the atomists and Aristotle, the next significant theory was advanced by the Peripatetic Strato of Lampascus, who became the third scholarch of Aristotle's Lyceum, after a sojourn in Alexandria. Diels (1893) argues that Strato's theory was first developed by Theophrastus' pupil Erasistratus (see also Irby-Massie and Keyser 2002, 205–211). In his text on the void, Strato rejected Aristotle's view that no void can exist. Strato rather seemed to unify the theoretical perspective of Aristotelian physics with atomic theories, and he formulated the idea that the elements are constituted of particles separated from each other by interstitial *vacua*. Diels has argued convincingly that such a new physics of elements must be understood within the context of the realism that was artistically *au courant* under Alexander the Great of Macedon (356–323 BCE). This caused the emergence of a kind of empiricism, *ante litteram* ("before the recorded account"), which is well reflected in Hellenistic treatises on pneumatics.



Figure 9.3 Great cistern built at the turn of the first century BCE at Misenum, near Naples, to supply the city with fresh water from the aqueduct Aqua Augusta. Its capacity was 12,600 cubic meters (147,275 cubic yards). Engraving of Giovanni Volpato, circa 1750. (*Source:* Private Collection /The Stapleton Collection /Bridgeman Images.)

After Strato, the science of pneumatics developed continuously for at least two generations with the work of Ctesibius and Philo. Like Strato, these engineers and mathematicians were connected to the Museum of Alexandria (Gille 1980, 54–81). Ctesibius, whose works are entirely lost and whose elemental theory cannot be reconstructed from the sources, is considered the father of pneumatics, but Athenaeus mentions of one of his artifices—a trick vessel in the form of a traditional "rhyton" (*Deipnosophists,* 11.497d–e). Throughout antiquity, artifacts such as the force pump and hydraulic organ were attributed to him, and his text on pneumatics was in use at least until the time of Vitruvius, who most probably used it as a source. As usual for Hellenistic engineers, Ctesibius was also active in developing military machines, including, apparently, a catapult whose functioning was based on a pneumatic apparatus and whose effect was achieved by exploiting the expansive force of compressed air. According to these few references, we can conclude that Ctesibius showed that air compression could have efficient technological applications.

The first extant text on ancient pneumatics is book five of Philo's nine-book *Mechanical Syntax,* preserved in some Greek fragments and extensive texts in both Arabic and Latin (also extant is book 4 on artillery construction).[2] Philo described his theory of elements and their behavior by closely integrating his theory with descriptions of the functioning and effects of some pneumatic devices (Carra de Vaux 1902, 98–104). First, Philo showed how a certain quantity of air must be considered as a body. Then, by alluding to his pneumatic predecessors—most probably Strato, who referred to Philo's theory of elements (particles and interstitial *vacua*)—to which he attributed a physical nature. Philo mentioned especially air, while the other elements seem to contain *vacua* in the extent to which they are mixed with air. In the context of a practice-oriented pneumatics, such a conception was necessary to explain a variety of observed phenomena. Most obviously, for example, when one breathes into a vessel, closes it with a finger, and immerses it into water, one thus observes the air exiting. This can be explained by supposing that the action of breathing forcibly compresses the air within the vessel. Not found in Philo's text, however, such an explicit explanation is known only from later treatises. On the other hand, his treatise does contain a series of descriptions of devices which work on this principle. Finally, he explained the functioning of a siphon, a device used for the great constructions mentioned earlier, but also the basis of many small-scale pneumatic devices. Philo made use of the concept of *pneuma* as moving air. The siphon is needed, for instance, to transfer liquid from one vessel to another, and it begins to work only when the air in it has been sucked out, when one of its extremities is immersed in liquid and the other end is positioned at a lower place. According to Philo, the water first moves upward, contrary to its natural motion, because it follows the air as if there were an attraction between the two elements. This idea, often referred to as Philo's principle of continuity, was then reformulated during antiquity within the debate concerning the existence of extensive vacuums in nature.

Apart from the ideas concerning the nature of elements, Philo's theory is clearly formulated within the general Aristotelian worldview where elements move to their natural places. This view was never fundamentally refuted in antiquity.

Vitruvius used both Ctesibius and Philo, especially in describing the force pump and hydraulic organ (10.7 and 10.8, respectively. For a comparison between Vitruvius' and Hero's descriptions of the hydraulic organ from the perspective of the early modern reception, Valleriani 2010). Vitruvius' work is relevant for understanding how

knowledge was transferred in antiquity but, in this case, only in reference to practical knowledge.

The most significant pneumatics theory after Philo was formulated during the first century CE by Hero (the standard edition is still Schmidt 1899; for a good English translation, Woodcroft 1971). Hero's text falls into two parts: a theoretical section, in which principles are explained on the basis of practical experiments; and a series of descriptions of apparatuses and devices. The theoretical chapters show clearly the development of the science of pneumatics and its links to other theoretical domains. Hero further elaborated the theory of the interstitial *vacua*, arguing that all four elements are constituted of particles. Moreover, Hero also demonstrated that extensive voids can be created artificially by force, moving further away from the Aristotelian point of view. Phenomena of compression are therefore explained by means of the capacity of the interstitial *vacua* to be enlarged or reduced. In spite of this development, however, apart from his theory of elements, Hero remained grounded within the Aristotelian worldview. According to Hero, the compression of air implies a process of condensation so that volume decreases and weight increases, but the transformation from one element to another (for example, from air to water) does not necessarily occur. Hero furnished a general theory of the transformation of elements which integrates the idea of interstitial *vacua* but does not change the general structure of Aristotelian physics. Hero, furthermore, added a series of considerations that are clearly derived from alchemy (see ALCHEMY). Probably spreading through the *corpus hermeticum* (Holzhausen 1997), these show that Hero was aware that the science of pneumatics was, finally, a science concerned entirely with the constitution of matter. Contrary to what is often stated, however, Hero did not introduce the concept of elasticity or spring of air. The phenomenon of the release of compressed air is explained by the fact that the interstitial *vacua* tend to be reshaped in order to regain their natural status. While the elements as such tend to move to their natural place, their volume tends to acquire its natural status. This shift in meaning of the Aristotelian concept of "natural place" is dictated by the necessity to explain observed phenomena. Had Hero introduced the concept of spring of air, he would not have needed to introduce the concept of extensive vacuum. This, however, implies that Hero also abandoned Aristotle's principle of rarefaction.[3]

Concerning the siphon, Hero adapted Philo's principle of continuity in terms of the impossibility of the existence of a natural void. Clearly, Hero did not enunciate the medieval theory of the *horror vacui*, but rather he moved toward a mechanistic explanation by making use first of an analogy between the siphon and the equal armed balance and secondly of Archimedes' principle of the natural spherical distribution of liquids. With this, the link between hydrostatics and pneumatics is finally formulated on a theoretical level.

In spite of great technological achievements, no further theoretical development of pneumatics can be found in the Roman west. This can be explained by analyzing the differences between the Greek Hellenistic and Latin Roman intellectual networks.

4. Accumulation and Network

As di Pasquale has pointed out (2012, 40–41), the process of codifying practical knowledge had already started at the beginning of the sixth century BCE. The first texts compiled by engineers were more or less lists of measurements, that is, metrical compilations

(*anagraphē*). This was the first form whereby implicit or tacit practical knowledge was made explicit. The nature of this codified knowledge was such that it was useful only to other engineers who had the same experience as the compilers and, normally, such codifications were instigated externally to provide a method of recording and preserving knowledge. As economies became more and more dynamic, technological activities increased in intensity, at least locally. As shown earlier, peaks of intensity were achieved particularly during the third century BCE. Correspondingly, it is in this same century that theoretical treatises were formulated in both hydrostatics and pneumatics. As practical knowledge continued to accumulate, it was also increasingly codified. After *anagraphē*, codification involved describing entire and elaborate apparatuses, as in the case of Ctesibius. Once series of such descriptions were available, codification moved toward a unifying principle that aimed to explain how all, or many, of the apparatuses functioned. As in the case of the pseudo-Aristotelian *Mechanical Problems*, which describes a series of heterogeneous mechanical problems explained on the basis of a single theoretical principle, that is, the principle of the lever, Philo's treatise, roughly contemporary with the *Mechanical Problems*, tends to unify the practical and theoretical under the nature of the elements. Archimedes' *On Floating Bodies*, though more challenging from a mathematical point of view, plays the same role by furnishing principles that are able to synthesize the enormous amount of accumulated practical knowledge. Such a mechanism of abstraction, which literally transforms practical knowledge into theoretical knowledge, was obviously not the result of a conscious attempt to achieve a unifying theory. Rather, it has to be seen as an inherent mechanism of the amassing of knowledge over centuries.

Surprisingly, our sources show that such a process of transformation from practical to theoretical knowledge only involved Hellenistic treatises. This is quite surprising because the most significant large-scale technological achievements were realized during the early Roman Imperial era. But no Latin-language treatise on hydrostatics was ever written. Roman-era scientific writings were consistently marginal regarding theoretical matters. In order to explain this lack of sources, rather than repeating the fruitless conclusion that the Romans were unable to understand Greek science, we now have different historiographical data that allow for a more accurate explanation.

As Malkin (2011) has shown, the emergence of the Hellenic world during the Archaic period—decentralized but with a unifying identity—can be explained historically as the effect of a functioning network of hubs, where the efficiency, speed, and volume of the connections played a large role. Though fascinating, Malkin's approach accepts the view that the ancient economy became stagnated because it was unrelated to technology and, therefore, it fails to consider the development of scientific knowledge during antiquity. His approach, however, can be used to investigate the relations between knowledge networks and therefore the accumulation and exchange mechanisms concerning knowledge.

In such a system of autonomous but intensively interconnected centers, technology and research were also autonomous, though not isolated. When knowledge was to be transferred from one place to another, it had to be made comprehensible. Knowledge, in fact, was not only diffused but also exchanged. When the King of Syracuse ordered the construction of the *Syrakousia*, he did so because he wanted to institute a more efficient and regular stable route between his city and Alexandria. Networks of exchange are the external factors that embed increasing knowledge in a framework such that knowledge is transformed through a series of increasingly abstract layers of codification.

In the case of the Roman Empire, knowledge was spread—but not explicitly exchanged—by the army, whose training, expertise, and approach were centrally defined. Their primary goal was to Romanize the empire, not to engage in cultural exchange. Under these conditions, knowledge simply did not need to be codified and, when the institutional structure in which it was embedded disappeared, the knowledge also disappeared. The Romans diffused technical knowledge in the form of artifacts, but for them the efficient use of these artifacts was far more important than understanding how they functioned. This, finally, explains the great efforts in Roman culture to regulate the technology. Frontinus' treatise and Remmius' metrological poem are the fruit of this intellectual network.[4]

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The most complete and source-based overview on Hellenistic science and technology is Russo 2004.

NOTES

1 In particular, Archimedes visited Conon of Samos and Dositheus of Pelousion, to whom he dedicated some works and with whom he corresponded. For Archimedes' life and theoretical works: Dijksterhuis 1956; see also Chondros 2007; Netz 2004, 2008.

2 For the Arabic text and French translation, Carra de Vaux 1902. For the entire tradition of the Latin texts and further medieval and early modern manuscripts in the vernacular, Prager 1974. For an English translation of some relevant sections, Irby-Massie and Keyser 2002, 216–219. For convincing considerations concerning the originality of the Arabic version, Lewis 1997. As Philo's theoretical approach is present in all versions with almost no variations, questions of originality and attribution are not discussed here.

3 For an introduction to the Aristotelian principle of rarefaction and condensation and how they were both transformed by Hero and received in the early modern period, see Valleriani 2007.

4 This chapter was written in the frame of the project "Globalization Processes of Knowledge" at the Max Planck Institute for the History of Science and of the project "Water Management" (Excellence Cluster TOPOI "The Formation and Transformation of Space and Knowledge in Ancient Civilizations").

CHAPTER 10

The Science of Harmonics and Music Theory in Ancient Greece

Sophie Gibson

1. Introduction

The importance of music in Ancient Greek culture is demonstrated in the extensive and varied evidence left to us: instruments and performers portrayed on vases, the bards of Homeric verse, and the harmonically structured soul of the universe that Plato describes in the *Timaeus* (35b–36d). Every level of society participated in musical events, from intimate settings such as symposia to state-sponsored dramatic competitions and festivals. Music was considered essential to the education of youth, and it was part of every ceremonial occasion from birth to death.

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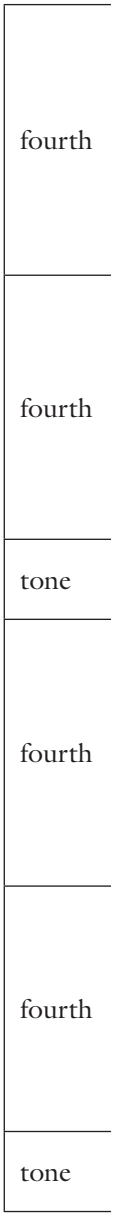
From the sixth century BCE, music formed part of a developing scientific exploration about the nature of the world and the universe beyond it. Within this discourse, theories about music took several forms: some discussion was limited to describing and explaining musical structures; other authors related musical systems to the abstract realm of number mysticism and cosmology; others again were more concerned with the normative potential of music in society. Some authors of harmonic treatises attempted to incorporate all three perspectives.

Our central concern is the first of these approaches: the science of harmonics which claimed to set out the notes, intervals, and scales of melody. Yet it is difficult to know how far the science reflected the tonal structures that musicians were using in the ancient world. A few elements in the treatises do clearly reflect musical reality: tuning techniques or the melodic innovations of, for instance, the poet Timotheus (fifth/fourth century BCE). However, despite mention that certain tunings fell into disuse, or underwent subtle variations, and despite a natural expectation that musical practice changes over time, much of the information in the corpus of music theory remained static over a period of some eight hundred years, from Aristoxenus in the fourth century BCE to Boëthius in the sixth century CE. The scales and tunings that form the bulk of the theoretical treatises over this period undergo nothing more than slight standardization. References to contemporary musical pieces are noticeably absent from the theoretical treatises (although they do occur in the more general works, such as the first/second century CE *On Music* transmitted erroneously under Plutarch's name), and the subject appears to have become entirely divorced from performance practice.

2. Organization of Musical Space

Music for the ancient Greeks was primarily melodic, and from its earliest stages harmonic theory was concerned with how musical sound is organized. To put it another way, it addresses a few fundamental questions. Out of an infinite continuum of pitch, how have musicians selected one particular set of notes to use in melody? How do they stand in relation to one another? And how can they be described?

The Greek scale system was based on tetrachords (fourths). Descriptions of early scales, from the Classical period, include those of seven notes, some spanning less than an octave, but by the fourth century, authors consistently described or assumed a basic scale constructed of two tetrachords separated by a tone (the disjunctive tone), reasonably represented by the notes C-F-G-C in the modern Western system. This formed a central octave which could be extended by adding another fourth above and below. A double octave is achieved by adding a final note one tone below the lowest fourth (the note [*phthongos*] "taken-in-addition" [*proslambanomenos*]). Conjunct tetrachords share a note (such as the two higher and the two lower tetrachords), and disjunct tetrachords are separated by a tone (as in the central octave).


fourth
fourth
tone
fourth
fourth
tone

The scale is completed by placing, within each fourth, two notes whose pitch is less fixed. The Greeks employed several different tunings, *genera* (singular: *genus*), by adjusting the position of these two notes within the tetrachord. There were three *genera*, with approximately these divisions:

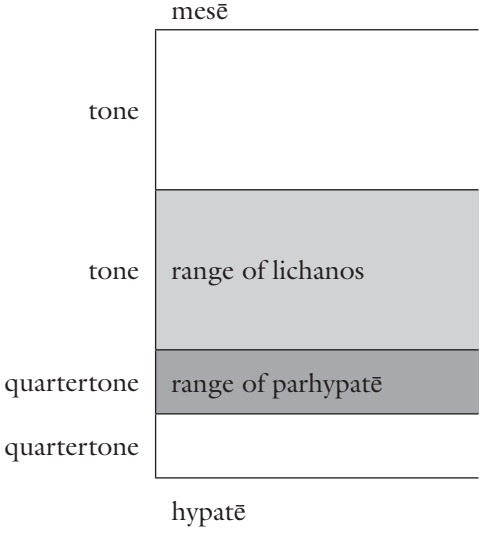
Diatonic *genus*: semitone, tone, tone

Chromatic *genus*: semitone, semitone, tone and a half

Enharmonic *genus*: quartertone, quartertone, ditone

These tunings are not exclusive, but rather the moveable notes are variable within a range. The smaller intervals, some smaller than a semitone, are always at the lowest pitch of the tetrachord. In the chromatic and enharmonic tetrachords, the group creating the two small intervals is called the *pyknon* ("compressed") and, combined, does not exceed the size of the remaining interval. Once the *pyknon* becomes larger than the rest of the tetrachord (at about a tone and a quarter), it ceases to be a *pyknon*, and the tetrachord is diatonic. Several authors offer more than one tuning for each *genus*, and indeed much of the discussion within the science of harmonics concerns the exact intervals within the tetrachord.

A single tetrachord could be conceived like this: the *mesē* ("middle") and *hypatē* ("topmost:" not the highest in pitch, but the string in the highest position when the lyre was played) are the fixed, bounding notes, a fourth apart, with *mesē* the higher. *Parhypatē* ("alongside *hypatē*") could be positioned anywhere from a quartertone to a semitone above *hypatē*, while *lichanos* ("forefinger") could be positioned anywhere between a semitone to a tone and a half above *hypatē*. Other notes are also named for their position on the lyre rather than for their pitch: *nētē* ("bottom"), *paranētē* ("alongside bottom"), and *tritē* ("third"). The tetrachords are similarly named for their position in the system: *mesōn* ("of middle notes"), *diezeugmenōn* ("of disjoined notes"), *hyperbolaiōn* ("of overshoot notes"), and *hypatōn* ("of *hypatē* notes").



The following table sets out the notes of the Greater Perfect System (a Lesser Perfect System, with the top two tetrachords replaced by a single conjunct tetrachord *synēmmenōn*—"of conjoined notes"—is omitted in the interests of brevity and simplicity). The fixed notes are in bold, the moveable notes in plain type.

	Nētē hyperbolaiōn	
Tetrachord	Paranētē hyperbolaiōn	Fourth
Hyperbolaiōn	Tritē hyperbolaiōn	
	Nētē diezeugmenōn	
Tetrachord	Paranētē diezeugmenon	Fourth
Diezeugmenōn	Tritē diezeugmenōn	
	Paramesē	Tone
	Mesē	
Tetrachord	Lichanos mesōn	Fourth
Mesōn	Parhypatē mesōn	
	Hypatē mesōn	
Tetrachord	Lichanos hypatōn	Fourth
Hypatōn	Parhypatē hypatōn	
	Hypatē hypatōn	Tone
	Proslambanomenos	

Beyond this single arrangement is a broader, integrated system of scales, *harmoniai* (singular: *harmoniā*). To the school of Eratocles (circa 450–390 BCE) Aristoxenus attributes the description of a cycle of seven standard *harmoniai*: Mixolydian, Lydian, Phrygian, Dorian, Hypolydian, Hypophrygian, and Hypodorian. Later authors, such as Aristides Quintilianus (circa 270–330 CE) and Cleonides (possibly second century CE) also preserve this group of seven, which are essentially inversions of the same octave, changing the order of intervals in the scale. For example: the Dorian *harmoniā* (in the enharmonic *genus*) used the interval sequence appearing in the octave which ascended from *hypatē*

mesōn to *nētē diezeugmenōn*—quartertone, quartertone, ditone, tone, quartertone, quartertone, ditone; the Phrygian *harmoniā* used the interval sequence appearing in the octave which ascended from *lichanos hypatōn* to *paranētē diezeugmenōn*—ditone, quartertone, quartertone, ditone, tone, quartertone, quartertone.

In addition, Aristides (*On Music* 18.5–19.10) offered an irregular set of six "ancient" scales which he claimed to be those mentioned by Plato in the *Republic*. The source of Aristides' *harmoniai* has sparked much inconclusive discussion (cf. Barker 2007, 43–55), but parallels between these scales and Eratocles' cycle suggest a possible origin in individual, regional styles which became standardized by theorists.

The idea that different *harmoniai* could influence a listener's soul in different ways, and that they were suitable for different contexts, was current from the fifth century. This ethical focus on music, expounded in particular by Damon of Oa (a district of Athens, *ca*. 465–425 BCE), was significant in theories of music in education and the role of music in society. Some *harmoniai* were not considered suitable at all: for instance, Plato allowed only the Dorian and Phrygian in his ideal state (*Republic* 399a). In the final book of the *Politics*, focusing on music and education, Aristotle confirmed the view that different *harmoniai* affect the soul in certain ways: the Mixolydian inspires mourning, the Dorian moderation, and the Phrygian religious ecstasy (1340a40–b6). Aristoxenus (circa 350–310 BCE) also emphasized the need for suitable choices in the elements of a composition, including appropriate *harmoniai*, but he noted that understanding of *ethos* goes beyond the study of harmonics (an opinion preserved indirectly in the pseudo-Plutarchean *On Music* 1142f–1143a). A flat denial of the effect of music on character comes from the author of the fragmentary *Hibeh Papyrus* (I.13), dated to the third century BCE, but whose content was probably considerably earlier. (For a discussion of *ethos*, see Anderson 1966; West 1992, 157–159, 246–253; Barker 2007, 243–259, 308–311.)

Whereas *harmoniā* can be connected to the modern idea of "mode," *tonos* can more closely be related to the idea of "key." In the *tonoi*, the arrangement of intervals within the scale stayed the same, and the overall pitch of the scale changed. Aristoxenus may have done much to create a standard system for *tonoi*: he certainly complained in his *Harmonics* (37.8–38.6) that there was no consistency in their arrangement by earlier writers. Following his work, theoretical treatments of *harmoniai* placed them in a coordinated system of thirteen or fifteen *tonoi*. (For more detailed descriptions: Barker 1989, 11–27; 2007, 12–18; West 1992, chapters 6, 8.)

3. Pythagoreans and *Harmonikoi*

Having established this simplified outline of scales, we can now examine how these structures are described in theory. Four intervals at once stand out as particularly important in the Greek system: octave, fifth, fourth, and tone. The first three of these are concords, audibly and strikingly recognizable as consonant, and distinctly more harmonious than other intervals. While the tone is not a concord, it is, importantly, the difference between the two smaller concords (a fifth and a fourth). It formed part of the scale as the tone of disjunction between two tetrachords, and often as one of the intervals dividing the tetrachord. Taking these four intervals as fundamental to music, two principal approaches developed: the surviving treatises can be broadly divided into authors who take an arithmetical view of intervals (Pythagoreans) and those who emphasize perception and take a geometric view (later called Aristoxenians). So what

effect did the two systems—arithmetic and geometric—have on how the Greeks talked about music?

From an arithmetical perspective, the conception of musical intervals comes from the nature of pitched sound itself. Two notes of an interval can be measured by the lengths of string that it takes to produce them (if the strings are of consistent thickness and tension). One string will sound an octave lower than another string exactly half its length, giving the ratio for an octave as 2:1. The mathematical simplicity of the ratio happily reflects the pleasing sound of the concord.

Further, concords also have simple ratios: 3:2 for the fifth, and 4:3 for the fourth. Added together (when adding ratios, it is necessary to turn them into fractions and multiply them), the fourth and fifth make an octave ($3/2 \times 4/3 = 2/1$). All concords in the two-octave range—with one important exception—have the form of "epimoric" ratios (in the form x+1:x) or "multiple" ratios (in the form of xy:x) comprising the numbers one to four. An octave plus a fifth is 3:1, and 4:1 is a double octave, the usual range within which the division of musical space is discussed. The octave is a multiple interval, as proved in the pseudo-Euclidean *Sectio Canonis* ("Division of the Canon"). The exception to the epimoric/multiple rule for concords is the octave plus a fourth, with its ratio of 8:3. Different authors deal with its inconvenient form in various ways, from ignoring it to rationalizing it. Working from an empirical perspective with no reference to ratios, Aristoxenus resolved the problem for his followers by saying that any concord plus an octave is a concord (*Harmonics* 20.18–22).

Nicomachus of Gerasa (*Enchiridion* ["Manual of Harmonics"] 245.18–248.26, possibly 100–150 CE) tells the story that Pythagoras discovered the ratios of concords after listening to notes produced by differently sized hammers in a smithy, but the story is undermined by its acoustic falsehood. This is typical of the evidence for early explorations in the subject: while there are indications of the school's general inquiry into harmonic ideas, particular advances in harmonics are often difficult to attribute accurately either to Pythagoras or to any other member of his group. Whereas some of the results claimed for experiments are easily discredited, other reports of investigations are more reliant on empirical data. For example, a certain Pythagorean Hippasus (probably early fifth century BCE) conducted experiments with disks of equal diameters and differing thicknesses (*Scholia* to Plato *Phaedo* 108d4 = DK 18.12). These experiments would have produced the results stated, with the same ratios for the disks as for the consonant intervals of fourth, fifth, and octave.

Aristotle's description of the Pythagoreans in the *Metaphysics* (985b32–986a4; cf. Huffman 1993, 57–64) emphasizes their interest in numbers and observes their tendency to associate particular objects with certain numbers as part of their general investigation into the universe. The Pythagorean approach to music was no exception, and Pythagorean reverence for the number ten in particular (noted in *Metaphysics* 986a8–9 and in the second century CE by Sextus Empiricus, *Against the Mathematicians* 7.94–95)—as the sum of the first four numbers—fits nicely with the ratios of the octave, fourth, fifth, octave and a fifth, and double octave. This serendipity encouraged some Pythagoreans to indulge in number mysticism, associating notes and intervals with different concepts (see, for example, Aristides Quintilianus 101.24–103.21, drawing on Pythagorean sources).

Aside from the concords, the tone is the most important interval. Its epimoric ratio of 9:8 (to find the difference between two ratios, turn them into fractions and divide them; thus, $3/2 \div 4/3 = 9/8$) cements the ideal role in melody for epimoric intervals

consisting of numbers higher than four. However, difficulties arise when attempting to divide the fourth into smaller units—to fill in the notes within the fourth. As the Pythagorean arithmeticians realized, there is no way to divide an epimoric ratio into two or more equal parts; accordingly, there is no equal unit with which to divide the fourth into smaller intervals. While the tone provides an obvious starting point, taking two 9:8 tones away from a fourth leaves an interval slightly smaller than a semitone, with the awkward ratio of 256:243. Several Pythagoreans—and Plato—accepted this as a division of the fourth in the diatonic *genus*, but it is not quite satisfactory, and the precise values to be allocated to each interval in the fourth became a concern of Pythagorean theory.

More certain evidence for the Pythagorean school, preserved in Nicomachus (252.3–254.2), concerns the fifth-century Philolaus of Croton (*TEGP* 16; cf. Huffman 1993, 145–165; Barker 1989: 36–38). Crucially, Philolaus' discussion is not limited here to the merely musical: *harmoniā* expresses the idea of a "fitting together" of the parts of the universe, and his discussion of intervals comes in the context of describing cosmological organization. Philolaus set out the ratios of octave, fifth, and fourth, and he stated that a fifth exceeds the fourth in epogdoic (9:8) ratio. The authenticity of the fragment, although debated, finds support in the archaic terms used to designate particular intervals. Where later writers tended to use *dia tessarōn* ("through four"), *dia pentē* ("through five"), *dia pasōn* ("through all") to designate the intervals of fourth, fifth, and octave, Philolaus used *harmoniā* for an octave (as well as for its metaphysical associations), explaining that it is the sum of *syllaba* (a fourth) and *di'oxeian* (a fifth). Further unusual terminology in the names of notes (e.g., *tritē* or "third" for what later writers call *paramesē*) indicates that Philolaus was describing a scale of seven notes, with the upper tetrachord divided into two intervals (of a tone and a tone and a half) instead of the usual three.

Similarly, what Philolaus called a *diesis* (the remainder of a fourth after two tones have been taken from it), most later theorists called a *leimma* (*diesis* tends to refer to the smallest interval of the enharmonic tetrachord—approximately a quarter tone). Philolaus noted that a fifth is three epogdoics (tones) plus a *diesis*, and a fourth is two epogdoics plus a *diesis* (a division of the tetrachord in the diatonic *genus*). Philolaus' description of the octave—five epogdoics and two *dieses*, instead of six epogdoics—indicates strongly his awareness that the *diesis* is not a true semitone, although the fragment does not mention specifically the ratio of 256:243. Philolaus' diatonic division of the tetrachord may preserve something of musical practice, as it can be found by tuning strings up a fourth and down a fifth, a method perhaps used by practicing musicians (such tuning by concordance is described by Aristoxenus, *Harmonics* 55.11–24, and connected in the second century CE to citharodes by Ptolemy, *Harmonics* 44.1).

A generation after Philolaus, the musical discussion of Archytas of Tarentum was somewhat less dependent on a cosmological framework. While he acknowledged a connection between the sciences of astronomy, geometry, numbers, and music (Barker 1989, 40 note 44 on the authenticity of the section), he discussed sound and music without resorting to cosmological comparisons or number mysticism. In his first fragment (preserved in Porphyry's third-century CE *Commentary on the Harmonics of Ptolemy* 56.5–57.27), an early and influential treatment of acoustics, Archytas expressed the idea that sound occurs only with an impact, and that high-pitched sounds are swifter in transmission and more powerful than low-pitched sounds. This latter point, reiterated by Plato

(*Timaeus* 67a–c) and others, was amended by Aristotle (*GA* 786b20–788b2), rejected by Theophrastus (Porphyry, *Commentary* 63.1–64.24), and revised in the introduction to the *Sectio Canonis* (148–149).

In another fragment (fragment 2 = Porphyry 93.6–17), Archytas described the "means" of music: the *arithmetic mean*, where the first term exceeds the second by the same amount as the second exceeds the third (for example, 12:9:6); the *harmonic* (or subcontrary) *mean*, where the part of the third term, by which the second term exceeds the third, is the same as the part of the first term by which the first term exceeds the second (for example, 12:8:6); and the *geometric mean*, where the first term exceeds the second term by the same proportion as the second term exceeds the third (for example, 4:2:1). The geometric mean produces adjacent intervals of the same size: the series 4:2:1 gives consecutive octaves. The numbers giving the first two means can be combined to create the sequence 12:9:8:6, which, if translated into musical pitches, sets out the fixed notes of the central octave of the Greek system: two tetrachords, separated by a tone. The harmonic and arithmetic means tackle the problem that an epimoric interval cannot be divided into one or more equal intervals, and this technique of dividing an octave is also applied to smaller intervals in Archytas' tetrachordal divisions.

Divisions proposed by Archytas			
Diatonic	28:27	8:7	9:8
Chromatic	28:27	243:224	32:27
Enharmonic	28:27	36:35	5:4

Ptolemy preserved Archytas' ratios for each of the *genera* (*Harmonics* 30.9–31.18; DK 47A16), though he criticized Archytas' calculations as not in tune with the senses, and for having the same lower interval in each *genus*. Ptolemy noted that while Archytas began with the principle that melodic intervals should be *symmetros* ("commensurate," understood by Ptolemy as epimoric), Archytas included several non-epimoric intervals. At first, Ptolemy's criticism seems justified. In other theorists, the lowest interval of the enharmonic is always smaller than that of the diatonic and chromatic. However, despite the appearance of several non-epimoric intervals, Barker's examination of Archytas' divisions demonstrates that they are an interdependent series of intervals, each of which can be found entirely through epimoric ratios (2007, 292–302). Archytas was attempting a mathematical representation of what he could hear in musical practice, as Winnington-Ingram (1932) pointed out, and his intervals were not so different from those of Aristoxenus.

Plato's approach to harmonics is seen in his criticism of the Pythagoreans for not going far enough in their examination of numbers in music. In the *Republic* (531c), Plato acknowledged that Pythagoreans sought the numbers in concords, but condemned them for not elevating the study of the subject to a more universal level in order to "investigate which numbers are concordant and which are not" (cf. Barker 2007, 311–18; all translations are from Barker 1989). In the *Timaeus* (35b4–36b6), Plato applied the numbers of Pythagorean harmonics to the division of the world's soul when he used Philolaus' diatonic division of the tetrachord—including the 256:243 interval—and Archytas' means (cf. Barker 2007, 318–323).

Yet Plato was even more disapproving of another group of theorists who used a geometric conception of harmonic space to describe scale structures without reference to ratios. A geometric view of musical space corresponds loosely to the way pitch presents itself on a piano keyboard and to the way in which intervals are most obviously perceived. Pitch, then, is set out as a line divided into units of measurement. A tone is one interval which provides a unit, because the difference between a fourth and fifth is easily perceptible. An octave is six tones, a fifth is three and a half tones, and a fourth is two and a half tones. However, Plato's comments describe a group trying to find a much smaller unit by perception. In the *Republic*, Glaucon describes them as seeking the "smallest interval, by which measurement is to be made." Socrates responds that they "bully the strings and interrogate them with torture" (531a–b).

Plato's comments form part of the piecemeal evidence for this group, and he was highly dismissive. As someone more sympathetic to their approach, Aristoxenus (see §4) gave us further information on "the so-called *harmonikoi*" (*Harmonics* 40.26). *Harmonikoi* seems to be a general term, used in different ways by different writers, but implying those who employed an empirical approach and described musical space geometrically. Often they used a quarter tone (*diesis*) as a unit to measure other intervals. According to Aristoxenus, one technique of these theorists was to construct *katapyknōsis* ("compression") diagrams (2.12; 7.20–33; 28.1) in which several scales seem to have been projected, overlapping, onto a single diagram divided into quartertones. Aristoxenus' constant rebuke for those who could fall under the title of *harmonikoi,* though, is their lack of methodical study: he claimed that *harmonikoi* only refer to the enharmonic *genus* and work within a single octave (2.8–25). In the first book of the *Harmonics*, Aristoxenus mentioned Lasos and Epigonus (3.20–23), who failed to give a satisfactory description of a note, and Eratocles (6.13–31), who was unsystematic in his attempt to describe *systēmata*. In his second book, Aristoxenus censured Pythagoras of Zacynthus and Agenor of Mytilene (36.33–37.1) for failing to discuss the *systēmata* (scales or parts of scales) meticulously.

A familiarity with both Pythagorean and geometric approaches passed into nonspecialist treatises. Like Plato, Aristotle never devoted a treatise to music, but occasionally he used harmonics to demonstrate nonmusical points. In a typical example in the *Posterior Analytics* (79a1–4), Aristotle compared a harmonic science based on hearing to one based on mathematics to distinguish between different types of science: knowing the fact that something happens and knowing the reason why. The first seems to refer to the *harmonikoi's* methods of describing scales, the second to the Pythagorean calculation of intervals. Aristotle rejected harmonics as an independent science because it is subordinate to arithmetic (also *Posterior Analytics* 75b14–17).

The limited nature of Aristotle's explorations in the field of music are suggested, however, by his inconsistent use of technical terms: in *Posterior Analytics* 84b37–39, he noted that the unit of measure for melody is the *diesis* (cf. *Metaphysics* 1016b22), presumably referring to the quartertone used by the *harmonikoi*. In the *Metaphysics* (1053a12–17), he said that there are two *dieses*: not those for the ear, but those found in ratios. This clearly refers to Pythagorean methods, but it confuses having a method of measuring intervals (ratios) with having a unit of measurement (a quartertone). While the Pythagoreans did use the term *diesis* to describe the smaller intervals of the tetrachord, and in the enharmonic *genus* a tetrachord could have two (different) *dieses* (as in Archytas' enharmonic tetrachord of 28:27 | 36:35 | 5:4), neither *diesis* was commensurate with the other intervals of the scale and could not have been used as a measure.

Another fragment from the Peripatetic school rejects both empirical and mathematical methods: in his *On Music,* Theophrastus criticized those who consider the differences in pitches as ratios (Porphyry, *Commentary* 62.2–12) on the basis that, by extension, anything expressible as a number would then form a melody. He also ridiculed the empirical *harmonikoi* for confusing the cause of a pitch with the interval between one pitch and another (Porphyry, 64.24–27): the difference between notes cannot be purely quantitative. Unfortunately, the fragment is too short to show what, if anything, Theophrastus proposed in place of these theories (cf. Barker 2007, 411–436).

Aristoxenus mentioned two other non-Pythagorean techniques of harmonics—one based on notation (*Harmonics* 39.4–41.24), another on instruments (*Harmonics* 41.24–43.24), each condemned by Aristoxenus as only indicating the magnitude of the intervals rather than *genus* or the position of the notes in the scale. (Much later diagrams of notation, handed down through Alypius [third/fourth century CE], do indicate the position of notes within the scale.) It is difficult to tell much about either school, but they are worth a brief mention as they indicate the variety of discussion and exploration, as well as the tenuousness of their transmission, before Aristoxenus.

The empirical or geometrical method, where the precise interval calculations exposing the problems of the 256:243 ratio were not so apparent, ignored the difficulty that epimoric intervals cannot be divided in equal parts. Their unit of measure avoids the problem of irrationality which plagued the Pythagoreans—if pitches are perceived as occurring like points on a line, intervals can be multiplied or divided in an infinite variety of ways, including being divided in half. (Modern music, by the way, overcame this difficulty with the introduction of equal temperament, where the octave is divided into 1200 cents, and each semitone is 100 cents.)

4. Aristoxenus

Born in Tarentum in around 360 BCE, Aristoxenus is best known for his works on music. These include the very technical *Harmonics*, in three books; the *Peri Mousikēs* ("On Music"), a more general work, cited extensively in the pseudo-Plutarchean *De Musica* ("On Music"); the *Rhythmics*, of which we have a portion; and various writings on composers, instruments, dancing, and poets, surviving only in fragments. For the *Harmonics*, Aristoxenus developed an innovative approach to melody, based on Aristotelian scientific theory, applied again in the *Rhythmics*.

Aristoxenus' early influences were Pythagorean—Tarentum was a center of the school and Archytas' hometown—and Aristoxenus wrote extensively on Pythagoras and his followers. He could not have been unfamiliar with their mathematical approach to music theory. The concern with ratios which so dominated Pythagorean musical writings, however, plays no part in Aristoxenus' treatise on harmonics. Aristoxenus argued not that the Pythagorean ratios are false, but rather that such ratios did not reflect how musical intervals are perceived. So complete was his omission of Pythagorean views that he complained that earlier theorists only described the enharmonic *genus*, ignoring Philolaus' diatonic and the three Archytan divisions (*Harmonics* 2.10–11).

Although Aristoxenus did not engage with the work of Pythagoreans, he did respond to the work of the *harmonikoi*. Indeed, despite his sniping at their incomplete and haphazard treatment of *systēmata* and their lack of demonstration, the *harmonikoi* gave Aristoxenus a starting point for his own approach. Like the *harmonikoi*, Aristoxenus,

emphasizing perception, advanced a geometrical view of musical space, and claimed that a fourth is two and a half tones (not less, as the mathematicians had proved) because that is how we perceive it.

But most significantly, Aristoxenus' *Harmonics* was influenced by his time spent as Aristotle's student. Using the Aristotelian theory of science, as set out in particular in the *Posterior Analytics*, Aristoxenus applied it to music in two primary ways: (i) the idea of first principles, and (ii) the "same domain" rule (Barker 2007, 109–110). In the *Posterior Analytics*, Aristotle discussed how it is not possible to demonstrate knowledge in one field by using the means of another (75a38–9). However, where Aristotle stated that harmonics is an exception to this rule, because it is so related to arithmetic and subordinated to it (75b14–7), Aristoxenus sought to apply the same domain rule to harmonics and to elevate it to the status of an independent science.

Similarly, Aristoxenus applied Aristotle's idea of "first principles" (which could produce theorems about a subject) to this new harmonic science. Principles need to be "true, primary, immediate, better known than, prior to, and causing the conclusion" (*Posterior Analytics* 71b20–23; cf. Barker 2007, 105–112). Aristoxenus similarly aimed "to adopt initial principles which are all evident to anyone experienced in music, and to demonstrate what follows from them" (32.31–33.1).

Considerable ink has been spilled on whether the three books of the *Harmonics* is to be considered as a unified whole (Bélis 1986), whether the second book is a revision of first (Gibson 2005), or whether the first book belongs to a different type of treatise (Barker 2007). There is clearly repetition between programs set out in Books One and Two, but there are also differences. Both treatments include *genera*, intervals, notes, *systēmata*, *tonoi*, and modulation. Book Two also anticipates a discussion on the subject of composition, but this has not survived.

Book One contains an extended treatment of the movement of the voice (8.13–15.13), referring to earlier acoustic theories, only to dismiss them. Aristoxenus emphasized the need to use perception in defining five fundamental terms: tension, relaxation, height, depth, and pitch. He explained that movement of the voice occurs when it travels from one pitch to another. He disconnected from this any idea of impacts or motion, the concern of theorists such as Archytas: "We shall say, nonetheless, that the voice stands still when perception exhibits it to us not setting off towards the high or the low … The voice appears to do this when it sings; for it moves while it makes an interval, and stands still on a note. If when it moves in what we call motion it is acquiring a difference in speed in the motion of which these people speak, and if when being at rest in what we call rest its speed remains constant and retains one and the same pace, that need make no difference to us" (12.13–29).

The passage on movement of the voice leads into the definition of a note as "the incidence of the voice on one pitch: for it is when the voice appears to rest at one pitch that there seems to be a note capable of being put into a position in a harmonically attuned melody" (15.15–21). This is the crux of the section—whatever the physical, mathematical, or acoustic definition of musical sound, harmonics needs to concern itself primarily with how notes are perceived as part of a melodic system. This approach of excluding the acoustic discussion in favor of a perception-based definition is extended in Book Two. As Aristoxenus refined his definition of harmonics, the treatment of the movement of the voice is excised entirely, and he was particularly

concerned to define and enumerate the parts of his newly independent science only in their own terms.

In Book Two, adjusting his definition of notes, Aristoxenus said that he would treat notes and "whether they are pitches, as most people suppose, or functions, and also just what a function is" (36.9–12). This concept of function—*dynamis*—which permeates the second book is the distinguishing difference between Books One and Two, although the idea is foreshadowed at the end of Book One, where Aristoxenus began a discussion of continuity (*synecheia*) and succession (*hexes*). These concepts contain the idea that there is a natural and necessary order to melody, that the intervals are not placed in random arrangement, and therefore that some combinations of intervals are impossible.

Aristoxenus' idea of *dynamis* (translatable in this context as "function," but with a range of meanings relating to power, force, or faculty) looks at the position of a note in the scale structure as well as its pitch. It proposes that understanding melody has two parts. "Through hearing we assess the magnitudes of intervals, and through reason we apprehend their functions" (33.7–9). *Dynamis* promotes the idea that melody is understood in a temporal way, that each note only makes sense because of those which have preceded and will follow it.

This concept allows a note to be placed on one of an infinite number of positions within a certain range while still retaining its identity. The moveable note *lichanos*, for example, might be pitched anywhere from one to two tones below *mesē*, and still be perceived as having the function of *lichanos* in the scale (26.14–18). This reflects a geometric concept of pitch, recalling Aristotle's discussion of infinite space in *On Generation and Corruption* (see especially 317a7–9). Similarly, although the *pyknon* is measured as smaller than the remaining interval, it is the perception of a "compressed" set of notes that marks it as a *pyknon* (48.26–31). Accordingly, as well as setting out six tetrachordal divisions, Aristoxenus explained the range of pitch of each note across the three *genera*.

Dynamis gives Aristoxenus' discussion structure and, because of the flexibility it allows in measuring intervals, has the added benefit of sidestepping the mathematical problems which plague the Pythagorean calculations. It moves away from the rigid measuring of ratios in the mathematical treatises and toward an understanding of music much closer to the way the mind perceives it. However, a problematic point about his tetrachordal divisions is that, despite his emphasis on perception, Aristoxenus used quite subtle differences in interval sizes: Aristoxenian intervals are as small as a quartertone even though the smallest interval measurable by perception (using the method of up a fourth, down a fifth) is a semitone. Between the third of a tone in Aristoxenus' chromatic and the quartertone in his enharmonic, Aristoxenus is distinguishing intervals that differ by a twelfth of a tone, a difficult distinction to make by perception alone.

Barker (2007, 197–228) shows that the third book of the *Harmonics*, what seems to be a clunky description of the possible order of intervals, is a systematic attempt to create theorems that refer to all melody, thereby fulfilling the ambition of an Aristotelian axiomatic science. The final section, unfortunately lost, promised a discussion of composition and most likely would have set out *harmoniai*, *tonoi*, and modulation. It survives only in the summary treatments of later authors such as Cleonides and Aristides Quintilianus (see §6).

5. The Euclidean *Sectio Canonis*

The Pythagorean counterpart to Aristoxenus' treatise appears in the form of the *Sectio Canonis*, a short work composed around 300 BCE. The authorship, date, and unity of the work are uncertain (Barbera 1991, 3–36; Barker 2007, 364–410), but its initial attribution to Euclid emphasizes its mathematical foundation and suggests a date not far from that of the mathematician (MATHEMATICS). The treatise consists of an introduction and twenty propositions concerning mathematical ratios of intervals, a method to find some notes of the enharmonic tetrachord, and finally, the eponymous division of the canon ("ruler") which gives measurements for the fixed and moveable notes of the diatonic scale. The canon refers to a technical instrument used to produce intervals by measurement. It consists of a single string (a monochord) stretched between two fixed bridges over a sounding board. An additional moveable bridge could vary the pitch of the notes produced.

The treatise's concise introduction is quite separate from the following propositions in style and content, and several commentators have argued that it (along with the final propositions offering the division of the canon) is not part of the original work. The arguments are presented by Barker (2007, chapter 14), who favors the unity of the work and asserts the value of the introduction in establishing the acoustic foundation for the rest of the treatise. The tract begins with connecting movement to pitch: "If anything is going to be heard, impact and movement must first occur" (148.5–6). While this initial idea echoes Archytas' concept of sounds as impacts, the *Sectio Canonis* omits the Pythagorean association of higher pitch with faster speed of transmission. Instead, it establishes clearly the link between frequency of impacts and pitch: "… since of movements some are closer packed, others more widely spaced, those which are closer packed producing higher notes and those which are more widely spaced lower ones" (148.9–11). Furthermore, by explaining that—because it is necessary to subtract movement in order to lower a pitch, and to add movement to raise pitch—notes are made up of parts, and all things made up of parts can be compared to one another in a ratio, the author justifies the use of ratios to describe intervals.

At the end of the introduction, three types of ratio are distinguished: multiple, epimoric, and epimeric (this is not multiple or epimoric, but "number to number" as Plato referred to the 256:243 *leimma* in *Timaeus* 36b). In a sentence which sadly lacks the clarity of the rest of the introduction, the author set apart the first two types of ratio as "spoken of in relation to one another under a single name" (149.15–16), but did not provide the name. He also stated that concordant notes make a blend, while discordant ones do not, and that the former are also spoken of "under a single name in relation to one another, being either multiple or epimoric" (149.21–22). It is not clear whether the single name refers to the nature of being multiple or epimoric, or whether it refers to the way that Greek can express these intervals in a single word—*diplasios* ("double"), *hēmiolios* ("half-in-addition," 2:3), *epogdoios* ("eighth-in-addition," 8:9), and so on—or refers to something else entirely. In any case, it sets apart these intervals as having a special role in melody (cf. Barker 2007, 375–376).

Although the connection between musical intervals and ratios has been made, as well as the particular role for epimoric and multiple intervals, the first nine propositions are purely mathematical and make no specific reference to melody. They treat relationships

between intervals (*diastēma* is not necessarily a musical term) and refer to their combination and division. Yet the propositions are undeniably focused on musical issues. For instance, Proposition 6 demonstrates that the duple interval [2:1] is composed of the two greatest epimorics, the hemiolic [3:2] and the epitritic [4:3]. This proves that the octave ratio is the sum of the ratios for a fifth and a fourth, but it is expressed purely in mathematical terms. No musical reference is made until Proposition 10, which states that an octave interval is multiple. Many of the propositions in the second half of the treatise refer to earlier proofs, translating abstract intervals into musical intervals. For example, Proposition 9 (six epogdoic intervals are greater than one duple interval) is used for Proposition 14 (the octave is less than six tones).

The *Sectio Canonis* consolidates earlier work in the Pythagorean school. Boëthius cited Archytas as the author of an almost identical proof of Proposition 3—that epimoric intervals cannot be divided into two or more equal intervals (*On Music* 3.11). The long-known ratios of the concords (omitting any reference to the awkward interval of the octave plus a fourth) are set out in Proposition 12. The treatise also builds on the work of earlier theorists in its division of the canon. Propositions 19 and 20 give a method for finding all the notes of a diatonic scale of the form of 9:8 | 9:8 | 256:243, as used by Philolaus and Plato. Like Philolaus, the Euclidean author did not mention or justify the awkward 256:243 interval remaining in the tetrachord.

Vitally, the *Sectio Canonis* establishes important points that directly contradict Aristoxenus' approach. Proposition 15 (the fourth is less than two and a half tones, and the fifth is less than three and a half tones) and Proposition 16 (the tone will not be divided into two or more equal intervals) explicitly oppose Aristoxenus' claims about the sizes of intervals. Proposition 3, on the unequal division of epimoric intervals, is one of the central blows against the empirical perspective. This on its own undermines Aristoxenus' measurements for tetrachordal divisions, and the size of the fourth and fifth, which depend on equal division of epimoric intervals. Where Aristoxenus argues that perception is to be the judge of interval size, the *Sectio Canonis* uses mathematical calculations to prove that the intervals used by perception-based theorists are impossible (cf. Barker 2007, 389–394).

Despite the fundamental difference in method between the *Sectio Canonis* and Aristoxenus' *Harmonics*, there are some similarities of purpose. Both attempt an irrefutable exposition using a proposition/theorem structure. Both aim to keep the discussion free from irrelevant topics: despite its Pythagorean background, the Euclidean treatise never descends into number mysticism, for instance. Both ground their discussion in musical practice by referring to tuning by concordance (pseudo-Euclid Propositions 17, 18; Aristoxenus, *Harmonics* 55.13). However, the *Sectio Canonis* does not have the Aristoxenian ambition of describing all musical structures. Where Aristoxenus painstakingly described basic scale forms, the *Sectio Canonis* presumes a familiarity with the shape of the scale and with the names of the notes; it makes no attempt to divide the enharmonic *pyknon*, but it merely proves in Proposition 18 (relying on Proposition 3) that it cannot be divided equally. It offers no division (or even a mention) of the chromatic tetrachord, and even its diatonic division of the canon does not complete the two moveable notes of the upper tetrachord. What the *Sectio Canonis* does offer is a concise and systematic exposition of the mathematical basis of musical theory, building on the work of earlier Pythagoreans.

6. Later Developments

After Aristoxenus and pseudo-Euclid, it is a long time before the next surviving treatises on music appear in the second century CE. And when the evidence reappears, not much has changed in the substance of harmonic theory. The division between Pythagorean and Aristoxenian approaches is still clearly defined, although adherents of one school, nevertheless, show how they have been influenced or contaminated by the other. It is important to note that the Pythagorean approach has little to do with Pythagoras' school but is merely a way of labeling the arithmetical system of describing musical sound. The tendency of the Pythagoreans toward number mysticism and cosmological associations was nonetheless present in these later treatises, and it even spread into works which were otherwise heavily dependent on Aristoxenus.

From this tradition, Cleonides' *Eisagōgē Harmonikē* ("*Introduction to Harmonics*," probably second century) is little more than an epitome of Aristoxenus' *Harmonics*. It includes the sections on *tonoi* that were missing from Aristoxenus' work, but so stripped of methodology that they do little to illuminate the lost portion of Aristoxenus' treatise. On the other hand, Nicomachus' *Enchiridion* is essentially a Pythagorean work, with an emphasis on numbers and ratios, and associating musical and cosmological structures. While it uses and cites a variety of Pythagorean sources, it also shows the influence of Aristoxenus in its systematic description of musical scales and its discussion of continuous and intervallic movement of the voice. In defining the note, Nicomachus gave three definitions, one of which clearly recalls Aristoxenus: "the incidence of sound on a single simple pitch" (261.5–6).

A more sophisticated treatise from the second century is the *Harmonics* by Ptolemy of Alexandria. It combines the Aristoxenian ambition of a systematic description of musical structures, notes, intervals, *genera*, and *tonoi*, with an emphasis on tetrachordal division expressed in Pythagorean ratios. Ptolemy's discussion of musical phenomena (9.16–10.29) uses many of the same terms and concepts as Aristoxenus' passage on the movement of the voice. Ptolemy is an important source for earlier harmonics, as he cited and criticized the theories and tetrachordal calculations of Aristoxenus and several Pythagoreans, while nonetheless keeping himself from either school. His own tetrachordal divisions consist entirely of epimoric ratios apart from the "ditonic diatonic," the standard diatonic tetrachord with two tones and a *leimma* of 256:243. Ptolemy took the epimoric division to extremes as he used Archytan means to produce an "even diatonic" of 12:11 | 11:10 | 10:9 (38.18). His preference for Pythagorean theory is plain in his continual references to the canon: he stated that the aim of the student of harmonics is to "preserve in all respects the rational postulates of the *Canon,* as never in any way conflicting with the perceptions that correspond to most people's estimation." (5.13–15). In the final book, Ptolemy revealed his Pythagoreanism with extensive demonstrations of the correspondence between cosmological and musical structures.

Aristides Quintilianus (circa 270–330 CE) also used a combination of Aristoxenian and Pythagorean ideas. His *On Music* aims to "present music itself, in its entirety" (3.27–28), and the work is, accordingly, of very broad scope. The first book uses an Aristoxenian exposition, setting out musical structures. His program for harmonics is the same as that in the second book of Aristoxenus: notes, intervals, *systēmata*, *genera*, *tonoi*, modulations, and melodic composition. He transmitted, in addition, a truncated

idea of *dynamis*, saying that the notes are unlimited in number by nature, but limited by *dynamis* to twenty-eight (7.15–18). The first book continues with an Aristoxenian-style treatment of rhythmics and metrics. The second book treats musical education and *ethos*, and the third begins with a discussion of Pythagorean interval ratios before heading off into number mysticism and musical cosmology.

We close by mentioning Boëthius' *On Music*, even though it is a Latin work, because it is a vital source for Greek music theory. Like Ptolemy, one of his sources, Boëthius' approach was Pythagorean, heavily influenced by Aristoxenian descriptions of musical phenomena. Unlike Ptolemy, Boëthius (in the part of the treatise dependent on Nicomachus) only offered one tetrachordal division for each *genus* (4.5–12), each making some use of the 256:243 interval. Through Boëthius, Greek music theory was transmitted into the Middle Ages. Despite Aristoxenus' influence on almost all later theorists, it is nonetheless the Pythagorean approach, which became dominant in later antiquity.

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FURTHER READING

Barker 2007 is a comprehensive treatment of the methods and aims of the Greek music theorists: the culmination of Barker's career of rigorous, clear insight into the subject. West 1992 offers a systematic and detailed examination of the broader subject, including instruments, musical notation, and the scores of musical works. An indispensable and extensive bibliography is contained in Mathiesen 1999, which also covers musical life and instruments, as well as music theory. S. Hegal, *Ancient Greek Music: A New Technical History* (Cambridge: Cambridge University Press, 2010) offers an innovative

and multi-faceted analysis. For texts in translation, Barker's two-volume *Greek Musical Writings* is invaluable: the first volume (1984) focuses on the musician and musical performance and the second (1989) on musical theory. Greek texts of Aristotle, (pseudo-) Euclid, Nicomachus, Bacchius, Gaudentius, and Alypius can be found in Jan's Teubner edition of *Musici Scriptores Graeci* (1895, 1995). For Aristides Quintilianus there is Winnington-Ingram's Teubner edition (1963), and for Aristoxenus the edition and Italian translation by Da Rios (1954).

PART III

Earth Sciences

CHAPTER 11

Hydrology: Ocean, Rivers, and Other Waterways

Georgia L. Irby[1]

"Thus it is proper for me to … make the sea the advisor." (Strabo 8.1.3)

1. Introduction

Seas, the circumambient Ocean, rivers, lakes—waterways—were integral to the fabric of Greek culture. The sea was the lifeline of Greek communities, essential to *polis* subsistence (through fishing), commerce (the Rhodians were prosperous owing to the sea: Strabo 14.2.10), and defense (Sparta alone of the prominent Greek *poleis* was landlocked). The sea was the backdrop for mythology. Heracles, Jason, and Odysseus traveled by sea. Heracles saved Hesione, princess of Troy, and Perseus rescued the Aithiopian beauty Andromeda from sea monsters. Two major gods held sway over the Ocean: Poseidon represented the wild, unpredictable nature of the sea; Athena represented man's maritime conquest, subjugating Poseidon's rolling sea with her boats, as she had bridled her uncle's wild horse. Colonization was largely a maritime enterprise, as were great voyages of exploration (Hanno, Pytheas, Alexander). It is only natural, then, that the Greeks would inquire into the nature of the ocean, seas, and other waterways. Aided by data collected from sailors, merchants, and explorers, they investigated sea and river depths, currents, tides, silting, estuaries, riverine anomalies (most notably the Nile flood), and other aquatic phenomena.

Hydrology, like Geography, was informed by philosophical prejudice. Knowledge of waterways, in turn, guided geographical and cartographical discourse from the earliest days. Geographical writers—Homer, Eratosthenes, Strabo, Pliny—carefully noted the relationship between settlements and waterways, the length of coastlines, littoral shape and character, and proximity to the sea. We know where places are by their deployment with

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respect to well-known waterways. In the catalog of ships (*Iliad* 2.494–759), Homer frequently notes relationships between community and sea: Asine lies down the deep gulf; Chalcis and Antron are by the shore; and Cerinthus is a sea-borne island. Major waterways are given as boundaries between continents (the Nile and Phasis rivers separate Libya and Asia) and countries (the Euphrates delimits Cilicia and Armenia: Herodotus 5.52; Evans 2005).

We also note that ancient nomenclature was often ambiguous. What distinguishes a lake from a sea, for example? The landlocked Caspian, usually referred to as a "Sea," fits Polyclitus' criteria for lakes: it produces serpents and the water is sweet (as reported by Strabo 11.7.4, in whose day the Caspian was not considered landlocked). Herodotus also admired the Pontus (Euxine/Black Sea), which was so large that there are lakes within it (4.85–86).

Our evidence comes from glimpses in works on geography (Eratosthenes, Pliny, Strabo: see GEOGRAPHY) and philosophy (Aristotle, Seneca the Younger), as well as travelers' accounts (*Periploi*: see CARTOGRAPHY). We know of only one dedicated monograph, Poseidonius' *On Ocean* (110–51 BCE), sadly lost, but preserved in fragments contained primarily, like so much else geographical, in Strabo. The title may be in imitation of Pytheas' geographical treatise *On Ocean*.

2. The Circumambient Ocean

Even into the first century CE, the Ocean was a source of terror. When Claudius prepared to invade Britain in 43 CE, his men responded with mutiny (as Gaius' troops likely had done, three years previously): the English Channel, opening into the vast Atlantic, beyond the calm waters of the Mediterranean, represented the edge of the known world, and crossing the rough waters of the Channel meant plunging into the unknown. Homer gives us the earliest Greek worldview of Ocean, vividly depicted on Achilles' shield (*Iliad* 18.607): encircling the inhabitable world (*oikoumenē*) was the river Ocean (Okeanos). This "river," almost always "wine-dark," was sometimes "gently-flowing" (*Iliad* 7.421–422; *Odyssey* 19.433–434), sometimes violent "with a swell of current" (*Odyssey* 4.567, 10.139, 12.1–2)—perhaps here we see the distinction between the Atlantic ("outer" Sea) and the much calmer Mediterranean ("inner" or "our" Sea). Homer offers conflicting views on the Ocean, which is sometimes merely a river with a flow and outlet. The poets describe Okeanos as misty, unending, undraining, deep flowing, unharvested. Personified in Hesiod, Okeanos, is ultimately the source of all bodies of water (*Theogony* 240–242). Okeanos' children include Nereus and Doris, who, in turn, were the parents of fifty daughters, representing as many lesser waterways. Early tradition places Okeanos' source "at the sun's rising," whence it flows around the earth.

Although rejected on the lack of empirical evidence by Herodotus (4.8) and Hipparchus of Nicea (perhaps from pusillanimity toward Eratosthenes), the circumambient Ocean model endured, finding support in Aristotle (*Metaphysics* 354b), Eratosthenes (f39), Poseidonius (f214), and Strabo (1.1.8–9). Attempts to prove the conjecture consistently met with failure: Hanno (circa 500 BCE) turned back when supplies ran out; the feckless Persian Sataspes, sent to circumnavigate Africa between 479–465 BCE, detested the isolation of his long voyage and turned back in fear, asserting that his "ship was held back and could not be made to move forward" (Herodotus 4.43). We shall never know if Eudoxus of Cyzicus' circumnavigation of Africa succeeded—the account breaks

off after Eudoxus sought asylum in Iberia (Strabo 2.2.3–5). Necho's expedition may have been the only one to succeed, with reports of crossing the equator, faithfully reported by a disdainful Herodotus (4.42.2–3). Despite the failures, Eratosthenes was sufficiently convinced that the external Ocean must be continuous because most of it had been sailed (f39; Roller 2010, 156). The circumambient ocean was finally rejected by Ptolemy, who replaced it instead with an encircling *terra incognita* of indefinite expanse, inspired by new geographical data regarding peoples to the far east (*Geography* 7.5).

3. The Nature of the Oceans and Seas

Salt

Early thinkers may have taken for granted the fact that some waters are sweet and other salty, suggesting that salt water was simply fresh water flavored by earth, absorbing flavors "like things strained through ashes" (Aëtius 3.16.5; cf. Aristotle, *Meteorology* 354b5–7). Xenophanes gave the first (extant) suggestion that, over time, water dissolved earth, and the two elements were constantly mixing, offering as proof inland imprints of fishes and seaweed (*TEGP* 59). Early thinkers saw this process as cyclical: according to Anaximander, Ocean was currently drying up (*TEGP* 34); in Heraclitus the triple exchange between fire, sea, and earth was simultaneous (*TEGP* 51). Empedocles cleverly suggested that Ocean water became salty as the sun heated it, as if the earth were sweating (*TEGP* 100). Aristotle derided this explanation as sheer silliness, since sweat implies a failure to digest, and there is no need at all for the earth to digest anything nor is there any indication that the earth is currently "sweating" (357b7–13). Aristotle's explanation relies on his theory that elements seek their natural place: only the lightest (sweet) water (with small quantities of salt) is evaporated, returning to the earth as rain, the heavier, thicker salt water remains, sinking below sweet water. The sun's warmth, apparently, attracts the sweeter parts up (cf. Pliny, *NH* 2.222). Aristotle assures us that his personal experiments prove that vaporized salt water remains sweet, not recondensing into salt (358b12–17). The greater density of brine is demonstrated empirically: a sea-going vessel will nearly sink on a freshwater river with the same cargo, and eggs will submerge in fresh water but float in brine (359a6–15).

Why, then, is the sea salty? Because of the admixture of moist (watery) and dry exhalations (earthy, containing residues that result from the natural process of generation: 358a16–26; Taub 2003, 102). As proof that earthy stuff in water makes it salt, Aristotle referred to a fabled Palestinian lake where nothing sinks, with waters so bitter that no fish can survive and clothes can be cleaned simply by dipping and shaking. (Strabo gives a vivid account of the Dead Sea [which he mistakenly calls "Lake Sirbonis"] at 16.2.42; cf. Pliny, *NH* 2.226 on the bitumen-producing lake Asphalitis in Judea).

Tides

Tides were known as long as ships have plowed the seas, described in both Homer (*Odyssey* 12.1–2, 235–243) and Hesiod where "the Ocean flows back" (*Theogony* 240–242). Strabo (1.1.7) praised Homer for knowing about flood tides. They perplexed Alexander's troops, who were either unfamiliar with tides of the "Great Ocean" or not

sufficiently observant of the gentle Mediterranean tidal activity (Arrian, *Anabasis* 19.1). Particularly high Channel tides at the full moon frustrated Caesar's invasion of Britain (*Gallic War* 4.29; Mohler –1945; Kidd 1972, 774–775). While it was recognized since Pytheas that the moon influenced tidal activity, the Roman poetical astronomer Manilius (10–30 CE) suggested that the stars also affected tidal amplitude (2.89–92). Careful observation of tidal behavior aided Scipio's attack of New Carthage in Spain (210 BCE: Polybius 10.14.2; Livy 26.45.8; Lovejoy 1972). Knowledge of tides also informed ship construction. Thus, the coastal peoples of Belgica built broad-bottomed boats with high sterns and prows to withstand dramatic Atlantic tides (Strabo 4.4.1; see also Caesar, *Gallic War* 3.12–13).

Tides were a cause of great curiosity, and tidal rivers bordered on the paradoxical (Pliny reported rivers flowing back when Nero died: *NH* 2.232). Strabo described tidal rivers and estuaries at Torudetania in southern Iberia (*NH* 3.2.4), where in some areas the flood tide "is just like the flow of a river" and the sailing is "just like sailing down rivers (as there is no resistance)." Strabo dismissed as unbelievable the report that the Cimbrians were reportedly driven out by an excessive flood tide, "a phenomenon that is so regular and predictable" (7.2.1). Cicero, in fact, offered tidal regularity as a example of nature's harmony (*On Divination* 2.14).

Poseidonius ascribed a tidal theory to Aristotle: that high rugged headlands off Spain and Morocco caught the ocean waves and hurled them back to sea. Sternly critical, Poseidonius had seen for himself the low sandy beaches along that coast (f220)—there was nothing against which the waves could bounce. Aristotle, however, had no real experience of tides, and likely proffered no tidal hypothesis—nor is Poseidonius' conjecture substantiated in the *Meteorology* (Kidd 1972, 790). But Aristotle's authority was unimpugnable, and a popular belief that tides were caused by the winds may also go back to him (Aëtius 3.17.1).

Pytheas of Massilia was perhaps the first Greek thinker to consider tides in any systematic way. He was fascinated by the dramatic tidal activity around the British isles, among the largest in the world, allegedly reporting tidal swells of up to 80 cubits (37 m [118′]: Pliny, *NH* 2.217), an impossibility, but perhaps resulting from a storm surge (Roller 2006, 76–77): the Jersey Channel Islands have tides up to 12.5 m (41′), and tidal amplitude at the Bay of Fundy in Canada, renowned for its high tides, can reach up to 17 m (56′) (see Waddelove and Waddelove 1990). Aëtius (3.17.3) suggested that Pytheas was correlating the half-daily tides to phases of the moon ("fullness and faintness"), though it may be more likely that Pytheas was observing a spring tide—when the sun and moon are both in the earth's equatorial plane and thus exert a greater gravitational pull in the same direction—coinciding with an equinoctial tide, together yielding dramatic tidal amplitude (correctly noted by Seneca, *NQ* 3.28.6. The anonymous author of the *Periplus of the Erythraean Sea* also remarked that *nocturnal* spring tides have the greatest force: Eckenrode 1975, 279–281, 286).

Building on Pytheas' remarkable achievement, Seleucus of Seleucia (165–35 BCE) was the first to write a monograph on tidal theory. Through the lens of Stoicism, Seleucus suggested that the moon's orbit and earth's rotation (Seleucus was a rare proponent of heliocentrism) disturbed the intervening *pneuma*. This disturbance resulted in the swelling of the Ocean. Tides varied seasonally, depending on the lunar zodiac sign, and they differed from sea to sea, an idea also favored by Hipparchus, but flatly rejected by Strabo, who staunchly maintained that the ocean in general and tides in particular behaved

uniformly (1.1.9; Dicks 1960, 115; Kidd 1972, 760–763; Roller 2005, 115–117). Seleucus also ascertained inequality in the diurnal tidal activity of the Red/Babylonian Sea (Indian Ocean) (Figure 11.1): tides are "regular" (neap, with no great difference between high and low tide) when the moon is in equinoctial signs, but "irregular" (with extreme differences in amplitude) when in solsticial signs. Seleucus surmised that this irregularity was proportional to the moon's distance from the earth's equinoctial (on the equator) and solsticial planes (greatest north/south declination). Thus, Seleucus concluded that, when the moon is on the equator (equinoxes), the Indian Ocean has two daily cycles of equal highs and lows. When the Moon is at 90° to the equator (solstices), the diurnal highs and lows are unequal. Darwin (1898, 86–87) confirms Seleucus' observation: the diurnal inequality in the Atlantic is practically non-existent, whereas in the Indian Ocean, trees that are "completely visible at low tide are completely covered at high tide" (Strabo 16.3.6), and Seleucus likely saw the phenomenon first hand.

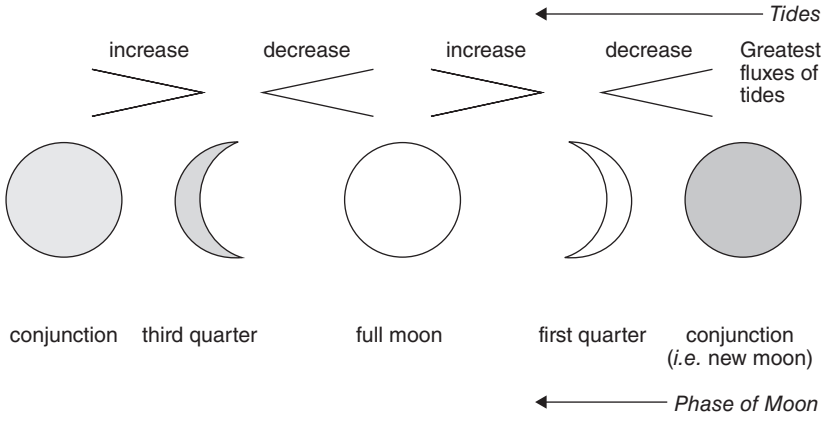


Figure 11.1 The effect of lunar phases on tidal amplitude. Kidd 1972, 284, Figure 14. (Courtesy of Cambridge University Press.)

Seleucus' bold statement must have piqued Poseidonius' curiosity, and Poseidonius may have traveled to Gades to test Seleucus' claims (Kidd 1972, 776). Poseidonius spent thirty days on Spain's Atlantic coast, where he could observe tides that reached higher than in the protected Mediterranean, and there he formulated a tidal theory which formalized and quantified earlier tidal hypotheses (f217b). When the moon is one zodiac sign above the eastern horizon (30°: Figure 11.2), the sea rises visibly until the moon reaches the meridian (90°). Water levels then begin to recede until the moon is 30° above the western horizon, holding steady until the moon is 30° below the horizon. Water levels again rise until the moon reaches the meridian below the earth, when they start to ebb, holding steady as the moon travels from 30° below to 30° above the eastern horizon. In addition to the diurnal cycle, Poseidonius correlated varying tidal amplitudes to phases of the moon, noting that sea levels are greatest in conjunction with full and new moons, smallest in conjunction with quarter moons. Poseidonius' explanations of diurnal and monthly tides are substantially correct. The good people of Gades, however, seem to have led him astray in reporting that the annual high tides occurred in conjunction with the solstices, when in fact highest tides coincide with the equinoxes.

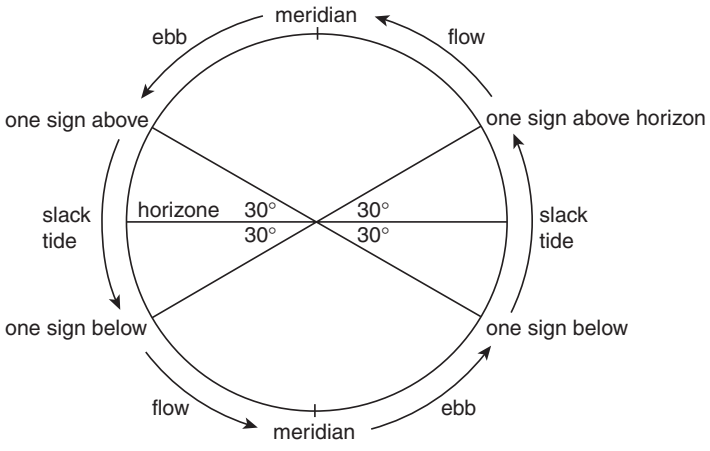


Figure 11.2 The tidal diurnal cycle. Kidd 1972, 283, Figure 13. (Courtesy of Cambridge University Press.)

Poseidonius may have misunderstood the locals, or Strabo may have misinterpreted Poseidonius. Despite the slip, Poseidonius succeeded in marshaling the empirical evidence into a unified theory of tides, a "remarkable contribution" (Kidd 1972, 281, 775–776). This error, furthermore, was not perpetuated: Seneca (*NQ* 3.28.6) and Pliny (*NH* 2.215), who both presumably followed Poseidonius, gave the maximum high tides at the equinoxes (see also Tacitus, *Annals* 1.70.2). In the end, however, Poseidonius was deliberately looking for high tides at Gades at the solstices (Strabo 3.5.9), and his observation of another high sea coinciding with the summer solstice near Sicily (f227), due to a volcanic eruption, may have confirmed in his mind the high solsticial tides.

Finally, in addition to repeating well-known facts, Pliny the Elder made a number of original observations. He was the first to note nearly constant luni-tidal intervals according to places (according to the risings of the "stars"—it is, however, the moon's declination that changes with time and place and affects tidal amplitude and time, which Seleucus understood), as well as the retardation of daily tidal intervals (or "lag" time: high lunar tides occur at intervals of between twelve and thirteen hours—Pliny merely noted that daily tides occur at different times). He elaborated on Seneca's phase inequality (*NQ* 3.28: spring tides occur slightly after new and full moons). Pliny reported that lower tides occur when the moon is in the northern hemisphere (higher tides occur when the moon is in the southern hemisphere—for waterways in the northern hemisphere). And he made note of the eight year tidal cycle of recurring lunar phases (*NH* 2.212–221; Eckenrode 1975, 280–282).

Water Depths and Surface

Aristotle maintained that seawater flows to the deepest place, finding its natural place (weighed down by the salt, of course, because water's natural place is between earth and air), so the deepest parts of the earth are filled by sea (*Meteorology* 355a33–b5, 355b17–19). Because of the complex interplay between water and earth, rivers, and ocean, there is a progression from shallow to deeper: Maeotis, Pontus, Aegean, Sicilian, and the Sardinian and Tyrrhenic seas are the deepest of all (*Meteorology* 354a14–21).

Water flows from the higher regions in the north, but intense alluvial activity makes the northern seas shallower and the outer seas deeper. Aristotle recorded that the Caspian is unfathomable: "no one has yet been able to find bottom by soundings" (*Meteorology* 351a9–14; cf. Pliny, *NH* 2.224). Poseidonius reported the Sardinian Sea as about one thousand *orguiae* deep (1.8 km [1.16 miles], in reality closer to 3 km [1.86 miles]), the deepest of those that have been measured (f221). We do not know how the reading was taken (Kidd 1972, 794–795). In contrast, in the Arabian Gulf there is a shallow sea, about two *orguiae* (3.75 m [12′]), which "appears grassy with seaweed and other weeds showing through" (Strabo 16.4.7), perhaps the Sargasso described by Avienus (122–129), through which vessels go slowly and sluggishly.

Following Strato, Eratosthenes believed that the sea was wholly confluent but with changing levels and an uneven seabed (easily proved by the experience of sailors in the Greater and Lesser Syrtes, who could quickly run aground even in the "depths": Strabo 16.3.20). These changing sea bottoms helped to explain a number of phenomena, including the creation and behavior of straits and widespread impressions of marine animals and inland salt deposits. Strato hypothesized that the Hellespont, opening into the Black Sea, was created when rivers flowing into it forced an opening. Likewise, the Pillars of Heracles were broken open when rivers flooding into the sea uncovered areas that had once been under shallow water (Eratosthenes f15). Currents in narrow straits resemble flow and ebb tides, which Eratosthenes viewed as caused by the water sloshing between higher and lower levels. Strabo, refusing to engage with scientific explanations of strong currents in straits ("a more scientific discussion than appropriate in this treatise"), dismissed Eratosthenes, preferring an *ad hoc* approach ("there is no single explanation"). The phenomenon, however, is well known, occurring conspicuously at Messina, the Euripus at Chalcis, and the Hellespont. Very likely apocryphal is the tradition that Aristotle sought to explain the change in current at Euripus, and his inability to find a satisfactory solution caused his early death (Procopius, *History of the Wars* 8.6.20).

Eratosthenes also hypothesized that bodies of water had discrete surfaces and discrete levels, rejecting his friend Archimedes' postulate that "the surface of all fluids that remain immovable will have the surface of a sphere, having the same center as the earth" (*On Floating Bodies* 1 proposition 2). In 302–1 BCE, when Demetrius Poliorcetes had hoped to construct a canal for his troops, his engineers at Cenchreae noted a higher sea level on the Corinthian Gulf than at Cenchreae. Assessing the environmental risks, they advised against construction since cutting the canal would cause the isthmus to flood, rendering the proposed passage futile (f16; Roller 2010, 132). Some twenty years later, Ptolemy II Philadelphus' engineers calculated the surface of the Red Sea as three cubits (1.4 m [4.6′]) higher than the Nile's, and the Nile's surface higher than the Mediterranean's (Pliny, *NH* 6.166).

Sea and Land

> The sea most of all describes the earth and determines its form, by producing gulfs, the open sea, straits, as well as isthmuses, peninsulas, and capes, with both rivers and mountains providing assistance. (Strabo 2.5.17)

As we saw earlier, there is constant reciprocity between land and water, underscored, for example, by the myth of Atlantis (Plato, *Timaeus* 24e; Strabo 2.3.6; Pliny, *NH* 2.205).

Inland deposits of seashells raised questions about erosion and deposition, sea depth and changing levels, and even the age of the earth (Herodotus 2.12). We also recall Herodotus' comments on the effects of silting on the land of Egypt. Because of this process, Egypt was famously called a "gift of the Nile" (Herodotus 2.5).

Democritus hypothesized that the sea was receding and drying up, an absurd notion to Aristotle's mind (*Meteorology* 353b). Arguing that the earth and sea are mixing, Xenophanes conversely suggested that earth would be eventually dissolved (again) as evidenced by inland marine impressions (*TEGP* 59). And so the cycles of Presocratic cosmogony continue to play out. Using the same evidence (inland marine deposits), Strato speculated that plains in Armenia were once sea, as Eratosthenes (f15) surmised that the oasis at Ammon was once under water (Roller 2010, 129–130). Likewise, in Homer's time, Pharos island, where stood Alexandria's famous lighthouse, was in open sea (*Odyssey* 4.354–355), and it was generally accepted that the sea levels around Egypt had been higher in years past. In Homer's defense, Strabo (1.3.17) offers eyewitness testimony of a flood in the Pelousion region that turned Mt. Kaison into an island and made roads navigable.

Aristotle subscribed to the cyclical interplay of water and earth (*Meteorology* 351a19–352b16). Because of heat and cold, the earth grows and decays, causing gradual siltation as land encroaches on the sea or gradual erosion as the sea infringes on the land. Aristotle reported that Egypt is gradually becoming drier, and that newly silted land is marshy, since water remains most in newly formed lands. But over time, as the silted land ages, the water is dried out. Egypt, in fact, once used to be wetter. Aristotle maintained that the change is not cosmological; the world is currently fully formed (in its final state). These changes, he declared, are mere trifles "compared to the bulk of the size of the earth." Along the same lines, rivers change course (e.g., the Achelous and the eponymous Meander).

This process of silting can even change the nature of bodies of water from salt to sweet, as with Lake Maeotis. We saw earlier how silting affected the navigability of the Maeotis. Polybius (4.40.4–10) also reported that the Maeotis was once a salt-sea confluent with the Pontus, but is now a sweet lake since the salt has been forced out by deposits and inflow from prevailing rivers. The Pontus, furthermore, continually receives alluvial deposits and will eventually become sweet, and Lake Maeotis will be entirely filled up. Polybius even offers a timetable, considering rates of accretion and the ratio between the basins and alluvium. This will occur not in some remote future, but soon. For this same reason, alluvial deposition, the Pontus was also recognized as the sweetest sea: since rivers flowing from the north and east are numerous and large and fill [the sea] with sediment, but other rivers remain deep (Eratosthenes f15).

Alluvial deposition was a common feature of rivers—Nearchus called plains, for example, the offspring of rivers (Strabo 15.1.16). And this riverine silt, as in the Maeotis and Pontus, filling up lakes and creating deltas, could reach well out into the sea, as was predicted for the Pyramus river in Cilicia, whose growing delta was predicted might one day reach Cyprus (Strabo 12.2.4).

Such extreme siltation, however, cannot be noted in the open sea because of the natural oscillation of the surf. Whatever sediment flows from rivers into the open ocean will be returned to land because the landward wave has more force: "casting all kinds of strange things on the land and 'pouring out much seaweed'" (Strabo 1.3.8, citing *Iliad* 9.7). This oscillation is compared to breathing (Strabo 1.1.9, 1.3.12, 3.5.7), the same

analogy employed by Athenodorus of Tarsus (60–20 BCE) to describe tidal ebb and flux in his monograph on tides, and one going back to Plato and Aristotle (Roller 2006, 85–86 on Pytheas' "Sea-lung"). The image derives from Stoic physics wherein *pneuma* ("breath" or soul) permeates and interconnects all matter, imposing order and harmony, equilibrium and stability.

Interconnectedness of the Bodies of Water

The ancients also inquired into the source of water, and whether all waterways derive from the same or different sources, whether water comes from the sea or if terrestrial waters create the sea. In Hesiod, Ocean, the father of all other bodies of water, is literally the source (*Theogony* 337–370). This notion is rationalized by Hippon, who maintained that the sea is deeper than freshwater. There is more water in the sea, which, consequently, must be the source. Anaxagoras had it the other way: waters within the earth produce the sea, and rivers are replenished by rain (*TEGP* 38). Seneca (*NQ* 3.6.7), contrarily, argued that no rainfall is ever sufficiently heavy to produce something as large as river, but it rather merely dampens the surface of the ground, never reaching below ten feet.

In the *Phaedo* (112a–113d), Plato named Tartarus as the source of all waters, flowing and standing, always surging to and fro, but with no fixed seat, and this oscillation causes the flow of rivers, and the filling of rivers and lakes (including "our sea," the Mediterranean). Because of this ebb and flow, bodies of water, so Plato argued, sometimes return to the channel of their sources, at other times they flow toward opposite channels. Different qualities in bodies of water, color and taste, for instance, derive from the earth through which particular waterways flow (Vitruvius 8.3.12). Aristotle (*Meteorology* 357a15–23) found this conjecture irrational and impossible. On this theory, rivers then would flow according to the surging of Tartarus. Would they then flow upward when Tartarus surges? That, of course, is impossible! Furthermore, rivers do not return to their own sources, so Aristotle surmised. Aristotle resolved the debate by having it both ways. Bodies of water are one and the same: the sea is one in form and volume; but the sea also comprises discrete parts that are in continual change—some parts change more rapidly, others more slowly. While the bulk remains constant, the parts do not.

Whirlpools and Tidal Waves

Water could be a dangerous thing. The Greeks knew the sea too well to trust it, and the Romans preferred to avoid it altogether. Mythology preserves the memory of a destructive flood, sent by Zeus to punish the hubris of mankind, and Seneca vividly imagined the course and effects of such a colossal storm (*NQ* 3.27–29; Inwood 2002; see also Ovid, *Metamorphoses* 1.262-92).

A natural whirlpool exists in the northern portion of the strait of Messina between the eastern tip of Sicily and the "toe" of Italy, and this whirlpool likely inspired the myth of Charybdis (Homer, *Odyssey* 12.105; Vergil, *Aeneid* 3.420–423; Strabo1.2.16, 36). The explanations were largely mythological: that the whirlpool was caused by the deadly sea monster Typhon, whom the gods buried under Mt. Aetna. Whenever he turned over, he caused water and flames to erupt. Pindar (*Pythian* 1.15–28) suggested instead that

water surges up through interconnected subterranean cavities because the entire strait is inflamed. There are no subsequent attempts to explain the phenomenon (Strabo 6.2.3; Seneca, *NQ* 3.29.7; Pliny, *NH* 3.87).

Strabo also suggested that earthquakes and volcanoes could cause major floods and tidal waves. At Pithekoussai, an island west of Naples, circa 400 BCE, the volcano at Epomeus Hill erupted, shaking the island, enflaming the land, and causing the sea to withdraw for three *stadia*. The sea quickly refluxed and quenched the fire (Strabo 5.4.9). Poseidonius (f227) witnessed a tidal wave caused by a volcanic eruption between Vulcano and Panarea, north of Sicily (126 BCE). The sea was raised to an extraordinary height, sustained by an upward blast, until crashing back down, leaving in its wake dead fish, terrible heat, and an unbearable stench (sulfur?), followed days later by mud surfacing on the sea and flames continuing to flicker. Of uncertain date, though perhaps during Poseidonius' lifetime, a major seismic event that originated in the Levant is traceable all the way to northern Euboea (Poseidonius f232; Strabo 1.3.16). Strabo (16.2.26) thought that movements of the seabed caused a tidal wave that destroyed Tryphon's army on the Syrian coast between Ptolemais and Tyre, 144/3 BCE. If Poseidonius' speculated on the tidal wave's cause, his hypothesis has not come down to us (f226).

4. Rivers

Rivers figured prominently in Greek and Roman lore. In Homer (*Iliad* 21.300–327), glutted with the armor of so many warriors slain by Achilles at Troy, the enraged Simois leaves his riverbed to engage Achilles in battle. Vergil delimits the hegemony of the Roman empire with reference to major rivers: the Nile, Rhine, and the Euphrates (and the Caspian Sea: *Aeneid* 8.711-728). Ovid (*Fasti* 3.601–656) has the Tibur come to the rescue of Anna, Dido's sister, who has been shipwrecked in Italy and is now fleeing from Aeneas' jealous wife Lavinia. This Carthaginian Anna will be worshipped as the Anna Perenna at Rome, as other bodies of water are propitiated throughout the Mediterranean world.

Particular rivers captured the imaginations of the Greeks and Romans. Known to Hesiod (*Theogony* 349) and considered the greatest of European rivers by Herodotus (4.48) was the Ister (Danube) into which all other European rivers flow, and through which Jason and his Argonauts made their escape from Medea's xenophobic father—the Argonauts futilely imagined that the Ister might allow passage to the Adriatic (Apollonius of Rhodes, *Argonautica* 4.257–260, 282–293). Apollonius' description, however, does suit the Ister's course from the Hungarian plains into the Balkans (Green 2007, 303).

Arrian (*Periplous of the Black Sea* 8, cf. Pliny, *NH* 2.224) described the unusual properties of the waters in the Phasis river, the most important river in Colchis, cited in Hesiod (*Theogony* 340) and Apollonius of Rhodes: "broad-flowing and the utmost end of the sea" (*Argonautica* 2.1261). The waters are light, floating above the sea—just as the Titaresus floats on the Peneius "like oil" (Homer, *Iliad* 2.754; cf. Ovid, *Letters from Pontus* 4.10.63–64)—because of the great number of rivers flowing into it. The Aristotelian author of the *Problems* had made the same observation (*Problems* 23.6; Polybius 4.42; Strabo 1.3.4). Modern theories posit the reverse: that the salty Mediterranean broke into the Phasis, and the denser salt water sank to the bottom (Liddle 2003, 99). The river has a strange hue, as if tinged by lead or tin, but the waters clarify when

left to stand. Because of the salubriousness of the Phasis, immigrants are forbidden from importing water. When stored, the water even grows fresher over the years, so it was believed (Pliny, *NH* 6.12; Strabo 11.2.16–17, 3.4).

Arrian's descriptions of the Ganges and Indus replicate the wonderment found in Herodotus. These Indian rivers, swelled by rains, are large enough to accommodate full-scale ships (*Indica* 6.4; see Strabo 15.1.13). Eratosthenes had even maintained that the Indus flows south (f74). From Herodotus onward, Egypt and India, especially their great rivers with strange wildlife (e.g., crocodiles: Herodotus 4.44), were viewed as analogous. And some sources suggested that the Ganges, like the Nile, arose from unknown sources (Pliny, *NH* 6.65).

While it is easily recognized that rivers debouche into larger bodies of water, the source of river water is another question altogether, and the earliest answer was twofold: that rivers were created both by rainfall and water squeezed up from hollow cavities in the earth (Anaxagoras *TEGP* 38). The conjecture endured, finding expression in Pliny (*NH* 2.166), who envisioned ocean water as being squeezed up through underground channels to mountain tops—this derives from the Stoic belief that, in order to cohere, earth required a constant flow of water, percolating throughout (as anyone who has experienced both the humid tropics/subtropics and the dry, dusty desert climes might attest; cf. Aristotle, *GC* 335a1).

Aristotle was adamant that rivers do not originate from reservoirs (it would be impossible for a reservoir of sufficient size even to exist—he believed), nor do all rivers derive from a single source (*Meteorology* 349a11–53a26). Considering mountains and springs as riverine sources, refining Anaxagoras' hypothesis, Aristotle maintained that high ground is like a saturated sponge, whereas the plains are much drier. We have already seen that Aristotle considered the notion of upward-flowing rivers preposterous (*Phaedo*; see above). So naturally, rivers must flow from higher to lower ground: "The greatest rivers come from greatest mountains" (*Meteorology* 350a). Rivers could also originate at the foot of mountains or in marshes, or they might accrete gradually from the water naturally contained in the earth, "transmitted by a gradual percolation, drop by drop." Rivers also varied, affected by their environments—the size, density, and coldness of their mountains. Small, porous, stony, clayey mountains produce rivers that run dry more quickly. Finally, Aristotle also considered the effect of rivers on the oceans and seas into which they debouch. They seem to leave no trace, the sea is in no way increased with the "innumerable and vast rivers flowing into it every day" because the waters spread out over a vast area, "quickly evaporating" like a small cup of water poured over the top of a large table.

Around 500 BCE, the explorer Euthymenes of Massalia observed rivers that seemed to flow inland from the Ocean (Aristides 36.85–95). Poseidonius' curiosity was excited by the behavior of such rivers, reacting to the force of especially powerful tides in the Ocean, particularly the Rhine and the Thames in Britain, filled up by the sea at flood tide and seeming to flow away (rather than toward) the sea "for four days" (f219).

Underground Rivers

In Greece, the nature of the landscape makes underground debouchments common, and there was speculation about the interconnections between those waterways. That subterranean lakes exist is provable by aqueducts which collect water in pipes and trenches

"as if the earth in the higher ground were sweating the water out" (Aristotle, *Meteorology* 349b27–350a2; cf. Eratosthenes f96). Aristotle explained that channels are essential, otherwise places would flood. Because of pressure from the waters above, "some rivers are swallowed up." Those lacking visible outlets find underground debouchments instead, as noted on a small scale within Greece, but on a larger scale elsewhere (*Meteorology* 351a1–6). Seneca's explanation (*NQ* 3.7–10) is the only extant one. Imagining underground rivers as large as terrestrial rivers, he suggested three possibilities:

1) moisture is constantly expelled within the earth;
2) air converts to water by the forces of darkness and cold (since, according to Aristotelian and Stoic physics, all elements can arise from each other); and
3) earth is converted to water.

Several examples of riverine games of peek-a-boo are recorded. The Anias around Pheneus in the north central Peloponnese, alternately a plain or lake (as in Eratosthenes' day), carried water through underground channels ("zerethra") about 10 km (6.2 miles) to the southwest, to a depth of 400 m (1,312.5′), debouching into the Ladon and Alpheus rivers (Eratosthenes f 140; Roller 2010, 215). At one time, the lake receded, and the territory around the sanctuary at Olympia, near which flows the Alpheus, flooded. The Alpheus itself was widely believed to disappear, reappearing on the western side of the Aegean Sea as the Arethusa fountain on Ortygia, near Syracuse in Sicily, an inference based on the fact that objects thrown into the Alpheus' mouth reappeared later in the Arethusa (Pliny, *NH* 2.225; cf. Ovid, *Metamorphoses* 5.599–641; Pausanias 7.2). In disbelief, Strabo (6.2.4) argued that waters discharging into the Aegean would be salty, but the Arethusa was fresh; therefore, the Alpheus cannot flow into the Arethusa, Strabo concludes.

Likewise, the Tigris flows through lake Thopitis but then disappears, plunging under the earth with "a great noise and upward blasts," reappearing eventually near Gordaia (Eratosthenes f87). The Thopitis, however, is not in the Tigris basin, but, nonetheless, near the Tigris' source. The terrain was little understood, so it is understandable how even the locals might have believed that the river ran underground (Roller 2010, 190). Theopompus hypothesized an underground channel linking the Adriatic and Aegean seas (Strabo 7.5.9). Finally, although classified as a "sea" because of its size, the Caspian was recognized as landlocked, a sea that "does not mingle with other seas" (Herodotus 1.203.4). With no visible outflow, the Caspian seemed unfathomable (see above, §2), and Aristotle surmised that there must exist an underground debouchment into the Black Sea (*Meteorology* 351a). But even in the 280s BCE, Patrocles, who traveled there before venturing into India, postulated (erroneously) that the Caspian linked to the Ocean, and his (lost) account probably informed Eratosthenes' view that the Caspian was an inlet of the external Ocean (f110; Pliny, *NH* 6.58; Roller 2010, 19, 206). Occasionally, earthquakes caused rivers to be swallowed, for example, the Melas in Boeotia (Strabo 9.2.18).

Hence, underground rivers became a feature of Greek lore. Juba II of Mauretania even suggested that the Nile originated in the Mauretanian mountains of his country, flowing underground, to reappear as a large lake in the Masaesylian territory, sinking once again beneath the desert "for a distance of twenty days' journey, before arriving at its known course south of Egypt" (Pliny, *NH* 5.51–54; Ammianus Marcellinus 22.15.8; Roller 2010, 190; cf. Roller 2003, 192–196).

The Nile

Unusual in the Mediterranean, though not unique, is the fact that the Nile flows from south to north (along a natural decline). Also flowing in the waters of the Nile were two great mysteries: its source and the cause of its annual summer flooding (other Mediterranean rivers flood in the winter). Because of Juba's hypothesis that the Nile originated in Mauretania, explorers into the nineteenth century continued to look for the river's source in northwest Africa. The Greeks agreed that the river's source could not be pinpointed because the river flows through an uninhabitable desert, from a contrary (opposite) climate into our own (Diodorus Siculus 1.40.1). The sweetness of its waters confirm the river's passage through a hot clime. Aeschylus (*Prometheus Bound* 810–812) gave the Bybline (Papyrus) mountains as the river's source, unattested elsewhere. A third suggestion was reported by Herodotus (2.28), whose sources, with a single exception, professed ignorance. Herodotus' knowledgeable priestly scribe, however, was certain that the river originated between two mountains, the Syene and Elephantine, where the Nile enters Egypt, in a bottomless lake (whose depth was tested by Egypt's early king Psammetichus with a rope measuring thousands of *orguai*). In the time of Amenhotep III (1411–1375 BCE), the first Cataract and the Nile's inundation were connected (Wainwright 1953), and the priests may have simply been repeating this ancient record. Herodotus traveled to Elephantine but was unable to confirm the report because of the rugged terrain and treacherous nature of the river there. Diodorus' Egyptian priests reported that the Nile discharged from the Ocean (1.37.7). Alexander even thought that he had found the Nile's source when he saw crocodiles in the Hydaspes and Egyptian beans in the Akesines, two of the major rivers in the Indus valley (Arrian, *Anabasis* 6.1.1; Strabo 15.1.25; Burstein 1976). The source of the Blue Nile, providing the bulk of the combined Nile's water and fertile alluvium, was finally confirmed in 1875 by Henry Morton Stanley when he circumnavigated Lake Victoria and reported the great outflow at Ripon Falls on the Lake's northern shore.

Eratosthenes explicitly compared the summer flooding of Indian rivers with the Nile's summer flooding (f74), the cause of which was one of the great intellectual debates, whether due to Etesian winds (Thales), melting snow (Hippolytus), or summer rains (Agatharchides, on analogy probably with Indian rivers; Eratosthenes f99; Poseidonius f222; Strabo 17.1.5). Philosophical speculation also occurred: water expands in the summer (Oenopides of Chios: Diodorus Siculus 1.41.1), or the sun draws the earth's moisture into the river (scholiast on Apollonius of Rhodes 4.269). Examining four theories, Herodotus was the first to consider the question systematically (2.19–24). He dismissed Thales' hypothesis—that Etesian winds prevent the Nile from flowing into the Mediterranean. These winds do not always blow, nor do they have the same effect on other rivers (as they should, were Thales correct). Even less credible is Hecataeus' opinion that the Nile issues from the Ocean (Herodotus staunchly opposed the circumambient Ocean; see above, §2). Although plausible, Anaxagoras' melting snow hypothesis is the most erroneous, since the Nile flows through the warmest regions of the earth. Herodotus proposed yet a fourth explanation: that the sun, directly overhead in Libya in the winter, dries out the Nile which returns to its regular course in the summer. The sun draws up moisture which is seized by winds and returned to the earth in windy southerly and southwesterly monsoons (see Graham 2003). Annual heavy rains over the sources of the Blue and White Niles validate Herodotus' conjecture. Seneca devoted an

entire book to the question (*NQ* 4a), but "his preferred theory—if he had one—remains elusive" (Williams 2008, 218).

5. Springs and Fountains

Springs and fountains were viewed as sources of poetic inspiration, the most famous being the Hippocrene created by Pegasus and sacred to the Muses on Mt. Helicon. The question arose as to whether the sea could contain springs; this possibility was flatly denied by Aristotle (*Meteorology* 352b29–353b30) on the grounds that springs must belong to artificial (not flowing) bodies of water, but the Ocean/sea is neither flowing nor artificial, nor is natural spring water ever found on such a large scale. Aristotle's wisdom, however, was denied, and Pliny noted the ubiquity of springs, from mountain ridges to the sea where one can draw fresh water from, for example, the Gulf of Gades and at Brundisium. Pliny synthesized his sources on the universal properties of springs before digressing into vague observations about hydrostatics and specific density (*NH* 2.233): they are colder in summer than in winter, and chunks of bronze and lead sink, but sheets float.

Hot springs were also known, most famously at Aquae Sulis (Bath, England), sacred to Sulis Minerva, a popular healing sanctuary from pre-Roman times. Sacred to Heracles, protector of mankind, as at Thermopylae, where Athena created the springs for the hero (Herodotus 7.176.3), and at Trachiniae, where he died (see Malkin 2003: 228; Croon 1952; 1956, 210–217), springs became hot by virtue of underground alum, bitumen, or sulfur warming the soil above (Vitruvius 8.3.1). These sites and others were valued for their curative properties: heated in vitiated soils, waters became medicinal. Sulfuric waters restored muscular weakness by burning away poisonous humors; alum springs warmed the body overcoming the coldness that set into paralyzed and otherwise diseased body parts; bitumen springs were purgative (Vitruvius 8.3.3).

Several remarkable springs are described, including the cold fountain of Jupiter at Dodona that lights torches brought close to its waters, and which always stops flowing at noon. In Illyria, another paradoxical spring (perhaps containing naphtha?) sets fire to clothes. Cold sulfur springs give the appearance of bubbling because water colliding with deep subterranean fires results in violent currents of air forcing water up. The Fountain of the Sun is cold during the day but boils at midnight. Springs at Falerii render the oxen that drink from them white, while Boeotian springs turn sheep black. A spring on Andros, sacred to Liber (Dionysus), tastes like wine on the god's January festival, and a spring in Paphlagonia inebriates anyone who drinks from it. But other springs are poisonous, as at Terracina, where the locals blocked up the mortiferous waters. Other waters effect fine singing voices, or beauty, or abstemiousness in those who drink from them. Vessels are burst apart when they are filled with the icy waters from the Water of Styx at Nonacris in Arcadia. Springs at the mouth of the Timavus grow and recede with the tides (Pliny, *NH* 2.228–235; Vitruvius 8.3; Mela 1.39).

6. Floating Islands

Floating islands were a peculiar part of Greek lore, starting with Delos where Apollo was born (Vergil, *Aeneid* 3.73–77). Seneca claimed to have seen a floating island at Cutilia (Cytiliae), driven back and forth by even a "light puff," never keeping the same position,

either because the water, full of minerals, was especially heavy or because the island itself, although supporting trees, was composed of moveable, not solid material (*NQ* 3.25.8). Pliny the Younger (*Letter* 8.20) expressed great wonder at the floating islands in the sacred waters of Lake Vadimo. These numerous tiny islands, sometimes joined together, sometimes separated, could even support cattle, which often mistake them for the lake's edge. Mela described similar floating islands in the marshes of the Gallic coast (2.82). Pliny's uncle, the eponymous encyclopedist, mentioned Vadimo and its floating islands, though without his nephew's wide-eyed wonder (*NH* 2.209; Seneca, *NQ* 3.25; see also Dionysius of Halicarnassus, *Roman Antiquities* 1.15; Strabo 5.3.1), as well as others, including the Dancing Islands, which seem to move to the rhythms of chanted choral songs, though he omited Mela's marshes. Mela also described Chemnis, floating on an unnamed Egyptian lake, blown by the wind and supporting sacred groves and a large temple to Apollo (1.55).

7. Conclusion

Plato (*Phaedo* 109b) described the peoples dwelling between the Phasis River and Pillars of Heracles as "living around the sea like ants or frogs around a marsh." Just as the sea molded the coastline, so too did water shape Mediterranean cultures. Waterways provided a backdrop for myth, and a focus of cult. Water facilitated commerce and defense, and it inspired poets. It is only natural that a people as curious as the Greeks would seek to understand the origins and effects of bodies of water, large and small, and that they would formulate complex, interesting, and occasionally correct explanations for hydrologic phenomena.

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FURTHER READING

No monograph yet exists on ancient hydrology, so the interested reader is referred largely to primary sources: Aristotle, *Meteorology* 1.12–2.3; Theophrastus, *On Waters* (partially extant); Vitruvius 8.3; Seneca *NQ* 3–4a; Pliny, *NH* 2.212–235; Plutarch, "Whether Fire or Water is more Useful," *Moralia* 955d–958e. Especially valuable are Kidd 1972 on Poseidonius in particular and Eckenrode 1975 on tides in general.

Most scholarship focuses on the human interaction with waterways. Of particular note are the following:

Campbell, B. 2012. *Rivers and the Power of Ancient Rome: Studies in the History of Greece and Rome*. Chapel Hill: University of North Carolina Press. An expansive study that focuses on the human interaction with waterways in the ancient Mediterranean world.

Nissan, E. 2010. "Going West vs. Going East: Ancient Greek, Roman, Carthaginian, Mauretanian, and Celtic conceptions about or involvement with the Ocean, what early Rabbinic texts say about the Ocean and the formation of the Mediterranean, and beliefs about reaching the Antipodes." *Μήνη* 10: 279–310.

NOTES

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CHAPTER 12

Classical Geology and the Mines of the Greeks and Romans

Paul T. Craddock

Those great treasures beneath the earth,
Copper and iron, silver and yellow gold,
Who before me dare claim discovery?
(Aeschylus, *Prometheus Bound* 500–503)

1. Introduction

Through the first millennium BCE, the Classical world saw great developments both in secular academic learning (Guthrie 1962–1981) and technology (Oleson 2008). However, an understanding of the structure of the earth and the materials from which it was made was seemingly meager (Adams 1938). Forbes (1966, 237) remarked: "Unfortunately both geology and mining remained very much neglected in Antiquity." This may have been true for the more formal philosophical theories which to some degree had to fit into broader metaphysical schemes, but was this necessarily true of the general understanding based more on practical experience?

This was largely inevitable; by and large mines were in remote areas, and as an occupation mining was more likely to be a punishment than a career. Also, Greek philosophy increasingly tended away from the study of practical and material subjects. The Ionian philosophers of the sixth century BCE justified their deliberations on nature as helping man in medicine and agriculture, etc. They had developed a materialistic worldview, divorced from the divine, theocratic explanations of previous antiquity (Farrington 1944). In the fifth century BCE, Pythagoras and his followers began to add nonmaterial, mystic concepts to the nature of matter, based on number and geometry, and these were further embellished by Plato and then Aristotle in the fourth century BCE (MATTER). Socrates encouraged a fundamentally different approach to the whole study of philosophy. As

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expressed by Plato, the proper study of the philosopher was man, not the material world, and in the introduction to the *Metaphysics* Aristotle makes it clear that applied science was something that had already accomplished its task (Farrington 1944, 131). This position was largely adopted by the Stoics, who regarded the world as created by a beneficent nature for man, so reported Pliny (*NH* 2.154, 36.1), who further complained that this was a gift which man abused by all sorts of mining activities such that "if any beings of the nether world existed, assuredly even they would have been dug up by the burrowings of avarice and luxury" (*NH* 2.157–158).

In the fifth century BCE, the atomists postulated a purely materialistic and mechanistic world, ungarnished by any moral or human considerations (Adams 1938; Sarton 1959, 1.250–256). Vigorously opposed by Plato and Aristotle, this was adopted by the Epicureans (Sarton 1959, 1.588–599) and given its clearest and most uncompromising expression by Lucretius in the first century BCE.

There are many obstacles to forming a true assessment. First, there is the problem of uneven survival. Many works, including those of the early natural scientists, are almost totally lost, and we must rely on sparse, second-hand comments. Similarly, Theophrastus, Strato, and Philo are all believed to have written on metals, mining technology, and tools (Forbes 1966, 144, 249–250). Thus, we have come to rely on a small number of works that may well not be truly representative and are often by authors of enormous, unchallenged, and enduring prestige, above all Plato and Aristotle, whose works were to dominate thought in Europe well into the Post-Medieval period, but are now regarded as having had a negative influence on the development of science. As Sarton trenchantly expressed it: "The influence of the *Timaeus* (Plato) was enormous and essentially evil" (1959, 1.420–423), or Farrington's opinion of Aristotle's explanation of the four elements as "this travesty of science. (1936, 146).

Although it does seem that formal theoretical knowledge of the earth was somewhat limited, it is clear from the remarks made by the ancient authors in their surviving works on history, geography, and compendia that much more was actually known and recorded. These include Strabo's *Geography*, the *Histories* of Herodotus and of Diodorus Siculus, or general compendia, and above all, the *Natural History* of Pliny the Elder, who wrote at length on mining and extractive metallurgy, in part based on his first-hand experience as procurator of Hispania Tarraconensis in northwestern Iberia, where there were many mines that would have required his attention (Healy 1999, Chapter 20; SCIENTIFIC ENCYCLOPEDIAS).

Archaeological survey and excavation of early mines through the last century, backed by scientific examination, have greatly added to our understanding of the early texts. This, in turn, has led to a more balanced appreciation of the real knowledge that the ancients had of the planet upon which they dwelt.

2. Concepts of the Material World

The Earth's Formation and Geology

The achievements of the Greeks in cosmology and astronomy were impressive (Dicks 1970). In general, the academic community believed the universe to be both infinite and timeless, and it was realized that the sun and stars must be very distant. By the third

century BCE, Aristarchus of Samos (Heath 1913; Sarton 1959, 2.53–58; ASTRONOMY) had established a method to calculate the distance of the sun and moon from the earth, and Eratosthenes had calculated the circumference of the earth to within 0.5% of the current accepted value (Sarton 1959, 2.99–110; GEOGRAPHY), a triumph of ancient scientific measurement. Furthermore, according to Archimedes (Heath 1897, 221; 1913), Aristarchus held that the earth and planets orbit the sun.

Early natural philosophers proposed many theories of the *cosmos* (for which, see THE CREATION AND DESTRUCTION OF THE WORLD). Of particular interest is the atomic theory formulated in the fifth century, which envisaged the earth as formed from a vast number of particles, possibly the debris of earlier worlds (Lucretius 5.422–500). As the particles became compressed, first lighter particles were ejected to form the *cosmos* and atmosphere; then as contraction continued, the brine that was to form the oceans was forced out. The solid earth remained but was riddled throughout by vast caverns through which underground rivers and winds continually roared.

The belief in a huge network of underground channels was widespread among the main philosophic traditions. To some degree, this had its origins in the prevailing religious beliefs going back to at least to the times of Homer. Literally at the center of this was Tartarus, the great chasm in the middle of the earth, the abode of the souls of the eternally damned. The Pythagoreans believed in an eternal fire in the center of the earth, and Plato (*Phaedo* 113b) had his Pyriphlegethon, the river of fire and which was the source of the lava disgorged from volcanoes. Apparently alone, Empedocles, living near Etna, suggested that the lava flows were an indication that the earth could have a molten core (*TEGP* 92–94).

This developed into a complex system, as expounded by Socrates, for example, and recorded by Plato in the *Phaedo* (111–113), where geological reality intermingled with religious belief. Thus, the River Pyriphlegethon, as well as supplying lava, also transported the souls of the damned to Tartarus. Socrates envisaged a series of underground rivers encircling the globe, linked both to Tartarus and with the seas (see further, HYDROLOGY: OCEANS, RIVERS, AND OTHER WATERWAYS). Through a complex series of oscillations (possibly linked to the tides), winds and waters were perceived as continually ebbing and flowing through the earth. Lucretius also seems to have believed at least a variation on this when debating why the sea levels remained more or less constant, despite the fact that rivers continually discharge into them. He noted that evaporation must play a part, but then concluded that "lastly the earth is of an open texture and is contiguous with the sea, therefore just as the water enters the sea from the land, so it must trickle into the land out of the briny gulf. The brine is filtered out and the bulk of the water flows back to reassemble in full at the fountainhead" (5.608–638).

Underground channels could carry winds and fire. Strabo (1.3.16, 5.4.9, 10.1.19) believed there existed a whole interconnecting system of tunnels, filled with fire and wind linking the various volcanoes on Sicily, southern Italy, and the volcanic islands in between.

Volcanoes were generally regarded from the time of the Ionian philosophers as vents for the subterranean wind and fire (for an excellent history of ideas on volcanoes and volcanology generally, see Sigurdsson 1999). They acted as a safety valve for underground channels. While the volcanoes were open and in operation, underground pressure could be released, but, if blocked, then the resulting built-up pressure could lead to catastrophic earthquakes such as those that in previous ages were believed to have split the mainland coast to form islands—some believed even Sicily itself had been detached from Italy (see below).

Alternatively, the Epicureans believed that the collapse of caverns caused earthquakes and would lead inexorably to the ultimate destruction of the earth itself (Lucretius 6.542–543).

Geomorphology

The earth was regarded as essentially static. After the earth had stabilized, huge quantities of sediment collected to form the plains, leaving the tips of the original craggy material—which could shrink no further—exposed as mountains. The Epicureans, in common with most other philosophers, seem to have been largely unaware of agencies shaping the earth's surface other than the deposition of silt by rivers (see below). Several philosophers, especially Xenophanes (*TEGP* 59), had noted sea shells and other evidence of marine presence well inland and at considerable heights above sea level. These phenomena suggested that there must have been periods when the land was under the sea, and thus water levels could rise and fall. The clear implication here is that there had been a catastrophic flood, recalling both Mesopotamian and Mosaic legend. Much later, shells in stones were taken as evidence of the Flood, and thus water, albeit in the form of a single catastrophic event, was believed in the Medieval and succeeding periods to have played a major role in shaping the earth's surface.

Strabo, a follower of the Stoic philosophy, believed that the earth had been deliberately created with an irregular surface so that the seas could occupy the hollows, leaving dry land for man to occupy (1.3.4; 17.1.36). However, this situation was not static, as inland seashells, for example, demonstrated; the sea had clearly once covered this land, and, conversely, it was likely that parts of the present sea covered what had once been dry land.

It should be stressed that water levels were considered as changing and, in contrast, the earth was seen as more stable. It was rarely envisaged that land levels could have moved, although Strabo did suggest that major floods and tidal waves could be caused by movements of the seabed (1.3.4 and below).

Deposition by Water

The deposition of alluvial material was more widely understood than is credited by the purely theoretical works. The geographer Nearchus, for example, who stated that the plains are the offspring of the rivers, bringing down silt from the mountains, is quoted approvingly by Strabo (15.1.16). It was generally recognized that rivers carried large quantities of silt which could fill up lakes and create deltas out into the sea, often causing islands to become landlocked. Strabo gave many examples of where rivers have done this—clearly a continuing process. It was even thought that the Pyramus river in Cilicia, southern Anatolia, picked up so much sediment in the mountains that its growing delta would one day reach Cyprus (12.2.4). Similarly, the geographer Strato speculated that the whole Black Sea would one day silt up to become dry land (Strabo 1.3.4). Strabo considered delta formation in some detail (1.3.8), expressing it as a contest between the rivers and the sea, with the former depositing material into the sea, but the sea, through the agency of the waves, picking up the material, stopping it from being lost out into the deep sea, and driving it back, thereby building up and creating the shore. *On Plants*, which—though not by Aristotle—"reflects the teachings of his school" (Hett 1936,

viii), describes how sand was created by the sea on the shore, and in time these sands built up to form stones (2.2). Thus, it was very much the sea rather than the land that was creating the coastline.

Although it was widely appreciated that water could deposit huge amounts of material, there seems to have been a general failure to consider where material might have come from and, thus, the ability of water to shape the landscape by erosion. Aristotle (*Critias* 111) bemoaned that the soil of Greece had eroded away, deploring the loss of fertility and general decay rather than showing an understanding that the topography was actually changing. This is surprising given the widespread application of water to remove overburden by the ancient miners in the processing now known as hushing (see below, and Figures 12.4 and 12.5) and which is nothing more than artificial water erosion. Strabo recorded two instances of river erosion: the river Peneius, in Greece, that was eroding good arable land until stopped by embankments (9.5.19) and the river Maeander in southwestern Anatolia, which frequently changed its course and, in doing so, washed away headlands (12.8.19).

One of the most prescient observations on delta formation was made by Herodotus in the fifth century BCE. He not only thought that the Nile Delta had been built up from silts deposited by the river, but also that the Nile Valley had originally been an empty arm of the sea, similar to the nearby Gulf of Suez, at the head of the Red Sea. Furthermore, Herodotus speculated that, if the Nile could be made to flow through the Gulf, then over the course of a few tens of thousands of years, it too would become filled with silt (2. 4–5, 10–12). However, acute as this observation was, there was no explanation as to how either the valley or gulf was formed in the first place, they were just there. Herodotus did not consider that the Nile could have been responsible for actually cutting its valley. In general, the ability of rivers to erode the landscape seems not to have been appreciated.

Herodotus' appreciation of the very long time scales involved in geological processes is also remarkable. In general, although the universe was regarded as being eternal, the earth was not, decaying through internal collapse as the Epicureans believed, and expressed by Lucretius (6.609), who believed that the earth was fast approaching its end.

The converse situation, of the sea taking back the land by flooding and permanently changing the coastline, was accepted in principle by Strabo (17.1.36) but rejected in the only instance discussed in the *Geography*—specifically, in his commentary on the migrant Cimbri, who occupied the coastal lowlands of northern Germany between Holland and Denmark, and who had supposedly been driven from their peninsular homeland by sea floods (7.2.1). This region was subjected to frequent inundations since the last Ice Age, but Strabo dismissed the story as improbable, for how could a few sea tides drive a whole tribe away? Clearly, given his Mediterranean perspective, he had no concept of the potential of sea floods in the North Sea region.

Deposition by Plutonic and Volcanic Activity

The shaping of the earth's surface by tectonic movements and by the deposition of material in successive layers is now universally accepted. The role played by earthquakes and volcanoes in land formation, together with the supply of molten igneous material either injected plutonically beneath the surface, as granites, and so on, or ejected volcanically as basalt lava flows, and so on, is also realized as being major and continuing factors in shaping the earth's surface. In the Mediterranean, earthquakes and volcanic

activity could hardly be missed, and thus should have been included as land-forming agencies generally. However, this seems not to have been the case. An exception was Eratosthenes, quoted by Strabo (1.3.3; f 15), who held that the earth's surface had been shaped by water, fire, earthquakes, volcanoes, and other similar agencies. Earthquakes appear frequently in Strabo's *Geography*, but, without exception, either sinking the land or creating great chasms into which whole cities and rivers disappeared. Strabo, who had some concept of tectonic movement (1.3.4; see above), suggested that Sicily had been "cast up from the deep by the fires of Aetna" (1.3.10). In his discussion on the formation of islands, he accepted the common belief that small islands near to the mainland coast had been detached by earthquakes. However, for larger islands further from the mainland, he thought tectonic uplift was more likely, as exemplified by Sicily. This is the only instance in the *Geography* where Strabo raised the serious possibility that tectonic movements possibly affected land formation. Pliny (*NH* 2.201) also discussed the role of earthquakes, suggesting that where the underlying pressure could not be relieved by volcanic activity, earthquakes could raise the land.

No one seems to have considered the potential of sea erosion in forming coastlines, as leaving some areas detached as islands, but, as noted earlier, Classical philosophers and writers could not appreciate the tidal range and wave power of the oceans beyond the relatively calm Mediterranean.

Volcanic activity could create land, and Strabo gave several instances of islands of burning rock being thrust up from the seabed surrounded by boiling seawater. The flows of red hot lava on the island of Thermessa (now, Vulcanello), one of the Lipari group in the Tyrrhenian Sea, were recorded as having already partially filled the channel separating the island from the main island of Lipari (6.2.10). Volcanic eruptions were described in some detail, and at Aetna, for example, the molten lava running from the crater and the ash blown into the air are clearly distinguished (6.2.3). The ash covered the ground around Aetna to some depth, and lava ran down the volcano's side and built up into considerable thicknesses. Set into rock, the lava had to be quarried away to expose the original surface. This is of some significance as an incipient recognition of geological stratigraphy. At Vesuvius (5.4.8), the rocks looked as if they had been eaten out by fire, apparently displaying the familiar vesicular appearance of some lava flows. The distinctive black burnt rock was recognized at a number of other areas of volcanic activity. Thus, when describing the Dead Sea region, Strabo (16.2.44) recognized the signs—rocks that had been scorched, fissures and ashy soil, rocks dripping asphalt and boiling, evil smelling waters—although apparently without any clear understanding that the rocks and soil had been deposited. Also, in the Katakekaumene country (literally "burnt place"), above the Hermus river in western Anatolia, Strabo (13.4.11) suggested that the "burnt rocks" had once erupted from the three old pits or volcanic craters that were still visible, and that the ashy soil that covered the plain had been blown from them. He noted both here and at Aetna that the ash soon developed into a fertile soil. This he correctly attributed to some material in the original ash, which he labeled the "fat," but which is, in fact, the range of inorganic salts and minerals essential for plant growth.

Although there was a recognition of the deposition of considerable amounts of material in the immediate vicinity of volcanoes, there was, however, no suggestion that this could have been a more general phenomena, still less that much of the earth's surface could have resulted from volcanic or plutonic activity.

Overall, the philosophers seem to have had no real conception of the accretion of material by whatever agency to form geological strata. More specifically, there was no attempt at the association of particular ores with particular rock types, tin with granite, etc. There was also no explanation of how various ores, minerals, and precious stones had become concentrated to form deposits. On the contrary, in the traditional Aristotelian view, materials developed *in situ*. For example, the ancients believed that placer gold had originated in the gravels and was slowly developing there, apparently with no concept that the gold had originated in primary quartz deposits, much less that water had been involved in the laying down of sand and gravel beds as well as gold. Practicing miners must have had a different perspective (see below).

In contrast to this essentially static view, Strabo did understand the movement and deposition of materials in water-lain deposits, explaining how placer gold had washed down from the primary sources in the mountains (2.8). He was also aware that gold became purer (i.e., contained less silver) the further away from the source because, as he quite correctly reasoned, water had had more opportunity to wash it.

Matter and Minerals

In general, it was the four elements as expounded by Plato and Aristotle that held sway through later antiquity and the Middle Ages, well into the Post-Medieval period, although it had been abandoned by some thinkers, such as Lucretius (1.720–800), much earlier (cf. MATTER). The four elements were perceived as being in constant interchange (Forbes 1966, 76–78). Dioscorides, for example, repeatedly referred to metals and minerals as "growing" rather than "occurring" in particular locations (Gunther 1959). This concept was especially applied to metals. For example, the pseudo-Aristotle compilation *On Marvelous Things Heard* refers to Chalybian and Amisenian iron ore growing in the river sands (48), with no understanding that the ore had been brought down with the sands and water. Similarly, in the same work, salt was stated to be generated in stagnant water, without recognizing that it was leached from the surrounding soils (2.2). In the same manner, Pliny (*NH* 34.143) wondered whether the iron ores from Cappadocia were to be credited to earth or water, as they appeared after flooding by the Cerasus River. It seems likely that the iron ores, probably in the form of iron oxide sands, had been deposited rather than created, as Pliny seems to imply. The process of petrification in some calcareous springs fascinated ancient authors like Pliny (*NH* 36.125), who recorded that Theophrastus, presumably in a lost work, had described rock bones. These are likely to have been fossils, but there was no realization in antiquity that they had once been the bones of real creatures. That was to be Nicolas Steno's great realization in the sixteenth century (Scherz 1969, 1971).

Aristotle believed that minerals and metals had different origins (Holmyard 1957, 24; Halleux 1974). The sun's rays falling on dry ground produced a smoky, dry exhalation that was to form the basis of dry minerals such as sulfur or ochre. Pliny (*NH* 36.161, etc.; see Eichholz 1962, x–xv) recorded the opinions of the Stoic philosopher Poseidonius, who regarded translucent or transparent stones as having been produced from liquids either by heat, such as fluorspar (37.21), or intense cold, such as rock crystal, regarded as a form of permanent ice (37.23). The sun's rays falling on water produced a moist, cold vaporous exhalation that formed the basis for metals. This, after compression within the ground, developed into metals. Thus, metal ores were believed to be

slowly developing within the ground, ultimately becoming gold (Forbes 1966, 77). This concept was, of course, greatly developed by the alchemists, especially the Alexandrian School, which claimed that their treatments of base metals were hastening the natural transformation (Holmyard 1957; Forbes 1966, 30; lot *CAAG*; Hopkins 1934; Greco-Egyptian and Byzantine Alchemy).

If minerals and metals were continually growing, then it was only natural that the worked-out deposits in old mines and quarries could replenish themselves, and this was generally accepted. For examples of regeneration of ores in mines and quarries, Strabo listed the ores of Elba, the rocks of Rhodes, the marble of Paros, and the salt of India (5.2.6), and Pliny mentioned the marble of Italy (*NH* 36.125), alum (*NH* 35.184), and lead (*NH* 34.165), as regenerating. Pliny suggested the regeneration of lead in abandoned mines was caused by air, admitted into the deposit through the old workings, "infusing itself to saturation," presumably with the mine waters. In the context of Aristotle's prevailing theories on the constitution of metals, this was not unreasonable; and, as air was oxidizing the mineral remaining in the deposit, this would be valid according to modern theories.

As is often the case, it is possible at least to give some partial explanations for observed phenomena. In many abandoned mines, metalliferous waters percolating through the galleries would leave deposits on the walls and stones strewn on the floor. In an oxidized state with promising colors, these coatings would give the appearance of new ore; however, breaking one of these coated stones would soon reveal the disappointing truth. Similarly, the faces of the marble quarries would become coated with calcite deposited by the evaporation of water that had percolated through the rock and become charged with dissolved calcium carbonate. Although chemically similar to marble, the concretion is physically completely different, being a form of tufa. The regeneration of Strabo's mines on Elba is explained in *On Marvelous Things Heard* (93), which reported a mine on an island called Aethaleia (Elba?) off Tyrrhenia, where copper was once mined, but where iron ore appeared once again after a considerable lapse of time. In fact, the miners on Elba were simply changing priorities; many mines were worked for a variety of minerals, as at Rudna Glava, in Serbia (Jovanović and Janković 1982; Figure 12.3), Cwmystwyth, in Wales (Timberlake 2004; Figures 12.4, 12.5), Rio Tinto, in Spain (Salkield and Cahalan 1987; Figure 12.2).

Finally, there were materials which really did replenish themselves: asphalt, alum, and Indian salt. Semi-liquid asphalt would just ooze out of clefts in the rock face. Alum, a mixture of aluminum and iron sulfates, would form by the oxidation and hydrolysis of the minerals in the ore body. Pliny stated that solutions containing alum formed each winter in Cyprus (almost certainly in old mines, described in *NH* 35.186 and 398–399 as a sort of sweat from the copper ore) and collected in hollows, where they dried out and crystallized in the summer sun (an interesting description of the process of crystallization). "Indian salt" is largely composed of saltpeter (potassium nitrate) with some common salt, and in India, following the monsoon, water evaporates from the sodden soil of the major river valleys, especially the Ganges, leaving the "Indian salt" as an efflorescent deposit on the surface to be swept up each year (Marshall 1915).

Our concept of matter is firmly based on elements that have fixed invariable properties. For example, gold will always have the same density, color, and so on, and compounds will always have same composition, as expressed in the late eighteenth century by the law of constant composition. To us, this seems obvious, but in antiquity very different ideas prevailed. If materials, especially metals and gemstones, were developing

in the ground, they could have different properties depending on the stage of their development, Theophrastus (*On Stones* 27) described an unusual stone on Cyprus that was *smaragdos* (a green precious or semiprecious stone) and half *iaspis* (a general term for translucent semiprecious stones) as if it had not entirely changed from the watery state. The progress of development could be influenced by location; different environments could be expected to produce metals with different properties, and this would have been backed up by experience.

Rarely pure, ore minerals usually contain lesser quantities of other minerals. These often come through the smelting stage and even in trace amounts can have quite dramatic effects on the metal. For example, the iron pans found in bogs are rich in iron oxides, hematite, and the hydroxide goethite, and they were widely used as a source of iron. These iron pans frequently contain small amounts of phosphates, and the iron smelted from them often incorporates traces of phosphorus. Even a fraction of a percent of phosphorus in the iron makes it much harder, and this property was apparently appreciated in antiquity (Craddock 1995, 238–239). It would have been understood that this hard iron was the form of iron intrinsic to that particular environment rather than as due to the presence of another material.

Minerals were clearly of interest in the ancient world generally, and they feature in the works of ancient authors. The earliest surviving treatise on mineralogy is Theophrastus' succinct *On Stones*, which follows the teachings of Aristotle fairly closely. Minerals also feature prominently in Pliny's *Natural History* (Healy 1981), an account clearly based on Theophrastus' but much more extensive and with a more practical outlook. Pliny, for example, was unsure whether to attribute the properties of metals to their ores or to the technology of processing them. Thus, he remarked that "there are numerous varieties of iron depending on the kind of soil or climate, some lands only yield a soft iron.... others a brittle and coppery kind" (34.142–146). He continued (34.146): "In our part of the world, in some places the ore supplies this good quality (the ability to take a good edge, that is, a steel), for instance in Noricum (approximating to present day Austria)." However, Pliny went on to state that in other places the properties of the iron were due to the methods of smelting and smithing.

Pliny also seems to have had some understanding that differences could in part be due to impurities in the ores, and that some metals could have single and constant properties. Thus, when discussing particular varieties of copper (34.94), he described two main types. The superior *regulare* could be both hammered and cast, but *caldarium* broke upon hammering and could only be cast. All the copper from the Cypriot mines was ductile, but this was because of superior processing, "for all copper, after impurities have been rather carefully removed by fire and melted out of it, becomes *regulare*."

Similarly, when discussing various types of lead, Oviedo, Capraria, and Oleastrum, Pliny remarked that there was no difference between them, provided the slag had been carefully smelted away (*NH* 34.164).

This problem of regional varieties or types of metal was first addressed not as an academic question, but as a more practical and urgent problem occasioned by the introduction of coinage in the sixth century BCE (Ramage and Craddock 2000). The whole concept of a coin was of a token of precious metal, of guaranteed weight and purity, initially gold but very soon more usually silver. Gold normally occurs with varying amounts of silver, and in antiquity the natural alloys of varying degrees of whiteness from various places seemed to have been generally regarded as the gold of that particular place. However, it was also clear that such golds could be replicated by the addition of

silver, or even worse, an alloy of two parts silver to one part copper that largely preserved the color of pure gold. Clearly, if guaranteeing the quality of the metal was to have any meaning at all, then it had to be established what constituted "pure" gold, and how it could be produced and tested. It had long been known that treating base gold artifacts with acidic salts such as alum (sulfate), saltpeter (nitrate), or common salt (chloride) could produce a more golden surface. Treating finely divided gold–silver alloys with these salts (especially common salt) in a furnace process known as parting separated the alloys into pure gold metal and silver salts. A practical demonstration that an ultimate pure gold had been achieved was when further parting produced no further loss of weight. Thus, the concept that there was but one gold with one set of properties—what we would define as an element—had been arrived at through the necessity of developing a technical process on an industrial scale, rather than by academic enquiry.

3. Mining

Through the first millennium BCE, there were tremendous changes in mining technology, especially in the realm of new materials, notably iron, and in engineering and the related mathematical sciences. The latter were applied to the manipulation of water in open cast mining and in the drainage and ventilation of deep mines.

The introduction of iron and especially steel tools at the beginning of the first millennium BCE must have made a major impact on both quarrying and mining. Previously, some bronze picks and chisels were used in mines in the Eastern Mediterranean and Middle East as exemplified by the Timna mines (Conrad and Rothenberg 1980). Elsewhere, stone mining hammers continued to be used well into the first millennium BCE, as in Spain (Craddock 2013). Bronze is much more expensive and is softer than steel, and the tools must have worn out at an alarming rate.

Ancient authors make little reference to the geological formations indicative of the potential presence of particular minerals (although Pliny mentions *segullum* as a specific earth associated with gold: *NH* 33.67). Typically, these could be exposures of quartz veins (Figure 12.1), or the distinctive red deposits of iron oxides and hydroxide, where the main constituent of the deposit, iron sulfide, had oxidized at the surface forming the "gossan" or "iron hat" (Figure 12.2).

Open Cast Mines: Gold, Tin, and Iron Sands

Water could be used in a variety of ways, especially in open cast mines made in loose deposits such as sands and gravels, known as placers. Here, water could be used to move large quantities of material and wash and concentrate the heavier mineral. A variety of ores, for example, tin and some iron ores, were mined from such deposits; but the best-known placer mines were those worked for gold, including the Roman mines in northwestern Iberia (Jones and Bird 1972; Lewis and Jones 1970) so vividly described by Pliny (*NH* 33.66–78). The remains have been intensively studied, especially those associated with the mine at Las Médulas, in northwest Spain, where attempts have been made to link the features in the landscape with the descriptions given in the *Natural History* (Domergue and Hérail 1999; Bird 2004). The account is especially important because it gives some insight into the knowledge that the Roman mining engineers had of various geological deposits and how best to work them.



Figure 12.1 Quartz dyke near Bronze Age mines in southern Spain. The intrusive white quartz in the grey sedimentary rocks could contain metal ores. Photo by author.



Figure 12.2 Modern opencast at Corto Lago, Rio Tinto showing the weathered gossan deposits (red) above the unchanged pyrite deposits (gray). The argentiferous jarosite ore, mined by the ancients, formed at the junction and is full of ancient workings (one is circled). Photo by author.



Figure 12.3 The opencast at Rudna Glava. The deposit mined in the Chalcolithic period for copper in the white rocks on the right were reworked by the Romans as an open cast mine for iron. Photo by author.

Pliny distinguished three methods of mining gold. First, there were the relatively straightforward surface sand and gravel river deposits, which could easily be dug and washed, and as such were widely distributed. Second, there were the primary gold deposits occurring in hard rock (which Pliny called marble and silex, but more likely quartz). This primary gold will have been very finely dispersed in the rock, such that even after crushing and washing it would have to be smelted to melt the rock, releasing the much denser gold. By contrast, the gold from alluvial placer deposits was already free of the quartz vein material and only had to be collected and concentrated by washing.

The third form of mining, *arrugiae*, was the most spectacular, and Pliny's vivid account strongly suggests that he had observed it personally. It seems to have been a combination of underground mining and removal of surface overburden with water

that was probably unique to Las Médulas because of local geology. Mine galleries were driven into ancient buried placer deposits. These were fairly horizontal and not far beneath the surface. Arches of deposit were left in place to provide support while the mining proceeded. When it was decided that a particular vein had been exhausted, the gallery ceased advancing, and instead the miners worked back, taking out the arches and probably enlarging the galleries—a well-known method known as "retreat mining." But the next stage seems to have been unique. A point was reached when the galleries were no longer safe, and the mine was evacuated and deliberately collapsed, disturbing and loosening the ground above. This was then cleared away by releasing huge quantities of water onto it from large reservoirs positioned above the workings. This method, known as hushing (Craddock 1995, 89–91; Timberlake 2004), is attested at many other early mines (Figures 12.4, 12.5). The loosened ore was then washed in a series of trenches lined with gorse (or possibly the sticky shrub, gum cistus, *Cistus ladanifer*) to trap the gold.

Large-scale workings required huge quantities of water and could only have been contemplated once the necessary engineering knowledge for collecting and controlling water had been developed. Water was sourced from a wide catchment area and brought by leats extending for many kilometers to the reservoirs at the mine, situated above the deposit.



Figure 12.4 Hushing channels running diagonally across the hillside from the hushing reservoir (arrowed, see Fig. 12.5). When released, the waters would sweep away the waste from the Bronze Age copper mines (on the right-hand side), exposing the lead ore that the Romans wished to recover. Even though water was used extensively by the miners to move large quantities of material, the potential of water erosion in shaping the landscape was rarely appreciated. Note too that, as at Rudna Glava (Figure 12.3), Cwmystwyth provides another example of a mineral deposit being worked for different metals at different periods. Photo by author.



Figure 12.5 Small Roman hushing reservoir at Cwmystwyth, central Wales (arrowed on Fig. 12.4). Photo by author.

The clues that the formation of sand and gravel deposits were intimately connected with water action must have been obvious to prospectors and miners as the mined gravels were then washed to further concentrate the gold, mimicking the natural process (Figure 12.6).



Figure 12.6 Roman installation at Corta Lago, Rio Tinto, to wash and concentrate the jarosite ores. Photo by author.

Pliny was also impressed that man, removing mountains and creating new land in the sea with the debris carried down by the rivers from the mines, was dominating nature. He apparently had no idea that man was imitating nature. Mining engineers, who were actually conducting the operations, must surely have been more aware of how similar their operations were to natural water erosion and that the arrangement of the washed-out material bore a striking resemblance to the natural water-laid deposits.

Deep Mines: Copper, Silver, and Lead

From Pliny's descriptions, it is possible to piece together something of his understanding of the nature and occurrence of ore bodies, and how the various ores weathered. This is especially true of copper and silver.

Pliny (*NH* 34.117) described the principal copper ore, *chalcitis*, in some detail. He made it clear that, protected deep underground, *chalcitis* began to change on exposure to the air, becoming more friable. *Chalcitis* is to be identified as copper iron sulfide, principally chalcopyrite and bornite, which always occur with iron sulfides, pyrite, and marcasite. Pliny knew that *chalcitis* was unstable, the sulfides liable to spontaneous combustion on exposure to the air. He also stated that it was a mixed ore, formed of three components, copper, *misy*, and *sori*—the interpretation of the two latter terms have always created problems. Pliny described the production of *misy* at the copper works in Cyprus, where the golden fracture of pyrites was noted as different from the fracture of chalcopyrite (*NH* 34.121). *Sori* is likely to have been a product of oxidation. Thus, Pliny clearly had some concept of the weathering of the upper part of an ore body and the instability of the lower parts buried beneath when exposed to the atmosphere, as discussed earlier.

Pliny also described the weathering of ore bodies by water percolating through them (*NH* 33.86). The water dissolved minerals, forming solutions which then dried out in the summer to deposit a slime that formed a deposit as hard as pumice, known as *chrysocolla* and which Pliny understood as the decay of the vein. This must be the familiar ochreous iron oxides and clay in suspension in acidic iron-rich mine waters, and once again reveals Pliny's understanding of the complexity of an ore body. Pliny refers to *chrysocolla* several times in the *Natural History*. This term almost certainly covered several different minerals, all forming in weathering ore deposits, thereby creating great difficulties in its identification (Meeks and Craddock 1991). Where it is described as a gold solder, it is likely to have been an oxidized copper mineral. But elsewhere, in *NH* 33.86, etc., clearly iron minerals are meant. These could have a variety of colors, golden or green, depending to some degree on the ore minerals through which it had passed, but mostly on whether the iron minerals were in the oxidized, ferric, state (yellow) or the reduced, ferrous (green) condition.

Pliny described the mining and smelting of silver in some detail, concentrating on the mines in southern Spain with which he was more familiar. These mines were in the Iberian Pyrite belt, stretching for hundreds of kilometers across Andalucía into Portugal, and the silver was mainly contained in an ore known as jarosite. Jarosites are a decomposition product of variable composition and appearance, but are mainly the sulfates and oxides of iron, potassium, and aluminum, of general formula $Fe_3(OH)_6.X(SO_4)$, where X can be a number of metals depending on the deposit, including antimony, arsenic, copper, lead, bismuth, and silver (Williams 1950; Dutrizac et al. 1983). The ore formed at the junction of oxidized gossans and the primary sulfidic ores

beneath (Figure 12.2). As Pliny correctly stated, jarosites are dull materials which give no hint of being rich ores; they are not shiny like galena, nor even especially dense. Pliny continued: "The ore is sometimes red, sometimes ash colored. It cannot be smelted except when combined with lead." The potential of the jarosites was discovered by the Phoenicians (Diodorus Siculus 5.35) and worked at mines such as Rio Tinto for the next thousand years, before being abandoned and forgotten (Craddock 2013). Recent scholars, believing that Pliny was describing the mining and treatment of argentiferous lead, have understandably been at a loss to understand his descriptions, suggesting that Pliny was uncertain of the process (e.g., Healy 1999, 299–300). In fact, his descriptions are accurate and quite detailed as shown by excavation and scientific study of the silver smelting remains at Rio Tinto (Craddock et al. 1985; Craddock 1995, 216–221).

Deep Mining Technology

Up to the end of the Bronze Age, as exemplified by the copper mines at Timna in Israel (Conrad and Rothenberg 1980), there were major problems with ventilation, and thus a vein could only be followed for a very few meters before it was necessary to sink more shafts adjacent to the first. Similarly, with drainage, the mine could be bailed by hand to remove water entering the workings from the surface, but once the water table was reached, it became difficult to proceed much further.

The ability to direct the movements of air through the underground workings enabled galleries to be driven for considerable distances from the surface, while maintaining an adequate air supply. This meant that a small number of entrances could serve a complex network of workings. If this was to have any coherence, then accurate surveying was essential, and here again the advances made in mathematics, particularly in geometry, must have been invaluable.

Similarly, drainage was revolutionized by the introduction of a variety of mechanical devices. The Archimedes' screw, described by Dioscorides in Spanish mines (5.37), waterwheels (Palmer 1926/1927), and probably chain pumps were all employed to raise water within mines. At larger mines in rough or hilly terrain where the vein outcropped above the valley bottom, it was now possible to drive a gently sloping passage up from the valley to intersect with the lower parts of the working and let the water run out, as exemplified by the main drainage adit at Rio Tinto, the existence of which was hinted at by Diodorus Siculus (5.37). This was discovered in the late nineteenth century running for 3 km (nearly 2 miles) and still capable of draining the mine (Salkield and Cahalan 1987, 10, 40). Thus, mining operations were greatly facilitated not by any geological principles, but by advances in materials, mathematics, and mechanics.

The general failure to develop theories of geological deposition is reflected in the strategies for mining the ores. At most mines, once the vein had been located at the surface, it was worked simply by digging down into it. As Biringuccio in 1540 critically remarked, "The Ancients … instead of beginning from the bottom, as moderns do, they began their mine in the upper part where the ore appeared in the light of day at the surface, and digging down as in wells they followed it to the bottom, now here, now there" (Smith and Gnudi 1942, 19). This created problems of moving ore and waste to the surface, although archaeological surveys within the larger mines have shown that levels and inclines were often driven to aid movement (Figure 12.7).



Figure 12.7 Incline linking two galleries in the Roman workings at Rio Tinto; clearly many workings, especially in the larger mines, were quite sophisticated. Photo by author.

A vein could peter out or be displaced by faulting. When the latter occurred underground, the ancient miner seems to have been rather at a loss. Forbes (1966, 110) believed that the Romans had no concept of faulting and as such were unable to relocate a faulted vein. However, archaeological investigation has discovered that in some mines, when confronted with a fault, small workings were made into the fault and along it to try to relocate the ore (Healy 1978, 87), as exemplified by the Roman copper mines in the Wadi Amran, Israel (Willies 1991), and at Umm el Amad in the Wadi Feinnan in Jordan (Figures 12.8 and 12.9). From the haphazard nature of these trials and their lack of success, it is clear that the miners had no real concept of the vein slipping in a fault. In quarries at least, the nature of faulting should have been clearly visible in the working faces.



Figure 12.8 Small working at Umm el Amad, trying to locate the vein displaced by faulting by digging into the fault. Photo by the author.



Figure 12.9 Roman gallery system at the copper mines of Umm el Amad, Wadi Feinnan, Jordan. Note the arches left to support the roof. Photo by author.

4. Conclusion

Overall, the ancients perceived the earth as static but matter as changing and evolving, whereas we understand geology as a dynamic and continuing process, but the elements that comprise the world to be unchanging.

Deposition of material by rivers to form deltas and plains was regarded as a universal land-forming process. Conversely, erosion of the earth's surface was rarely considered at all and clearly was not regarded as a major factor determining topography. Volcanic activity was well known and described in some detail, but again there was no concept of igneous material as a major force in the creation of the earth's surface.

Theoretical concepts of matter seem to have made little reference to the occurrence of minerals in the ground, but the rather more practical descriptive works do reveal better understanding, being based on observation rather than on theory.

It is clear from Pliny and other sources that there existed a more practical understanding of the nature of ore bodies, their weathering once exposed, and so on. It is possible that, in a more rigorous climate of scientific investigation, these observations could have been developed. Instead, the four element theory held sway, and as Forbes (1966, 237) remarked "Practical experience gained in the field was not supported by guidance from scientific theories."

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FURTHER READING

Oliver Davies' *Roman Mines in Europe*, published in 1935, is perhaps the best-known survey of the remains of Classical mining, and despite its age remains a useful book. More specific regional surveys include Domergue's (1990) survey of mines in the Iberian Peninsula. Good individual descriptions of individual mines include Ardaillon (1897) and Conophagos (1980) on Laurium; and Willies (1997) and Salkield and Cahalan (1987) on Rio Tinto. More general discussions on Classical mining include those of Forbes (1966, 1971, 1972), Healy (1978), and Craddock (1995, 22–92; 2008); Cauuet 1999 on placer mining; and Fant (2008) on quarrying. The Loeb translation of the *Natural History*, books 33–37, should be treated with caution; they are very outdated.

An additional source is the 1912 edition of Agricola's *De Re Metallica*, published in 1556, edited by H. Hoover and L. H. Hoover (New York: Dover). Not only does Agricola make interesting comments on the ancient texts, but the Hoovers' copious footnotes are invaluable for the study of the ancient texts on mining and metallurgy.

CHAPTER 13

Greco-Egyptian and Byzantine Alchemy

Matteo Martelli

1. Collecting Alchemical Writings in Byzantium: The Art Called *Chēmeia*

The term *alchemy* has a clear Arabic shape (from *al-kīmiyā'*), and its use for denoting a kind of technical literature produced before the Arabic tradition may seem somehow anachronistic. However, this Arabic tradition is grounded in the translation of a wide selection of earlier treatises originally composed in Greek. Most of these writings (especially the earliest ones) are lost, and our best sources for reconstructing their original content are a few anthologies preserved in several Byzantine manuscripts. The anonymous compilers of these anthologies selected treatises, excerpts, and recipes that they evidently considered as dealing with a common area of expertise, called *al-kīmiyā'* by Arabic scholars, *chēmeia* in Byzantine sources (attested variously: *chymia*, *chēmia*, etc).

The two terms are connected: *kīmiyā'* is a simple transliteration of *chēmeia*. Regrettably, the origin of the Greek word is unclear, and scholars have proposed two main interpretations: (a) it might derive from the Coptic name for Egypt, *chēmi* (ⲭⲏⲙⲓ; from Ancient Egyptian *kmt*), which literally means "black earth;" (b) it might be related to the Greek root **chu/chew/chow*, at the base of *cheo*, "to melt," *chyma*, "ingot," and *choanos*, "melting-pot." In any case, despite this ambiguity, although rarely employed in the anthologies, *chēmeia* was often used by Byzantine scholars and usually associated with the production of precious metals. Significantly, the tenth-century lexicon *Suda* includes the definition of *chēmeia* as "the preparation of gold and silver" (χ 351 Adler).

Such an art was considered quite old and founded on a very ancient tradition, as we infer from the instructive example of Michael Psellus (1018–1078), whom Michael I Cerularius, Patriarch of Constantinople (1043–1059), asked to make a study of the

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ancient methods for transforming base metals into gold (*chrysopoeia*). In his *Letter on the Making of Gold,* Psellus explains the results of his investigation. He defines *chrysopoeia* as the "art of fire" and sets gold making in the wider framework of the techniques effecting a transformation of various materials, such as metals, glasses, stones, and pearls; afterward narrowing his focus in accordance with Cerularius' interests, he collects eleven recipes explaining how to process base metals and turn them into gold. These recipes, as Psellus claims, summarized all the wisdom of Democritus (Bidez 1928, 40).

As we shall see, a long and well-established tradition dating back to the first centuries CE considered our atomist among the earliest authors who wrote about such topics. In all likelihood, Psellus' inquiry investigated a specific set of written sources dealing with the making of precious metals. Cerularius himself is represented by Psellus as a keen collector of the books of Zosimus, Theophrastus, and Democritus that explain how to transform copper into silver and silver into gold (Bidez 1928, 77).

The circulation of this kind of technical literature is confirmed by the collection of writings preserved by *Marcianus Graecus 299*, a wonderful manuscript probably copied down for the Imperial Library of Constantinople at the end of the tenth century. The codex opens with a *pinax* ("table of contents") that records fifty-two titles of works or excerpts ascribed both to the aforementioned and other writers, such as Ostanes, Stephanus, Olympiodorus, and others. Most titles explicitly mention either the "making of gold" or the "holy and divine art of the making of gold," which was probably recognized by the anthology's compiler as the common thread of the selected texts. According to an introductory poem preserved immediately after the *pinax*, the compiler is probably to be identified with a certain Theodore, "assistant of the Emperors" (*despotōn parastatēs*), who is said to have hidden in his anthology rich "lodes of gold" that only expert readers would be able to detect and exploit (*CAAG* 2.3–4).

The promising chance of producing gold out of less precious substances seems to have attracted state dignitaries, patriarchs, and even emperors, who developed a certain interest in an art (*technē*, τέχνη) that was expected to produce specific drugs (*pharmaka*) capable of changing the nature of the treated metals. For instance, the Byzantine emperor Constantine V (718–775) is said to have stored two specific kinds of white and red powder in a building probably next to the Imperial Palace. According to the Persian chronographer Ibn al-Faqīh al-Hamaḏānī, the ambassador 'Umāra ibn Ḥamza, after visiting Constantine's court, reported to his caliph al-Manṣūr that he saw these substances and tested their properties. At some point, Constantine V ordered two ingots of lead and copper to be brought to him. After these were melted and treated respectively with the white and red powder, the first turned into silver, the second into gold. At the end of his account, 'Umāra commented: "I reported this to al-Manṣūr and this was the reason that induced him to become concerned with alchemy" (Strohmaier 1991).

Byzantine authors confirm the identification between alchemy and silver and gold making. In his *Universal History*, for instance, the chronographer John of Antioch traces the books on *chēmeia* back to the Roman province of Egypt under Diocletian's reign (284–305):

> Diocletian full of hatred and grudge against those who rebelled against his power in Egypt, was not satisfied with ruling the country unfairly and cruelly, but traversed it and damaged Egypt with proscriptions and murders of distinguished people. He tracked down and burnt the books on the *chēmeia* of silver and gold, which had been written by their ancestors: so

> Egyptians would have no longer gained money out of this art (*technē*) and thenceforward they would have no longer had confidence in the abundance of their substances and risen up against Romans. (fragment 191, Mariev)[1]

John of Antioch was probably contemporary with the emperor Heraclius (ruled 610–641 CE). It seems not coincidental that the chronographer devoted particular attention to alchemy, about which Heraclius was probably quite passionate. The *pinax* of the *Marcianus* codex records three alchemical treatises ascribed to Heraclius, which—perhaps because of the loss of some squires in the manuscript—are no longer included in the collection: (1) a treatise *On Alchemy* addressed to Modestus, patriarch of Jerusalem; (2) eleven chapters on gold making; (3) a work on the opinions of the philosophers on the "holy art." Moreover, as we shall see (see §4), the lectures on the alchemical art written by Stephanus of Alexandria confirm emperor's interest in this subject. Mertens asserts (2006, 222):

> It seems undeniable that the sacred art enjoyed some sort of vogue in seventh-century Byzantium; consequently it is not unreasonable to suggest that this was the time when one or several collections [of alchemical texts] were put together and they were the indirect source of our main manuscripts.

As already mentioned, our knowledge and understanding of Greek and Byzantine alchemy depends mainly on these anthologies. However, they present just a selection of a wider corpus of writings circulating at that time. It is likely that such a selection was oriented by the specific criteria that compilers followed in choosing and often epitomizing the texts at their disposal. In particular, widespread interest in the making of gold and silver could have, to some extent, affected the selection of those texts that, according to John of Antioch, were first produced in Egypt. This information is confirmed by the most ancient writings included in the Byzantine collections, composed by authors living in Egypt during the first centuries CE. On the other hand, the earliest texts covered a variety of topics that cannot be simply reduced to the making of precious metals: they reflect, rather, a broader perspective that resembles the approach of Psellus, who considered *chrysopoeia* as part of a wider set of arts in working not only metals but also stones, glass, and pearls. Here, we shall try to untangle the anthologies preserved by Byzantine manuscripts and to present the most relevant authors in relation both to their own cultural context and to the role they played in constituting a textual tradition afterward inherited and reworked by Byzantine scholars.

2. The Earliest "Alchemists" (First to Third Centuries CE)

Byzantine anthologies include just a few treatises dating back to the first centuries CE—often in epitomized versions. However, further information is provided by later alchemists (from the third century CE onward) often referring to earlier authors whose teaching was considered fundamental for a full understanding of typical alchemical procedures and techniques. In this respect, later authors presented themselves as the heirs of a written tradition par excellence: they often evoke, quote, and comment on a wide set of ancient written sources whose authority guaranteed the accuracy of the transmitted knowledge. These writings were believed to transmit a kind of perfect and original

wisdom as revealed by ancient and sage masters, often identified with famous philosophers or divine figures.

The alchemist Zosimus (see §3), for instance, refers to several ancient writers who first revealed the basic principles and most important procedures of what he called "divine art" (*theia technē*). In the same way as John of Antioch (see §1), Zosimus stresses the close connection between this art and Egypt, presented as the country where various authors composed the earliest treatises on different aspects of the "divine art." At the beginning of the *First Book on the Final Quittance* (Festugière 1944, 1.363–364 = *CAAG* 2.239–240), Zosimus draws a picture of the earlier developments of an articulated *technē* that included both "four valued arts" (*tessarai timiai technai*)—that is, as we shall see, (a) gold making, (b) silver making, (c) precious stones making, and (d) purple dyeing—and two ways for processing gold minerals (either washed or artificially treated to isolate the precious metals). These arts, Zosimus claims, were under the strict control of both Egyptian kings, who supervised the activities of gold miners, and also of those experts who knew how to work precious metals and strike coins. This knowledge was kept secret, as Zosimus explains:

> Some people blame Democritus and the ancient authors for not mentioning those two arts [i.e., the two ways to process gold minerals], but only the so-called valued arts. But they blame them without reason: they could not have done otherwise, since they were friends of the Egyptian kings and boasted to be among the "prophets" of the first order. How could they have openly shared this knowledge against kings' will? How could they have given to others the control of (Egyptian) wealth? […] Only Jews could secretly practice these arts, describe them in their writings, and make them public. For instance we find that Theophilus, son of Theogenes, described all the gold mines indicated in the map of the country; the same is the case with the description of furnaces by Maria and with other Jewish authors. (Festugière 1944, 1.364–365 = *CAAG* 2.240, 9–18)

While Byzantine manuscripts do not preserve any accurate information about the writing of Theophilus (seemingly mentioned by Zosimus, *CAAG* 2.198 and Stephanus of Alexandria, 9th *Lecture*, p. 246 Ideler: Letrouit 1995, 21), many alchemical authors often refer both to Democritus and Maria the Jewess as the earliest founders of the divine art. Taylor recognized these two authors as the "leaders" of two ancient alchemical schools: the school of Democritus, more focused on techniques for superficial coloring of metals and making metallic alloys; and the school of Maria, which developed a complex apparatus for distillation and sublimation (Taylor 1937, 37–42). Although the sources do not allow us to draw such a clear-cut distinction, the two authors seem to have played a key role during the earliest phases of the alchemical tradition.

As far as Democritus is concerned, almost all the authors collected by Byzantine scholars count the philosopher among the most important "alchemists." Democritus was generally credited with having written not only on the making of gold and silver, but also on the making of precious stones and on dyeing wool purple. The Byzantine manuscripts transmit, under Democritus' name, some scattered excerpts of a work that was originally structured in four books, each book devoted to one of the aforementioned four topics (namely gold, silver, precious stones, and purple).

The four books are likely to have been written in the second half of the first century CE, that is, four centuries after Democritus' death. Their attribution to the philosopher

was probably grounded on his reputation as an expert in any kind of art, and this must be understood in the framework of other pseudepigrapha circulating under Democritus' name from the late Hellenistic period onward (e.g., Aulus Gellius, *Attic Nights* 10.12,8).[2] Within the alchemical tradition, Synesius (see §4) provides the clearest information about the four books. They were composed—he claims—by the philosopher Democritus, who, after leaving Abdera, was initiated by the magus Ostanes in the Egyptian temple of Memphis. From Ostanes Democritus presumably learnt the aphorism "nature delights in nature, nature masters nature, and nature conquers nature," and, on the basis of this principle, he "composed four books on dyeing, on gold, silver, (precious) stones, and purple" (Martelli 2013, 123 = *CAAG* 2.57).

Regrettably, only an epitomized version of these books has been handed down in Byzantine manuscripts, which preserve two treatises drawing mainly from the original books on gold and silver. If we consider the Byzantine identification of alchemy with the making of precious metals, as discussed above, it is not surprising that the Byzantine compilers focused their attention especially on these two topics. They reworked the original four books, selected only two excerpts, and left both *On Stones* and most of *On Purple* aside. The first excerpt is a kind of patchwork handed down under the later title of *Physika kai Mystika* (*Natural and Secret Questions*). It is composed in two parts derived from two books that were originally separate: (a) a very short section on dyeing wool purple, probably depending on the otherwise lost *On Purple*; (b) a second longer section on gold making that represents what is extant of the original book *On Gold*. The second excerpt, *On the Making of Silver*, must be identified with an epitomized version of the original *On Silver*.

A section of the *Physika kai mystika* (§3 Martelli = *CAAG* 2.42–43) seems to confirm the mythological framework set by Synesius, emphasizing the role played by the Persian magus Ostanes. According to the pseudo-Democritean text, the author based his own books on the teachings of Ostanes, whose hidden writings had been discovered in the column of an Egyptian temple, perhaps identifiable with the temple of Memphis mentioned by Synesius. These discovered writings of Ostanes preserve the aphorisms on nature in the same form as cited by Synesius.

Regrettably, little is known about the alchemical works attributed to Ostanes, presented by ancient sources as a Persian magus who followed Xerxes in his expedition against Greece (Pliny, *NH* 30.8) and who was sent to rule Egyptian temples, presumably under the Achaemenid occupation (Synkellus, *Chronography* p. 297.23–26 Mosshammer). The Byzantine manuscripts preserve just a miscellany entitled *Ostanes the Philosopher to Petasius, on the Holy and Divine Art* (*CAAG* 2.261–262), where a recipe for the preparation of a reactive solution—called "divine water"—is introduced and followed by short sentences highlighting the miraculous properties of the substance: "every disease is healed by this precious and divine water," and "the eyes of the blind see, the ears of the deaf hear, the dumb speaks clearly." Scholars do not agree on the text's date, setting it either as an early (e.g., Taylor 1937, 45) or Byzantine composition (e.g., Letrouit 1995, 87). Moreover, similar doubts surround the date of another treatise sharing some similarities with Ostanes' work, namely, the *Dialogue between Cleopatra and the Philosophers* (Letrouit 1995, 83–85). Ostanes is one of the characters who asked Cleopatra to explain how "the blessed waters visit the corpses lying in Hades" and "how the medicine of life reaches them and rouses them" (Taylor 1937, 43).

The dialogue seems to explain some alchemical operations (mainly based on distillation and sublimation) with strongly allegorical language, similar to the style used by Zosimus in his famous *Visions* (see §3). Such language is very different from the technical explanations of dyeing procedures that we find in pseudo-Democritus (or at least in what survives), which collect several recipes explaining how to transform base metals into gold and silver (by dyeing them respectively yellow and white), and how to dye wool purple. Presumably, the lost fourth book *On Stones* collected similar recipes for making precious stones. The same topics are covered by the famous Leiden and Stockholm papyri, written between the third and the fourth centuries CE. As indicated by Principe (2013, 11), these papyri "are the only original documents currently known to survive from the Greco-Egyptian period" which organize their content according to the same fourfold division into processes for purple, gold, silver, and precious stones as the four books of pseudo-Democritus. The two papyri, in fact, preserve two collections of recipes focusing on the same four areas of expertise: the *Leiden Papyrus* contains eighty-eight metallurgical recipes that deal with various methods for producing yellow and white metals either by treating base metals with specific drugs or by composing metallic alloys (sometimes including small amounts of silver or gold) and eleven recipes explaining how to dye wool purple by using surrogates of the expensive Tyrian purple. On the other hand, the *Stockholm Papyrus* includes nine recipes dealing with silver, seventy-nine that explain how to dye crystal quartz several colors in order to produce artificial gemstones (such as emeralds, beryl, and jaspers), and seventy-one for dyeing wool purple.

While comparison between these texts seems to show how widespread this fourfold division of dyeing techniques was in Egypt during the first centuries CE, scholars have noticed that the papyri still maintain a certain distinction between dyed products (those that look like gold, silver, and so on) and the proper metals (Halleux 1981, 24–30). Such a distinction is not equally clear-cut in pseudo-Democritus, who seems to equate a change of color with a change of nature. We can compare, for instance, the following two recipes:

Leiden Papyrus 73	Pseudo-Democritus, *Physika kai Mystika*, §13 Martelli = *CAAG* 2.46,7–15
Gilding. […] Dilute equal parts of scissile orpiment, copper flower, golden realgar, mercury, gum tragacanth, and pith of arum with the bile of a goat. (It is applied) upon burnt copper objects, upon silver objects, etc.	Grind *sōri* and copper flower together with unburnt sulfur; *sōri* looks like azurite that easily peels off and is always found in *misy*. It is also called green copper flower. Roast it at moderate heat for three days, until it becomes a yellow drug. Lay it on the copper or on the silver that is made by us and it will be gold.

Both recipes explain how to prepare a yellow drug to apply to silver and copper. However, while the *Leiden Papyrus* presents the technique as a gilding method, pseudo-Democritus claims that the yellow drug makes copper and silver gold. In pseudo-Democritus, the change of color becomes the key transformation of the metals, attained by employing the right ingredients. Moreover, in several recipes, the author provides a detailed explanation of the processes by listing several substances (often associated by

the same color) that could produce the same result. Such an attitude reveals the author's effort to classify the substances and recipes according to general criteria. Both *On Gold* and *On Silver* organize the recipes in two sections: the first dealing with the dry drugs (*xēria*) used for treating base metals, and the second devoted to the liquid substances (*zōmoi*, lit. "washes") employed for dyeing metallic leaves. Moreover, both books include theoretical sections, where the author discusses the properties of the employed substances by drawing interesting comparisons with the practices of physicians (see, e.g., *Physika kai mystika* 15–16 and 20 Martelli = *CAAG* 2.46, 22–48, 3 and 49, 7–22). The two books in their original form were in all likelihood introduced by two catalogs—following the same division between dry and liquid ingredients used for the recipes—of the substances useful for gold and silver making (Martelli 2013, 26–29).

Similar topics were probably covered also by the second ancient author mentioned by Zosimus in the passage quoted earlier, namely, Maria the Jewess, who probably lived between the first and third century CE. According to a later recipe book included in the Byzantine collections—edited by Berthelot-Ruelle as *Deep Tincture of Stones, Emeralds, Rubies and Jacinth from the Book Taken out from the Sancta Sanctorum of Temples* (*CAAG* 2.350–364)[3]—she wrote treatises on the making of pearls (*CAAG* 2.356, 14–18) and stones (*CAAG* 2.357, 19–23). These topics seem to show a certain similarity with some sections of the alchemical papyri and probably with pseudo-Democritus' *On Stones*. However, Maria's treatises are lost and, consequently, their possible relations with pseudo-Democritus' writings remain difficult to assess. Later sources seem to draw a certain connection. In particular, Synkellus (*Chronography* p. 297, 24–28 Mosshammer) presents Maria along with pseudo-Democritus as a student of Ostanes in the Egyptian temples, and the Arabic treatise *Kitāb al-Ḥabīb* (Berthelot-Houdas 1893, 76–115) mentions both that pseudo-Democritus commented on a statement of Maria (Berthelot-Houdas 1893, 83) and that Maria quoted the philosopher (Berthelot-Houdas 1893, 86). However, the reliability of these sources is uncertain, and it is difficult to understand their possible dependence on Maria's original production. Only quotations from her writings have been preserved in the works of Greco-Egyptian and Byzantine authors, most notably Zosimus, who held Maria in high esteem. According to these testimonies, Maria explained different techniques for dyeing base metals and transforming them into gold and silver (Patai 1982, 180–181). Moreover, Zosimus (7.10–12 Mertens) claims that she described "the construction of several instruments, not only the instruments for the sulfur waters, but also different types of *kērotakis* and furnaces." The so-called *kērotakis* (quoted also in *Stockholm Papyrus* 31—dealing with the making of precious stones; see Halleux 1981, 190) was probably a device composed by different parts slotted together: it was used for dyeing metallic leaves exposed to the action of volatile and reactive substances, such as sulfur or arsenic minerals (Mertens 1995, cxxx–clii). On the other hand, the devices for producing sulfur waters are to be identified with different kinds of stills, whose names changed in accordance with the numbers of descendant tubes attached to the receivers, that is, the vessels into which the distilled product was collected (Taylor 1945, 190–195). Zosimus (3.1–20, 8.15–30 Mertens) explicitly attributes to Maria the description of a *tribichus*, that is, a still equipped with three receivers (*bichoi*); however, it is likely that she also illustrated simpler alembics with only one or two receivers, as they are frequently represented in Byzantine manuscripts, and Zosimus himself illustrates an alembic equipped with only one receiver immediately after his description of Maria's *tribichus* (3.21–27 Mertens). Although Zosimus quotes

Maria as the main authority on alembics, we must mention that, according to Synesius (§7 Martelli = *CAAG* 2.60), pseudo-Democritus also described a still used for distilling a liquid identified with a kind of "sulfur water" (Taylor 1945, 195–197).

Finally, next to Maria the Jewess, a kind of Jewish background is detectable also in *Isis the Prophet to Her Son Horus* (*CAAG* 2.28–33), handed down in the Byzantine manuscripts. Probably dating to the same time as Maria's writings (second to third century CE; see Mertens 1983, 124–126), this brief text opens with a detailed account of the revelation that Isis received from two angels. Despite its attribution to an Egyptian goddess, the section clearly reuses material taken from the mythological framework of the *Book of Enoch*, an Apocrypha dating back to the third/second century BCE. The beginning of the Isis treatise reads:

> O son, as you were about to leave and fight a battle against the unfaithful Typhon for the kingdom of your father,[4] I went to Hormanouthis (?) <…> (city, sanctuary?) of the holy art in Egypt, where I spent a long time. According to the recession of the convenient time and to the necessary course of the spherical movement, one of the angels living in the first firmament, after looking at me from above, came with the wish to have a sexual intercourse with me. When he arrived and started taking this direction, I did not give myself, because I wanted to learn the preparation of gold and silver. (Mertens 1983, 128–129 = *CAAG* 2.28–29)

The next day, a second angel called Amnaēl appeared "when the sun was in the middle of its course" and revealed to Isis the holy art of Egypt, identified by the author with the "preparation of gold and silver." This introductory account is followed by five metallurgical recipes explaining how to treat base metals and transform them into silver and gold. Although the technical explanation of the processes recalls the recipes found in pseudo-Democritus and the papyri, our author seems to narrow the scope of his inquiry only to the making of precious metals, thus anticipating, so to speak, the definition of *chēmeia* given by Byzantine scholars.

3. Zosimus of Panopolis (fl. circa 250–300 CE)

The term *chēmeia*—never attested in the earliest alchemical works—appears for the first time in a treatise written by Zosimus, one of the most important Egyptian alchemists. Born in Panopolis, an important city of Upper Egypt, and after traveling (we assume) through the country, he reached Alexandria, where he says he consulted several books in the famous library belonging to Serapis' temple (*Serapeion*; see 1.84 Mertens). Since Panopolis was part of the Thebaid, he is also called Zosimus from Thebes in the Byzantine manuscripts that preserve a selection of excerpts from his treatises, usually addressed to his pupil Theosebeia.

Zosimus introduces the term *chēmeia* in a passage based on the same Enochic myth we have already seen in the Isis treatise, and he presents the art *chēmeia* as the revelation of the fallen angels. The passage is omitted from the Byzantine collections, but it does survive in an indirect tradition, quoted by Synkellus (p. 14.4–14 Mosshammer):

> The Holy Scriptures, i.e., the books, tell, my lady, that there is a race of demons who have intercourse with women. Hermes also mentioned this in his *Physika* as well as nearly every

> well-known or secret discourse. Thus the ancient and divine scriptures said that certain angels desired women, and having descended taught them all the works of nature. For this reason, he says, they fell and remained outside heaven, because they taught mankind everything worthless and not helpful for the soul. The same scriptures say that from them the giants were born. Theirs is the first exposition about these arts [*Chēmeu*].[5] They called this (exposition) the *Book of Chēmeu*, whence also the art *chēmeia* takes its name.

Synkellus does not cite the rest of the text, preserved only in Syriac translation. Indeed, the Syriac Cambridge manuscript Mm. 6.29 does preserve the complete account, where Zosimus also explains the content of the *Book of Chēmeu*. Divided into various sections, the treatise explains how to dye base metals several colors and how to transform lead into tin, copper into iron, and any metal into gold and silver. In addition, Zosimus warns against later commentators who focus only on the techniques for transforming silver into gold (Berthelot-Duval 1893, 238–239).

According to the *Book of Enoch*, several angels, attracted by the beauty of women, decided to leave heaven; one of their leaders, Azaēl, instructed mankind in a wide set of arts, including jewelry-making (in particular, how to work gold and silver), cosmetics, and coloring tinctures. It is not surprising that Zosimus, well acquainted with pseudo-Democritus' four books on dyeing techniques, recognizes a certain similarity between the Enochic account and the previous tradition upon which he built his own alchemical theory. However, Zosimus discusses the dyeing techniques only within a metallurgical context and seems to narrow the range of arts originally considered by pseudo-Democritus. Since we find the same focus on metals also in the Isis treatise, which identified the angelic revelation with the making of gold and silver, we cannot exclude that a particular interest in a single aspect of dyeing, identified with *chēmeia*, developed within an Enochian framework, based on a specific interpretation of the myth of the fallen angels. Regrettably, the loss of most of the earliest "alchemical" treatises does not allow us to understand to what extent this mythological background influenced the earliest developments of the *technē* that Zosimus identified with alchemy.

What is more certain is the fact that strongly emphasized within this narrative was the mandate to keep secret the revealed art. Isis had to swear a particular oath in order to receive the final secret revelation about gold and silver making. She swore to the four elements, to heaven and earth, to Anubis and the other Egyptian gods that she would never pass this arcane knowledge to anyone except to her son Horus (Mertens 1983, 131–132 = *CAAG* 2.29–30). On the other hand, Zosimus sets the Enochic myth within a wider and more complex framework influenced by Hermetic and Gnostic elements. In particular, in Zosimus, the fallen angels are transformed into demons. According to the fully developed account in the *First Book on the Final Quittance* (Festugière 1944, 1.363–368 = *CAAG* 2.239–246), at some point the demons became jealous of the knowledge they had disclosed to mankind; they tried to hide the dyeing techniques previously revealed, and they tried to regain control over mankind. This idea of demonic influence and control over dyeing techniques is encapsulated in the concept of the "opportune dyes" (*kairhikai baphai*), that is, the dyes whose results depend on astrological conjunctions and, consequently, on the influence of the demons. Demons tried to introduce these opportune dyes instead of the original natural ones (*physikai baphai*), in order to be worshipped by those who want to obtain results through similar processes. However, Zosimus strongly recommends to his pupil Theosebeia that she

refuse the influence of the demons: she does not have to trust either their dyeing processes or those people who are deceived by them.

Such a process of liberation from the control of demons is made possible by a deep study of the treatises of ancient alchemists who explain the proper and natural *baphai*. For instance, in *On the Letter Omega* (1.11–24 Mertens), Zosimus condemns those practitioners who trust the "opportune dyes" and, for this reason, neglect the treatise *On the Furnaces*, probably ascribable to Maria the Jewess (Mertens 1995, 63 note 12). In this respect, Zosimus particularly emphasizes the central role played by Hermes, considered the first to have openly explained and written about the "natural dyes." While Hermes is not mentioned in earlier treatises (insofar as they survive), his relevance in alchemical literature strongly increases in the later tradition. An anonymous Byzantine alchemist, the *Anepigraphos* ("without title") philosopher, opens his short history of alchemy (*CAAG* 2.424) by mentioning the thrice-greatest Hermes, who preceded Democritus in putting into writing the secrets of gold making (*chrysopoeia*); moreover, such a role is clearly stressed by Arabic alchemists, who patently considered Hermes as the founder of alchemy and significantly identified him (or at least one of the three figures into which Hermes was split within the Arabic tradition) with the Biblical patriarch Enoch (see Von Bladel 2009, 121–164: it seems possible to see a certain consistency with the relevance assumed by Hermes in Zosimus' reworking of Enochian material).

On the other hand, a correct understanding of alchemy could derive also from a kind of personal revelation. In the so-called *Visions*—probably Zosimus' three most famous writings preserved in the Byzantine manuscripts (10–12 Mertens)—the Egyptian alchemist gives a detailed account of a set of five dreams wherein correct alchemical procedures are explained through strongly allegorical imagery. The most important metals and ingredients come to life and become living beings—a priest called Iōn (perhaps "he who performs the *ios* (rusting) process," i.e., a superficial change of color: Mertens 1995, 36 note 14), men of copper holding lead tablets, a barber, and a white-haired man—who are skinned, cut into pieces, dismembered, and boiled in altars having the shape of an alembic (10–11 Mertens). Zosimus provides a double register of meaning: (a) during the dreams, he talks with these characters, who give a preliminary explanation of what Zosimus was witnessing; (b) after awaking, Zosimus himself explains the meaning of his dreams, explicitly interpreted as describing specific alchemical operations.

Scholars have read these elaborate and difficult images in many ways. To sum up, in general, Zosimus' spiritual approach to alchemy is recognized and emphasized: alchemy would have represented, in fact, a spiritual experience and a method for liberating the soul from the body (see, e.g., Fowden 1993, 121–126). However, although within a syncretic and allegorical framework, *chēmeia* keeps a strongly practical and experimental side that emerges in the majority of Zosimus' texts as preserved in the Byzantine anthologies. These collections hand down just some scattered and epitomized excerpts of a wider production, described by the *Suda* (ζ 168 Adler) as organized in 28 books on alchemy (*chēmeutika*). The extant excerpts are organized into three main groups of texts, transmitted under the titles of (1) *The Authentic Memoirs*, (2) *The Chapters to Eusebeia* (probably a Byzantine woman for whom these chapters were collected: Mertens 1995, lvii.), and (3) *The Chapters to Theodore* (Mertens 2006, 209–212). The *Visions* represent just three excerpts of the first group that contains also strictly technical texts dealing with sublimation, distillation, and the description of the related tools. All the chapters included in the second group cover practical topics. In each of *The Chapters to*

Eusebeia (Mertens 1995, liv–lx), Zosimus discusses methodological and technical problems related to the classification of the ingredients, the various treatments of both metallic bodies and specific substances—such as *magnēsia* (unidentified substance), ochre, alum, sulfur—and, in general, many applications of the dyeing techniques.

These technical discussions are largely grounded on the treatises of the earliest alchemists often quoted and commented on by Zosimus. In accordance with the outlook of our author, who emphasizes the centrality of a deep investigation of the dyeing procedures as explained by the art's ancient fathers, *The Chapters to Eusebeia* clearly show Zosimus' attempt to interpret and correctly understand the works of his predecessors. He seems to have developed a specific hermeneutical approach aimed at decoding the alleged secret language used in his sources. He regards many names of the ingredients employed in the texts as code names ("*Decknamen*") to decrypt, often in accordance with his own view of the described processes. A significant example regards a substance called "divine water" or "sulfur water,"—originally a reactive "solution" of sulfur and lime able to change the superficial color of metals (*Leiden Papyrus* 87; Principe 2013, 11)—whose relevance in the alchemical practices is strongly emphasized by Zosimus. He considers this water as a kind of universal dyeing product, able to deeply change the nature of the treated materials. Following this position, he reads the names of many substances mentioned by pseudo-Democritus as hidden references to this water:

> Therefore he (Democritus) says in the pyrites (recipe): "take pyrites and process or crush it with vinegar and brine and so on," words that hint at the white water of untouched sulfur. Afterwards in the cinnabar (recipe): "Make cinnabar white by means of oil or vinegar or honey or so on;" in the *androdamas* (recipe) again in a similar way: "by means of brine or vinegar and brine;" then he adds: "boil with water of untouched sulfur," so that you understand that seawater and urine and vinegar and the oil mentioned in the cinnabar (recipe) and honey are the water of untouched sulfur. (*CAAG* 2.185, 6–12; see Martelli 2013, 21–22)

This passage clearly displays an approach to ancient texts, which will become peculiar to the subsequent alchemical tradition. On the one hand, any explanation of processes will be based on the teachings of the ancient masters, among whom Zosimus himself is quickly included. On the other, the secrecy of such ancient teachings, already stressed by Zosimus, will be strongly emphasized: only a correct interpretation of the earliest writings and of their hidden meaning could disclose the right way to perform the alchemical procedures.

4. Alchemy after Zosimus (Fourth to Seventh Centuries CE)

During the fifth century, alchemy seems to spread beyond the "experts" who attempt to put dyeing or metallurgical techniques into practice. Two Neoplatonic philosophers explicitly refer to alchemy in their writings: Proclus denies the possibility of transmuting base metals into gold in his commentary on Plato's *Republic* (2.234, 14–25 Kroll); Aeneas of Gaza (died 518 CE), on the contrary, in his dialogue *Theophrastus*, considers it possible for those people who are capable of turning silver and tin into gold and producing glass by mixing sand and soda together to transform matter into a superior state (p. 62.27 Colonna).

This interest in the "holy art"—expressed by philosophers who were concerned with theoretical questions but did not necessarily belong to alchemical circles—coincides with the tendency of alchemists themselves to provide more systematic explanations of dyeing techniques. Already in the fourth century CE, the short texts by Pelagius and Synesius attest a similar approach. Pelagius, in *On the Holy and Divine Art* (*CAAG* 2.253–261), recognizes six operations—namely, *iōsis* (the treatment of metals with sulfur water), *exiōsis* (the washing of metals with liquid substances), blackening, whitening, thinning (*exichnōsis*), and yellowing—as the basis of the "dyeing art" (*baphikē technē*), and he comments on several passages from pseudo-Democritus and Zosimus. Synesius, in what survives of his dialogue *The Philosopher Synesius to Dioscorus, Notes on Democritus' Book* (*CAAG* 2.56–69 = Martelli 2013, 122–151), focuses on pseudo-Democritus' catalogs of dyeing substances and provides a deep interpretation of the names of the ingredients. In particular, Synesius emphasizes the role played by mercury (*hydrargyros*) in the dyeing processes, by showing a certain familiarity with philosophical categories, such as "potentiality (*dynamis*)" and "actuality (*energeia*)," or "matter (*hylē*)" and "form (*eidos*)." For mercury is white in actuality and red in potentiality—that is, when combined with sulfur to produce cinnabar (§11 Martelli = *CAAG* 2.63, 9–64, 3)—and it has a double nature by acting both as a body (identified by Synesius with the solid and fire-resisting matter) and as a spirit (identified with the volatile and dyeing part of solid substances). On the one hand, mercury is used for extracting the spirit (or the "form," i.e., the color) from any solid body that is crushed, mixed with *hydrargyros*, and often sublimed. On the other hand, after attracting and "hosting" this spirit, mercury—in this phase acting as the material support (or vehicle) of the extracted form—transfers such a quality to the base metals to be dyed (§§9–10 Martelli = *CAAG* 2.61.24–63.8).

These tendencies to give a theoretical and philosophical explanation to alchemical processes become more evident in the works of the two most important later alchemical authors: Olympiodorus (sixth century CE) and Stephanus of Alexandria (late sixth–early seventh century CE). Although Byzantine alchemists identified these figures with the homonymous Neoplatonic commentators working in Alexandria and Byzantium (see, in particular, *CAAG* 2.425,4–6), the question is still debated (see, e.g., Letrouit 1995, 49–61; Papathanassiou 2006, 164–166). Under the name of Olympiodorus, the Byzantine manuscripts preserve a commentary (*CAAG* 2.69–104) on Zosimus' lost *Kat'energeian* (*According to the Actuality*). The beginning of the text has the same structure as the Neoplatonic philosophical commentaries: Olympiodorus first gives a verbatim quotation from Zosimus and afterward provides his own line-by-line interpretation. The second part of the treatise, on the contrary, seems a kind of patchwork of aphorisms from ancient authors (pseudo-Democritus, Maria the Jewess, Zosimus, and Synesius are often cited). In this second section, the author includes a peculiar doxography—according with the peripatetic tradition (Viano 1995)—in which he draws an interesting comparison between ancient alchemists and Presocratic philosophers (Thales, Parmenides, Diogenes, Heraclitus, Xenophanes, Anaxagoras, and Anaximenes).

Finally, Stephanus of Alexandria composed *On the Great and Holy Art of Making Gold* (2.199–258 Ideler), organized as a series of lectures addressed (according at least to the title of the last one) to the emperor Heraclius. Presented by the Byzantine sources as a "philosopher and ecumenical teacher," Stephanus is likely to have written his work at the beginning of the seventh century CE. Polemical against those interested in the art only for economic reasons, Stephanus structured his lectures as a kind of commentary

on selected passages of earlier alchemical texts. Papathanassiou (2006, 172) states "this work presented the author with an opportunity to demonstrate wide rhetorical prowess, extensive learning and a significant breadth of philosophical understanding."

Stephanus' work greatly influenced the later writings included in Byzantine anthologies, in particular, the four iambic poems attributed to Heliodorus, Theophrastus, Ierotheus, and Archelaos (Letrouit 1995, 82–83). Next to these poems, the Byzantine manuscripts preserve both anonymous commentaries, attributed to the so-called Christian philosopher and *Anepigraphos* philosopher (see Letrouit 1995, 62–65), and more practical recipe books. Such a mélange between subtle Byzantine exegetical texts and practical descriptions of alchemical techniques testifies the continuous interplay between practice and theory that is one of the more typical features of the alchemical tradition. This tradition seems to have been already well established under Heraclius, as we saw at the beginning of the chapter. Under his influence, scholars probably started collecting and assembling those texts that are at the basis of our understanding of the art of dyeing called *chēmeia*.

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FURTHER READING

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On pseudo-Democritus (English translation and commentary in Martelli 2013) see: Hershbell, J. P. 1987. "Democritus and the Beginnings of Greek Alchemy." *Ambix* 34: 5–20.

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Taylor, S. F. 1937. "The Alchemical Works of Stephanos of Alexandria. Part 1." *Ambix* 1: 116–139.

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For a general introduction to ancient alchemy, with particular focus on its interconnection with ancient technology, see:

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For the connections between alchemy and magic: Keyser, P. T. 1990. "Alchemy in the Ancient World." *ICS* 15: 353–372.

On the problematic relations between Greek alchemy and late-antique philosophy, see: Viano, C. ed. 1995. *L'alchimie et ses racines philosophiques. La tradition grecque et la tradition arabe*. Paris: Vrin.

NOTES

1 This tradition may be related to Diocletian's monetary reform, introduced to solve economic instability due to the increasing tendency of reducing the amount of precious metals in coins. See Principe 2013, 22–23.

2 Among the authors who "exploited" Democritus' name, the Egyptian Bolus of Mendes (circa 250–115 BCE) has been considered as the author either of proto-alchemical treatises or even of the four books on dyeing, an identification that must be rejected; moreover, the scant surviving evidence does not even allow us to reconstruct the content of Bolus' writings: Martelli 2013, 36–48.

3 This section comprises various recipes on the making of precious stones and more theoretical paragraphs, where the compiler discusses the identification of several ingredients, their uses, and some technical details on the basis of ancient authors, especially Maria, pseudo-Democritus, Ostanes, and Zosimus.

4 The beginning of the story clearly refers to the Egyptian myth of Horus fighting against Seth. The identification between Seth and Typhon is common in Hellenistic and Roman Egypt.

5 I accept the correction proposed by Mertens 1983, 67, who expunged the first *Chēmeu*.

CHAPTER 14

Meteorology

Liba Taub

1. Introduction

Today "meteorology" refers to the scientific study of the atmosphere. For ancient Greeks, and those Romans who incorporated Greek ideas and methods into their own thinking and practices (Roman Responses to Greek Science and Scholarship as a Cultural and Political Phenomenon), *meteōrologia* was the study of *meteōra*, "things high up." *Meteōrologia* sought to explain weather phenomena including wind, rain, thunder, and lightning (now classified as atmospheric), as well as comets and earthquakes (now regarded as astronomical or seismological). Unlike modern meteorology, *meteōrologia* was not particularly concerned with weather prediction.

In fact, there seems to have been something of a division of labor between those who wished to explain meteorological phenomena and those who aimed to predict weather, as attested by a sharp distinction between surviving Greek and Roman works addressing these concerns. Texts which explain meteorological phenomena were typically written by philosophically motivated authors, including Aristotle (whose *Meteorology* is the earliest extant work on the subject), Epicurus, and the poet Lucretius. Those associated with weather prediction, astrometeorological *parapēgmata* (tracking star phases and weather phenomena: Time-Telling Devices) and lists of weather signs, are in many cases the work of unknown authors or compilers. Several are associated with famous names, such as Claudius Ptolemy's *Phases of the Fixed Stars* and *On Weather Signs*, traditionally attributed to Theophrastus, the author of a separate text explaining *meteōra*, the *Meteorology* or *Metarsiology* (see Falcon 2005, 3, note 6 on terminology). Somewhat exceptionally, Pliny the Elder's *Natural History* addresses both explanation and prediction of meteorological phenomena, but in different books (Books 2 and 18, respectively).

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The beginning of the twentieth century saw the publication of work that was foundational for studying both *meteōrologia* (Gilbert 1907) and weather prediction (Diels and Rehm 1904). Students and scholars in a number of fields, including Classics, history, philosophy, and archaeology, show renewed interest in these topics in the early twenty-first century, and recent studies highlight further possibilities for future research to better understand the explanation of phenomena and the prediction of weather (e.g., Beardmore 2013).

2. Coping with the Weather

Explanation and prediction of meteorological phenomena can both be understood as attempts to manage the effects of typical seasonal weather and extraordinary events. Planning for and coping with weather was necessary for basic practical economic activities, including agriculture and trade, while potentially terrifying and devastating phenomena, such as storms and earthquakes, also had to be explained and dealt with. For some people, gaining intellectual control over and understanding meteorological phenomena was related to broader philosophical questions about the world and how we come to understand it, as well as our own place within it.

In the earliest extant Greek writings, meteorological phenomena are often linked to personifications, epiphanies, and actions of gods. In the Homeric poems, Zeus is, among other things, "cloud-gatherer" (*Odyssey* 5.21; *Iliad* 1.511); "earth-shaker" Poseidon causes seismological and other meteorological phenomena (*Odyssey* 1.74, 5.423), and Athena (as well as other gods) both sends and stalls winds (*Odyssey* 5.382–385). Such phenomena are similarly within the power of gods in Hesiod's *Theogony*, where violent weather plays an important role in the account of the gods' genealogy, as Zeus hurls thunderbolts.

The epic accounts of traditional gods and their meteorological manifestations and activities may be understood as a form of explanation (Taub 2003, 6; 2008, 33–35; Lehoux 2011). And the control of weather events also has great symbolic import. The epic poets significantly influenced later Greeks and Romans seeking to explain or predict meteorological phenomena; throughout antiquity, the authority of these earliest poets was valued. Even though, in some works, the links between traditional gods and weather phenomena were severed in favor of other, physical, explanations, the poets were still revered as offering relevant information. Furthermore, Hesiod, through his *Works and Days*, is understood by both ancient and modern thinkers as being at the start of a tradition of prediction, linking astronomical phenomena to weather (Pliny, *NH* 18.201; Goldstein and Bowen 1983, 331).

In the explanation of *meteōra* and the prediction of weather, tradition itself and conservatism were both valued (Kahn 1960, 109; Taub 2003, 10 *et passim*). While not all explanations and predictions were recycled from earlier sources, explicit engagement with earlier authorities is a key characteristic of ancient scientific texts. *Parapēgmata* that correlate stellar phases and weather phenomena often name specific individuals as sources, often a famous astronomer. Explanations frequently reflected the doxographical approach found in natural philosophical texts more generally. This approach relied upon collecting opinions (*doxai*), especially reputable opinions associated with particular individuals or schools of philosophy (*endoxai*) (Taub 2003, 72, 117; 2008,

16–17; Runia 1999). However, it is worth emphasizing that authority could be vested in many types of people: farmers, sailors, philosophers, astronomers, and poets.

3. *Meteōrologia*: Explaining Meteorological Phenomena

The earliest Greek philosophers are usually understood as having offered naturalistic explanations of meteorological phenomena, rejecting the roles of traditional gods. Aristotle states that the term *meteōrologia* was used to refer to the subject by "all our predecessors," indicating that it was regarded as a specific area of study (*Meteorology* 338a25–26; see also Falcon 2005, 3, note 6). Meteorology aimed to offer "naturalistic" or physical explanations (*physis* is often translated as "nature"). Some of the earliest Greek philosophical ideas may be understood as linked to theological revisionism (Graver 1999, 47). The absence of traditional gods in Presocratic accounts of meteorological and other physical or "natural" phenomena is conventionally taken as a key characteristic of Greek philosophy. Even a brief look at accounts of their views illustrates the style of explanation. For example, reporting the views of Anaximander, the doxographer Aëtius (first century CE) states:

> Concerning thunder, lightning, thunderbolts, fire bursts, and hurricanes, Anaximander [says] these all happen as a result of wind. For when wind surrounded by thick cloud breaks out violently owing to its rarity and lightness, then the tearing action produces the sound, the separation against the dark cloud the flash. (*TEGP* 30)

Aristotle, himself an important source concerning Presocratic views, testifies that Anaxagoras says that lightning

> [C]omes from the upper aether, which he calls fire, falling down from above. Now the flash of this fire is lightning, the sound and hiss of its quenching is thunder, so that lightning really occurs before thunder, just as it appears to. (*Meteorology* 369b14–19 = *TEGP* 50)

Gods are excluded from these explanations. The importance of what is seen and heard (the phenomena = what is apparent) is emphasized.

Concerns about our relation to the divine, and the limits to our powers to observe and acquire knowledge, underlie many meteorological accounts. Meteorology was to some extent powered by theological and epistemological issues, for the study of those phenomena that occur beyond (including high above and far beneath) our powers of observation involve considerations regarding the limits of knowledge. One way to explain phenomena that are difficult to comprehend is through divine agency; when that agency was denied in ancient accounts of *meteōra*, epistemological issues still remained a concern for ancient philosophers (Graver 1999, 45–47).

Even while offering rational explanations of meteorological phenomena in which no direct role was played by traditional gods, many philosophers retained ideas regarding divinity within the *cosmos* (Taub 2003, 73–74). For example, Seneca reports Thales' explanation of earthquakes: "He says that the earth is supported by water and floats like a ship, and it is being tossed by the waves, thanks to its mobility, when it is said to be quaking" (*NQ* 3.14.1, trans. Hine = *TEGP* 19). Yet while there are no gods in this account, not even Poseidon the earth-shaker, this is not to say that Thales did not

discuss divinities, for Aristotle reports that Thales thought that "all things are full of gods" (*On the Soul* 411a8 = *TEGP* 35).

There is a strong sense of philosophers' desire to confront issues relating to fears associated with the traditional gods and their control of the *meteōra*. Some scholars have argued that Greek natural philosophy excluded the gods as agents in the natural world. However, this is an oversimplification. In most ancient philosophical schools, there was an assumption of the existence of some "divine" (that is, eternal) presence in the *cosmos* (NATURE AND THE DIVINE). Furthermore, in those philosophical schools wherein the existence of gods was accepted, the role of gods was subject to debate, and questions about whether the gods play a role in causing meteorological phenomena recur (cf. Mansfeld 1992, 319–324; Taub 2003, 158–159, 166–168 *et passim*).

Many philosophical authors wrote about meteorology within a broader philosophical framework in which the explanation of meteorological phenomena played only a minor part. Nevertheless, authors generally shared the aim of explaining meteorological phenomena as due to physical causes, rather than the extra- or supernatural. The Greek word *phaenomena* refers to "what is observed." Accordingly, there was an emphasis on studying meteorological phenomena as observed events, that individuals themselves witnessed or about which they had heard testimony, in contrast, for example, with something imagined or hypothetical. Furthermore, it was assumed that, when observation is limited, the ability to explain may be affected. As a way to seemingly counter this limitation, a common feature found in many meteorological explanations is the use of analogies to everyday experience, for example, comparing the sound of thunder to the noise produced when a blacksmith throws a hot iron into water (Theophrastus, *Meteorology* 1.10–11). By referring to something familiar, it is possible to extrapolate about something difficult to access.

Engagement with earlier thinkers and writers is another signal characteristic of ancient meteorology, but explanations were not simply borrowed from earlier writers, whose views are often criticized. Several authors, including Aristotle and Epicurus, particularly discuss the methodology used in their meteorological studies, and they deliberately confront issues involved in achieving adequate empirical access to phenomena. Although many Greek and Roman explanations of meteorological phenomena shared certain themes, such as the assumption of the possibility of rational understanding and a link between the heavens and the earth, variations in these and other ideas were neither insignificant nor restricted to simply rearranging details (Taub 2003, 10; cf. Kahn 1960, 109).

The earliest Greek work on meteorology to survive in its entirety is Aristotle's *Meteorology* (*Meteorologica*). Aristotle presents this work as part of his larger project to develop a comprehensive philosophy of the natural world, following from his studies of natural motion in *Physics*, astronomy in *On the Heavens*, and the four elements in *Generation and Corruption*. These works, including the *Meteorology*, are preliminary, he explains, to his work on animals and plants. Aristotle does not appear to have taken up meteorology because of a particular interest, but because he thought meteorology was part of a comprehensive elucidation of the natural world. For Aristotle, meteorology sits, almost literally, between the study of astronomy and of life on earth, in many ways central to the study of nature as a whole, reflecting a view that meteorological processes play a crucial mediating role between the motions in the heavens and living things on earth (Taub 2003, 91; Wilson 2013).

Aristotle defines the objects of meteorological study as "everything which happens naturally, but with a regularity less than that of the primary element of bodies, in the region which borders most nearly on the movements of the stars." They include "all phenomena that may be regarded as common to air and water, and the various kinds and parts of the earth and their characteristics," embracing, for example, "the causes of winds and earthquakes and all the occurrences associated with their motions" (*Meteorology* 338b1–339a2, trans. Lee). A broad range of phenomena are included, from comets to earthquakes, including shooting stars, colorful phenomena at night (perhaps the aurora borealis), rain, clouds, mist, dew, snow, hail, rivers and springs, coastal erosion and silting, the sea, thunder and lightning, hurricanes, typhoons, whirlwinds, halos, and rainbows. For Aristotle, most of the *meteōra* are explained with reference to two "exhalations" (342a28–9), which is why they can be treated within one study (Taub 2003, 88–91).

At many points, Aristotle reports, and often criticizes, the views of Presocratic philosophers, distinguishing his own explanation from those of his predecessors, who posited only one exhalation. But while he mentions the dual exhalations several times, he does not offer a single, comprehensive definition. Nevertheless, the *meteōra* can be understood as forming an integrated unity, based on a unity of cause: exhalations. Aristotle's emphasis on his dual-exhalation theory assists his goal of presenting a theory with an integrated structure (Wilson 2013).

In the *Meteorology*, epistemological and methodological issues are foregrounded from the very beginning. Aristotle warns that meteorological phenomena are difficult, possibly impossible, to understand. Complete knowledge cannot be guaranteed (339a2–33). To some extent, difficulties in explaining meteorological phenomena arise from constraints on accessing information. Limiting factors include distance from observers (e.g., of clouds) and rarity (as with lunar rainbows). Acknowledging various limitations, Aristotle states "we consider that we have given a sufficiently rational explanation of things inaccessible to observation by our senses if we have produced a theory that is possible" (344a5–7, trans. Lee).

Aristotle uses several explanatory tactics, including drawing analogies with familiar experiences, to explain distant and difficult-to-observe phenomena. For example, he suggests that the noise of thunder (by his account produced when the windy exhalation in a cloud strikes a dense cloud formation) is like the noise of a crackling flame when an exhalation suddenly erupts in a log fire (*Meteorology* 369a34–35). He also reports "experiments" or contrived observations that might be undertaken to understand phenomena, such as the saltiness of the sea as due to a mixture of substances (358b34–359a14; Hydrology: Oceans, Rivers, and Other Waterways).

Aristotle uses empirical arguments, often citing observational evidence that conflicts with his predecessors' theories and supports his own. From a modern philosophical perspective, Aristotle's emphasis on a structured unity of cause (dual exhalations) may seem at odds with what appears to be thoroughgoing empiricism, but empirical evidence has been selected to support his theory. We seldom see Aristotle considering evidence that might undermine his own general principles (Wilson 2013). Aristotle draws conclusions that he assumes can be taken for granted based on earlier work (*Physics; On the Heavens; GC*). The *Meteorology* has an empirical flavor, because the basic foundations, as part of natural philosophy, have already been established (Wilson 2013; on empiricism in Aristotle's physical works: Bolton 1991).

Because the *Meteorology* was envisioned as part of Aristotle's bigger philosophical project, encompassing all of nature, the absence of reference to the purposes served by *meteōra*, their teleology, might seem surprising. For example, rain is not described as necessary to support life. However, the absence of the final cause within the *Meteorology* itself is possible because the work is part of a larger undertaking concerned with nature and teleology (Wilson 2013).

In contrast to Aristotle's emphasis on a unity of cause, his student and colleague Theophrastus held the view that, for some meteorological phenomena, a number of different causes may exist. In his *Metarsiology* (Mansfeld 1992), surviving only in apparently partial Arabic and Syriac versions (edited and translated by Daiber 1992, see 282–288; Kidd 1992), Theophrastus specifies which causes are responsible for particular phenomena, often presenting a number of possibilities. So, for example, thunderbolts may be due to fire hidden in a cloud suddenly slipping away, or to wind hidden in a cloud catching fire as it circulates (*Metarsiology* 6.16–28 = Daiber 1992, 264). Some phenomena have only one explanation: hail is due to drops of water hardened by cold. For some phenomena, Theophrastus invokes both analogies and direct experience, such as when he states that "we can see with our own eyes" that snow contains air, by compacting it in our hands (*Metarsiology* 9.5 = Daiber 1992, 267; see also Sedley 1998, 179–182; Taub 2003, 115–127).

Theophrastus' emphasis on the possibility of multiple causes for particular meteorological phenomena was shared by Epicurus, whose *Letter to Pythocles* is a key extant text concerned with *meteōra*. Produced apparently as an aide-memoire requested by one of his followers, the text is preserved in Diogenes Laërtius' account of Epicurus' life. One aim of Epicurean philosophy was the attainment of freedom from anxiety ("being undisturbed"), and Epicurean meteorology was motivated by a desire to alleviate fear of gods. While Epicurus recognized the existence of gods, he denied the possibility of their influence in the world. He put forward a strictly materialist philosophy, providing natural explanations of phenomena often regarded as due to the actions of gods, such as thunder, lightning, hail, and earthquakes. If such potentially violent natural phenomena are not caused by gods, there is no reason to fear their involvement in the world. Epicurean meteorology explained *meteōra* without recourse to the gods (Taub 2009).

In many cases, Epicurus provided several possible explanations for a phenomenon, without favoring one in particular. Thinking it sufficient to offer plausible explanations, he aimed to show that phenomena could in principle be explained naturally, for if "we think that an event could happen in one or other particular way out of several, we shall be as tranquil when we recognize that it actually comes about in more ways than one as if we knew that it happens in this particular way" (*Letter to Herodotus* 80, trans. Hicks). The suggestion of multiple possible causes is a hallmark of Epicurus' approach in his *Letter to Pythocles*, where he offers his explanations of *meteōra*. For example, possible causes of thunder include: the rolling of wind in a hollow portion of cloud, as when air is trapped in ordinary vessels; roaring fire blown by wind; splitting of clouds; and friction in clouds when they have hardened. In Epicurus' view, any of these causes is possible and acceptable as an explanation; it is not necessary to identify one definitively.

Concerned with epistemology, Epicurus recognized limits to our ability to acquire knowledge and fully comprehend. In his view, meteorology is particularly difficult, requiring a set of methodological procedures different from those applied to general physical questions or human life (on the reliance of Epicurean ethics on scientific

doctrine: Wasserstein 1978). He justified his advocacy of multiple causation, explaining that "we do not seek to wrest by force what is impossible, nor to understand all matters equally well, nor make our treatment always as clear as when we discuss human life or explain the principles of physics in general." Epicurus cautioned against becoming too attached to one dogmatic explanation, for "when we pick and choose among [causes], rejecting one equally consistent with the phenomena, we clearly fall away from the study of nature altogether and tumble into myth" (*Letter to Pythocles* 86–87, trans. Hicks).

Epicurus strongly advocated the use of empirical observation, emphasizing that the causes proposed and accounts offered must not contradict experience. Agreement with the phenomena is an imperative requirement: even though a meteorological phenomenon may be explained by any number of causes, none of these may contradict sense perception. Furthermore, no divine cause can be offered for phenomena. Indeed, this is not only a key feature of his physics, but also of his theology. Epicurus believed that the gods reside in perfect bliss, unbothered by the world and our concerns (*Letter to Pythocles* 97; cf. 113–114).

Another key text for Epicurean meteorology is the Latin poem *On the Nature of the Things* by Lucretius, with an account of Epicurus' physical theory (Furley 1966; Clay 1983; Sedley 1998). However, we should not assume that Lucretius followed Epicurus completely (see Furley 1999, 419). Rather traditionally, the poem opens with a prayer to Venus for inspiration, but, like Epicurus, Lucretius denied a role for gods in the physical world, aiming to eliminate fear of their possible intervention in the world. Linking his own work closely to Epicurus' ideas, in the last book of the poem (6, which may be unfinished), Lucretius discussed meteorological phenomena, including volcanoes and earthquakes.

Like the Epicureans, Stoic philosophers were also concerned with achieving freedom from anxiety, and they sought to explain phenomena as due to natural causes. Toward the end of his life, Lucius Annaeus Seneca, embroiled in the politics of Nero's court (he had been Nero's tutor), wrote the *Natural Questions,* focusing largely on meteorology. A prolific author writing on a wide range of topics, he primarily aimed to inspire moral improvement, also a concern in the *NQ* (Williams 2012; cf. Inwood 2002, suggesting that Seneca sought to demonstrate literary virtuosity; on Seneca as a "Stoic," see Griffin 1976, Inwood 1995, 2002; Veyne 2003).

Unusually, there is clear evidence that Seneca was drawn to meteorology as a subject in itself, as he explained to his mother in 41 CE (*To Helvetia* 20.2). Indeed, of our Greek and Roman sources, Seneca seems to have been the only one addressing the subject for its own sake (Taub 2003, 142). He also mentioned that as a young man he wrote about earthquakes (*NQ* 6.4.2). Sadly, this work does not survive. The *NQ* was addressed to Seneca's close friend Lucilius, sometimes identified as the author of *Aetna* (Corcoran 1971/2.1.xii; Goodyear 1984), a poem that explained the volcano. Seneca and Lucilius seem to have shared a long-standing interest in meteorological, especially geological, phenomena.

The *NQ* does not survive in its entirety, and it is difficult to determine the original order of the extant books. The preface to Book 3 seems appropriate to the larger work, and Hine's 2010 translation of the *NQ* follows the order probably intended by Seneca: that is, Books 3 through 7, followed by 1 and 2 (also Gauly 2004, 53–67; Hine 1981, 4–23; Codoñer Merino 1979, xii–xxi). (Here, we use the traditional order of the books.) Each book treats particular meteorological topics: terrestrial waters, the Nile, clouds

(along with rain, hail, and snow), winds, earthquakes, comets, fires in the sky (including meteors and rainbows), lightning, and thunder (Taub 2003, 143–159; on particular phenomena, Williams 2005b, 2006, 2007, 2008a, 2008b). Several of the extant books include prefaces and epilogues, wherein Seneca engages in moral exhortation. Book 4b, on snow, ends with a criticism of the luxurious fad of using snow to chill drinks (4b.13). The *NQ* accords with Seneca's overall program of moral improvement, while the detail in which the phenomena are explored argues against the view that the meteorological focus is merely a vehicle for Seneca's ethical messages (Taub 2003, 141–161; cf. Inwood 2002, 156).

Seneca's approach to explaining meteorological phenomena shares much with his predecessors, whose ideas influenced his choice of topics (Williams 2012, 2). With very few exceptions, such as the Milky Way, he addressed the same subjects covered by Aristotle in *Meteorology* 1–3. Like Aristotle, Theophrastus, Epicurus, and Lucretius, Seneca employed familiar analogies, some that were notably homely and offered details about contemporary Roman life (including the fashion for cooling drinks). Seneca was particularly interested in etymology and in providing clear definitions of terminology. He touched only briefly on the use of "experiment" and mentioned mathematical approaches almost disparagingly. He also provided a rather detailed, at times historical, discussion of signs and auspices. Throughout the work, he discussed and criticized, at great length, others' explanations in the course of arguing for his own views. Like Aristotle, Seneca provided information on the history of meteorology, mentioning many thinkers whose works are lost to us. For example, in his discussion of comets, he focused on the theories of Epigenes and Apollonius of Mynda, otherwise practically unknown (Pliny, *NH* 7.193 refers to Epigenes as an important author; see also Corcoran 1971/2, 2.233 note 4; Hall 1977). Seneca, significantly, reports the ideas of Poseidonius of Apamea, of whose writings only fragments survive (Kidd 1988; 1996; cf. Clarke 1999, 130 on Poseidonius' reputation; Taub 2003, 222 note 65; Hydrology: Oceans, Rivers, and Other Waterways; Geography; Greek and Roman Cartography).

For Seneca, the study of the physical world is not separable from human concerns and activities, including morality (Williams 2012). He encouraged others to study nature in order to leave behind sordid things, to keep the mind separate from the body, and to exercise the mind on hidden matters, so as to deal with ordinary ones successfully (*NQ* 3 preface 18). In the *NQ*, Seneca created a literary-scientific prose discourse in which ethical messages are integrated into the surrounding "scientific" material (Williams 2012, 11–12; Williams 2005a; cf. Graver 1999).

In the anonymous *Aetna*, the volcano's eruptions are explained as principally due to wind moving at high pressure in subterranean channels. In addition to offering a physical explanation of the volcano, the *Aetna* poet also encouraged others to participate and engage in the study of natural phenomena, offering advice and examples regarding good "scientific" practice, while also providing examples of what to avoid. In particular, the *Aetna* poet warned about myths referring to gods, emphasizing the importance of rational explanation. He stressed the intellectual benefit of studying the natural world, suggesting that the pursuit of knowledge is a worthwhile activity in itself.

Perhaps surprisingly, the poem ends with a legend about nature, man, and a god, extolling the virtuousness of nature in not harming two devoted brothers who saved their parents during an eruption: Nature shielded the family from harm, and Pluto gave them a special place in the underworld (*Aetna* 606–646). The poem exemplifies the

complicated character of many ancient Greek and Latin accounts of the physical world, in which gods are not totally absent, even as their role in the human realm is restricted or even denied (Taub 2008, 45–55; Toohey 1996, 190–192).

As we have seen, the subject of meteorology was addressed by authors with various concerns. In later antiquity, commentaries were produced on Aristotle's *Meteorology*. Although the genre of "commentary" is not wholly homogeneous, commentaries are explicit about their relation to and dependence upon earlier "target" texts (Sluiter 2000, 183–184). Significant portions of three commentaries on the *Meteorology* survive, by Alexander of Aphrodisias (circa 200 CE), John Philoponus (circa 490–570 CE, whose commentary on the *Meteorology* was produced after 529), and Olympiodorus (writing after 565). While explaining Aristotle's work, these commentators included their own ideas and criticisms and, like other meteorological authors, they were broadly concerned with philosophical questions and attended to other Aristotelian texts.

As an example of how commentators expressed originality, Philoponus, who did not always agree with Aristotle, was concerned to distinguish his own views, some of which were absolutely opposed to Aristotle's, even as he sought to explicate the *Meteorology* (Verrycken, 1990, 241–242). A Christian Neoplatonist who repeatedly asserted the doctrine of creation, Philoponus attempted to eliminate *aither*, Aristotle's eternal and divine fifth element (Westerink 1990, 327). He rejected Aristotle's claim that the world is eternal; for if the world is eternal then creation, an important tenet of Christianity, is denied. (Philoponus' lost *De Aeternitate Mundi contra Aristotelem* [*On the Eternity of the World against Aristotle*] is partially reconstructed in Wildberg 1987.)

However, while Philoponus' views were at times in sharp contrast to those of Aristotle, he did, like the other ancient commentators on the *Meteorology*, incorporate many of Aristotle's explanatory tactics. Philoponus used analogy, the citation of different types of authorities (including poets and mathematicians) and lettered diagrams (as had Aristotle in discussing halos and rainbows), but not always precisely in the same ways or to the same end. Philoponus disagreed with Aristotle on some fundamental points regarding the nature of the world, and he was not the only commentator to criticize and innovate.

Aristotle often indicated his own debt to his frequently anonymous sources for their reports of particular meteorological events, as well as for various explanations. Similarly, all these commentators referred to a range and different types of sources and authorities, yet each commentator introduced sources unique to his own discussion, incorporating quotations from "new" (post-Aristotelian) authors. Obviously, chronology plays a role here, but that is not the only factor determining whether a particular source or authority is named. For example, like Aristotle himself and other commentators, Olympiodorus used etymology as part of his explanatory approach, with reference to specific sources and types of authorities. Commenting on *Meteorology* 370b3, in his discussion of whirlwinds (typhoon), Olympiodorus explained a type of sudden storm:

> Homer calls it *Thuella*, but Aristotle Typhon, in consequence of vehemently striking against as it were and breaking solid bodies. Sailors however call it Siphon, because like a siphon it draws upward the water of the sea. But the Alexandrians call it in their native tongue *anemosoure*, because it resembles the circular bed-chambers of women, which the inhabitants [call] *anemsouris*. And physicians from the similitude of the passion produced in the spirals of the intestines, call it *borborugmos*. (3.1; Stüve 1900, 200; trans. Taylor 1807, 540 note 1, slightly altered; Taylor explains that *borborugmos* is meant to refer to the noise of the intestines)

Here, Olympiodorus presented an unusually wide range of sources in one passage. He mentioned the names used by, arguably, the most influential epic poet (Homer) and the philosopher who wrote most systematically on meteorology (Aristotle), but he did not confine himself to terminology used by these two illustrious figures. Instead, his list of terms describing whirlwinds includes words used by ordinary people, as well as words used by professional specialists, including sailors and physicians, whose livelihoods relied on an understanding of the effects of meteorological phenomena. Olympiodorus' commentary was learned, citing Homer, but some of the erudition was incorporated from contemporary Alexandrian informants. Such adaptations of Aristotle's tactics (introducing different sources and authorities) highlight the flexibility of commentary to explicate and update. Even when focused on tradition, and on Aristotle's canonical text, meteorology was not so conservative that it did not experience some degree of innovation.

4. Predicting Weather

In numerous Greek and Latin texts, weather phenomena are correlated to other natural occurrences, including the risings and settings of stars and the activities of birds. Scholars distinguish two types of texts offering such correlations, both presumably intended to aid in weather prediction. But the status of those predictions is not well understood; nor is it clear how seriously (or consistently over time and in various situations) the predictions were regarded. Astronomical phenomena, likely calculated rather than observed, were correlated with weather in astrometeorological *parapēgmata*, surviving in stone inscriptions and literary treatises (e.g., Geminus; see also Time-Telling Devices). These may be understood as tracking cyclical phenomena, such as stellar phases, and seasonal weather trends. No direct causal link is posited between stellar phases and weather events. In contrast, works such as *On Weather Signs,* traditionally attributed to Theophrastus, are lists of various phenomena (primarily, but not exclusively, in nature, e.g., the activities of animals) understood as indications of particular weather events, such as rain. These have been interpreted as providing what might be regarded, in modern terms, as "short-range" forecasts (Sider 2002, 100), such as "If there is a cloud in front of the setting sun which splits up its rays, this is a sign of stormy weather. And if the sun sets or rises while burning hot and there is no wind, this is a sign of rain" (*On Weather Signs* 11; trans. Sider and Brunschön). The signs are presented as conditional sentences: "If X, then Y," where X is the sign and Y is the weather (Sider 2002, 107).

The term *parapēgma* seems originally to have described "something on which you fix something next to something else." Fragments of two stone *parapēgmata*, late second and early first century BCE, found at Miletus, have peg-holes, representing days in the year—a peg was placed in the hole to mark the appropriate day. The following is a sample from the Milesian fragment 456D. The symbol "°" represents a peg-hole, while the square brackets indicate gaps in the original, partially restored by the editor (Lehoux 2007, 225):

> °…] the south wind blows according to
> Eudoxus [and the Eg]yptians; and
> according to the Indian Cal[laneus,]
> Scorpio sets with thunder and wind.

As tools to track astronomical events (such as star phases) and seasonal weather, *parapēgmata* could be used in conjunction with local civic and astronomical calendars. The discovery of inscriptional fragments aided in elucidating textual *parapēgmata*, such as Ptolemy's *Phases of the Fixed Stars*. (The ancient name for these inscriptions seems to have been applied to the literary texts. That usage persevered, even when knowledge of the inscriptions was lost. But see Lehoux 2004, 231, who urges caution in assuming that inscriptional *parapēgmata* predated literary versions.) The information given is often attributed to famous figures, such as Euctemon and Democritus. In the *Phases of the Fixed Stars* Ptolemy names nineteen parapegmatists. In contrast, the signs offered in lists, such as *On Weather Signs*, are generally reported anonymously. However, a number of these lists were nevertheless associated with famous names (e.g., Theophrastus). Several were appended to and circulated with works widely available in antiquity, including Aratus' *Phaenomena* (also translated several times into Latin). While compilations of weather signs seldom name sources, the opinions of experts are valued (*On Weather Signs* 3). Thus, examples of both types of texts valorize specialist sources.

The relationships between the *parapēgmata* and lists of weather signs have not been much studied (but see now Beardmore 2013). To some extent, both types of texts can be understood as being in the form of a list, and as a compilation of information gathered from various sources. Like the lists of weather signs, some *parapēgmata* (particularly those in literary form, e.g., that of Columella) refer to non-astronomical phenomena, including the appearance of birds. Numerous questions about these texts and their uses remain. While the information presented has often been understood as based on observations (cf. Geminus 17.23), Lehoux (2004, 236) argues that, in some cases, calculations were used. Ptolemy did not himself observe the weather, but relied on reported observations of earlier authorities, converting them into a common format and standardizing this "traditional" knowledge concerning the occurrence of meteorological events (Grasshoff 2016). The compiler of *On Weather Signs* (1) explains that some observations are the product of autopsy, others are reports from people of good repute.

The usefulness of transferring information based on one place to another was questioned (Pliny, *NH* 17.19–32, focusing on heat and cold in different locations at *NH* 31–32; at *NH* 18.190, he notes that "everyone should know their own soil and water"). The compiler of *On Weather Signs* (3) also stresses the importance of location. The practicality of using a list of weather signs, organized by weather events (such as rain, hail, or wind) rather than by sign, has also been addressed (Sider and Brunschön 2007, 30; Beardmore 2013). And there are questions concerning for whom these written tools and texts were intended. The importance of the knowledge of seasonal weather patterns for agriculture is obvious, but, as both the compiler of *On Weather Signs* and Pliny mention, different places have different weather patterns and different agricultural conditions. While scholars stress the usefulness for agriculture and navigation, this presumes that farmers, or bailiffs, and sailors, or captains, would have had the necessary literacy to read these texts. Furthermore, the provision and inscription of a stone *parapēgma* would have been a laborious and costly procedure. It is worth remembering the investment represented. Those fragments that do survive are relatively large, and this suggests a very public setting (cf. Hannah 2001, 144). Literary *parapēgmata* were presumably intended for use by individuals.

In the *parapēgmata*, statements about weather phenomena are often of the form "according to X," where X names a well-known person. Such references to the work

of earlier "authorities" like Eudoxus and Euctemon are a telling indication of the traditional character of approaches to Greco-Roman weather prediction (Taub 2003, 26). *Parapēgmata* allow non-expert but literate users to take advantage of astronomical information for weather prediction. The ability to locate the peg in the inscription (or the date in the written calendar) obviated the need to look at the sky to determine the stellar phases and the time of year (Lehoux 2004, 239; Grasshoff 2016). They conveyed knowledge based on which people could make decisions using the sources of information at their disposal, including other texts and personal experience. Events linked to the weather (signs such as the migration of birds) might be predicted but are not specifically listed in the *parapēgmata*. Such information was either handed down orally or recorded in other formats. For example, sailors knew which winds would allow them to embark on the dangerous route from Alexandria to Rome (Grasshoff 2016; Navigation and the Art of Sailing). However, that knowledge of astronomical signs was not purely the domain of specialist astronomers is made clear by a much later author, Vegetius (circa 450 ce), writing on military navigation (4.40): "The days of new moons too are filled with storms and are very much to be feared by navigators, as is understood not only by scientific study but the experience of common people" (trans. Milner; see Taub 2011). This indicates the value of "common" knowledge, information not necessarily collected and transmitted through texts. Vegetius' reference to "common" people echoes Olympiodorus' trust in the information provided by everyday Alexandrians.

The practice of correlating meteorological phenomena to astronomical and other natural events to predict the weather is often traced back to Hesiod. *Parapēgmata* may be linked to the sort of "farmers' almanac" presented in the final section of his *Works and Days* (Goldstein and Bowen 1983, 331), where non-astronomical weather signs are offered as well. Just as modern farmers' almanacs offer suggestions of what to do when, so too did Hesiod. Consider the description of the end of winter and beginning of spring:

> Now, when Zeus has brought to completion sixty more winter
> days, after the sun has turned in his course, the star
> Arcturus, leaving behind the sacred stream of the ocean,
> first begins to rise and shine at the edges of evening.
> After him, the treble-crying swallow, Pandion's daughter,
> comes into the sight of men when spring's just at the beginning.
> Be there before her. Prune your vines. (564–570, trans. Lattimore)

Attention is turned to counting days and watching the sky, not only the stars, but also the swallow, mentioned as a harbinger of spring. This is done with a view to ordering agricultural activity (see also 597–608 and 609–617), amid references to a god and to myth. Indeed, Hesiod's poetic farmer's almanac is situated within a wider-ranging ethical work, explaining how to behave and what to do to improve life. The *Works and Days* may be the earliest representative of what later developed into *parapēgmata* and lists of weather signs (see also Pinsent 1989, 33–34; Mair 1908, 104–146 "The Farmer's Year in Hesiod," appended to his translation; Stokes 1962, 1963). Similar approaches to weather prognostication can be found in medieval and even modern weather calendars and almanacs, attesting to the longevity of traditions of weather prediction.

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FURTHER READING

Aristotle's *Meteorologica* is the earliest work on the topic to survive from antiquity, and was influential for many later, including medieval and early modern, thinkers.

Johnson, M. R. 2009. "The Aristotelian Explanation of the Halo." *Apeiron* 42: 325–358. Discusses the quantitative aspects of Aristotle's approach, and the influence on modern explanations of the halo and rainbow.

Lehoux 2007. Discusses the tools used to track astronomical events and seasonal weather, providing translations of relevant texts.

Philoponus, J. 2011. *Philoponus On Aristotle Meteorology 1.1-3*, with translation, introduction, commentary by Inna Kupreeva. Bristol: Bristol Classical Press. Together with the following volume, offers the first English translation of this important commentary on Aristotle's *Meteorology*.

Philoponus, J. 2012. *Philoponus: On Aristotle Meteorology 1.4–9, 1.12,* with translation, introduction, commentary by Inna Kupreeva. Bristol: Bristol Classical Press.

Hine's 2010 translation of *Natural Questions* is preceded by two very helpful introductions.

Taub 2003. The first book in English to deal with the subject.

Taub 2008. Considers whether the ancient philosophers replaced myth with rational explanations, closely reading the anonymous Latin poem about the volcano Etna.

Sider and Brunschön's 2007 edition and translation of *On Weather Signs*, traditionally attributed to Theophrastus, is very helpful, especially the introduction.

Williams 2012. A detailed and richly rewarding examination of Seneca's *Natural Questions*, arguing that he wishes us to engage with lofty things, not only in a natural philosophical but also in a moral sense.

Wilson 2013. A detailed and philosophically oriented treatment of this Aristotle's Meteorology.

CHAPTER 15

Geography

Duane W. Roller

1. Introduction

Geography as a scholarly discipline began with the two treatises of Eratosthenes of Cyrene, the *Measurement of the Earth* and the *Geographika*, both written in the second half of the third century BCE. To be sure, interest in matters geographical and topographical had existed long before that time, but it was Eratosthenes who created the new discipline and its terminology.

Knowledge of the surface of the earth—beyond one's immediate home region—originated in prehistoric times. The topographical reality of the Mediterranean as an enclosed sea made its exploration relatively easy, and in the Bronze Age, Egyptians voyaged to Crete and Anatolia (Cary and Warmington 1963, 21–43). The earliest to understand the extent of the eastern Mediterranean were the Minoans. Greeks remembered their seafaring as the thalassocracy of King Minos (Herodotus 1.171; Thucydides 1.4). The western Mediterranean was first explored by Phoenicians, who, moreover, perhaps as early as 1000 BCE, went out of the Mediterranean into the External Ocean and founded Gadir (Gadeira or Gades, modern Cádiz) on the Iberian coast of the Atlantic. All these early voyages were for commercial reasons, and although much geographical information was acquired, it was generally not processed in any scholarly manner (Thomson 1965, 44–48).

2. Early Greek Geography

The earliest literary evidence for Greek exploration is Homer's *Odyssey* (and, to a much lesser extent, the *Iliad*). The actual date of any particular incident described in the *Odyssey* is not always clear, although by necessity it is earlier than the eighth century BCE, when

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the poem reached its final form. Its farthest geographical extent is, in the west, the land of the Lotus Eaters (islands off the modern Tunisian coast: *Odyssey* 9.82–104) and the Aeolian Islands north of Sicily (the modern Lipari: *Odyssey* 10.1–5). Both these regions were described accurately enough to confirm that Homer received his information from sailors who had been there. Any attempt to place Homeric locales farther west remains speculative and improbable. Vague references to the Aithiopians (*Odyssey* 1.23; 5.282) demonstrate that Homer knew something about Africa south of Egypt. In the north and east, his knowledge did not extend beyond the northern Greek peninsula, western and southern Anatolia, and the coastal Levant. Yet by the time of Hesiod, perhaps a generation or two later, the Greek geographical landscape had changed dramatically: Hesiod's world had expanded into the Black Sea, with knowledge of the Istros (Danube), which entered it from the west, and the Phasis (Rioni), at its southeast corner (Hesiod, *Theogony* 339–340). His reference to the story of Medea and Jason (*Theogony* 961, 997–1002) may also demonstrate knowledge about the far reaches of the Black Sea, although the tale is not localized. Hesiod reflected the expansion of the Greek world in the Iron Age. By the late seventh century BCE, Greeks were establishing settlements beyond the Greek heartland, such as Cyrene (circa 630 BCE) and Massalia (modern Marseilles, circa 600 BCE). These cities themselves established further ones, spreading Greeks throughout the western Mediterranean. Greeks also began to venture beyond the Mediterranean: around 630 BCE, Kolaios of Samos (Herodotus 4.152) ended up in the wealthy metal-producing district of Tartessus on the southwestern coast of the Iberian peninsula. Like many explorers from ancient to modern times, he claimed that he was off course (Roller 2006, 3–7), but this is unlikely, and the voyage must be seen as a Greek attempt to learn about the fabled riches of the region; presumably, they had received reports about Phoenician activities in the area. Kolaios made great profits from his cruise, a tenth of which was dedicated to Hera at Samos. This not only inaugurated a period of greater wealth for the Greek world, especially Ionia, but led to further Greek interest in the western Mediterranean and the adjacent Atlantic coast. Such exploration was especially promoted by the city of Phocaea in Ionia, which established Massalia and became responsible for the Greek discovery of much of the western Mediterranean. Phocaeans or Massalians ventured far along the Iberian coast: an explorer named Midakritos went to Kassiteris Island and returned home with lead (Pliny, *NH* 7.97). The island is not precisely located, but the geographical context is off the coast of Brittany or Cornwall, or on the Cornish coast itself. The name "Kassiteris" is derived from the Elamite word for tin, indicative of the history of the tin trade (Roller 2006, 12–13).

Other voyages continued to expand the Greek geographical horizon. Not all of these were made by Greeks, but Greeks usually soon learned about them. Since Libya (Africa) was unique among the three continents in having access to the External Ocean at both ends, so it seemed, early attempts were made to circumnavigate it. The first recorded expedition was by Phoenicians around 600 BCE (Herodotus 4.42–43), and there were several others in the following century, by Persians and Carthaginians as well as Phoenicians. It was believed that one of the Phoenician attempts was successful, according to the famous report by Herodotus.

To the east, Greeks came to rely on information from the Persians, whose reach extended beyond the Caspian Sea into the region where Cyrus the Great made his fatal expedition in 529 BCE (Herodotus 1.201–214), and to the Indus River, which Scylax of Caryanda was commissioned to explore around 500 BCE (Herodotus 4.44). Trade

routes into interior Africa were also known by the fifth century BCE, as far as the Niger in West Africa, and well up the Nile in East Africa (Cary and Warmington 1963, 202–229). There was some penetration north of the Mediterranean into interior Europe via the Istros, as the toponyms "Alps" and "Pyrenees" were also known to Greeks by the fifth century BCE, if somewhat misplaced. As an indication of how sketchy the information was, and how it depended on the joining together of trade routes, it was believed that the Pyrenees could be accessed from the rivers emptying into the Black Sea.

Thus, by the fifth century BCE, Greeks knew the entire Mediterranean and some of the Atlantic coast, southern Europe, northern Africa, the Black Sea coast and its rivers, and as far east as India. Trade routes occasionally provided confused information farther into the interior. The accumulation of data resulted in the creation of maps, a tool that ever thereafter would be an essential adjunct to geography (Dilke 1985). The invention of map making was credited to Anaximander of Miletus, active around 600 BCE and a significant figure in the history of Greek natural science and cosmology (Graham 2008; Greek and Roman Cartography). A century later, maps were common enough that they could be used (unsuccessfully) as a strategic tool in the Ionian Revolt (Herodotus 5.49–52). From the very beginning, they were seen as having a dual role: they could mislead as well as inform. Nevertheless, they made it possible to relate distant portions of the earth to one another.

Anaximander was remembered not only as the first map maker, but also as the first to theorize about the shape of the earth, believing that it was like a column (probably meaning the surface of a drum), an analogy that reflected the monumental stone architecture of his day (Roller 1989). Yet it had long been known to sailors that the surface of the earth was curved, and so Anaximander's concept soon yielded to the Pythagorean theory that the earth was a sphere.

Anaximander and the Pythagoreans represent the beginning of scholarly speculation about the nature of the earth. Around 500 BCE, Hecataeus of Miletus wrote a treatise titled *Circuit of the Earth* (*FGrHist* #1), the first known work to concern itself with topography. It is difficult to assess today because it survives only in fragments, most of which are toponyms listed in the *Ethnika* of Stephanus of Byzantium, so it is not clear how much analytical material was actually included. Nevertheless the range of the toponyms is astonishingly extensive: as far west as the Iberian peninsula and the Celtic territory to its north, north into eastern Europe and the Black Sea, east to the Caucasus and India, and south to Aithiopia. Hecataeus may have been the first to divide the world into continents (probably originally the two of Europe and Asia, as the third, Libya, is not documented until later [Herodotus 4.42]). He would have had access to maps, since they were being used in his home town in his day (Herodotus 5.49–54). Later, in the fifth century BCE, Herodotus (2.34) was able to relate distant places to one another, probably using sailors' reports, and to create a rough meridian line of Egypt, Cilicia, Sinope, and the mouth of the Istros, the first attempt to establish, however crudely, a plan of the inhabited earth.

The Pythagoreans believed that the earth was a sphere, which led to questions about the relationship of its inhabited portion to the whole. Basic ideas about climate had long been noted—roughly speaking, it became colder as one went north and warmer to the south—and thus the theory developed that the earth was divided into climate zones. Originally there were three: the arctic (from its position in the north, under the Bear), temperate, and burning. But it was obvious that the inhabited region only lay north of

the equator, and thus it was not difficult to suggest that the same climate pattern existed south of the equator. This meant there were actually five or six zones, depending on whether one believed in a single burned zone that existed on both sides of the equator, or whether the equator created two burned zones, one on either side. Such ideas are attributed to Parmenides in the fifth century BCE (Diogenes Laërtius 9.21–22; Strabo 2.2.2). The inhabited portion came to be known as the *oikoumenē*, a word popularized by Aristotle (*Meteorology* 2.5), and it became clear that the *oikoumenē* was only a small portion of the entire earth (Plato, *Phaedo* 109b–110a). Whether the rest of the earth was water (since the *oikoumenē* seemed surrounded by it) or whether there were other landmasses, remained a matter of speculation: the Pythagoreans believed in the latter (Diogenes Laërtius 8.25–26). It also seemed that the inhabited earth was much longer east–west than north–south, and since it was placed on a spherical earth, in theory one could go west from the Atlantic coast to India (Aristotle, *Meteorology* 2.5; *On the Heavens* 2.14). By contrast, if one went north, one reached impenetrable forest, and to the south there was only uninhabitable desert, although it was presumed that in both instances the External Ocean lay beyond.

By the middle of the fourth century BCE, the current state of knowledge had been summarized by Plato, Aristotle, and especially by Eudoxus of Cnidus in his *Circuit of the Earth*. Moreover, Ephorus of Cyme, writing the first universal history, shortly before 340 BCE, found geography so relevant to historiography that he innovatively included a section on world geography in his treatise, seeing the world as defined by ethnic groups (*FGrHist* #70, F30a, 131–134). There was still no formal discipline of geography, but by this time much geographical data were available, and speculation had moved beyond the merely topographical to the theoretical.

3. Pytheas, Alexander the Great, and Dicaearchus

In the second half of the fourth century BCE, there were two striking changes to the extent of geographical knowledge. First, there was the extraordinary voyage of Pytheas of Massalia, probably in the 330s or 320s BCE (Roseman 1994; Roller 2006, 57–91). He went from his home city across the Celtic territory to the northwest extremity of Europe, and then to Great Britain, where he stayed a year or more. From its northerly tip, he headed farther north, probably with local fishermen, eventually reaching a place where the sea was simultaneously boiling and frozen. He called this place Thule: the description of adjacent volcanic and glacial phenomena indicates that it was Iceland. From Thule, he crossed over to the Norwegian coast and entered the Baltic. Details become even more skimpy at this point, but he seems to have explored the inner Baltic. He perhaps even used the riverine system of extreme eastern Europe to reach the Black Sea. Upon his return to Massalia, he published his findings in *On the Ocean*.

Although Pytheas' voyage—like all ancient exploration—may ultimately have been grounded in trade and commercial concerns, he also had scientific interests, a rarity among ancient explorers. He reported on local ethnography, and was the first to describe the unusual phenomena of high latitudes, such as the midnight sun. Having experienced some of the highest tides in the world, he was well placed to create a tidal theory—again probably the first to do so—suggesting that tides were connected to lunar activity (HYDROLOGY: OCEANS, RIVERS, AND OTHER WATERWAYS). Most importantly for geography, he made latitude calculations wherever he went, doing this by determining

the height of the sun at the solstice. Thus, his latitudes, even though from exceedingly remote locales, could be connected with known latitudes in the Greek world, a procedure that was a further significant step toward making an overall plan of the inhabited world.

Like many explorers of remote places that had unusual phenomena, Pytheas was disbelieved and ridiculed when he returned home, and most of the ancient testimonia about him and his journey is unfavorable. *On the Ocean* may not have survived long and today exists in only a handful of fragments, which nevertheless are astonishing in their character.

The second event of geographical significance during the latter fourth century BCE was the journey of Alexander the Great. Many of the places Alexander and his entourage visited had been vaguely known to Greeks for some time; nevertheless, his travels—exhaustively recorded by many of those accompanying him—added new information, especially about the world east of the Caspian Sea, the routes from there to the Indus, India itself, and the coastal voyage from the mouth of the Indus to the Persian Gulf. Moreover, Alexander's unfulfilled plans for the conquest of the Arabian peninsula produced the first data about that region and its wealthy aromatics (Dognini 2008).

Theoretical considerations were also extensive in the era of Alexander. Aristotle provided the first extant figure for the circumference of the earth (400,000 *stadia*), and its size became a matter of increasing speculation. His student Dicaearchus of Messana suggested 300,000 *stadia* and also created a base latitude parallel, from Sardinia through Sicily, the Peloponnese, southern Anatolia, and the Taurus to the Imaion (Himalaya) Mountains north of India. The line was less than perfect but was the first attempt to create such a lengthy connection of points within the *oikoumenē*. Dicaearchus' treatise, another *Circuit of the Earth*, was the first to incorporate data from Pytheas and Alexander (Keyser 2001).

Moreover, it had long been realized that the earth was not static. Herodotus had seen seashells in Egypt far from the sea (2.12), and in the early third century BCE, Strato of Lampsacus began to examine places where the earth had visibly changed, including maritime phenomena away from the coast, as well as terrestrial locations that were far below sea level (Roller 2010, 130–131). Questions were asked about the flow from one sea to another, how this might affect the land, the differing levels of the seas, and even their depths (Strato F54 = Eratosthenes F15 = Strabo 1.3.3; HYDROLOGY: OCEANS, RIVERS, AND OTHER WATERWAYS). Volcanic phenomena, especially conspicuous in south central Anatolia and around Sicily, were always of interest (CLASSICAL GEOLOGY AND THE MINES OF THE GREEKS AND ROMANS).

The territory from the Mediterranean to the Indus came under Greek control as a result of the expedition of Alexander and the establishment of the Seleucid kingdom, and this meant a closer relationship with the far eastern regions, especially the Indian peoples. At the end of the fourth century BCE, Megasthenes (*FGrHist* #715), sent by the Seleucid government to the court of Chandragupta at Pataliputra, wrote an *Indika* that included the first Greek reports on the Ganges, southern India, and Taprobane (Sri Lanka). Deimachus, or Daimachus, of Plataea (*FGrHist* #716), an envoy to Chandragupta's son Bindusara (reigned 294–269 BCE), also wrote an *Indika*. In the 280s BCE, Patrocles (*FGrHist* #712), another Seleucid official, explored the regions east of the Caspian Sea and the river systems of central Asia, seeking connections to the eastern External Ocean.

4. Eratosthenes

By the middle of the third century BCE, the Greek geographical horizon extended from Iceland to Central Asia and the Indian peninsula. Africa was less well understood, although Massalians had made sporadic trips down the Atlantic coast, perhaps as far as the Senegal River (Roller 2006, 15–18), and the trans-Sahara trade routes had been known for some time (Herodotus 2.32). West Africa was Carthaginian territory and Greeks were not allowed, although there was occasional probing. The Ptolemaic kings of Egypt were sending explorers up the Nile: during the reign of Ptolemy II, Philo (*FGrHist* #670) went to the Aithiopian capital, Meroë; Dalion (*FGrHist* #666) went far beyond the city; and Simonides (*FGrHist* #669) lived at Meroë, probably as Ptolemaic ambassador, for five years. Collectively they gathered the first information about central Africa and its mountains and lakes.

In terms of theory, by the middle of the third century BCE, there was continued speculation about the size of the earth (by now recognized without question as spherical) and the *oikoumenē*. There was consideration of the formative processes of the earth and how it had reached its present state. A vast amount of topographic data had been collected but barely coordinated. Nevertheless, there were the first desultory attempts to create an overall plan of the inhabited earth through latitude calculations and construction of rudimentary parallels and meridians.

In the second half of the third century BCE, the disparate evidence and theorization about geographical matters came together through the work of Eratosthenes of Cyrene (Roller 2010). Ptolemy III of Egypt, who came to the throne in 246 BCE, appointed Eratosthenes as librarian at Alexandria and tutor to his son (the future Ptolemy IV). Eratosthenes had distinguished himself in Athens as a mathematician, philosopher, and philologist. As his inaugural dissertation for his new position, he wrote a poem on how to double the cube.

Over the next 40 years, extending into the reigns of Ptolemy IV and V, Eratosthenes created the discipline of geography. He invented the word *geographia*, probably by analogy with *geometria* (land measurement), which through the relatively recent work of Euclid had become the term for the scholarly discipline of geometry. Eratosthenes' first effort toward creating a discipline of geography was his treatise *On the Measurement of the Earth*, one of the most profound scholarly feats of antiquity. In it, he moved beyond the speculation regarding the circumference of the earth and calculated an actual distance. He realized that the north–south course of the Nile from Alexandria to the First Cataract at Syene, a distance of 1000 km (620 miles), provided a baseline to measure the surface of the earth. The location of Syene at the summer tropic (Tropic of Cancer) meant that the sun was directly overhead at the solstice, and this created a right angle. Using Euclidian geometry, Eratosthenes was able to determine the circumference of the earth at 252,000 *stadia* (probably adjusted from 250,000 to provide a figure divisible by 60). Three centuries later, Pliny the Elder (*NH* 2.247) called this "a daring presumption, but expressed by such a subtle argument that one is ashamed not to believe." Although the exact length of the *stadion* used by him is not known with certainty (Roller 2010, 271–273), by all accounts Eratosthenes' figure is remarkably close to the modern calculation of 40,008 km (24,859 miles) for a terrestrial circumference around the poles.

After completion of the *Measurement*, Eratosthenes wrote his three-book *Geographika*, which examined the earth, how it was formed, and the human presence on it. It was probably completed before 218 BCE since Eratosthenes showed no knowledge of the Roman activity in northwest Greece which began that year. In those three books, Eratosthenes outlined the history of geography, the history of the earth itself, and he created the first systematic plan of the inhabited world. He started with the quasi-geographical information provided by Homer, Anaximander, and Hecataeus, but generally relied on more recent sources, especially those from the period of Alexander and his successors, an indication of how greatly geographical knowledge had changed in the previous century. There was also a discussion of the formative processes of the earth, relying on the material from Strato and others. Book 1 closed with an examination of fantasy geography, a literary genre that in many ways had originated with Homer and the *Odyssey*, and which continues today in its latest version, science fiction. As geographical knowledge expanded, there was a tendency to disbelieve new and ever-more-remote discoveries (a situation most notable with Pytheas) as well as to fabricate remote places, often as cultural allegories (such as Plato's Atlantis). India, with its complex and strange diversity, was fertile ground for such fantasies.

Book 2 discussed the shape of the earth, and incorporated material from the *Measurement*, although probably not its highly technical calculations. It also included a consideration of the *oikoumenē* and its location on the surface of the earth as a whole, as well as the latitudinal zones. Book 3 is the actual topographical description of the *oikoumenē* (see Figure 15.1). Eratosthenes began by establishing a series of prime parallels from that of Meroë in the south to that of Thule in the north. There was also a series of meridians east and west of a prime meridian through Meroë, Alexandria, and Rhodes. This created, for the first time, a grid system covering the entire inhabited earth. To be sure, it was problematic in many ways: meridians and parallels were constructed through known points and thus wobbled, and there were many gaps in the grid, especially at the extremities. Nevertheless, it is a striking innovation and the basis of all future geographical scholarship.

The remainder of Book 3 catalogs approximately 400 places, starting with India (a reflection of the orientation of the world in the century after Alexander) and ending at the Atlantic coast. Because the *Geographika* is only known through later quotations, survival of its topographical data was erratic and becomes more deficient toward the west: two-thirds of the extant fragments come from the *Geographika* of Strabo of Amaseia, completed in the 20s CE, when the western Mediterranean was much better known than in Eratosthenes' day and preservation of his data on those regions was not considered necessary. In fact, Eratosthenes' treatise did not survive long—perhaps not beyond the second century CE—because continuing evolution in both geographical knowledge and methodology made it obsolete. Nevertheless, this does not diminish its significance, for it was the work that established geography as a scholarly discipline.

The major flaw in Eratosthenes' methodology—although inevitable—was his use of travelers' reports to establish the locations of places. Because there was no alternative, his parallels and meridians frequently follow existing roads or sailing routes and are far from being straight lines. For example, his prime meridian runs from Lysimacheia in Thrace to Olbia north of the Black Sea, which is 400 km (250 miles) to the east but the most important city in the region. Moreover, places are related to one another in terms

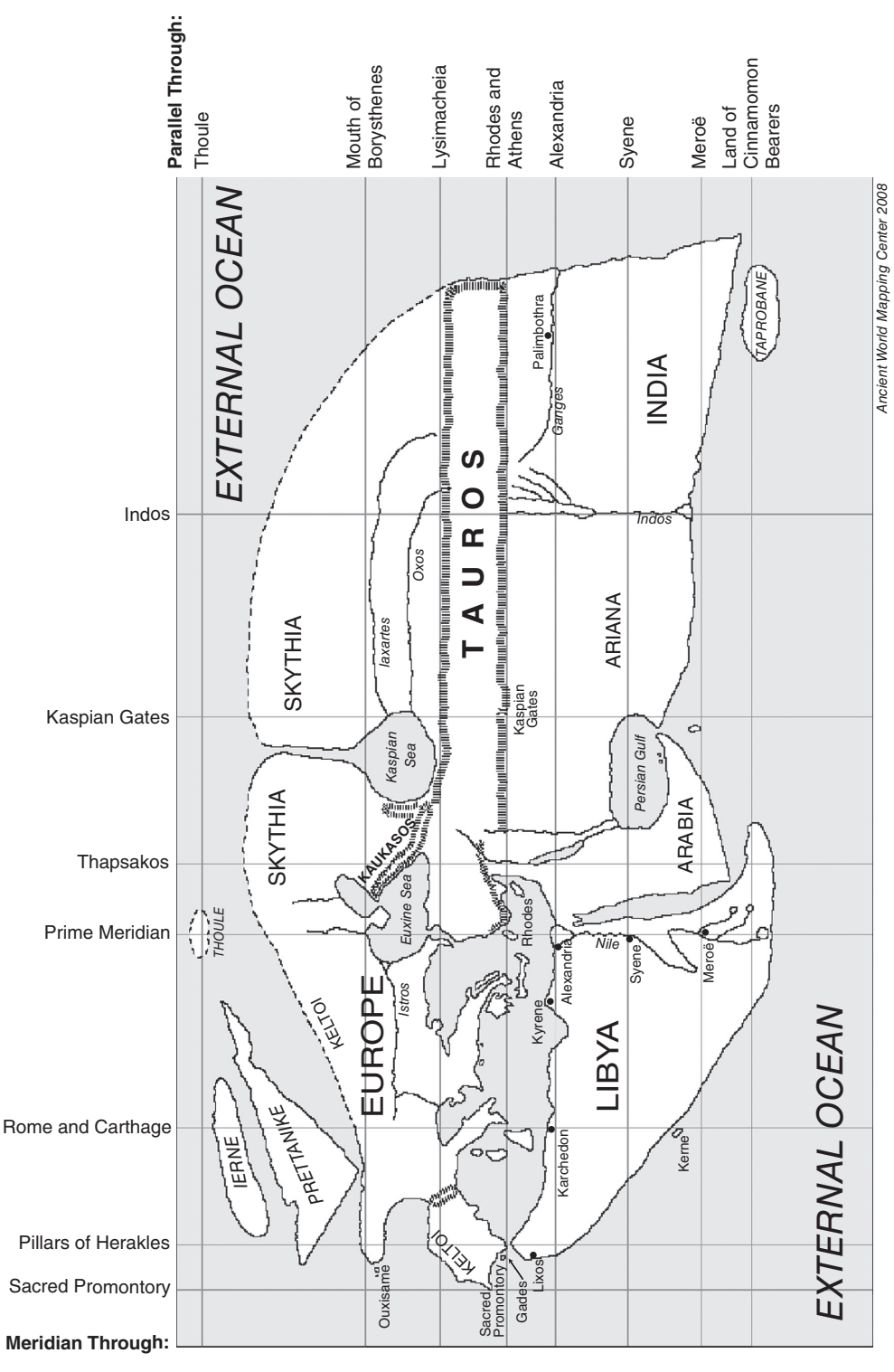


Figure 15.1 The World according to Eratosthenes. [Source: Ancient World Mapping Center, The University of North Carolina at Chapel Hill, based on Grosser Historischer Weltatlas (fifth edition, Munich 1972), p. 12.]

of schemes of reporting overland routes that are not always reconciled: before Eratosthenes there was little need to think of long distances in any way other than sailing days or camel days. Units of measurement, even when available, varied from place to place.

5. Hipparchus

Although the *Geographika* was a highly innovative work, its erratic manner of relating places to one another means that within a century it was attacked for its methodology. Hipparchus of Nicea, a mathematician and astronomer, wrote *Against the Geography of Eratosthenes*, probably around the middle of the second century BCE (Dicks 1960, 1–19). He felt that Eratosthenes' use of overland and maritime measurements which had been received from travelers and sailors was too inaccurate to be useful, and, moreover, that only through mathematics and astronomy could one determine the location of places. Thus, Hipparchus believed that these two disciplines were essential tools for a geographer. Like the *Geographika* of Eratosthenes, most of the fragments of Hipparchus' critique are only available through Strabo's citation of them. Thus, the modern reader is drawn into a three-way tangle between Strabo, Eratosthenes, and Hipparchus. The latter two can be interpreted only as Strabo saw them, and so exact understanding of either can be difficult.

Hipparchus was not a geographer, and his work has the characteristics of a polemic. Nevertheless, his basic thesis was correct: mathematics and astronomy could offer greater accuracy than the overland measurements Eratosthenes had used. Yet, Hipparchus ignored Eratosthenes' awareness of the limitations of his own technique and his admission that his measurements were, in fact, often approximate (Eratosthenes F52, 131 = Strabo 2.1.39, 41). Hipparchus seems to have validated the methodology that Eratosthenes had used to calculate the circumference of the earth, but he believed that Eratosthenes could have applied this technique in locating places beyond the Syene-Alexandria axis. The extant fragments of Hipparchus' treatise often appear to be a series of complaints about errors found in Eratosthenes' work, but Strabo, who generally supported Eratosthenes over Hipparchus, probably overemphasized the latter's seeming pedantry.

Hipparchus' most significant contribution to geography was his realization that it was now possible to determine the number of *stadia* in a degree of the circumference of the earth (700). Thus, he was able to create a much more detailed grid for the surface of the earth (Hipparchus F39 = Strabo 2.5.34), and in theory could locate points with much higher accuracy. But the necessary astronomical data were simply lacking for many of the places that Eratosthenes had cited, and Hipparchus gave an illusion of accuracy by providing degrees and minutes for locations that had actually been determined by the traditional method of overland measurements (Dicks 1960, 37). Nonetheless, he was able to calculate some new latitudes and straighten some of Eratosthenes' wobbly parallels.

6. The Rise of Rome

Hipparchus was not in the mainstream of geographical theory. His basic idea—that mathematics and astronomy could, in theory, determine locations more accurately—was perfectly valid, but geographical scholarship moved toward ethnographic rather than mathematical geography, to be exemplified by Polybius, Artemidorus, and, above all, Strabo.

In the time of Eratosthenes, Greek knowledge of northwest Africa and the Atlantic was minimal, because this was Carthaginian territory, and they made it perfectly clear that others were not welcome in their sphere of influence (Polybius 3.22; Roller 2006, 57). Yet this changed in 146 BCE, when Carthage fell to the Romans. Access to its archives and libraries meant that the wide range of Carthaginian exploration came to be understood, something that previously had been little known to the Greeks.

The polymath Polybius was commissioned by the conqueror of Carthage, P. Cornelius Scipio Aemilianus, to take a fleet and explore the Carthaginian territories on the West African coast (Polybius 34.15.7 = Pliny, *NH* 5.9–10). This expedition marked the beginning of Roman interest in exploration. Polybius went as far as the tropics and wrote *On the Inhabited Parts of the Earth Under the [Celestial] Equator* (Polybius 34.1.7–14 = Geminus 16.33), in which he concluded—disagreeing with accepted opinion—that the equator was at high altitude (Polybius 34.1.16 = Strabo 2.3.2). It is by no means certain how he came to this idea, but he had available the report of the Carthaginian explorer Hanno, who around 500 BCE had reached Mt. Cameroon, lying on the coast just north of the equator at an elevation of 4069 m (13,350′) (Roller 2010, 29–43). Polybius may have seen the mountain himself. He further believed, also contrary to previous theory, that the equatorial regions were not hot, but in fact more temperate than the hot regions on either side. Knowledge of Mt. Cameroon may have suggested this, as well as data collected by the explorers of Ptolemy II who had gone up the Nile and had learned about the mountains near the source of the river. Polybius suggested that this temperate quality was because the sun did not remain over the equator for very long. He also may have traveled to the mouth of the Liger (Loire) River in an attempt to trace Pytheas' journey. But in questioning Massalians about Pytheas (Polybius 34.10.6–7 = Strabo 4.2.1), he allegedly learned nothing, since the Massalians, like the Carthaginians, were reluctant to talk about their trade secrets. Thus, Polybius came to believe that Pytheas had made it all up, a point of view later reinforced by Strabo.

Polybius also included a book on geography within his history (Walbank 1970–1979, 3.563–569). Although reconstruction of this book remains hypothetical, it seems to have begun with a theoretical outline, largely about the terrestrial zones (since Polybius' views on these were idiosyncratic) and the relation of the inhabited part of the earth to its whole. This was followed by a description of Europe, including a discussion of the wanderings of Odysseus as well as polemics against Pytheas and Eratosthenes.

A number of geographical treatises were written in the first half of the first century BCE, although it is uncertain how these added to the works of Eratosthenes, Hipparchus, and Polybius. There was little if any new topographical knowledge gained at this time, although Roman penetration of northwestern Europe provided a clearer understanding of some regions previously known only vaguely, such as the northern parts of France and the Rhine valley.

Artemidorus of Ephesus, active around 100 BCE, wrote a geographical treatise that seems to have been eleven books long. As such, it would have been the longest work on the topic to date (Stiehle 1856). It has not survived, and is known mostly through citations by Strabo and Pliny, supplemented by with toponyms in the *Ethnika* of Stephanus of Byzantium. The circuit begins at the Iberian peninsula and continues across Europe, and then crosses to Libya and then east to India, returning to Anatolia. As there are about one hundred extant fragments, it is difficult to understand how eleven books could have been filled, but there was a certain amount of ethnographic and scientific

material: examples include a discussion of hydrology at Gadeira (F14 = Strabo 3.5.7) and one on the climate of West Africa (F77 = Strabo 17.3.8). Artemidorus seems to have seen himself in opposition to Eratosthenes; his intent may have been to update the earlier scholar and provide much greater detail.

Poseidonius of Apamea was another scholar active in geographical scholarship in the early first century BCE. A polymath who was important in the transmission of Greek knowledge to Rome, he traveled widely: in addition to moving from his home in Syria to Rhodes and then to Rome, he undertook, probably in the 90s BCE, an extensive journey to the far west, including the Iberian peninsula and the Celtic regions (Poseidonius, T14–26). His geographical work, *On the Ocean* (its title derived from that of Pytheas), is known from a lengthy yet somewhat confusing summary by Strabo (F49 = Strabo 2.2.1–2.3.8), which leaves many gaps, and in some cases emphasizes seemingly minor points in the original treatise at the expense of more substantive discussions. Much of Strabo's focus is on the terrestrial zones, an intellectual issue going back to Parmenides in the fifth century BCE, who had originally suggested that there were five zones: two cold, two temperate, and a burning zone of double width (Strabo 2.2.2). Polybius had split the burning zone into two, creating six, and he may have suggested that there was a seventh zone, a narrow strip along the equator itself. Poseidonius generally rejected Polybius' modifications—as well as the latter's idea that the equatorial region was at high altitude—and tended to uphold Parmenides, but he also believed that human geography was relevant to the topic, and that the ethnic characteristics of those living in particular zones reflected the climate of that zone.

After the fall of Carthage, the Romans became more interested in geography, but inevitably for political, not scientific, reasons. Scipio Aemilianus had underwritten Polybius' explorations, since understanding the extent of Carthaginian knowledge was essential to the Romans. Yet Roman territorial expansion also added to knowledge. As the Romans moved into the Iberian peninsula and the Celtic territories to the north, local field commanders included ethnographic data in their reports: the best-known example is the works of Julius Caesar, who used the treatise of Eratosthenes in his topographical research.

Other Roman officers had Greek scholars accompanying them. Theophanes of Mytilene (*FGrHist* #188) traveled with Cn. Pompeius Magnus on his eastern campaign in the 60s BCE, which reached the west coast of the Caspian Sea (Theophanes F4 = Strabo 11.5.1), a region where existing information—not updated since the time of Alexander the Great—was vague or suspect. Theophanes provided new data about the territory between the Black and Caspian Seas, and examined the course of the lower Tanais (modern Don), the boundary between Europe and Asia (F3 = Strabo 11.2.2). He also included local ethnographies (F4–6 = Strabo 11.5.1, 11.14.4, 11). Thus, he remains one of the best examples of how the Romans relied on Greek or Greek-educated scholars to record their expanding geographical knowledge.

Roman geographical literacy was also enhanced by Greek scholars resident in Rome. Poseidonius was in the city from the 80s BCE until around 50 BCE (Cicero, *To Atticus* #26 [2.6]). There was also his contemporary, the geographer Tyrannion of Amisus, one of the teachers of Strabo (Strabo 12.3.16). Thus, by the middle of the first century BCE, Greek geographical theory and knowledge were firmly established among the Roman elite, even if their interest was primarily to support their military and political needs.

The best example of this blending of Greek education and Roman needs was a person who was neither Greek nor Roman, Juba II, the allied king of Mauretania and the dispossessed heir to the Numidian kingdom (Roller 2003), who married Cleopatra Selene, the daughter of Cleopatra VII and Antonius. Using his wife's Ptolemaic heritage and the benefits of an excellent education in Rome (he was raised in the home of Octavia, Augustus' sister), he wrote two significant geographical and ethnographic treatises. The first was *Libyka*, which examined his own kingdom, North Africa, the source of the Nile, and the Canary Islands (which he discovered). The second, *On Arabia*, carried *Libyka* to the east and discussed the Arabian peninsula and the routes to India. Much of Juba's work was based either on autopsy or expeditions that he commissioned, and together the two treatises created a thorough discussion of the southern part of the inhabited work from the Atlantic islands to India, regions about which it was Augustan policy to be informed.

8. Strabo

The culmination of Hellenistic geographical scholarship is the *Geographika* of Strabo of Amaseia. Practically everything that is known today about earlier Greek geography appears in this unusual seventeen-book work: were it not for Strabo, there would be little evidence for the theories of the formation of the earth put forth by Strato, the development of concepts about the terrestrial zones, the explorations of Pytheas, or the geographical scholarship of Eratosthenes, Hipparchus, Polybius, or Poseidonius. The *Geographika* is the only extant work of its genre in Greek and one of the longest surviving pieces of Greek literature.

Strabo was a member of the Pontic aristocracy, born in the 60s BCE. He lived until the CE 20s, and thus his lifetime saw immense changes in the Greco-Roman world. He was broadly educated in Nysa, Alexandria, and Rome, and came into contact with many of the major scholars of his day. He served in Egypt during the 20s BCE, and also traveled extensively in Italy, the eastern Mediterranean, and western Asia as far as Armenia. He seems to have worked on the *Geographika* for nearly half a century, although the final drafting of the treatise took place during the reign of Tiberius.

The *Geographika* of Strabo is difficult for the modern reader to understand (Engels 1998, 63–114; Lasserre 1982–1983, 867–896). It is lengthy, complex, and varied, including many topics that can only marginally be considered geographical, such as Homeric criticism, cultic history, linguistics, autobiography, and the nature of Roman power. The vocabulary is unusual in terms of the extant repertory of Greek literature, in large part because the treatise preserves a vast amount of Hellenistic scientific and ethnographic material unknown elsewhere. The text is so highly digressive and ambiguous that a modern reader can easily lose the thread of the discussion, an issue complicated by its long gestation period.

The first two books, examining the history of geography and the formative processes of the earth, present technical data from Eratosthenes and Hipparchus about how to measure the inhabited earth, including Eratosthenes' grid system. Most of the extant fragments of the geographical works of both these scholars are included within these two books. Strabo's survey of the inhabited world begins with the third book, starting at the southwestern corner of the Iberian peninsula. His account then moves through Iberia and the Celtic world, the Italian peninsula and Sicily, and the Greek peninsula

and the islands. The most detailed part of the treatise is the four books devoted solely to Anatolia and the Black Sea littoral: clearly, part of Strabo's agenda was examining in detail (probably for Roman audiences) the virtues of his home region. This part of the treatise also includes a large amount of cultural history. The *Geographika* continues with India, the Iranian plateau, and Mesopotamia, and contains some of the earliest extant data about the journey of Alexander the Great. The final book discusses Egypt and North Africa, ending with Cyrene, Eratosthenes' hometown. Within the seventeen books are thousands of toponyms, many more than were known to Eratosthenes two centuries earlier.

There are many other topics covered in the treatise. Homeric commentary (Strabo's original area of study) is an almost constant feature, although generally geographically oriented. Strabo believed that Homer was the first geographer and always saw Homeric topography as unassailably truthful. He valiantly attempted to expand Homer's limited geographical knowledge into the realities of the first century BCE, especially in the Iberian peninsula. Despite this bias, Strabo's arguments are often precise and sharp, with a strong critical sense, and he was the originator of topographical research as it is still practiced today. Yet his obsession with Homer sometimes drove him in peculiar directions, and he often resorted to the excuse of faulty transmission of the text to explain what modern scholars would simply find to be an obvious error or geographical limitation on Homer's part (1.1.7, 1.2.16).

As a structural precedent, Strabo used Hecataeus of Miletus rather than Eratosthenes, moving from west to east, from Iberia to India, and then back west to Egypt, a format that in fact may have been designed to place Rome at the center of the inhabited world (Clarke 1999, 210–228). He then jumped from Egypt to Mauretania and headed back west across North Africa to finish his description at Cyrene, significantly the home town of Eratosthenes, the inventor of the discipline of geography. The treatise ends with a eulogistic summary of the Roman contribution—"since they have surpassed all former rulers of which we have a record"—and the final lines of the *Geographika* (17.3.25) lay out the division of the world into provinces and allied kingdoms. This is based on the Augustan settlements of the 20s BCE but was updated half a century to the situation after the accession of Ptolemy of Mauretania in CE 24. Thus, the ending suggests that the *Geographika* was in part designed to outline the present state of the inhabited world under Roman control.

Strabo's *Geographika*, then, merged geography and politics. Like his contemporary and colleague Juba II, Strabo used geography to assist in the implementation of Roman policy, yet he stressed that there would be no Roman policy to implement without a Greek foundation on which to build it. This was best manifested in the intellectual output of Anatolia, and to stress its importance, he listed over 200 Anatolian luminaries of the past and present. Although Strabo's wandering digressive style is difficult to follow, he took essentially everything that was known about geography (from Homer as he saw him to his own era of Nikolaos of Damascus and Juba II) and put it into a single treatise. Unlike many Greek scholars in the Roman world, Strabo was fluent in Latin, which allowed him access to the latest Roman geographical data, especially about the Iberian peninsula, the Celtic world, the British Isles, and Germany. He used sources such as the commentaries of Julius Caesar and Asinius Pollio, and little-known field reports of other Roman commanders in the west. Other parts of the *Geographika* rely on Greek sources such as Poseidonius and Polybius, and thus one of the problems in interpreting

the treatise is its layering of sources from throughout the Hellenistic period (discounting Strabo's problematic emphasis on the assumed wide geographical knowledge of Homer). It is not always possible to be certain exactly to what period the data preserved by Strabo belongs. The work is notable for its wide use of sources (over 200 are cited, from Homer to Strabo's contemporaries). In addition, by his own account (2.5.11), Strabo traveled widely, from Armenia west to the northern Italy, and far up the Nile, although never west of the Italian peninsula. Consequently, autopsy is an important part of the work. Perhaps immodestly, Strabo was well aware of the monumental quality of his work (1.1.23).

In many ways, Strabo represents the peak of the Greek geographical tradition. His ability to bring together all the known information about the history of the discipline and his role in preserving much of the extant material from authors such as Eratosthenes, Hipparchus, and Artemidorus makes the *Geographika* one of the most valuable works surviving from Classical antiquity.

9. After Strabo

Additions to Greco-Roman knowledge of the inhabited world after the time of Strabo are due to limited, although fascinating, penetrations by merchants and officials into specific areas (Cary and Warmington 1963, 219–221). In Africa, the Romans Septimius Flaccus and Julius Maternus reached the region of Lake Chad around the middle of the first century CE (Ptolemy, *Geography* 1.8). There were a number of journeys down the east coast of the continent as far as the Zanganai (modern Zanzibar), particularly the travels of Diogenes, who late in the century went east into the interior and discovered the lakes that were the source of the Nile and the adjoining Mt. Selene (Ptolemy, *Geography* 4.8), the fabled "Mountains of the Moon" of nineteenth-century explorers.

The most extensive addition to topographical data during the first century CE was to the far east. A Macedonian merchant, Maes Titianus, provided data on the great eastern trade route, the "Silk Road" of later times. He departed from a place called the Stone Tower, somewhere east of the Caspian Sea (Berggren and Jones 2000, 151). The route led east to Sera ("Silk"), inhabited by the Seres ("Silk People"), a journey said to take seven months (Ptolemy, *Geography* 1.11). Sera and the Seres had been vaguely known since the time of Alexander the Great. How this toponym and ethnym related to China or the Chinese has long been a matter of controversy, but it may merely be terminology describing the region's most famous product. Another set of terms may be the true toponym and ethnym, variously Thina (Casson 1989, 64), Sina, or Sinai (Ptolemy, *Geography* 1.14, 17; 7.5; 8.27.12), said to be a great city in the east and clearly a version of the name "China."

Other remote eastern toponyms or ethnyms were known by the early second century CE, such as Kattigara (Ptolemy, *Geography* 1.11, 13–14, 17, 23) and Zabai (Ptolemy, *Geography* 1.14). Their location is highly speculative but would be somewhere in far southeast Asia, the Malay peninsula, or Indonesia (Berggren and Jones 2000, 155–156). Information about these far-flung places would have reached the Mediterranean only after passing through many hands, and, as always, may not reflect the actual locality itself but merely a point of contact between different groups of traders. Nevertheless, they are demonstrative of the far-flung trading network of the world of the empires of the Romans, Parthians, and Han Chinese.

The final state of Greek geographical scholarship is represented by the *Geography* of Claudius Ptolemy, of the mid-second century CE, the only cartographic treatise surviving from Classical antiquity, and based on a slightly earlier lost work by an otherwise-unknown Marinus of Tyre (Berggren and Jones 2000, 23–24). Map making had long been an adjunct of geography, yet it remains uncertain as to whether treatises such as Eratosthenes' *Geographika* were published with maps (GREEK AND ROMAN CARTOGRAPHY). Ptolemy was essentially a mathematician and astronomer—his system of the universe was the standard until early modern times—but, like Hipparchus, he turned his talents to geography. The work includes a theoretical section—basically, instructions on how to make a map of the inhabited world—followed by a list of all the known places in the *oikoumenē*, about 8,000 in number. Although many places were located with greater precision than previously, and there were far more places than had been recorded by Eratosthenes and Strabo, actual positioning still retained vestiges of the long-established system based on overland measurements and the longest period of daylight.

There are later Greek works on geography, such as the *Chorographia* of Pappus of Alexandria, written in the first half of the fourth century CE, or the geographical treatises of Marcianus of Herakleia, of uncertain date between CE 200 and 530, but these tend to be derivative summaries of earlier material. The *Geography* of Ptolemy effectively marks the end of the Greek geographical tradition. In late antiquity, geography moved in new directions. Cosmas Indicopleustes' *Christian Topography*, from the early sixth century CE, demonstrates a need to Christianize the discipline. Somewhat later, Islamic geographers had their own agenda.

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FURTHER READING

The traditional work on ancient geography is Thomson 1949, which is exceedingly thorough and detailed, although now out of date. More recently, Roller 2015 is a handbook on the topic for the general reader. Cary and Warmington 1963 remains excellent for explorers and exploration. Clarke 1999 is more conceptual, about the nature of ancient geography and its role as a cultural phenomenon. Some works on specific geographers are listed in the bibliography, and *EANS* catalogs all known ancient geographers.

PART IV

Life Sciences

CHAPTER 16

Greek and Roman Botany

M. Eleanor Irwin

1. Introduction

Botany, the study of plants, began in Greece with the recognition of plants which had a practical use and therefore needed names. Along with names came attention to similarities and differences to ensure that the correct plant was used and that those who needed particular plants were able to find and grow them. Physicians, root cutters, and pharmacists prescribed, gathered, and prepared plants for medical use. Farmers passed on what they had learned about growing food plants. Those active in such industries as woodworking, dyeing, perfume making, and wreath-making had their own reasons for knowing about plants. So the study of plants often had economic implications. And even when the study was scientific, the needs of medicine, agriculture, and other occupations were always present.

There are three important writers whose works on Greek and Roman botany survive: Theophrastus, Dioscorides, and Pliny the Elder. The first two wrote in Greek, the third in Latin. Although Dioscorides and Pliny were contemporaries, they show no indication that they knew one another's work. Both Pliny and Dioscorides had a continuing influence on botany in western Europe because they remained available to readers of Latin, with Dioscorides in a Latin translation. Medicinal plants were excerpted from Pliny's *Natural History* in *Medicina Plinii* ("Pliny's Medicine"), and the plants in Dioscorides' work were rearranged in alphabetical order in some manuscripts. In contrast, Theophrastus' work, not translated into Latin until the fifteenth century, was unknown in western Europe until the Renaissance (Morton 1986, 95).

In order to appreciate the work of each of these authors, we need to know the context in which they were working. It is possible to sketch what was generally known about plants when each author was writing. Thus we can assess both the written and oral sources which they consulted and evaluate their contributions and reputations as botanists.

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2. Naming Plants in Greece

Theophrastus named about 500 plants in his *Enquiry into Plants* (*Historia Plantarum* [*HP*]) and *Causes of Plants* (*Causae Plantarum* [*CP*]). As he himself acknowledged, there were also nameless wild plants about which few people knew (*HP* 1.14.4) as well as foreign plants which had no Greek names. Modern botanists estimate more than 5,000 plants native to Greece (Strid and Tan 1997, 18–19), far more than ancient botanists included. (In this comparison between ancient and modern botanists, we must factor in the geographical differences between modern Greece and the ancient Greek world, which extended beyond present-day Greece to settlements along the coast of present-day Turkey and the Black Sea as well as Egypt, North Africa, and the western Mediterranean.)

Theophrastus did not invent these names, nor did he assign names to nameless plants, but he adopted names already in general use. The Linnaean system of nomenclature uses a genus and species name which places a plant in a family and distinguishes it from other plants. The *Rosa gallica*, for example, is a particular species of rose, distinguishable from all other roses, and its placement in the family *Rosaceae* allows us to discover related plants, like raspberry (*Rubus idaeus*), stone fruits (species *Prunus*), and flowering plants (species *Spirea*).

Theophrastus employed names in common use with the result that the same name can be used for different species, sometimes with an additional adjective, for example, black violet (*melan ion*) and white violet (*leucon ion*), black being our violet *Viola odorata*, and white our stock *Matthiola incana* (*HP* 6.6.7). Theophrastus knew of three kinds of all-heal (*panaces*: *HP* 9.11.1), named for a healer: Asclepias' all-heal, Heracles' all-heal, and Chiron's all-heal, identified by Thiselton-Dyer (Hort 1926, 468) as *Ferula nodosa*, *Opopanax hispidus*, and *Inula helenium*, respectively. In Theophrastus' experience, the same plant might have different local names, for example, *narkissos* (our narcissus), which is also called *leirion*, a name also used for the lily (*HP* 6.8.3).

Much effort has been expended on identifying Greek plants, beginning with Wimmer's index derived from Sprengel and Fraas in his edition of Theophrastus (Paris, 1866, 531–547), Thiselton-Dyer's identifications in Hort's translation of Theophrastus (1926, 437–485), Andrews' revision of the index in the Loeb translation of Pliny (Jones 7.485–550), and Aufmesser's book on plants in Dioscorides (2000) as well as the plant entries in *A Greek English Lexicon*, to which Thiselton-Dyer and D'Arcy Wentworth Thompson contributed (Liddell-Scott-Jones [LSJ], ninth edition, 1925–1940).

Identification is made more difficult by refinements in modern botanical nomenclature and shifts from one genus to another, as well as uncertainty from lack of information in the ancient sources. There is some continuity between ancient Greek and modern botanical nomenclature (*krokos*/crocus, *narkissos*/narcissus), though there are false friends where the Greek name has been transferred from a Greek plant to one not native to Greece. For example, *Asclepias* in Greek is defined (LSJ, s.v. *asklepias*) as swallow-wort, white hellebore, and laurel but is now the scientific name given to the genus of the North American native milkweed.

Homer named fifty plants in his poems (Forster 1936). One of the most memorable of these botanical passages is the comparison of a dying warrior to a poppy in a garden, its head "weighed down with seed and spring rains" (*Iliad* 8.306–307). Odysseus gives

a rudimentary description of moly, an unfamiliar magical plant "with a black root and a flower like milk," which Hermes uprooted and gave to him (*Odyssey* 10.304–305). Homer's landscapes are settings for human or divine action: fertility is suggested when Earth makes crocus, hyacinth, and grass grow in response to the love-making of Zeus and Hera on the peaks of Mount Ida (*Iliad* 14.347–349), and mortality is implied when Menelaus' killing of Euphorbus is compared to the wind uprooting an olive tree in bloom (*Iliad* 17.53–60).

Hesiod in *Works and Days* was more concerned with what to do and when to do it than with plants, though he used plants as markers for seasons: the heat of summer when the golden thistle blooms (*scolymus*: *Works and Days* 582) and the beginning of navigation "when the leaf of a fig tree is as large as a cow's hoof print" (*Works and Days* 678–679).

Herodotus named 60 trees and plants. His interest is mostly in the availability of plants or their lack: as when he reported that the Assyrians grew neither vines nor olive trees and instead got oil from sesame seeds and wine from dates (1.193). He admired the many-petalled roses in the garden of Midas of Gordias (8.138.2), which Forster (1942, 62) singles out as the only plant Herodotus mentioned purely for its attractiveness.

Xenophon in his *Anabasis* similarly reported various products used as substitutes for oil, wine, and flour. He also observed plants which presented dangers to his troops like those which were the source of honey in the country of the Macronians (4.8.20). He not only wrote about the wooded parks (*paradeisoi*) owned by Persian royalty and nobles, but he also recreated one on land near Olympia (5.3.7–13).

As travelers like Herodotus and Xenophon brought back accounts of unfamiliar plants, Greeks became aware that different plants grew in (and needed) different climates, whether this meant temperature, rainfall, or altitude. This practical knowledge had an impact on Greek colonization as sites were chosen where olive trees and vines would grow (Irwin 2003).

3. Theophrastus and the Beginning of Scientific Botany

Born at Eresus on the island of Lesbos in the Aegean about 371 BCE, Theophrastus began his studies on Lesbos with Alcippus and then, in his early twenties, became a student of Plato's at Athens (Diogenes Laërtius 5.2.36; Mejer, 19). After Plato's death, he became Aristotle's student and then colleague, accompanying him first to Assus and Mytilene, and then to Macedonia, where Aristotle had been invited to tutor the young Alexander. Theophrastus eventually succeeded Aristotle as head of the Lyceum in Athens.

Our chief source for Theophrastus' life, the third century CE writer Diogenes Laërtius (5.2.36–57), had access to written material which has not survived. In his biography, we learn that Theophrastus' lectures were well attended and that he continually revised his lectures, presumably based on questions and discussions with his audience (from a letter to Phaenias, his fellow countryman: Diogenes Laërtius 5.2.37). This gives us an insight into the way Theophrastus worked, composing works in progress, with many additions and revisions. In his will, Theophrastus bequeathed property in Athens for the common use of his students and colleagues. Non-Athenians were not ordinarily allowed to own property in Athens, but through the support of one of his former students, Demetrius

of Phaleron, Theophrastus had been able to acquire a tract of land (Diogenes Laërtius 5.2.39) large enough to have houses adjoining it and walks planted with shade trees. Here Theophrastus wished to be buried, and it is reasonable to imagine that Theophrastus observed and tested his ideas about plants here.

Philosophical and Scientific Questions about Plants before Theophrastus

Natural philosophers before Theophrastus were interested in botanical questions about how plants grew and why different plants behaved as they did. Theophrastus read these early Greek philosophers, including Democritus, Empedocles, and Anaxagoras, and he considered the questions they raised about plants, even when he disagreed with their answers.

Theophrastus weighed the opinions of these early writers with his own observations. Seeds carried food to nourish a plant; thus, Empedocles' description of seeds as eggs seems appropriate (*CP* 1.7.1). Democritus declared that straight trees with thin roots lived shorter lives than crooked trees with thick roots, an idea Theophrastus refuted by a comparison of the length of life in various trees and inspection of their roots (*CP* 2.11.7–9). Anaxagoras asserted that air contained the seeds of everything and that these seeds were carried down in rain and generated (Matter; Motion and Energy); Theophrastus countered that there is growth when rivers change course and streams burst their banks. Thus, moisture helps in the generation of seeds in the ground (*CP* 1.5.2). In a discussion of savors, Theophrastus summarized Plato's argument in *Timaeus* (65c1–6, *CP* 6.1.4) and disagreed politely with the Pythagorean Menestor, who thought that there were an infinite number of tastes and smells (*CP* 6.3.5).

Theophrastus' Methods of Gathering Information

Theophrastus observed plants on Lesbos, the Troad, Macedonia, Euboea, and Athens, and he gathered information from various sources, naming Thrasyas of Mantinea and his student Alexias (*HP* 9.16.8, 17) as well as Eudemus of Chios (*HP* 9.17, 18) on medicinal plants. Although he did not name Diocles of Carystus, Theophrastus may have used Diocles' (lost) *Rhizotomicon* for *HP* 9. Theophrastus referred to Cleidemus for the best time to sow (*CP* 3.23.1), Hippon for the difference between wild and cultivated forms of a plant (*HP* 1.3.5, 3.2.2), and Androtion as an authority on olives, myrtles, and pomegranates (*HP* 2.7.2, 3; *CP* 3.10.4). Satyrus, who collected plant samples in Arcadia, may have been a source for plants in the Peloponnese (*HP* 3.12.4). Theophrastus received reports from those accompanying Alexander on his expedition to the east, including Androsthenes (*CP* 2.5.5), who wrote his observations of plants along the Persian Gulf and on the island of Tylos (Bahrain). In addition to these named sources, Theophrastus included what he learned in a particular location, for example, "the people on Mount Ida say" (*HP* 3.12.3), "the people in Macedonia say" (*HP* 3.12.2), and other locations as well, but more frequently he simply recorded that "they say" (*phasi*, without an expressed subject).

Theophrastus' Work on Plants

Theophrastus' surviving botanical works are *HP* in nine books, *CP* in six books, a book *On Odors,* and a sizeable fragment from *On Honey.* (His surviving work on *Weather Signs* is not directly related to plants but would certainly be of interest to botanists.) Diogenes Laërtius records that Theophrastus wrote other books on botany: one book *On Wine and Olive Oil*, five *On Juices,* and one *On Fruits.* The titles of these books show how important economic questions were in the development of botany as Theophrastus discussed plants which produced odors for perfume, vines for wine, and olive trees for oil as well as fruits.

Theophrastus' Methodology

Theophrastus constantly revised and augmented his work while retaining a clear structure and direction to his argument. Aristotle's influence is evident in the questions that Theophrastus raised about plants, even to the title of one of his works (*History of Plants* corresponding to Aristotle's *History of Animals.* Our English "history" comes from Herodotus' *historiai* as the title for his work, but "enquiry" or "investigation" would better represent the meaning.) Theophrastus dealt with the parts of plants in *HP* (cf. Aristotle's *PA*) and plant generation in *CP* (cf. Aristotle's *GA)*. An *On Plants* attributed to Aristotle is generally thought to be spurious, extant in a corrupt text translated from Latin back into Greek.

Theophrastus defined plants by their differences from animals: plants, unlike animals, are rooted (mostly) and do not move, they take in nourishment but do not excrete a residue as animals do, and they are not perceptive as animals are (Lloyd 1996, 41–43, 67). When Theophrastus considered the definition of a plant and its parts, he found that while generally a plant has roots, a stem, branches, and twigs, there are exceptions. For example, some plants (like mushrooms) have no root, some have no stem. Plants also have parts which may become detached or die, like flowers, fruits, leaves, while the rest of the plant continues. Stems and leaves have component parts named by analogy with animals: flesh, veins, fiber, core (heart or marrow), and muscle, the last of which Theophrastus says is continuous, long, easily split, and unnamed. Theophrastus must have examined and dissected many different plants, not limiting himself to the external but looking at component parts of stems (trunks), leaves, and flowers. Roots are generally not visible above ground, so to describe roots he must have examined uprooted plants.

Theophrastus defined botanical differences adopted by botanists and still in use. Some of the most obvious are distinctions between annual plants, which produce seed at the end of their growing season; biennials like celery, which produce seed in the second season of growth; and perennials, which can survive and bear seed for many seasons (*HP* 1.2.2). And he noted distinctions between plants with enclosed seeds (angiosperms) and those with naked seeds (gymnosperms: *HP* 1.11.10).

Theophrastus arranged plants into four forms (*eidos*): trees (*dendron*), shrubs (*thamnos*), undershrubs (*phryganon*), and herbaceous plants (*poa*). He used these divisions to organize his work, though he recognized that climate, cultivation, prunings, and location may make a shrub a tree or vice versa (*HP* 1.3.1–3). He described trees first (*HP* 2–5), then other forms (*HP* 6–8), and, finally, medicinal plants separately in *HP* 9.

By observing the variety in which root, stem, branch, as well as leaf, flower, and fruit appear, Theophrastus provided terms by which any plant may be described, and he laid the groundwork to produce the plant entries that later botanists assembled. His terminology also ensured that his students and informants could give him a satisfactory description of plants that he had not seen.

A closer examination of Theophrastus' descriptions of leaves shows how comprehensive his observations were (*HP* 1.10). As a general division, a plant may be evergreen, that is, always in leaf, or deciduous, though some are evergreen only in certain climates or situations. (Fig trees and vines are evergreen in southern Egypt but lose their leaves in Greece: *HP* 1.3.5.) The leaf may be attached to the stem, branch, twig, or root, either directly to the plant (sessile) or by an intermediate stem (petiolate). The leaf may be round, oblong, lobed, or hollow. The edge may be smooth or serrated, and leaves may be single or divided.

After his introductory section of classification and terminology, Theophrastus proceeded to consider trees: cultivated trees and their propagation (*HP* 2), wild trees (*HP* 3), and trees and other forms native to different regions (*HP* 4). The inclusion of trees in Egypt, Libya, and Asia, and to the north of Greece shows that Theophrastus was gathering material on plants from a wide area, in some cases with the assistance of informants rather than from personal inspection. Unfamiliar trees not native to Greece are compared to similar Greek trees. For example, the Egyptian *persea* is like the pear tree, but the fruit has a stone like the plum (*HP* 4.2.5). The banyan tree (*Ficus benghalensis*), reported by those who accompanied Alexander, was compared in its various parts to the Greek fig tree (*HP* 4.4.4).

Theophrastus included aquatic plants in his study. He gathered information about plants growing in or near the shore of the Mediterranean, the Atlantic Ocean, and the Persian Gulf, as well as in and by rivers, marshes, and lakes, especially in Egypt. Theophrastus gave a detailed account of the plants of the lake near Orchomenus (now Lake Copais), which varied in depth and sometimes drained completely. It interested him that some water plants in this lake were completely submerged, whereas others were only partly submerged. Theophrastus' interest in Lake Copais, not far from Athens, suggests that he may have spent time in the area.

At the end of *HP* 4, Theophrastus discussed diseases, pests, and weather which affect plants, often giving specific examples from eyewitness accounts: the damage done by caterpillars in Miletus, the premature dropping of olives in Tarentum, plants losing leaves in a frost and leafing out again in Philippi, and the Olympian wind in Chalcis.

HP 5, given to trees used for timber, covers when to cut, the differences in trees, and uses of various kinds of trees. Here Theophrastus' frequent use of "they say" shows his reliance on tree cutters and carpenters. In *HP* 6–7, he considered wild and cultivated undershrubs, plants used for garlands, and cultivated and wild potherbs. His calendar of bloom (*HP* 6.8.1–4) is a reminder of the importance of wreaths for Greek cult and celebration. In *HP* 8, proceeding to cereal plants, Theophrastus discussed planting, the importance of soil and climate, and the tasks of the farmer: for example, manuring and irrigating (Greek and Roman Agriculture; "Ecology" in the Ancient Mediterranean). *HP* 9 deals with medicinal plants: sap in plants whose juices are collected and used for medicine as well as spices and aroma (*HP* 9.1–7) and roots, especially those used for medicine (*HP* 9.8–20).

Causes of Plants

In *CP*, Theophrastus began with the plant's distinctive nature: generation, sprouting, flowering, and fruiting (*CP* 1). He next discussed external occurrences: weather, soil, and water, and their effect on plants (*CP* 2). In *CP* 3–4, contemplating how human action (agriculture) may help plants, he began with a consideration of plants that do not prosper under cultivation. In *CP* 5, he examined the causes of disease and death in plants and (again) how human action may contribute. *CP* 6 discusses plants from which flavors and odors are obtained. Theophrastus noted that while the goal of a plant is to produce seed, the intent of the farmer is to produce food, and for this the farmer works to provide the appropriate soil and air for the plant.

Theophrastus' Reputation and Legacy

It would be hard to exaggerate Theophrastus' accomplishments in botany. For example, Greene (1909/1983, 140–142) attributes seventeen botanical discoveries to Theophrastus, many ignored until Linnaeus and later botanists. In addition to providing a vocabulary for identifying parts of plants, Theophrastus divided plants into flowering and flowerless, monocotyledon and dicotyledon, and angiosperm and gymnosperm. He investigated how plants take in food, the effects of climate on plants and how "art," that is, agriculture, may increase a plant's life-span and fruitfulness.

HP was made available in English in the Loeb Classical Library (Hort 1916, 1926) with an index of plants by Thiselton-Dyer included in the second volume. Amigues has recently completed her text and French translation of *HP* (1988–2006). *CP* did not receive the same attention from translators. Apart from Dengler's translation and commentary on *CP* 1 (1927), translations remained hidden away in typescript until Einarson and Link's Loeb translations (1976, lxvi).

Project Theophrastus began under the direction of William Fortenbaugh in 1979 with the intention of collecting, editing, and translating the fragments of Theophrastus. The botanical fragments were published in 1992 and a number of articles in *RUSCH* have addressed botanical matters (Van Ophuijsen and van Raalte).

4. After Theophrastus

In the centuries between Theophrastus' death and the writings of Dioscorides and Pliny, there are a few figures of interest in botany. It is regrettable that *On Plants* by Theophrastus' student Phaenias has not survived. To judge by places where Athenaeus in the *Deipnosophists* ("Learned Banqueters") made reference to both Phaenias and Theophrastus on the same plant, Phaenias followed Theophrastus and expanded on his material (e.g., 1.31f–32a wine, 2.54f chickpeas, 2.61e–f mushrooms and truffles, 2.64d hyacinth bulbs, 2.70d cactus, and 9. 371d carrot).

Crateuas, physician to King Mithridates VI of Pontus (120–63 BCE), made a significant advance when he commissioned illustrations of the plants, whose medicinal uses he was describing, for his *Rhizotomicon* (Singer 1927, 5). Although his work does not survive, his continued influence is evident from quotations incorporated into a sixth-century CE manuscript of Dioscorides (*Codex Vindobonensis*), and it has been argued that

the best of the illustrations in this manuscript were copied from Crateuas (Singer 1927, 17). Pliny said that Crateuas (and two other writers, Dionysius and Metrodorus) added illustrations of plants to their work. However, Pliny (*NH* 25.4) was critical of the illustrations because of the difficulty in producing colors true to nature, the inaccuracy of the artists in their depictions, and of illustrations showing plants at one season only, while a plant changes its appearance from season to season. In spite of Pliny's caveat, the style of illustrating botanical texts has been a useful tool in identifying plants. In particular, the concern about a plant's changing appearance with the seasons is overcome by showing bud, flower, and seed. Crateuas was a source for both Dioscorides and Pliny.

Two poets during this period displayed an interest in botany in different ways. Nicander of Colophon borrowed material for his poems on medicinal plants and poisons (*Theriaca* and *Alexipharmaca*) from the *Alexipharmaca* of Apollodorus (third century BCE), who in turn had used material from the *Rhizotomicon* of Diocles of Carystus. Gow and Scholfield are critical of the botanical information in Nicander (1953/1977, 8, 23–25) and of the illustrated manuscript with labeled drawings (appendix 1, 222–223). Nicander also composed a poem on farming, *Georgica*, the longest fragment of which treats gardens and flowers (f74: Gow and Scholfield 209). The descriptions are either too general to be of use (e.g., campion [*lychnis*: fragment 74.36] has flowers of "dazzling hue") or oblique (e.g., cyclamen is "modest:" fragment 74.71, where Gow and Scholfield see a possible reference to its reflexed petals).

Another poet, Theocritus (born 310 BCE), named an astonishing 87 plants in his *Idylls* and demonstrated an unusual accuracy in his descriptions. He was careful to locate plants in an appropriate habitat: plane trees beside water, oak and cedar on mountains, and plants of the maquis in the foothills (Lindsell 1937/2000, 67–68). His descriptions suggest that he had examined plants closely: the poppy is not just red, it is "soft;" celery is not just green but "much twisted …. very descriptive of the frilly leaves of the celery" (Lindsell 1937/2000, 66). Raven's assertion (2000, 26) that "Theocritus possessed an interest in and a knowledge of wild plants without precedent in the whole range of early Greek literature" is supported by examining the plants which Theocritus placed near the pool into which nymphs dragged Hylas (*Idyll* 13). Raven argues that each plant is right for the habitat and that the adjective which describes each is botanically precise: particularly *dark* celandine (to distinguish it from the greater *lighter colored* celandine) and *creeping* grass to capture its habit of rooting as it creeps (Raven 2000, 25–26). Raven agrees with the proposal made by Lindsell (1937/2000, 66) that the knowledge of plants may have come to Theocritus from Theophrastus himself.

5. Dioscorides

We know little of Pedanius Dioscorides' life beyond what he told us in the letter addressed to his teacher and colleague Areius of Tarsus in Cilicia which prefaces his *De Materia Medica*. Born in the first century CE in Anarzarbus near Tarsus, Dioscorides was a medical practitioner. He wrote of his "soldier's life" (*stratioticon ton bion*, preface 4), leading some scholars to conclude that he was an army doctor, and others that he referred to the hardships and discipline of his life rather than his occupation (Riddle 1985, 4; Scarborough in Beck 2005, xvi; see also PHARMACY). Dioscorides claimed to have made "personal observation in utmost detail" of most of the items included in his work

(Beck 2005, 3, preface 5). He apparently traveled widely in the Mediterranean, visiting Egypt, Syria, Palestine, Asia Minor, Greece and the islands, and Greek communities in Sicily, southern Italy, and southern Gaul (Riddle 1985, 3).

De Materia Medica

Dioscorides included about 600 plants as well as minerals and living creatures in his five-volume book on medicinal material; its Greek name, *Peri Hyles Iiatrices*, was translated into Latin as *De Materia Medica*, the name by which this work is usually known. We shall concentrate on Dioscorides' plant entries. Book one treats plants often characterized by smell or taste: aromatics, oils, unguents, saps, resins, gums, asphalt, pitch, evergreens, and fruit trees. In the second book, after discussing animals used for medicine, Dioscorides described cereals, vegetables, and pungent (sharp) herbs. In book three, he included roots, plant extracts, herbs, and seeds. Roots are continued with herbs in book four. Vine, vine products, and minerals are described in book five.

Explicitly rejecting the alphabetical ordering of his predecessors, Dioscorides organized material instead according to "properties." For example, iris (1.1), akoron (1.2), and others which follow are "warming;" onion (2.151), garlic (2.152), garlic leek (2.153), mustard (2.154), and garden cress (2.155) all have "sharp" properties. Dioscorides intended this grouping of medical materials with similar properties to assist physicians looking for treatments; if a particular substance was unavailable, material with a similar property could be substituted. But in spite of Dioscorides' explanation in his preface, the earliest surviving manuscripts reorganized the material in alphabetical order (Riddle 1985, 25).

To judge from papyrus fragments, previous pharmacologists had discussed plants one at a time. Some, at least, illustrated their manuscripts to assist in identifying plants. Most famous was Crateuas, whose work is known largely because some of his entries were added to Dioscorides' manuscripts (see above, §4). Like his predecessors, Dioscorides had a separate entry for each plant. Some plants are described fully, whereas others are simply named. When Dioscorides commented on certain plants as "well-known"/"familiar" (*gnorimos*), he gave little or no description (e.g., 1.96: papyrus). Whether he illustrated his work is not certain. Riddle (1985, 28) argues that without illustrations Dioscorides' descriptions would have been insufficient for identification. Scarborough (2008) is inclined to think that the text was not illustrated and that the plants not described in detail would have been well known. Illustrations, nonetheless, were included in later copies, and the style of entry and illustration became a model for later botanists. Dioscorides treated each plant entry in a standard order. A typical entry includes the plant name followed by synonyms; the habitat where the plant grew, for example, woods, plain, mountain, and riverbank; a botanical description; medical uses; and any geographical locations where the best specimens were found (Riddle 1985, 25–26). Not all components were given for every plant.

Let us compare the entry on hyssop (*Satyreia graeca* L. = *Micromeria graeca* Benth.) with the one on Achilles' woundwort (*Achillea millefolium*). The entry on hyssop (3.25) is brief. Dioscorides wrote simply that it is "well-known" (*gnorimos*) and that there are two kinds, "for one grows on mountains and the other in gardens; the best grows in Cilicia" (Beck 2005, 190–191). In contrast, he described Achilles' woundwort at great length (4.36), including a synonym *sideritis* which was also the name in the previous three entries (4.33–35):

> [Achilles' woundwort] bears shoots that are a span long or even longer, spindle-shaped, and surrounded by thin little leaves that have frequent slits at the sides; they resemble the leaves of coriander, they are somewhat bitter, slimy, strong-smelling, not unpleasant, but medicinal in scent. On top it has a rounded flower-head. The flowers are white, becoming later golden. It grows on fertile lands. (Beck 2005, 263–264)

The description captures in detail, even to the smell, the plant we know as yarrow.

Whereas Theophrastus discussed the individual parts of many plants but did not give a complete description of any particular plant in one place, Dioscorides treated whole plants individually. He did on occasion compare a part of one plant to the same of another, as in the example of Achilles' woundwort, whose leaves were compared to those of coriander.

Dioscorides' Sources

In his preface, Dioscorides explained why his own work was necessary by identifying the shortcomings of his pharmacological predecessors, whom he cited by name. Iollas of Bithynia and Heraclides of Tarentum (preface 1–2) did not cover the subject adequately, while Crateuas the root-cutter and Andreas the physician neglected to include many "highly serviceable" roots and certain herbs. Dioscorides acknowledged the accuracy of these last-named writers while being critical of more recent authorities, Julius Bassus, Niceratus, Petronius, Niger, and Diodotus, followers of the physician Asclepiades, who treated diseases with diet rather than medicines (preface 2, Beck 2005, 2). Pliny, too, named almost all these writers among his sources; Niger is Pliny's Sextius Niger, and many similarities between Dioscorides and Pliny have been attributed to their common use of Sextius Niger and other sources.

Dioscorides' Reputation and Legacy

Dioscorides' work was translated into Arabic, Syriac, and Latin, and it remained the standard authority in Europe until the sixteenth century. Even later, he was a reference for botanists like Sibthorp who, between 1786 and 1795, traveled in the Mediterranean area, gathering samples for his *Flora Europaea*. The manuscript tradition is complicated because, as early as the third century CE, the entries were reorganized alphabetically and copyists inserted synonyms for plant names and notes on various plants (Scarborough in Beck 2005, xviii–xix).

The rather quaint English translation by John Goodyer (1655) with modifications by Robert T. Gunther (1933) did not help Greekless readers wishing to consult Dioscorides. Beck's English translation (2005), based on the Greek text and employing recent scholarly work and modern botany, will make *De Materia Medica* more accessible in a more accurate rendition.

A study of Dioscorides must take account of the famous and much-admired manuscript of *De Materia Medica* presented to Anicia Juliana in 512 CE (Mazal 1998). In this codex, now in Vienna (Med. Gr. 1), each plant entry is accompanied by an illustration, some excellent (e.g., *Aristolochia sempervirens*, folio 17v, Riddle 1985, 185), and others neither accurate nor artistic.

6. Transition to the Roman World

The Greeks were often interested in plants for their medicinal uses, and many of those who wrote on plants paid particular attention to medicinal plants (e.g., Theophrastus, *HP* 9; Dioscorides, *Materia Medica*). For the Romans, the study of plants was often directed to agriculture. Three Roman prose authors, Cato the Elder, Varro, and Pliny's contemporary Columella, advised farmers on how to be successful in raising plants and animals for food. In the case of plants, Roman authors wrote about choosing good locations for planting crops, fertilizing, and shaping fruit trees through pruning and grafting. They emphasized the importance of agriculture and the fertility of Italy, and ordinarily they did not describe plants except in discussing varieties of olives, vines, and fruit trees (Greek and Roman Agriculture).

The poet Vergil was also interested in agricultural plants. He drew on Theophrastus and Varro as sources for his *Georgics*, a poem on farming. In *Georgics* 2, Vergil described methods of grafting and the care of vines and olive trees. (Some of his grafting examples would not have been successful because the graft did not belong to the same botanical family as the rootstock: Sargeaunt 1920, 4; Thomas 1988, 2.19–21, 161.) In Vergil's total poetic output, we find the names of about 80 plants (Sargeaunt 1920), though some seem to have been mere names, borrowed from Greek poets, rather than plants known to the poet. One plant, however, *amellus* (*Georgics* 4. 271), has been admired for the botanical precision of its description (Martyn 1811, x, 449; Sargeaunt 1920, 14–16). The poet, who learned the name of the plant from farmers, distinguished the golden disk (*flos … aureus ipse*) from the surrounding ray florets (*folia*) in which purple shines beneath dark violet (*violae sublucet purpura nigrae*). With a touch of humor, Vergil says the plant sends up a vast forest (*ingens silva*) from a single root clump or stool (*caespes*). Its bitter flavor, as well as its use for sick bees, indicates a direct experience with the plant which we can identify with confidence as *Aster amellus* L., the European Michaelmas daisy, a member of the *Compositae* family.

Pliny's contemporary Columella used Cato, Varro, and Vergil in his work on agriculture, in which he discussed soils, viticulture, fruits, and olive trees, as well as farm animals and beekeeping. His tenth book on gardens and flowers was written in hexameters, in homage to Vergil and to satisfy a perceived lack because Vergil did not include garden flowers in the *Georgics*.

From these works, we can appreciate what Romans knew about native plants, especially agricultural plants, but it is to be noted that foreign plants usually remained nothing more than names. Pliny's *Natural History* differs from these agricultural works because he included reports of exotic plants, the descriptions of which he garnered from his reading in both Greek and Latin, as well as plants that he had observed first hand in Spain, Africa, and Germany.

Pliny chose to include material on animals, plants, minerals, and art in *NH* (Scientific Encyclopedias). Pliny's list of topics by book in *NH* 1 may have encouraged his readers to go directly to a topic of interest, bypassing others, but this method loses the characteristic Plinian flavor of information mixed with anecdote (Murphy 2004; Doody 2010, 30).

7. Pliny the Elder

Pliny the Elder was not a philosopher like Theophrastus, nor a physician like Dioscorides. His interest in plants was not part of his professional life but rather arose from a general and lively interest in the world in which he lived. He was more familiar with the western Empire than the eastern, having served in his twenties in the Roman army in Germany, where he met the future emperor Vespasian and his son Titus. Pliny served in Africa, became procurator in Spain, and accepted a naval commission and charge over the fleet at Misenum on the Bay of Naples. It was in that capacity that he observed the eruption of Vesuvius in August 79 CE and lost his life. Years later, his nephew Pliny the Younger described how his uncle was proposing to make a closer examination of the cloud of volcanic ash that was shaped like an umbrella pine. When he received a letter asking for help, the Elder Pliny sent the fleet to rescue the stranded inhabitants (*NH* 6.16). Curiosity seems to have been a characteristic of Pliny, but so too was the desire to serve.

We know rather a lot about Pliny's methods because of a letter written by this same nephew (3.5). Rising while it was still dark, his uncle worked into the evening; slaves read to him as he ate, bathed, and was carried in a litter. Pliny dictated passages—which he found interesting or relevant—to be incorporated into his writings. As he dictated, he apparently translated into Latin many of the Greek passages read by his slaves. His method of note-taking was well known, for his nephew records that he was offered a large sum of money for his notes, an offer he rejected.

Dedicating *NH* to Titus, Pliny included a list of the topics so that Titus would be able to find what interested him without needing to read through the whole work. Familiar with many authors now lost to us, Pliny scrupulously acknowledged his sources, including, for his botanical sections, both pharmacological and agricultural writers, poets like Homer and Hesiod, and contemporary figures like the future emperor Domitian, as well as philosophers like Theophrastus, and his Roman predecessors Cato, Varro, and Vergil. Pliny also credited Sextius Niger (who wrote in Greek in spite of his Roman name: *NH* 12, 13, 20, 21–30, 32–34), Nicander (*NH* 20, 21, 22, 26), Solon of Smyrna (*NH* 20, 24, 25), Crateuas (*NH* 24, 25), Cornelius Celsus (*NH* 27), and many others. Pliny's work, therefore, differs from Theophrastus' and Dioscorides' in being mostly material gleaned from others rather than first-hand experience, though Pliny confirmed his data when possible.

Pliny called his work *Naturalis Historia*, recalling Theophrastus' title *Historia Plantarum*. Though *NH* is commonly translated *Natural History*, it might be better translated *Enquiry into Nature* or, as Murphy (2004, 33) suggests, tongue in cheek, *Enquiry into Everything*, because, as Pliny said, "nature, that is, life, is my subject" (preface 13).

Of the 37 books in *NH*, books 12–27 deal with plants. Like Theophrastus, Pliny began with trees: an overview of trees throughout the Empire (12), trees outside Italy (13), fruit trees (14–15), forest trees (16), and cultivated trees (17). He then discussed crops, grains, and gardens (18–19), medicinal plants (20), flowers for garlands (21), herbs and dye plants (22), and trees with medicinal uses (23–24), with a discussion of the value of plants (25), medicines by classes and diseases (26), and some remaining plants and medicines (27).

While Pliny at times provided seriatim entries on individual plants, he interrupted the encyclopedic flow with tales of strange plants and people associated with plants. For example, in his discussion of flowers for garlands, Pliny described the history of wreaths, then some individual flowers (rose, lily, narcissus, violet, and others), turning next to plant fragrance and color. After discussing several more plants, he described wreaths made of a variety of plant material, especially leaves. He provided a sequential bloom calendar of wreath plants from spring to autumn, ending with a digression on bees and honey. After discussing garden plants, he turned to wild plants, prickly plants, plants with flowering spikes, and medicinal plants. And he finally then returned to the rose, lily, narcissus, and violet. In the midst of his discussion of wreath plants, Pliny related an anecdote about Cleopatra VII, who secretly dipped flowers into poison and then suggested that her revelers "drink their wreaths" by throwing the flowers into their wine. The queen brought in a prisoner, who drank the poisoned wine and died (*NH* 21.9). Pliny described the dangers of the Pisidian iris (which raises blisters on the hands of those who gather it: *NH* 21.19) and the usefulness of *cnecus* (an Egyptian plant, which protects those who hold it from venomous snakes and scorpions: *NH* 21.57). Reading only the entry on one plant as one would do if using *NH* as an encyclopedia, the reader misses the narrative flow. Reading the whole book, the reader is carried along and, I dare say, entertained.

Pliny was not a scientist, and his methodology indicates that he did not see himself as an original thinker. It would be easy to denigrate Pliny's accomplishment in *NH* and to dismiss him as a mere collector of information, credulous, and naïve. But, though he learned from books and was scrupulous in acknowledging his debt, he also kept his eyes open. He added notes about places in the Empire where plants grew. He spent years in Africa, Germany, and Spain, so when he wrote of German asparagus (*NH* 19.145), or beans on islands on the North Sea (*NH* 18.121), or crops planted in the shade of trees in Africa (*NH* 17.41), he was adding information from autopsy. He criticized other writers for not describing the plants they were writing about and recounted how he acquainted himself with almost all the plants in *NH* by visiting the garden of Antonius Castor (*NH* 25.5, 9), where he saw most of the plants he mentioned. This garden must have been a remarkable place, for Pliny says that Castor tended "vast numbers" of plants until he passed the one hundredth year of his age.

Pliny's Reputation and Legacy

Although Pliny was highly regarded up to the eighteenth century, his reputation dipped in the nineteenth century: he had made mistakes in material gleaned, for example, from Theophrastus; he had shown poor judgment in including unbelievable material; and he was not a field botanist but a mere compiler.

Pliny also has his defenders. André (1955) explains some botanical errors in Pliny's texts as the result of oral transmission of information from reader to Pliny to his secretary. Stannard (1965) points out that Pliny is valuable for tracing the development of botany and calls attention to Pliny's own contributions with particular admiration for his entry on the lily, which surpasses that of Dioscorides (21.23; cf. Morton 1986, 94).

More recent work has begun to consider Pliny's work as a whole rather than individual entries. Beagon (1992, 79–91) emphasizes that in the botanical books Pliny saw human

activity in partnership with nature, for example, in gardening and grafting. Pointing out Pliny's diligence in consulting so many authors, non-Roman (Healy 1999, 327) and Roman (1999, 146), Healy defends Pliny's inclusion of anything which might be useful to his readers, even the marvelous (1999, 77, 64). Murphy (2004, 23) argues that plants are part of Pliny's definition of the Roman world, with different plants mapping the extent of the Empire. Tracing the reception of and changing attitude to Pliny's *NH*, Doody (2010, 11–14) argues for rethinking the term encyclopedia for Pliny's work.

Pliny's *NH* remained accessible without interruption in western Europe and was consulted by those interested in botany. Subsequent writers were largely derivative, for example, *Medicina Plinii*, which reissued Pliny's material on medicinal plants in the fourth century CE as a separate work.

8. Conclusion

The need to identify plants and to understand factors influencing their growth developed from their medical and economic use. Plants which received attention were in the broadest sense "useful," and for this reason they had names and were described and differentiated from similar plants. Theophrastus built on the knowledge of plants acquired by those who needed and used them, but he did not simply gather information; he reached a definition of "plant," described the parts of plants with their habit of growth, and considered the effect of climate, rain, and altitude on plants. Theophrastus laid a foundation by developing a vocabulary to describe plants and by raising questions about the way human action could improve on nature and the limits of that improvement. Later writers moved from the big picture to concentrate on individual plants. Dioscorides described individual medicinal plants with their properties without any general discussions of plants. Pliny gathered material and anecdotes from many authors and sources, but he too was interested in individual plants rather than wider questions. In the period covered by this study, Theophrastus was the giant on whose shoulders later writers stood.

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CHAPTER 17

Zoology

Tiberiu Popa

1. Introduction

The history of ancient zoology divides conveniently into three major segments: pre-Aristotelian speculation and unsystematic observations; Aristotle's studies on the nature and generation of animals; and subsequent authors who emulated, plundered, or tried to enhance the Aristotelian heritage and tended to focus on the exotic and marvelous. Such a triptych belies the remarkable arborescent complexity of this history. We should, therefore, remain mindful of three challenges inherent in any effort to map the early history of zoology in greater detail.

(a) Disentangling genuinely zoological investigations from, say, medicine or cosmology is a delicate and potentially risky enterprise. We must be careful to eschew our own preconceptions of what qualifies as zoological research. Ancient authors rarely provided explicit criteria.
(b) Establishing intellectual lineages in ancient (proto)zoology, as in other fields of ancient science, has long been the delight and despair of scholars. What might appear a simple and direct filiation (Plutarch's borrowings from Pliny) may well amount to an inextricable knot of influences, use of common sources, and textual interplay. Even when we can trace details in later works (e.g., Oppian) to their ultimate source (e.g., Aristotle), the extent to which those details were culled directly from the original source or filtered through successive anthologies often remains opaque and intractable.
(c) Several studies, despite contemporary popularity, survive only in summaries or as fragments and allusions. Among these are works by Speusippus of Athens (*fl.* 380–339/338 BCE), who wrote about similarities between different animals;

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Bolos of Mendes (*fl.* 250–115 BCE), known for his peculiar interest in the magical qualities of plants, animals and minerals; and Alexander of Myndos (*fl.* 10 BCE–40 CE), whose treatise on animals was admired.

Animals pervade Greco-Roman literature and culture, but we focus here only on largely intact treatises that provide a systematic discussion of animals, including studies on comparative anatomy and physiology, animal behavior, and, particularly in Aristotle's case, a clear and robust philosophical foundation for research in this newly demarcated domain.

Let us begin with the Presocratics. According to Anaximander, animals first came about in moisture (*TEGP* 37–38); humans were born originally from other animals (*TEGP* 19), possibly from fishlike creatures (*TEGP* 38–39; The Failure of Evolutionary Thinking in Antiquity). From Parmenides, we have two short, rather tantalizing fragments (*TEGP* 54–55) on embryogenesis (Embryology). From Empedocles, we are fortunate to have several fragments on the cosmic cycle governed by Love and Strife, including the emergence of all forms of life (*TEGP* 41, 45), and the rough outline of a distant precursor of the theory of natural selection (*TEGP* 119, 121; The Failure of Evolutionary Thinking in Antiquity). Empedocles also discussed reproduction (e.g., *TEGP* 130). Diogenes of Apollonia (*fl.* 445–425 BCE) believed that differences in shape, behavior, and intelligence—responsible for the variety of what we call species, and even for differences between individual specimens within a species—are due primarily to the various attributes (especially degrees of heat) of the *aēr* that constitutes them (*TEGP* 9). Diogenes also ventured theories regarding whether and how the fish breathe (*TEGP* 28).

Early writers, including Plato, showed keen interest in human anatomy and physiology, but they exhibited little curiosity about the diversity of animal life, despite Plato's division of living beings into winged, aquatic, and land animals (*Timaeus* 91c–92d). In contrast, the Hippocratic *On Regimen* book 2 (probably late fifth century BCE) examines types of food and their effects (warming, cooling, drying etc.) on our bodies. Chapters 46–49 concentrate on characteristics of meat. Edible animals are divided into a variety of quadrupeds (goats, pigs, sheep, donkeys, dogs, wild boars, deer, foxes, hares, and hedgehogs), birds (partridges, pigeons, etc.), and aquatic animals (octopus, oysters, lobsters, many kinds of fish—torpedo fish, eel, etc.) Some are grouped into wild and tame (wild animals are drier than tame ones) or divided according to habitat (fishes and other kinds of aquatic animals). There are also brief mentions of anatomical features and correlations (pigs are fleshy and have small veins with little blood; animals with thin flesh also have thin milk and blood). These few short chapters constitute an intriguing early attempt to divide animals according to overlapping criteria, not limited to nutritional properties.

Early historical and ethnographic studies also include interesting references to the physical characteristics and the behavior of animals. In his *Histories*, Herodotus frequently mentions wild animals and their habitats (i.e., European aurochs and lions: 7.126, 127; Egyptian hippopotamus, ibis, several kinds of snakes: 2.68–74). Herodotus also offers a memorable description of the crocodile's morphological features, its behavior, and interaction with other species (2.68–70).

Ctesias of Cnidus, who worked as a physician at the Persian court (circa 405–390 BCE), seems to have inspected exotic animals first hand, including elephants, and some of his descriptions are rather accurate. Ctesias, however, was also captivated by marvels and fantastic animals (including the hybrid martichora, whose curious appearance

and fierce temperament were probably inspired by stories about tigers). Even though Ctesias' *Indica* and *Persica* have not survived intact, references and criticisms by later authors (including Aristotle, Pliny, and Aelian) point to a wide popularity and lasting influence.

Although such accounts are important to us, pre-Aristotelian commentary on the nature and generation of animals tended to be ancillary to medicine and cosmology, among other fields. With Aristotle, the study of animals becomes a well-defined scientific domain with a specific set of goals, concepts, and methods.

2. A Science Is Born

Aristotle dealt with "zoology" (he lacked a term for this new field of study) in several works of various lengths, falling into two categories. The *Enquiry into Animals* (*HA*) is concerned principally with organizing facts (e.g., differentiating between tissues and instrumental parts of distinct kinds of animals or ways of life or types of reproduction)—no evolutionary perspective should be assumed here: Aristotle was convinced that species are eternal, and *historia* has the more general meaning of "inquiry." *Generation of Animals* (*GA*) and books 2–4 of *Parts of Animals* (*PA*) are intended to offer causal explanations for distinctive characteristics. A few shorter treatises, including a set of works known as *Parva Naturalia* (*Short Treatises on Nature*), as well as a three-book *On the Soul*, complete this vast corpus.

Those two groups of biological works correspond to two interconnected types of investigation, examined in Aristotle's theory of scientific inquiry (*Posterior Analytics*) and in his discussion about the method to be followed in zoological studies (*PA* 1). A celebrated passage in the second book of the *Posterior Analytics* (89b36–90a34) states that, at a rather basic epistemic level, we can seek to grasp the fact (the "that") and whether something is the case (e.g., if the moon is/exists); once we know the fact, we can then try to discover the "why" (e.g., why the moon is eclipsed). Implicitly, we seek to determine whether there is a "middle" common to both premises, representing the cause. If the first step in a scientific inquiry is concerned mainly with establishing facts, the next step is determining what those causes—the middle terms—are.

Although the discourse of the *Posterior Analytics* is expectedly generic, we find a theoretical discussion of the science of animals in particular in the first book of *PA*. In keeping with crucial aspects of his natural philosophy and metaphysics, Aristotle here urges the student of nature to pay attention to the material constitution of various kinds of animals and also the functions of the parts, and the physiological processes and capacities that circumscribe the natures of animals (in contrast with most of Aristotle's predecessors: *PA* 640b5–641a33). These formal and teleological aspects of biological study ensure ultimately that we are able to grasp the "why" and to achieve a scientific understanding. After all, the form of a living being is its essence (*ousia*, *PA* 641a25), its soul (*psychē*). These two types of "causes" (*aitiai*), matter and form, are connected in important ways, primarily by virtue of a conditional necessity (*PA* 639b21–40a11), which applies both to works of nature and to artifacts. Aristotle summarizes his theory of conditional necessity at *PA* 639b25–6: "If a house or any other goal is to be achieved, it is necessary that material of such kind will be available." In a biological context, it is necessary for flesh or bone (or their analogues) to have certain material properties, like flexibility or hardness, if their functions are to be realized in the course of an organism's

activities. Aristotle's explanatory apparatus based on natural teleology is employed most profitably in *PA* 2–4 and *GA*, pointing to the theoretical framework to be followed in the study of animals. Collecting the relevant facts and organizing them suitably in *HA* is an important step, but this by itself will not allow us to fully comprehend the nature of those animals. Rather, it should be regarded as conducive to the next step—a causal explanation of those facts, centered on natural teleology and thus on a systematic appeal to functional accounts.

Conspicuously avoiding references to final causation, the *HA* focuses instead on the "what." A casual reader might be impressed by the sheer volume and range of the data carefully collected in *HA* 1–9 (Book 10, concerned with causal explanation, was likely not originally a part of *HA*)—from the anatomy of chameleons (503a15–b28) or the nature of sponges (548a33–549a13) to minute and accurate notes on the development of a chick's embryo (561a3–562a21)—and by the extraordinarily keen sense of observation detectable in those memorable passages. Modern scholars have often discussed a handful of examples of zoological observations, regarding, for example, the octopus (which uses its hectocotyl arm for copulation: 524a2–9), the smooth dogfish (one of the peculiarities of this shark is that the embryo develops live inside the womb, surrounded by a membrane—not unlike four-footed animals, Aristotle writes—and it remains attached to a sort of placenta through an umbilical cord: 565b2–12), and the catfish (the male rather than the female fiercely protects the eggs: 621a20–b2). Aristotle clearly relied on reports from fishermen, hunters, and travelers, but his seemingly autoptic accounts are particularly remarkable in their detail. Significantly, Aristotle seems to have performed dissections, and he wrote on the topic (*Dissections*, lost).

Astoundingly accurate as some of those observations are, *HA* is more than a mere assemblage of "facts." The overall goal of *HA* is to "establish first the existing differences and the attributes in all [animals]" (491a10–12; cf. *PA* 645b1–2), where "differences" and "attributes" are virtually synonymous. Hinting transparently at *PA* and *GA*, Aristotle added that "we must then try to discover their causes." That much is clear; what is considerably more elusive is the particular organizing principles employed by Aristotle in his treatment of those differences. One of the striking features of *HA* is the number of correlations among many sets of essential or accidental differentiae: animals with a bladder also have a bowel (489a5); no egg-laying animal has an epiglottis over the windpipe (540b3–4); and viviparous four-legged animals with horns but without teeth in both jaws have four-chamber stomachs (507a34–35). Such correlations and a host of comparisons between kinds of animals with regard to their attributes seem to indicate an attempt at a wide-ranging division.

As Balme (1987, 69–89), Lennox (2001, 7–38), and others have argued convincingly, *HA* is meant to organize a staggering amount of data pertaining to almost four hundred species, according to criteria that reflect, at least in part, a number of theoretical precepts expressed in the *Posterior Analytics* (e.g., 2.13) and, especially, in the first book of *PA*. The *HA*'s overarching purpose is to provide a division of animals that would eventually enable Aristotle to find the causes (the "middles") which underlie and explain the defining characteristics of the kinds of animals studied in *HA*. Modern readers who hope to find in *HA* a classification of animals by genera and species need to adjust their expectations. Now, Aristotle does list several "very extensive kinds" (*HA* 490b7–9, cf. *PA* 1.4), themselves further divisible, and references to the relation between kinds (*genē*) and forms (*eidē*) of animals are a staple of his terminology. Three of these are

kinds of "blooded animals"—birds, fishes, cetacean; four are "bloodless"—"potsherd-skinned" animals (shellfish), soft-shelled animals (like crabs and lobsters), "soft ones" (like calamari and cuttlefish), and insects. Elsewhere in *HA* (490b31–91a4, 505b25–31, etc.), Aristotle speaks of four-legged "live-bearers" and four-legged "egg-layers" as kinds which comprise many forms of animals. Some of the categories mentioned in *HA* have common names (birds, fishes, humans, etc.); others are nameless (490b32), labeled as "blooded," "bloodless," etc.

This being said, while forms are generally understood as subdivisions of kinds, those forms and kinds can be situated at various levels of generality: a *genos* could correspond to, say, our modern class or order; *eidos*, for example, to an order, species, or subspecies.

As if trying to solve one of his own methodological dilemmas in *PA* 1 (639a16–24), Aristotle decides that, instead of investigating every aspect of the nature of a certain animal individually, it would be preferable, because more economical (*PA* 645b11–14 on the avoidance of unnecessary repetition), to discuss attributes common to many kinds of animals. In *HA* 1–4, we find an impressively sustained and detailed discussion of morphological differentiae—internal and external organs or instrumental parts, from the parts of the head to limbs, and uniform parts (bones, flesh, marrow, etc.). These differences are marked out in terms of degree ("the more and the less," e.g., 486a22–23) when attributes belong to similar sorts of animals (birds with different types of feathers, beaks, behavior) or in terms of an analogy between types of parts that fulfill comparable functions, when the comparison is made between significantly different kinds of animals (lung: gill; nail: hoof; hand: claw; feather: scale—e.g., 486b16–17). Most divisions operate within the confines of very large categories of animals, both blooded and bloodless. Books 5, 6, and 9 (7) are focused on differences in modes of reproduction, nesting, and the rearing of offspring; book 9 (7) is devoted to human beings. Books 7 (8) and 8 (9) deal with diet, ways of life, the influence of seasons on health, and character or temperamental dispositions, respectively. (Balme's 1991 and 2002 editions follow the order of the books as presented in the manuscripts, rather than in various modern editions.)

A consequence of this complex division based on multiple differentiae is that in order to get a rich (though not complete—teleology is all but absent from *HA*) picture of the nature of the elephant or bee, whale or ostrich, one must track down the relevant attributes under each major set of differentiae: uniform and non-uniform (external and internal) parts, breeding, temperamental dispositions, diet, likely causes of disease, and so on. The use of multiple differentiae is accompanied by a firm rejection of Plato's method of dichotomy (*Statesman* 264a1–6; cf. Aristotle, *PA* 643b19–25), a type of division which, Aristotle argues, is fundamentally arbitrary and does not guarantee a complete set of essential properties of any given kind of animal. To avoid this outcome, Aristotle introduces a requirement for successive differentiation intended to ensure that the final differentia entails its antecedents. Animals are divisible into, for example, footed and footless; footed animals as a group can be divided into two-footed (people, birds) and many-footed, which in turn can be divided into four-footed, and so on. If footed animals were divided into gregarious and solitary, it would be apparent that these attributes could not be derived from "footed," except accidentally. Aristotle's method of division is too complex for an adequate description here, but it is important to reiterate that Aristotle, as proved in *HA*, was mindful of his own philosophy of science and, in particular, of his philosophy of biology, when pursuing his zoological project.

Causal explanations, virtually absent from *HA*, are among the cardinal features of *PA* books 2–4, *GA*, and *On the Locomotion of Animals*. The general purpose of *PA* 2–4 and *GA* is to elucidate the "why"; why it is that some animals exhibit certain characteristics and not others, with respect, for example, to their constitutive parts or modes of reproduction. Explanations are couched predominantly in teleological terms, a concept that pervades *PA* 2–4, whose leitmotif is "nature does nothing in vain" (e.g., *PA* 658a36; *GA*: 741b4–5, 744b11–12; for Aristotle on final causation, see Lennox 2001, 225–302; Gotthelf 2012, 3–150; Leunissen 2010). This need not surprise us since in his treatise on what we might call philosophy of biology, *PA* 1, Aristotle proclaimed that final causes should hold a privileged place in the study of nature (639b13–16). Yet, conforming also to other sections of *PA* 1 as well as to the *Physics* (e.g., 198a22–25, where Aristotle reminds us that the natural philosopher should be aware of all four types of causes), *PA* books 2–4 do not dispense with efficient or material causation—the link between these and the final cause ("that for the sake of which") constituting Aristotle's concept of conditional necessity (see above).

PA 2 begins by listing three types of combination (*synthesis*). The four basic contraries (not to be considered "stuffs")—hot, cold, moist and dry—are the matter from which the four simple bodies—earth, water, air, and fire—are constituted. These simple bodies mix to form the homoeomers or uniform stuffs: blood, fat, suet, marrow, brain, flesh and bone. Finally, non-uniform parts—face, neck, limbs, and so on—are in turn comprised of such homoeomers. These forms of synthesis are the principles that determine the very structure of *PA* 2–4. Following a discussion of the general nature and functions of the uniform parts (650b14–655b27), Aristotle embarks on his study of non-uniform ones, noting that all animals have three indispensable parts: one for the intake of food, one for its elimination, and one that serves as a principle (*archē*) of life (655b30–656a13). Since human beings have a share of the divine (656a8), Aristotle examines first the instrumental parts (organs) of the human body, starting with the parts of the head—the brain (although presumably a uniform part, already discussed generically in 652a24–653b18), sense organs, and their components (Aristotle rejects the brain as the seat of sensation, a function he attributes rather to the heart). The discussion, however, grows to include the parts of other species (e.g., the elephant's trunk and nostrils, 658b34659a1). Aristotle's discussion of the parts of the neck—the esophagus, larynx, windpipe, and the epiglottis—is followed by a largely chiasmic structure: the internal parts of blooded animals such as the heart, blood vessels, and viscera (665a.28–678a26); internal parts of bloodless animals (678a27–682a34); external parts of bloodless animals (682a33–685b29); and external parts of blooded animals (685b30–697b13), starting with the head and neck, followed by accounts of the limbs, breast, excretory organs, and others.

The most distinctive feature of *PA* 2–4 is Aristotle's systematic reliance on final causation, intended to explain the presence and nature of uniform and instrumental parts in various types of organisms. The brain is not some pointless residue; rather, it fulfills the important role of cooling the body by offsetting the heat produced in the region of the heart (652b20–22). Incidentally, the lungs serve a similar purpose, as the air breathed in is supposed to cool the body (more precisely, the lungs exist for the sake of breathing [669b8] and breathing occurs for the purpose of thermic equilibrium). The same applies to gills since fish draw in water from their environment to prevent their bodies from heating excessively (668b34–669b13). Eyelids (657a25–658a11), eyebrows, and eyelashes (658b15–28) protect the eyes, which are moist to enhance the clarity of

our vision. In some cases, animal parts can have multiple ends: the trunk enables the elephant to breathe (even when submerged in water), and to fell trees or to graze, since it is flexible (an example of conditional necessity, the elephant's trunk illustrating the relation between material and final causes); it is as if the elephant's trunk were a hand (659a2). Lips protect the teeth, and the tongue functions as a sense organ (lips and the tongue also enable humans to speak: 659b25–28).

The conclusion of *PA* 4 announces the subject of *GA* 1–3: discussion of modes of reproduction, the nature of sexual organs, and embryogenesis in blooded animals as well as in bloodless animals (EMBRYOLOGY). Aiming to explain sexual differentiation, *GA* 4 explores a number of other topics, such as the production and nature of milk (776a15–777a26), while the fifth book places special emphasis on phenomena apparently not governed by final causation (e.g., the color of the eyes).

The metaphysical accents of *GA* become obvious from the outset. In the opening section, Aristotle lists the four causes (715a3) central to his study of sexual reproduction. We find a first generic definition of "male" (a principle [*archē*] of movement and generation) and "female" (a material principle: 716a19–23). Later in Book 1, Aristotle investigates the functions and formation of semen and menstrual discharge in greater detail. After pondering whether semen is essentially matter and implicitly a passive principle or a form and an active principle (724b5–7), he concludes that semen contributes the form of the future organism, whereas menstrual discharge contributes the matter. This pair of concepts—form and matter, so important to Aristotle's theory of substance and his natural philosophy—is accompanied in *GA* by his consistent use of another brace of concepts emblematic for Aristotelian philosophy: actuality and potentiality. The seed (*sperma*) is the hand or face or even the whole future organism in potentiality (*dynamei*: 726b18). This potentiality precedes and corresponds to the actual presence of this or that feature (e.g., an instrumental part like a hand) in the organism that will develop eventually (still, the actuality of the parent organism has temporal and ontological priority).

Several major topics in *GA*, including sexual reproduction and sexual differentiation, hinge on Aristotle's treatment of physical, more exactly thermic, processes. In blooded animals, blood is the end result of the process of concoction undergone by nutriments. Blood, in turn, is concocted into other organic homoeomers, from flesh and semen to brain and milk. The process of concoction, which tends to render some materials more definite and dense (what is concocted becomes denser and hotter, as a result of the agency of heat: *Meteorology* 380a4–6), is conditioned by the warmth regulated by the heart which, in a sense, serves as the principle (*archē*) of the fledgling organism, the first part to be formed, and distinguishable even at an early stage in the formation of the embryo. The male principle and the secretion of semen presumably entail the presence of more intense heat than the heat associated with the female principle and menstrual discharge. Not only is a specific physical organization present potentially in the semen, but also in the soul. The soul depends on *pneuma* contained in the semen (*pneuma* is somewhat similar to but still distinct from fire [*GA* 736b35] and air, and is in some way not unlike the *aithēr* constituting the heavens). Aristotle claims that the nutritive soul (736a36)—common to all forms of life, including plants—emerges first, followed by the perceptive or sentient aspect (736b2) of the soul. The mention of the perceptual soul in this context is significant, because it is sense perception that distinguishes animals from plants—a distinction not always clear, as, for example, with the sea cucumber

(cf. *PA* 653b23; *HA* 588b4–18). Aristotle perceives the divine capacity of the human mind (736b28) as a later addition "from outside," since intellectual activity and physical activity are completely distinct.

Throughout this section, our author hints transparently at relevant passages in *On the Soul* (e.g., *GA* 736a37–736b1). A more detailed presentation of Aristotle's biological studies than can be offered here would include also an analysis of *On the Soul* as well as his shorter but equally interesting *Movement of Animals*, *Progression of Animals*, and *Parva Naturalia*, which explore physiological phenomena, including perception, sleep, and breathing. The chief unifying principle in these treatises (and throughout Aristotle's surviving biological corpus) is a deliberate empirical approach guided by a consistent, if sometimes tacit or diffuse, application of his scientific method as discussed in theoretical works. We may find Aristotle's detailed observations and findings—some confirmed only relatively recently—arresting and admirable, but one should seek the main merit of Aristotle's zoological study in its theoretical underpinnings and philosophical implications. This corpus is also unified, quite plainly, by its author's unflagging passion for knowledge. Aristotle's zoological studies have intrinsic worth and are not meant *merely* as an application of dominant tenets in his metaphysics, philosophy of science, or natural philosophy. In the final chapter of *PA* 1, Aristotle urges us to savor the beauty found throughout nature. Our quest for understanding and our sense of wonder should not be inhibited by squeamishness or by a comparison of the nature of animals with the more exalted heavenly bodies. These qualities certainly contributed to Aristotle's enormous influence on subsequent natural philosophers into the modern age. The nature of animals remained a focus of philosophical reflection after Aristotle, including in the writings of his immediate successor at the Lyceum's helm, Theophrastus. Admired today, among other things, for his contributions to the emerging science of botany (Greek and Roman Botany), Theophrastus also wrote an *On Animals* (Athenaeus, *Deipnosophists* 9.378b), possibly inspired to some extent by his teacher's scientific agenda. Moreover, certain aspects of Theophrastus' botanical works too, especially his *History of Plants*, may well have been shaped by the organizing principles that we find in *HA* (see Gotthelf 2012, 307–342).

3. After Aristotle

It is fair to say that most subsequent works in "zoology" do not present the same sustained empirical approach, let alone the philosophical depth and methodological complexity, as we find in Aristotle's zoological inquiries. It is equally fair and indeed necessary to add that most later authors notable for their interest in zoological research, at least those whose works survive, were not devoted to the study of animals per se; but they pursued "zoology" to emphasize the practical relevance of animals to us (e.g., in the context of husbandry and agriculture: Greek and Roman Agriculture; Animal Husbandry; "Ecology" in the Ancient Mediterranean), to examine whether rationality is limited to humans, and to delight readers with exotic marvels or morally edifying accounts of various animals.

The authors we are about to explore, however, strove to remain distinguished, or at least distinguishable, in some way: by adding details not in Aristotle or other authorities, by compiling vast catalogs, or by dealing with otherwise arid topics like hunting

techniques and antidotes for poisons in didactic poems, a staple of Hellenistic poetry and its epigones. Instead of attempting to find any robust coherence in evidence gleaned from radically different genres with significantly different aims, let us simply proceed with a series of significant authors who wrote on "zoology": Nicander, Pliny, Philo, Plutarch, Oppian, and Aelian. Some are important by virtue of (quasi)scientific and philosophical contributions and the traditions they initiated; others deserve our attention for reasons pertaining to ancient perceptions of animals.

Nicander

Nicander of Colophon (see Gow and Scholfield 1953, 3–8) composed two hexameter poems: *Theriaca*, on poisonous beasts, their bites, and on how to heal such wounds; and *Alexipharmaca*, on a wide range of poisons, including animal poisons, and on corresponding antidotes. Nicander seems to have drawn profusely on the now lost *On Beasts* of Apollodorus Theriacus (*fl.* 280–240 BCE), so his own contribution is more poetic than scientific. Several dozen kinds of snakes, scorpions, and spiders are mentioned (as well as beetles, bees, and wasps). Many are endemic to southern Europe, but others are found in northern Africa or elsewhere. Identifying the exact species of some animals listed in Nicander's poems, especially the *Theriaka*, proves an arduous and sometimes hopeless challenge (Gow and Scholfield 1953, 19–20). There is no attempt at systematic division, but animals are grouped sometimes according to habitat or the sort of wounds they usually inflict. Nicander describes the habits of snakes and other creatures in colorful and imaginative detail.

Pliny the Elder

We find a very different sort of achievement in the massive encyclopedic *Natural History* of Pliny the Elder (SCIENTIFIC ENCYCLOPEDIAS), an avid reader, prolific writer, and distinguished military officer and administrator. Pliny was a passionate student of nature in good Stoic tradition. Not inclined to undertake purely theoretical studies, Pliny dwelt on those aspects of nature that relate most clearly and profitably to human activity: for example, how animals figure into technology, agriculture, medicine, pharmacology, inter alia. Presenting facts unknown to Aristotle, Pliny does not simply select relevant details from Rome's political and military history (for example, while the harbor at Ostia was under construction, Claudius' praetorian guard killed an orca feeding off the coast: *NH* 9.14–15). Pliny also employs his own observations and reflections (on Alpine species [*NH* 8.132, 217] and German fauna—European bison and aurochs [*NH* 8.38]), garnered from his extensive military and administrative travels.

Most of Pliny's zoological accounts are gathered in books 8–11, where he offers thoughts on land animals (8), aquatic (chiefly sea) creatures (9), birds (10), and insects (11). Pliny largely ignores Aristotelian divisions of animals, though occasional allusions linger: for example, *NH* 9.83, where Pliny calls some bloodless kinds *mollia* (corresponding to Aristotle's "soft ones"). Books 8, 9, and 10 start with the largest species that pertains to those respective groups (elephants and colossal snakes, whales, and ostriches). Occasionally and unsystematically, Pliny distinguishes between species and varieties: elephants (*NH* 8.27, 32; he notes twice that Indian elephants are larger than

African ones), lions (*NH* 8.46), camels (*NH* 8.67–68), sheep (*NH* 8.189), apes and monkeys (*NH* 8.215–16), hares (*NH* 8.217), crabs (*NH* 9.97–98), and eagles (*NH* 10.6–12). He organizes several sections in ways that mirror Aristotle. Pliny's analysis of parts of the head (horns, hair, brain, eyes, lips, teeth, and tongue), anatomy of the neck and nature of the heart follow an order somewhat reminiscent of Aristotle's *PA* 655b28–667b14, alluding to fundamental Aristotelian tenets (e.g., the region of the heart is the hottest part of the body). In some places, Pliny strays from Aristotle, while virtually quoting him elsewhere: Pliny's assertion that all bloodless animals have brains (with some exceptions, including the octopus: *NH* 11.132) follows *PA* 652b23–35 closely.

With the exception of the second half of Book 11, Pliny offers little in the way of comparative anatomy and physiology, let alone causal explanations (which tend to be rudimentary: e.g., the massive size of certain marine animals is due to the nourishment widely available in the sea: *NH* 9.2). Pliny's occasional appeal to final causation is a pale reflection of Aristotle's natural teleology, and is more indicative of popular Stoicism (the providence of nature: *NH* 9.20) or assuming an anthropocentric perspective (bees are meant to serve our interests: *NH* 11.11; cf. 7.1). The comparison between man and other species in Book 11 is largely descriptive, but includes a handful of functional explanations: nature intends the tear glands to keep the eye clean (*NH* 11.147); nature endows the eye with a narrow opening that serves to focus our gaze (*NH* 11.148). In books 8–11, the emphasis is squarely on behavior (the social behavior of elephants: *NH* 8.11; of bees: *NH* 11.20, 56), moral traits, and the economic usefulness of animals (oyster beds: *NH* 9.168–169; fish farms: *NH* 9.170; wool: *NH* 8.189–199; honey: *NH* 11.11–45; silk: *NH* 11.76–78; even coral: *NH* 32.23). Pliny also provides a variety of anecdotes and vignettes which are more startling than scientifically rigorous. The moral accents in books 8–11 are detectable both in Pliny's expression of outrage at the sumptuous lifestyle that encourages the exploitation of animal products (the elephant's tusks and our use of ivory: *NH* 8.31; pearls: *NH* 9.104–105; purple dye: *NH* 9.125–137), and in the moral depictions of sundry beasts (elephants' sense of attachment and honor: *NH* 8.1; and their capacity to experience shame: *NH* 8.12; lions' mercy toward supplicants: *NH* 8.48, cf. 56–58; their noble nature in times of danger: *NH* 8.50).

Some of the more interesting notes in Books 8–11 concern captive animals, the first zoos and aviaries (see also Xenophon, *Cyropaedia* 1.3.14 on early zoos; Animal Husbandry), and the amphitheater beast hunts (see, e.g., 8.16–21). Pliny seems keen to ascertain the origins of such kinds of entertainment. Quintus Scaevola (consul 95 BCE) was the first to organize a fight between lions (*NH* 8.53). Marcus Scaurus was the first to display a hippopotamus, along with five crocodiles, during the games he organized in Rome as aedile in 58 BCE (*NH* 8.96). Marcus Laenius Strabo opened the first aviaries, in Brundisium (*NH* 10.141). The Carthaginian Hanno was probably the first to handle and then show a lion after taming it (*NH* 8.55). Pliny also recorded elaborate circus acts: elephants walking on tightropes carrying litters with women pretending to be in labor (see also Arrian, who claimed to have watched an elephant playing the cymbals, while other elephants danced: *Indica*, 14.5–6. Arrian also described the mating practices and temperament of Indian elephants and their clever and sympathetic nature—some reputedly carried their dead mahouts for burial after battle: *Indica* 14.4). Such anecdotes, together with more scientifically sober observations, ensured the survival, longevity, and success of the *Natural History* and helped shape subsequent compilations and bestiaries

(Translation and Transmission of Ancient Scientific Texts). Books 8–11 form, above all, a sort of cultural history of animals which Pliny finds captivating primarily in their interactions with people.

Philo of Alexandria

The relation between animals and human nature is also central to several works by Philo and Plutarch, with an emphasis on the possibility that non-human animals are endowed with reason. The topic is not new. Aristotle contended that only humans have mind (*nous*), but other animals too display some form of judgment (*phronēsis*). Philo of Alexandria (circa 15 BCE–45 CE), best known for biblical exegesis and a unique blend of Greek philosophy and Mosaic thought, approached the topic from decidedly new angles. Philo's *On Animals*, surviving only in an early Armenian translation, is cast as a philosophical dialogue between Philo himself and Lysimachus, who reports the speech of Philo's nephew Alexander (see also Translation and Transmission of Ancient Scientific Texts). "It is the anthropocentric view of the *cosmos*, that all things—including animals—were made for man's sake, that is challenged by Alexander and defended by Philo" (Terian 1981, 36). According to Philo, putative intelligence in animals is mere instinctual impulse (85). Beasts are devoid of moral virtue (88, 89) and free will. Thus, they are inferior to humans. The lengthier speech of Alexander/Lysimachus (sixty-two chapters) fails to persuade that animals are endowed with intelligence and moral excellence, partly because it is replete with platitudes (spiders' ability to weave webs: 17–19; social organization of bees: 20–21; animals performing circus acts: 23–27; animals are paradigms of virtue and vices: e.g., the fox is sly: 66). Philo's twenty-four chapter counter-argument is memorable as the expression of an original synthesis between scriptural dogmas and an eclectic philosophical background.

Plutarch

While it would be an overstatement to suggest that Plutarch contributed to advancing zoological studies, some of his dialogues are noteworthy for emphasizing attributes that other species share with us. In his short *Beasts are Rational*, Plutarch argues playfully that apparently "mindless" beasts not only are endowed with a rational faculty (*logos*), but some even surpass humans in this respect. Animal sagacity is demonstrated, among other things, by their ability to learn to perform activities that are contrary to their nature, as with animals trained to perform in the theater (e.g., 992ab: dancing horses). Still, nature herself is usually the teacher, and animals are self-sufficient and naturally virtuous. It is, therefore, hard to deny that they possess reason or judgment (991f).

Likewise, *Whether Land or Sea Animals Are Cleverer* extols the acumen and moral virtues of animals. In the first section of this lively dialogue, Autoboulus (Plutarch's father) attempts to persuade his interlocutor, Soclarus, that animals are rational and can possess moral excellence. For one thing, perception cannot function properly without intelligence (961a). Besides, even if we were to assign certain shortcomings and vices to nonhuman animals, we should concede that vices are faults of reason (962bc). Also, reason (*logos*) can assume different forms; some creatures owe their reason to nature, whereas humans can acquire a superior sort of reason through education. Just because

only we can achieve this superior *logos* does not prove that other creatures are completely devoid of it. Animals have intelligence and judgment, and they possess reason (963b), but not to the extent that we do.

The second major part of *Whether Land or Sea Animals Are Clever* features a dialogue between two otherwise unknown interlocutors, Aristotimus and Phaedimus. Aristotimus maintains that land animals are more intelligent than sea creatures, and he invokes, among other qualities, their memory, emotions, and reactions when helped or harmed (966b). In support, Aristotimus enumerates the relevant characteristics of spiders, bees, ants, elephants, foxes, dogs, partridges, hares, bears, and hedgehogs. He recounts, with verve and humor, striking incidents of land animals as models of fine behavior or cleverness (968de, 972b–d, 972e–f: many of these anecdotes are found, with variations, in Pliny, Aelian, or both, perhaps pointing to common sources). Phaedimus responds that sea-bass are more courageous than elephants (977b) and that marine animals, unlike land animals, assist each other in danger. The contest ends in a draw, when the mediator Soclarus concludes that both positions argue effectively against those who deny that animals have reason.

Plutarch's *Natural Causes* or *Causes of Natural Phenomena*, perhaps not intended for publication, contains several tentative explanations for the behavior and physiology of certain animals. The octopus is seemingly capable of sensing an approaching storm because of its sensitivity to variations in water temperature (916ab). The ability of the octopus to change color to avoid predators is explained partly by the porous nature of its skin, which can retain particles dislodged from rocks (916b–f). That wild boars have sweet tears and deer have salty tears stems presumably from the fact that boars, unlike deer, are "fiery." Plutarch here also tackles other puzzles (e.g., how do dogs and other animals manage to find plants that cure their ailments?) whose answers derive from Aristotle, Theophrastus, or later authors. The appeal to explanations based on "concoction" and *pneuma* point to Plutarch's adherence to a generally Peripatetic theoretical framework.

Halieutica and Cynegetica

Whereas Plutarch was concerned with the rationality of animals, other authors treated fishing and hunting techniques in highly polished didactic poems. Two long poems of some relevance to the history of zoology have been attributed to Oppian, a poet from Cilicia. The *Halieutica*, likely written around CE 180, is a disquisition on fishing techniques. The *Cynegetica*, on the art of hunting, inspired by *Halieutica*, and probably composed at the beginning of the third century by a Syrian author, provides a comprehensive, though superficial, investigation of the nature of wild animals with general descriptions of a number of species (antelopes, elephants, porcupines, and giraffes), their color, swiftness, temperament, and mating rituals. Oppian's *Halieutica*, in contrast, is worth our attention for its voluminous catalog of aquatic animals. Scores of species of fish are grouped according to three overlapping criteria (1.93–445): "race" or kind, habits, and habitat or "path of the sea." Thus, fishes are divided, somewhat imprecisely, on the basis of whether they have their haunts in rivers or the sea, whether they feed in the mud, near weedy beaches, or among rocks, and so on. Oppian then employs modes of reproduction (1.446–645) to distinguish between aquatic animals, including

turtles, crustaceans, the octopus, and dolphins (whose mating, we read, resembles that of humans in some respects, 1.580–583). Certain kinds of fish are also noted for their peculiar behavior (for example, the pilot fish accompanies ships as long as the ships do not approach the shore, 1.186–187). The second book investigates the predatory and defensive behavior of fishes and other animals and their hunting methods, sometimes with moral comment: the fishing frog and cuttlefish are deceitful (2.86–87, 120–127), the grey mullet is righteous (2.641–655), other fishes demonstrate unique valor or astounding laziness and gluttony, etc. Although his reports are borrowed from many sources (principally from Leonidas of Byzantium [150–50 BCE] and Alexander of Myndos [10 BCE–40 CE]) and cannot lay claim to much originality, Oppian is informative and less prone to reporting miraculous stories than other "zoological" writers.

Aelian

Like Oppian and his imitator, Aelian was as concerned with literary aesthetics as with substance. His *On the Specific Character of Animals* (*On the Nature of Animals*), drawing from a wide range of sources, was probably based only in small measure on his own investigations. Aelian, who lived in Rome but wrote in Greek, made numerous references to Greek authorities, especially Aristotle. Yet, most of his sources must be authors of compilations. Indeed, one of the main merits of Aelian's treatise may be that it explicitly or tacitly preserves data collected in earlier (lost) works.

We should bear in mind that Aelian was a rhetorician, not a scientist, if we are to find his work more delightful than exasperating. One may balk at the structure, or lack thereof, of his dizzying miscellany of zoological observations and sometimes fanciful statements. His main goal was to astonish and amuse, and occasionally to inspire readers with Stoicizing morality tales. Aelian's accounts of various attributes of many species are not accidentally but rather studiously unsystematic. His account intimates his fondness of extraordinary and imaginative stories about animals (a feature shared with Pliny and others), from reports about elephants acting as if they were trained surgeons (7.45) or devoted nurses (11.14), and about elusive quasi-satyrs living in India, to stories about a serpent enamored with a pretty girl in Judea (6.17) and wild elephants tamed by music (12.44). Aelian's preamble betrays his particular interest in those characteristics that seem to reflect human attributes, including virtues. A certain camel, realizing that he had just mated with his mother, was so distraught that he killed the keeper who had tricked him into that unlawful act, and he then hurled himself off a cliff to atone for the crime of incest (3.47; cf. 4.7 for a mare and a foal, also forced to mate lawlessly and unjustly).

Aelian's theoretical statements are scant and perfunctory. He appears to attempt a division of sorts at 11.37. Roughly, the first third of this paragraph-length chapter faintly echoes Aristotle's terminology. The middle portion is a division of animals according to the nature of their teeth and of how the teeth in the two jaws meet. After briefly mentioning other criteria of grouping animals, he turns to feet, hoofs, and so on, and notes elliptically that humans and dogs belong to the same group in so far as they have toes. This approach is hardly impressive from a methodological standpoint. All in all, Aelian's *Nature of Animals* may be more entertaining than enlightening—precisely explaining the lasting popularity of this collection and its avatars.

Physiologus

Among those avatars was the *Physiologus*, possibly written (originally in Greek) as early as the second century CE, but no later than the end of the fourth century (see Curley, 2009, especially xvii–xxi; Muradyan, 2005, 1; TRANSLATION AND TRANSMISSION OF ANCIENT SCIENTIFIC TEXTS)). The *Physiologus* is an early Christian collection of short allegories which combine Christian teachings with zoological morality tales borrowed from Pliny, Aelian, and the paradoxographic tradition, among others. A few dozen real and fantastic animals presented there, starting with the lion, are meant to illustrate Christian virtues or symbolize divine attributes (self-sacrifice, for example, is symbolized by the pelican, which feeds its offspring with its very blood). Medieval bestiaries owe much to the various versions of the *Physiologus*.

4. Conclusion

For all its influence over many centuries, the tradition that culminates in the Medieval Bestiary is a far cry from Aristotle's accomplishments. A comparison with Aristotle may seem in itself misplaced and anachronistic, but it may also just prompt us to wonder whether there are *any* post-Aristotelian authors whose scientific contributions compare with Aristotle's, especially with respect to the science of animals. One can answer perhaps with a qualified yes, in regard to a few anatomists and physicians. Erasistratus, Herophilus, and later Galen made considerable advances in anatomy and physiology, in part because of the practice of human dissection (ANATOMY AND PHYSIOLOGY; SURGERY). Galen's *On Anatomical Procedures* reflects the fact that human dissection was still practiced in his time, but less systematically or freely than in Herophilus'. It hardly surprises that Galen dissected a variety of animals, including the Barbary macaque, which thus inspired mistaken conclusions about human anatomy. It is noteworthy, nonetheless, that dissections of this sort contributed to a better understanding of the morphology and physiology of many species, from pigs to elephants, even if not the primary goal. The ancillary role of zoology, then, in these medical contexts, is reminiscent, mutatis mutandis, of the place of (proto)zoological research before Aristotle. The part played by other ancient authors in the history of the study of animals is clearly not negligible or uninteresting. Aristotle's biological corpus, however, is the axis that marks the emergence of zoology as a new scientific domain and remains its most rigorous achievement until at least the dawn of modern science.

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FURTHER READING

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A very helpful overview of post-Aristotelian science, including zoology, can be found in Irby-Massie, G. L. and P. T. Keyser. 2002. *Greek Science of the Hellenistic Era: A Sourcebook*. London: Routledge.

Those interested in the historical and cultural context in which Pliny wrote his *Natural History* may want to consult Murphy, T. 2004. *Pliny the Elder's Natural History: The Empire in the Encyclopedia*. Oxford: Oxford University Press.

Readers who want to pursue the study of more particular fields and who are also interested in the specific terminology used in such contexts can benefit from a number of works, including the following:

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CHAPTER 18

"Ecology" in the ancient Mediterranean

Georgia L. Irby, Robin McCall, and Anita Radini

1. Ancient Near Eastern Approaches

It is impossible to discuss ecology in the ancient Near East (ANE) without also speaking about theology. This is, of course, obvious with respect to ancient Israel, the primary source material for which is the Hebrew Bible. It is no less true for Israel's Mesopotamian forebears and neighbors, including Sumer, Ugarit, Assyria, and Babylonia.[1] While ANE mathematics and science (particularly astronomy, chemistry, and medicine) are quite sophisticated, Mesopotamian peoples understood all elements of nature to be under the control of the gods. Mesopotamian deities interact with each other in dynamic ways: they battle with each other in rage and jealousy, form and dissolve alliances, and engage in sexual relationships. Nature is the arena in which these interactions can be seen most clearly. Droughts, dangerous storms, and crop failures indicate divine strife and wrath (e.g., Hosea 13:15); good weather, successful irrigation, and flourishing agriculture indicate divine harmony (e.g., Deuteronomy 28:12). Because the gods are the patrons of human cities, the complexity of divine relationships also mirrors, and is mirrored by, human demographics and politics. ANE ecology, theology, and politics are therefore always interrelated.

Ecology, Cosmogony, and Chaos

The various ANE cultures share, with some variation,[2] a tiered cosmography. The heavens, usually the residence of the gods (Walton 2006, 168), are separated from the earth by the dome of the visible sky (Genesis 1:6–8). The earth is below the sky-dome, at the center of the *cosmos*. Below the earth is the netherworld where the dead go. In the sky, the sun, moon, and stars move in their courses; the sun sinks below the earth

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into the netherworld at night, and the moon and stars do so during the day. The primordial waters swirl all around. Above, the dome of the sky holds them back, except when they fall to earth as precipitation because the gods have allowed it (*Enuma Elish* V.50–52; Genesis 6:17). Below, the earth floats on the seas, supported on pillars (Job 38:4–6; Walton 2006, 166–167). Many ANE traditions associate the earth with a mother-goddess figure who births both gods, humans (such as the Sumerian Nintur/Ninḫursaĝa: *Eridu Genesis* 37–40; Jacobsen 1981, 514–516), and the heavens with her spouse (in the *Eridu Genesis*, this god is An; Lambert 2013, 20–21; Lisman 2013, 77). A "tree of life" (as in the Babylonian myth *Erra and Ishum*, Dalley 1991, 291) or mountain (such as Israel's Zion, Micah 4:1–2) often functions as the nexus between heaven and earth, and the culture's most important temple is generally associated with this place (Walton 2006, 174–175).

The sea is understood throughout the ANE to be the vestige of the chaotic primordial waters that were bounded by the gods' act of creation. In the Assyrian and Babylonian cosmogonic myth, *Enuma Elish* (twelfth to seventh century BCE), the goddess Tiamat personifies the primordial waters. She is bound and then slain by the god Marduk (IV.101–104), who then dismembers Tiamat's corpse and stretches half of it across the heavens, fixing the upper waters in place (IV.137–140, V.47–52), while from the other half he forms the oceans, rivers, and streams (V.53–58). In the so-called Priestly cosmogony of Genesis 1:1–2:4a, YHWH's speech-act of creation is not, as it is popularly misconceived, one of *creatio ex nihilo*. Instead, it begins as a process of organization: on each of the first three days, YHWH establishes boundaries for the primordial chaos that result in biospheres. These biospheres are filled with their appropriate inhabitants on days 4–6, and on day 7 YHWH rests and positively evaluates the *cosmos*. Ugaritic literature does not include an extant cosmogonic myth; instead, the *Baal Cycle* (1400–1350 BCE) describes the storm-god Baal's efforts to establish kingship over the *cosmos* and maintain it (Smith 1994, 82). The epic poem includes accounts of the ongoing battle between Baal ("Lord") and his divine nemesis, Yamm ("Sea"). Yamm, like Tiamat, represents the primordial watery chaos that exists before creation and is held in check by the power of other deities—here, Baal (Smith 1994, 85). The Hebrew Bible likewise participates in these ideas. In Proverbs 3:19–20, the *tĕhômôt*, "primeval ocean waters"[3] (cognate with Tiamat's name), are "burst apart" (*bqʿ*) by YHWH. YHWH exerts his authority over the *tĕhôm* by fixing its boundaries at creation (Genesis 1:2–10), and we see YHWH's control over the chaos-waters again in the imagery of Exodus 14–15, when YHWH parts the waters of the Red Sea so that the Israelites may pass through it on dry land, but allows the waters to return to their depths and drown the pursuing Egyptian army.

These watery forces are consistently represented in the ANE as inimical to the creator-god. Rain, streams and rivers, wells, and the processes of irrigation were vital to agricultural fertility—indeed, to human survival (e.g., Genesis 21:14–19)—in the arid region of Mesopotamia, so one might expect water to be envisioned as a positive force. But while water was necessary, it was also highly unpredictable. In addition to its predictable seasonal aridity (cf. Psalm 32:4), Mesopotamia was prone to lethal droughts (1 Kings 17:6–14, 18:1–5; Joel 1:2–20). Conversely, when the seasonal rains and unexpected storms came, the land was also prone to flooding—in particular, flash flooding (cf. Job 27:20)—which was equally lethal. We find therefore that ANE cultures associate waters with chaos, but the ruling deity is able to control them, channeling their abundance in

positive ways (Job 5:10; Nahum 1:7–8), but unleashing their destructive power when he chooses (Job 12:15).

Nowhere is the dangerously chaotic power of the primordial waters more apparent than in the ANE flood narratives. The earliest of these is the Old Babylonian *Atrahasis* epic (circa seventeenth century BCE), which survives only in fragments. In *Atrahasis*, the clamor of the newly created human creatures on earth disturbs the sleep of the god Enlil (*ANET* II.1–8). The gods respond by bringing first a plague, and when that fails, 1200 years later, a drought. Finally, the gods unleash a worldwide flood, in which the cosmic waters above the sky are loosed to reemerge with the rising primordial seawaters and undo the entirety of creation. The god Enki, however, subverts the will of Enlil by instructing one human hero-figure—the eponymous Atrahasis—to build an ark that will save him and his family. In the second millennium BCE, a flood narrative that clearly borrows from *Atrahasis* was appended to the third-millennium Sumerian epic of *Gilgamesh* (*ANET* Tablet XI). Gilgamesh meets the hero saved in this flood narrative, Utnapishtim, during his journey to the underworld to find his friend Enkidu. After they survive the flood, Utnapishtim and his wife are made immortal (*ANET* XI.191–97). The Hebrew Bible preserves a flood narrative in Genesis 6–9 that is similar in many ways to these accounts. In all of them, the gods send a global flood, and a god commands a human to build a boat constructed to specific dimensions and sealed with pitch. The human heroes bring animals onto the boat, and in all of the accounts the hero and his family are saved when the boat comes to rest atop a mountain as the floodwaters subside. In every flood narrative, the hero sends out first a raven and then doves to ascertain whether the waters have subsided enough for the humans and animals to debark. Finally, these tales culminate with the human hero offering sacrifices to the gods and the gods responding with some kind of sign to indicate an oath not to destroy the world again. The reason for the biblical cosmic flood, however, is markedly different from the other ANE flood narratives (below).

The Environment and Anthropogeny

Some Mesopotamian accounts of the creation of humankind establish the link between humans and the environment in a literally substantive way: the gods make human beings out of a combination of dirt/clay and a divine element. The Old Babylonian *Creation of Man by the Mother Goddess* describes the goddess Nintu mixing clay with the blood of a slain god (*ANET* I.20–26), which is then birthed as human beings from the wombs of goddesses. While Genesis 1:26–27 reports only that "God created humankind in his image," Genesis 2:7 says that "YHWH God formed the human (*hā-ʾādām*) from the dust of the ground (*hā-ʾădāmāh*)." Instead of divine blood taken as a result of battle and strife, however, Israel's god imparts breath (*rûaḥ*, also "spirit") to the clay figure, whereupon it becomes alive. The notion that humans are made from clay most likely arises from two ancient observations: first, the pliability of clay that makes it suitable for forming into any number of shapes; and second, the process of decay after death, whereby a corpse gradually loses its form and becomes part of the earth (Lisman 2013, 184).

The difficult job of working the land is an ubiquitous motif in ANE myths about the creation of humankind. In the *Creation of Man by the Mother Goddess* (*ANET* I.1–9) and *Enuma Elish* (VI.33–34), humans are created for the purpose of working, so that the gods do not have to do so. The cosmogonies of Genesis both indicate that maintenance

of the land is a core duty of humankind. In Genesis 1:28, God commands the newly created humans to "subdue" (*kbš*) the earth, and Genesis 2:5 indicates that the land's fertility depends equally on rain and human care (the land needs humans *laʿăbōdʾet-hāʾădāmāh*, "to serve the earth").

The Israelites imagined that, had the *cosmos* retained the utopian quality it enjoyed at creation, working the land would have been pleasant and relatively easy. There is a modern tendency to understand the divine command to "subdue" (*kbš*) the earth in Genesis 1:28 as suggesting that, at least in Priestly Israelite thought, humans should ideally exhibit dominance over the environment. Simkins (1994, 39) points out, however, that "mastery-over-nature was rarely ever a primary value for ancient Israelites." As we have already seen with respect to their views on water, the ancient Israelites understood that their interaction with the environment was not, for the most part, in their control. The view of Genesis 1:28, then, is an idyllic one in which the often difficult vicissitudes of nature *are* controllable, and, with the simplicity of a single word, barren wilderness would be transmutable into fruitful kept land. This is a subjugation of the environment that does not involve predation on animals (1:29 describes the human diet as vegetarian; meat is not introduced as an acceptable food source until after the flood narrative, cf. 9:3), but instead encodes a perfectly harmonic existence between humans, animals, and the earth (see Brown 1999, 39–52). But, although science and technology has made control over the natural world at least partially a reality in the modern era (one that brings a new set of ecological problems that the ANE peoples could not have imagined), this was never the reality of life in Mesopotamia. The second biblical cosmogony seeks to explain why this is the case. The disobedience of the first humans, when they eat the fruit of the tree of the knowledge of good and evil despite YHWH's commandment not to do so (Genesis 2:16–17, 3:6), results in cosmic brokenness on every level: the relationship between YHWH and the humans is fractured; enmity is introduced between an animal (the serpent) and humankind (3:14–15); the relationship between the first humans becomes for the first time unequal (3:16b); work—for the woman, childbirth; for the man, agricultural labor—becomes onerous (3:16–19); and the land itself is cursed (3:17).

The biblical flood narrative of Genesis 6–9 further exemplifies this important Israelite innovation to Mesopotamian ecological thought: human moral choices impact the environment (cf. Simkins 1994, 202–06). Whereas *Atrahasis* and the tale of Utnapishtim in *Gilgamesh* attribute the cause of the worldwide flood simply to divine irritability with their pesky human creations, Genesis 6:5–7 attributes the flood to human moral depravity:

> When YHWH saw that the moral evil of humankind was great on the earth, and every purpose of the thoughts of their heart was only evil all the time, then YHWH was sorry that he had made humankind on the earth, and he was grieved to his heart. So YHWH said, "I will wipe out the human beings that I have created from upon the face of the land—humans, together with animals and creeping things and birds of the sky, for I am sorry that I made them."

Verses 11–12 introduce a ritual aspect to the problem:

> Now the earth was corrupt before God; the earth was full of violence [*ḥāmās*, which can refer more broadly to any kind of moral wrong]. And God saw that the earth was corrupt, because all flesh had corrupted its ways on the earth.

Human moral wrongdoing has brought about both moral and ritual corruption in the earth itself (see Klawans 2000, 26–31, especially 30). In Israelite Priestly thought, holiness and impurity are utterly incompatible: YHWH, who is holy, cannot tolerate this corruption. Unlike lesser kinds of impurity that can be ameliorated by ritual means, the corruption here is too extensive; the only redress is annihilation. As in other ANE flood accounts, one human is deemed worthy of salvation from the coming cataclysm: Noah is described as "righteous" (a moral and legal term), "perfect" (a ritual term), and one who "walked with God" (6:9; cf. 7:1). Noah, his family, and a pair of every animal on earth (6:19–20), plus seven pairs of ritually clean animals for sacrifice (7:2–3) are spared to repopulate the earth, and the rest are washed away in an undoing of creation. After the flood, YHWH vows never again to curse the ground or destroy creation on account of human failings, even though he recognizes that the propensity for evil remains unabated in the human heart (8:21).

This does not mean, however, that the earth is no longer affected by human ethical choices. The interconnectedness of the earth's well-being and human moral choice is a theme that especially permeates the biblical literature written during the Babylonian exile (sixth century BCE). YHWH makes the connection explicit in Leviticus 20:22:

> You shall keep all my statutes and my ordinances and observe them, so that the land into which I bring you to dwell will not vomit you out.

Israel's sins accrete in the same kind of contamination described in the flood account. Outside the flood narrative, the consequence of human moral failures is not divine punishment of the earth, but rather exile of the people from the land (Israel) that provides them with their socio-cultural, political, and (because the temple in Jerusalem is viewed as the nexus between heaven and earth) religious identity.

Ecology, Theology, and Politics

We have already seen the deep interconnection between ecology and theology across the ANE cultures. Both of these topics are also inextricably bound up with the political realities of Mesopotamian life. For example, although it was not apparently connected to a particular cultic setting or pattern, meteorological elements and ritual both figure prominently in the Ugaritic Baal Cycle. Minor deities in the Baal Cycle simply personify different aspects of nature and society (Smith 1997, 83), such as the divine messenger and psychopomp Shapsh ("Sun"). Since Baal is a storm-god, lightning, thunder, rain, and other natural phenomena serve to illustrate and underscore his power. (The Hebrew Bible appropriates this imagery to illustrate YHWH's dominance, in turn, over Baal; cf. 1 Kings 18:1–46.) The environment becomes the arena in which Baal's struggles play out: the turbulent meteorological interchange of dry, hot winds coming from the desert and the arrival of the autumn rains from the direction of the sea function, for example, as ciphers for the cosmic battle between Mot ("Death") and Baal (Smith 1994, 85). Baal's victories, like the weather, are impermanent; Baal engages his enemies repeatedly rather than vanquishing them once and for all. Moreover, the cosmic crisis that is evidenced in nature is also directly correlated with human day-to-day existence: Smith further observes that Baal's cosmic struggles "mirror the struggles of humanity against the vicissitudes of a dangerous world," while Baal's victories also reinvigorate human society.

In the Hebrew Bible, ecological imagery is employed frequently to express political views. For example, the eighth-century BCE prophet Hosea condemns ancient Israel for its syncretistic worship practices, and uses ecological imagery to link, implicitly but causatively, YHWH's wrath over the people's religious failings with the imminent fall of the northern kingdom of Israel to the Assyrian empire (722 BCE):

> Therefore they [Israel] shall be like the mist of morning,
> and like the dew which goes away early;
> Like chaff storm-driven from the threshing floor,
> and like smoke from a window. (Hosea 13:3)

Hosea's prophetic contemporary, Isaiah, employs flood imagery in an overtly political context, decrying the Syro-Ephraimite alliance against Assyria. The image of floodwaters evokes the familiar ANE primeval flood narratives, thereby subtly indicating to Isaiah's audience that the damage this alliance will wreak is potentially cosmic in extent:

> Therefore because this people has rejected the waters of Siloah that flow gently,
> and melt in despair before Rezin and the son of Remaliah,
> Therefore the Lord is bringing up against them the mighty and massive waters of the River—the king of Assyria and all his glory;
> It will rise up over all its channels and overflow all its banks;
> It will pour through Judah like a flash-flood reaching up to the neck,
> spreading out its wings, filling up the breadth of your land, O God-With-Us. (Isaiah 8:6–8)

Ecology was not a subject that ancient Mesopotamians thought about in isolation from other aspects of their lives. Instead, they understood the natural world as intimately bound up with their moral choices, their political situations, and their relationships with the gods. The health of the environment indicated the welfare of the divine–human relationship, and the stability of both dictated the well-being of the people.

2. Greek and Roman Theories of "Ecology"

Like the ANE societies, the Greeks understood that there was a strong relationship between humans and their environments. Whereas ANE peoples believed that their own moral behavior affected the health of the earth, in contrast the Greeks envisioned climate as a determinant in human culture. Some states (Athens, Thebes) even promoted a mythology of autochthony, that the first citizens were literally sprung from the earth (ANTHROPOLOGY: KNOWLEDGE OF MAN).

The Greeks had a strong belief that the environment (weather, seasonal variation, topography) shapes human character and physical traits, and these views were influenced by initiatives in philosophy and medicine. Many authors, from an array of genres (history, epic, tragedy, lyric), emphasize the affect of climate on the animals and fauna of an area. As a prelude to his accounts of the peoples who inhabit a place, Herodotus explores the connections between race and *topos*, and his ethnographic excurses seem to draw on advances in Ionian natural philosophy and medicine (Hartog 1988, 356–359; cf. Lloyd 1975; Thomas 2000, 103). The ethnographic digression, connecting the people

to their land, is commonplace in historical writers where climate affects cultural development, military practices, and discipline, and even serves as an aid to understanding the course of history (Polybius 12.25; Strabo 1.1.10). Understanding climate and the effects of environment and seasons on the body (even at different times of the year) is, furthermore, essential to treating illness in the Hippocratic Corpus and later authors: for example, Hippocratic *On Regimen* 1.2; Celsus 1.3; Pliny *NH* 7.17.

The Environment and Human Physical Traits

For Herodotus, the triad of climate, character, and culture is an interwoven arc: "Soft men come from soft places" (9.121.3). But in Herodotus, climate is largely an analogy of character and physical traits rather than their cause: the Egyptians (the healthiest peoples because their climate lacks seasonal variations: 2.77.3) exist *together with* their climate (not because of it: 2.35.2). Herodotus makes no inverse claims for the effects of the harsh Scythian winters on the health of the Pontic peoples (Chiasson 2001, 57–58, 64).

In the roughly contemporary Hippocratic *Airs, Waters, Places* (*AWP*), an aid for itinerant physicians in unfamiliar locales, we find the earliest articulation of a fully developed theory of environmental determinism (echoed in Hippocratic *Epidemics I–III*, *Humors*, *Aphorisms*, *On Regimen*, Plato, Aristotle, and the Roman authors Vitruvius, Celsus, and Vegetius). *AWP* covers environmental (climate, seasons, winds, water) and astronomical (orientation, solstices, and equinoxes) effects on human constitution, ethnic traits, and propensity for illnesses. The author notes local and seasonal diseases that vary according to individual constitution (bilious or phlegmatic), regimen, gender, and age.

Health was seen as dependent on a balance of properties, especially wetness and dryness. Temperate places are best, where well-balanced bodies can be maintained (Vitruvius 6.1.3). The temperate climate of Asia Minor, situated "midway between the heat and the cold," fosters mildness and gentleness of temper (*AWP* 12), yielding people of greater beauty and size. The Libyans are hot and dry, inhabiting a land whose climate is homogenous, and thus the people who dwell there are stronger. In contrast, the wet climate of Scythia produces small, weak peoples (*On Regimen* 37; Vitruvius 6.1.1, where desiccating solar rays cause physical weakness and paucity of blood). West-facing towns, overly exposed to wet westerly breezes, but obstructed from salubrious easterly and southerly winds, are unhealthy: the air retains its early morning moisture, and inhabitants suffer from "all diseases without exception" (*AWP* 6; cf. Aristotle, *Politics* 1330a-3739 where east-facing cities are the healthiest). The moistness of the Scythian landscape explains infertility there (the most "eunuch-like" people on earth: *AWP* 22) and renders the people weak, unable to stretch their bows or hurl javelins, unless they have been cauterized of excess wetness (*AWP* 20) whereupon strength can be restored.

Problematic are extreme fluctuations in Europe's climates (hot summers, severe winters, protracted drought, and frequent rains and winds), which also affect embryonic development (*AWP* 23; cf. Galen, *Capacities of the Soul* 8). Generative development can be affected by meteorological conditions: where the weather is more variable, so are embryonic vitiations, resulting in greater physical variation. Galen also addresses the role of climate (heat, cold, humidity, or aridness) on embryonic development and physical characteristics (*On the Natural Faculties* 1.3, 1.6; Ergin 2008, 452). Climate, further-

more, is a determinant in physical characteristics. A cold, wet climate accounts for the light complexion, soft, straight red hair, blue eyes, and plentiful blood of northern peoples. In contrast, those dwelling in warmer, drier climates have an opposite appearance: short and dark, they have coarse, curly hair, and black eyes (Aristotle, *HA* 517b16–20; Vitruvius 6.1.3–4; this contradicts Aristotelian *Physiognomics*, see above). In comparing Egypt and India, which were thought to be analogous in many regards, Strabo (15.1.24) observes that humidity causes straight hair in warm but humid India (in contrast with curly hair in warm, dry Egypt). Strabo here refutes the theory of Theodectes, who argued that the sun causes Egyptian hair to be dark and curly. Uniformity of climate engenders slackness and indolence; variation fosters wildness, endurance, and bellicosity (*AWP* 23).

As the theory develops, truculence is connected to quantity of blood, which is, in turn, determined by climate. Brave, coarse-haired northerners have an overabundance of blood, but cowardly and soft-haired southerners have a paucity of blood (Vitruvius 6.1.3–4; Vegetius 1.2; cf. Aristotelian *Physiognomics* 806b14–17). We assume that quantity of blood must relate to the balance of the humors: according to humoral theory, blood is naturally hot and moist (Galen, *Causes of Diseases* 7.21–22). A greater quantity of blood would thus to some degree balance the effects of a cold climate, whereas a lesser quantity of blood might offset the influence of a hot environment (cf., Aristotle, *Politics* 1327b22–38).

Intelligence is also connected to environment. The theory is summarized in Vitruvius (6.1.9), who notes a conjunction between intelligence and the quality of air: in the thin air of southern skies, people have sharp, quick minds; yet in the thick and moist (chilly) air of northern skies, minds become sluggish. Vitruvius implies that the condition is not congenital, but related rather to environment. In correlation with serpents, for example, who move quickly in hot weather, but sluggishly in cold weather, the human mind is sharper in warm temperatures, more lethargic in cold. Thus, mental celerity is seen as analogous with physical celerity. This relationship between intelligence and temperature is causal, but the trait is meteorologically malleable.

This link between humidity/aridity and motion, going back to Aristotelian *Problems* 1.24, was explicated in detail by Theophrastus, *On the Winds* 56. he excessively wet south wind induces weakness and lethargy. Our strength, Theophrastus suggests, lays in the joints, which in turn grow slack under the humid south wind, as the sticky fluid therein becomes hardened, thus hindering our ability to stretch (or even to move: Aristotelian *Problems* 1.24; cf. Hippocratic *On the Sacred Disease* 13). Aristotelian *Problems* 1.24 distinguishes more carefully between the effects of hardened and loosened joints. Hardened joints prevent motion altogether, whereas moist, loosened joints impede exertion. Strength and flexibility are restored under the equalizing and evaporative effects of the north wind. Theophrastus is explicit: (dry, warm) north winds dry and harden, (cold, wet) south winds moisten and dissolve, thus explaining why workers are stronger and more vigorous under north winds (*On the Winds* 58).

For Aristotle, the theory is politicized within the context of the tension between *physis* (natural law: necessary and not by agreement) and *nomos* (custom: supplemental, by agreement and not natural). Aristotle suggests that the intermediate geographical position of Greece, between chilly Europe and Asia Minor, engenders an intermediate type of character, both high-spirited and intelligent, hence enabling the best type of governments (*Politics* 1327b22–38). The peoples of Asia, on the other hand, may be

intelligent and skillful, but they lack spirit, and are thus under continuous subjection and slavery (Herodotus and the Hippocratic author of *AWP* attribute Asian indolence to their gentle climate; see above). Such attitudes endure into the Muslim world, where Ibn Khaldun attributes greater joy and levity among those who dwell in hot places near the sea, because there the sun's rays are more intensely reflected (see Ergin 2008, 451).

Politics and environment were viewed as symbiotic, and climate and topography were believed to shape political institutions (Ergin 2008, 453–456, 458–460). Plato (*Republic* 335d–e) asserts that governmental systems reflect the nature and character of their citizens. In discussing the ideal location for establishing a *polis*, Aristotle emphasized the importance of a site's healthfulness in contributing to political (and military) success (*Politics* 1330a34–b17). *Poleis* ideally should have a healthy easterly or southerly orientation, along with adequate access to fresh water (cf. Cicero, *Republic* 2.3; Vegetius 1.22, on choosing the site for a military camp). Strabo famously attributes the rise of Rome to her temperate climate (6.4.1; cp., Pliny *NH* 3.41).

Effect of Environment on Other Organisms

The botanist Menestor claimed that hot plants thrive in cold countries, a theory of environmental determinism in alignment with Hippocratic theories of health and "ecology," in which nature sought to balance counterpoised properties (Hughes 1985, 298–299). The Hippocratic author, for example, notes that the vegetation and livestock of Scythia are small and weak, like the human inhabitants (*On Regimen* 37). Theophrastus, who did not necessarily espouse a theory of environmental determinism, argued against Menestor: dry trees prefer dry countries (*CP* 3.6.8); hot plants come from hot countries (*CP* 1.21.5–6). The most ecologically minded author of antiquity, Theophrastus recognized that plants flourished best in their "appropriate places" (*CP* 1.9.3, 1.16.11, etc.). He distinguished plants according to ecosystems (marsh, desert), and discussed at length the effects of soil type and exposure to wind or sun or rain, anticipating "the terms that would become part of the lexicon of scientific ecology" (Hughes 2014, 61; cf. Greek and Roman Botany).

Aristotle, like his student, had a sophisticated awareness of the symbiosis of creature and environ, thus "introducing ecological considerations into scientific literature" (Sarton 1959, 565). Aristotle was interested in food preferences within an ecosystem, the relationships between predator and prey, competition for dominance within a species, migration, hibernation, symbiosis (e.g., the pinna-mussel soon dies when deprived of its defender, a small pinn-guard crab: *HA* 547b15–32). He observed the reciprocity of all living things (*Metaphysics* 107a17–20). And, seeking to understand the causes of physical traits, he wrote extensively on animal characteristics (Zoology), noting the effects of climate on long- and short-term traits. An unusual frost, for example, tends to lighten the dark plumage of dark birds (i.e., raven) because of the increased moisture (*HA* 519a3–5; Alexander's helmsman Onesicritus also cited water as responsible for physical traits: the coats of foreign cattle who drink from the Indus change to the color of Indian livestock: Strabo 1.1.24). Temperature affects the size of animals: cold climates engender small creatures, hot climates produce large ones. In cold Thrace and Epirus, the ass is small, but no asses exist in Gaul or Scythia, where it is too cold; in hot Arabia, lizards and mice are large; and in Libya, the length of serpents is appalling (like the heat: 606b2–14). According to Aristotle, the Nile also produces larger animals than the Indus because of

the "moderating force of the sun" in Egypt (Strabo 15.1.22, context unknown), but the large and extensive Indus valley somehow produce larger animals, which themselves are affected by the tropical ("boiling") rainfall, which is considered more "nourishing" (Strabo 15.1.23). Wild animals are wildest in Asia, boldest in Europe, and most diverse in Libya (606b16–19), thus paralleling the theories of human environmental determinism established by the Hippocratics.

Climate and Health

The Roman encyclopedist Celsus (2.1) examines the interstices of climate and health at length: certain diseases are more prevalent at specific times of year, in particular types of weather, and at distinct times of life. Climate and season especially affect the ill (preface 71), and a change of climate can be therapeutic (3.22.8; 4.32.1); some remedies prove more efficacious at certain times of the year (1.3.19); soil, climate, and habitat affect the quality of nutrients, which in turn affect health (2.18.8; cf. 3.4.6; NUTRITION). Celsus' arguments on the connections between health and season derive from Greek medical theory: the healthier seasons are those with the least variation (at which times pre-existing ailments can be mitigated: 2.4), with even temperatures and balanced mixtures. Spring is the healthiest season; ever-variable autumn is the unhealthiest. But here ends the thematic link. In Celsus, contrary to Aristotelian theory (and counter to Vitruvius; see above), the bracing (cold) north wind makes the healthy more "mobile and brisk" (2.1.10, instead of torpid), while the (warm) south wind engenders lethargy and blunt senses (2.1.11, instead of acute). After his theoretical introduction, however, Celsus proceeds with a prosaic catalog of remedies and treatments for a variety of common medical concerns, largely abandoning environmental theory.

Nonetheless, the theory endured in other contexts. The ancients believe that peoples from warm climates are constitutionally stronger and thus able to endure fevers. Sallust (*Jugurtha* 17.6) observes that disease rarely causes death among the Numidians, whose territory abuts lands seldom visited because of the harsh, hot desert climate (17.2). Sallust does not make explicit the connection between the torrid environment and the constitutional fitness of its inhabitants. He does, however, employ his ethnographic digression to underscore his thematic threads: the intractable landscape nurtures the fortitude and resolve of its inhabitants. Because their bodies are acclimatized to external heat, hot-weather peoples can endure internal heat. Northern peoples from frigid zones are less able to withstand internal heat, and thus they more easily become weak from fevers. This theory was seemingly borne out in 232 CE, when Severus Alexander's forces, encamped near the Euphrates in northern Syria, fell ill, unable to endure the "thickness of the air." The Illyrian troops, in particular, were accustomed to "moist, cold air," so reports contemporary historian Herodian (circa 170–240 CE; 6.6.2). Others of Alexander's troops, however, perished from frostbite (cp. Xenophon, *Anabasis* 4.5.12). The emperor and his surviving soldiers recuperated in Antioch, where they found cooler air and better water (Herodian 6.6.4; Nutton 2013, 25). Herodian explains disease and its cure as caused by the interaction of the soldier with the surrounding air. What is important here is the knowledge that the air is bad; the root cause is of secondary concern. This dangerous air can be countered in any number of ways, from changing one's surroundings or diet to altering one's breathing pattern (Hippocratic *Nature of Man* 9.6.54 Littré; cf. Galen, *Commentary on Hippocrates' On the Nature of Man* 2.3–4).

3. Human Impact on Ancient Mediterranean Environments

These highly evolved theories of ecology and environment are complemented by an equally rich archaeological (and literary) record attesting the realities of human impact on the ancient Mediterranean landscape. Reconstructing past human-driven changes in the environment, especially at a global scale, is becoming increasingly important in helping humanity predict future environmental challenges. The Mediterranean landscape, having experienced such complex interactions for over 6,000 years, has been the center of much research that synthesizes a wide range of evidence, from ancient literature, geological and archaeological deposits, and recently even ancient DNA in lacustrine sediments (e.g., Butzer 2005; Givet-Covex et al. 2014; Hughes 2014; Mercuri et al. 2014). Although there is no doubt of the impact of Ancient Mediterranean civilizations on the environment, such studies show that it is often difficult to distinguish the effects of the climate from human activities on environmental changes, and that these two aspects are very often interwoven.

Both Greek and Roman civilizations were complex sedentary societies, and as such they depended on agricultural production to create a surplus of food, a surplus then distributed to portions of society not directly involved in land cultivation and animal herding. Such groups of people could then engage in a wide range of other activities. As populations increased, larger areas of ancient woodlands needed to be cleared to make space for arable fields and hay meadows for grazing animals: more people meant that more food had to be produced. Also in demand were wood for fuel and construction. All this resulted in a growing demand for natural resources and increasing pressure on the environment.

The development of agrarian societies, Greeks and the Romans among them, almost inevitably incurred deforestation, loss of habitat, and various soil problems. The subject is wide, and the field advances quickly, so a complete synthesis is not possible here. We aim, however, to provide a cursory view of what can be considered the main aspects of the ecological impact of the Greek and Roman way of life on the Mediterranean landscapes and nature. Here, therefore, we focus on the impact of crops and animal husbandry, as well as deforestation, in the Ancient Greek and Roman world as major agents in the shaping of the Mediterranean landscapes.

The Environmental Impact of Plant Husbandry Practice

Redman (1999, 91) provides an excellent synthesis of agricultural fundamentals and implications. Before land can be cultivated, local natural vegetation must first be suppressed. Once the soil is cleared and crops sown, cultivated plants need protection from other plants and wild and grazing animals: the cleared soil should be maintained, and the plants kept free from natural vegetation by weeding (see also Greek and Roman Agriculture). There is strong paleo-environmental evidence of forest clearance associated with the emergence of agriculture and its spread across the Mediterranean (Currás et al. 2012; Currás et al. Mercuri et al. in press; Roberts 1998). Soil is a complex mixture of organic and inorganic matter, and it can take several hundred years to form in equilibrium with undisturbed vegetation cover and the geological setting (Redman 1999, 83). When exposed to natural forces and growing crops, soil loses its equilibrium, nutrients,

and water, and it has the tendency to thin. This occurs quickly in the Mediterranean regions, where rainfall is high in winter months and low in the summer, and where agricultural activities frequently occur along hillsides. Once the land has been cleared of unwanted vegetation and is no longer in equilibrium, the fertility and moisture of the soil become a central problem, especially when under pressure from a growing population and where land is limited, as in the ancient Mediterranean (McNeill and Winiwarter 2004, 1628).

To prevent the loss of soil fertility, ancient Greeks and Romans developed specialized knowledge. Crop choices specific to different soils, crop rotation, and also manuring techniques were common, all in order to maintain or even improve soil fertility, in what can be considered a form of soil ecology. Pliny the Elder, for example, devoted an entire book of his *Natural History* on "how to run a farm" (18) and one on "horticulture" (14). Crop rotation was well known, as was the soil-enriching properties of legumes. It was also known that certain crops, especially flax, could deprive soil of its quality. For example, the Roman agricultural writer Columella provides an extensive description of how to prepare the land and which crops to sow (book 2). He also discusses manuring in order to obtain high yields of crops and healthy soil, thus proving that the earth can be kept fertile (1 preface 1–3, 3 preface 1–3), in response to a growing belief that all things, including Nature itself, decay with time (e.g., Lucretius 2.5.247–836).

To prevent soil desiccation, the ancients developed some complex forms of irrigation, such as those seen in Ancient Egypt and Mesopotamia. The disadvantage of such practices was the salinization of the soil, as a direct consequence of water evaporation in the fields—water would leave behind salts that it had carried into the fields. The quality of soil and its problems were so important a part of the ancient way of life that they even characterized entire populations: Herodotus (4.183) described the Garamantes of Fezzan (the southern part of modern Libya) as "… a very numerous tribe of people who spread soil over the salt to sow their seed."

A further outcome of land clearance was soil erosion, an aspect particularly felt in the hilly and cliff-ridden Mediterranean. A lack of trees exposed the soil to weathering, resulting in the washing away of topsoil. The Romans clearly experienced this aspect of soil erosion (Butzer 2005). Columella (2.5.1) suggested putting higher amounts of manure at the top of the hill and top terraces, because soil was washed downhill by rainfall. In this way, a large amount of dust and soil, not just manure, was washed toward the flood plains, filling rivers, basins, and harbors as well, often resulting in changes of the coastline (Hughes 2014, 81–82). Roman attempts to prevent soil loss and increase its fertility, however, were not consistent: geomorphic evidence shows often different and opposing results, with phases and areas of soil erosion and devastation alternating with phases and areas where landscapes were stable for centuries (Dotterweich 2013). Some effects of woodland clearance, and subsequent soil erosion, were at times less visible than a disappearing forest, but they could still cause ecological problems. Among these was the combined effect on rivers and seas of the use of fertilizers rich in nitrogen (e.g., cattle manure) and phosphorous (e.g., bird manure) with waste water disposal (Lofrano and Brown 2010). Columella again provides us with an insight into the most common sources of manure in Roman times: birds, human, and cattle (2.14.1). Among birds, pigeon manure, naturally rich in phosphorous, is recommended as the best. The amount of such nutrients reaching natural bodies of water through soil erosion and hillside runoff can slowly contaminate both

freshwater and seas, causing blooming of algal species, which is sometimes poisonous (see Ashley et al. 2011). This can affect fish populations, a precious source of food, and impact water quality for drinking purposes. Human interference with the nutrient cycles has become a major ecological issue in the past few years, but it also occurred in ancient times (Ashley et al. 2011).

Grazing Animals

Another important ecological effect was caused by farming animals and animal herds: mainly cattle, goats, sheep, and pigs (Hughes 2014, 72; Animal Husbandry). Wood clearance to create hay meadows was a major cause of deforestation, and such meadows were attended with great care. Columella states that "one must not allow shrubs or thorn bushes or weeds of rather vigorous growth to remain in them" (2.17.1). Grazing activity can be useful for agriculture because it gives the soil time to recover and helps manure the fields, but at the same time it removes wood vegetation and prevents it from growing. In this sense, overgrazing damages woodland not because it can destroy old forests but because it prevents the establishment of new ones. Animal grazing on natural vegetation, especially overgrazing by sheep and goats, and consequent soil erosion has occurred in the Mediterranean for millennia. Some characteristic Mediterranean landscapes like scrub and heathland are thought to be "a cultural landscape," maintained largely by human activities (Rackham 1982).

Loss of Habitat and Human Impact on Wildlife

The removal of ancient forests to support agriculture and other aspects of human life (fuels, housing material, mining, shipbuilding, caulking, etc.) also contributed heavily to deforestation in the Mediterranean region. Records of the deforestation process that affected the Mediterranean region in antiquity are widely available, together with literary sources. Recent work by Mercuri et al. (in press), who used pollen analysis to detect changes of species composition across the Mediterranean world in the past, has shown a huge decline of wood species across the entire region. The wood ecosystem provides a number of species with food, shelter, and relief from the summer heat. It protects soil from desiccation and erosion, and it makes the hillside less prone to landslides during winter high rainfall.

The loss of habitat due to agriculture and the need of wood for fuel, building, and trade is highly visible in the archaeo-botanical record with the increasing abundance of species associated with disturbed ground, which today we call weeds. Species such as ribwort plantain (*Plantago lanceolata* L.), sorrels (*Rumex* spp.), nettles (*Urtica* spp.), and grasses (Poaceae) make their appearance with the beginning of agriculture. And the decline of wood species testifying to deforestation characterizes the vegetation history shown by the pollen record (Rackham 1982; Roberts 1998). The changes in the vegetation cover and the loss of habitat were well known to the Greeks and Romans. Hughes (2006, 20–21) reports a vivid example from Plato: timber used for the construction of buildings that were still standing in his time (fourth century BCE) had been cut in mountains where only "food for bees" could be found (*Critias* 111c). "Food for bees" likely refers to a number of herbaceous species and bushes that grow in disturbed

ground after wood clearance in the Mediterranean region today. Pliny (*NH* 13.19) noted that giant trees used to stand in ancient Egypt, and Diodorus Siculus (8.5.2) observed that Spain and Sicily were long ago rich in forests, but no more (Hughes 2014, 76). Although long-term human-induced climate change is beyond our aim here, we surmise, however, that deforestation of large areas of woodland must have affected the local microclimate too. Woodlands prevent soil erosion, they reduce the effects of prevailing local winds by decreasing loss of water from evaporation, and they also provide "heat" shelter in the hottest months as the process of transpiration absorbs heat from the environment.

There is no doubt that the extent of wood clearance resulting from agricultural practices affected the local wildlife through habitat loss. Many wild predators, such as foxes, wolves, and even bears, were regularly hunted almost to extinction for the protection of people, farm animals, and herds (and as valuable training for war). Other cultural aspects—especially the hunting and collecting of exotic animals for private collections and games, a practice that increased with the expansion of both Greek and Roman culture—greatly affected wild animal populations from far distant territories. In the beast hunts (*venationes*) of the Roman circus, the number of foreign animals increased from the third century BCE onward, to the extent that by the early first century CE the number of animals killed in a single *venatio* show could reach thousands (Jennison 1937). Reportedly, 11,000 animals were slaughtered for the celebrations of Trajan's Dacian Triumph (107 CE: see also Hughes 2014, 97). In general, entire categories of animals, such as those the Romans called "African Beasts," declined sharply by the early Roman Empire. Both Herodotus (7.125–126) and Aristotle (*HA* 579b7, 606b15) attest the presence of lions, for example, in areas where they were extinct by the first century BCE (Hughes 2003, 21–31), and their disappearance was even celebrated by the poets:

> O secluded Nasamonian lands of Libya, no longer are your expanses weighed down by bands of wild land animals, nor do you rebound in echo to the remote roars of lions even as far as the sands of the Nomads, since Caesar the son has fettered the countless race with his spearmen. Previously the lairs of roaming wild beasts, these ridges are now the cattle pastures of men. (*Greek Anthology* 7.626)

The ivory trade and warfare would certainly have exacerbated this phenomenon.

There is consensus that at least up to the Neolithic period, large-scale deforestation did not occur and that woodland cover was needed for fodder and for hunting game, still a major component of diet (Roberts 1998). Such needs were also felt in Greek and Roman times, and the elite practice of hunting game may have led to the protection of at least a part of the forests as a resource for wild game (Animal Husbandry), indirectly helping to reduce the impact of deforestation in areas where a wealthy elite was present, in ways similar to how the need for hunting game protected the forests in the early Neolithic period. Overall, however, between the loss of wildlife habitat, hunting practices, private collections, and the use of animals in shows, Greek and Roman civilizations did cause a decline of wildlife, and, in some cases, in particular in Northern Africa, the decline if not the disappearance from the Mediterranean region of several species of animals (Hughes 2014, 108–109).

4. Conclusion

Clearly, the ancient Mediterranean peoples had an impact on their environment, through growing population, agriculture, long-distance trade, and warfare, and they understood these ecological effects in both practical and theoretical terms. Human practices affected the fertility of the lands (through overplanting, irrigation, and overgrazing), and some of these practices were viewed as reversible (especially with manuring). Despite increasing urbanization, however, the connection between the people and their land remained palpable, and Greco-Roman traditions resoundingly echo ANE beliefs: like the Babylonian and Hebrew traditions, the Greek and Romans posited a theory that humankind was made from the dirt of the earth (Hesiod, *Works and Days* 61; Ovid, *Metamorphoses* 1.82). Greco-Roman flood narratives also preserve many elements of the earlier ANE variations: including the destruction of humankind for their moral transgressions and the survival of one pair (Deucalion and Pyrrha) as a reward for their singular esteem of the gods (Ovid, *Metamorphoses* 1.322–323). Fundamentally, ancient societies viewed their gods as personifications of the forces of nature: Zeus/Jupiter is rain; Poseidon/Neptune is the storm at sea and the force that causes earthquakes (see METEOROLOGY). And these societies connected their social and political success with the favor of their gods. For the Romans, the proper worship of the state gods ensured the political success of the Roman state, and the neglect of the state cult resulted in civil war, for example, or military setbacks (the Sibylline books, consulted by the Roman senate during times of emergency, frequently prescribed the importation of Greek gods, whose worship resulted in both physical and moral purification—e.g., Asclepius, imported in 293 BCE in response to a plague: Livy 7.27, 4.20–25). For ANE cultures, however, this connection was visceral: the health of the community was literally responsible for the health of the environment (for an intriguing comparandum: the Hopi of the New World believe that the *cosmos* is kept in order by life lived correctly in conjunction with cosmogenic rituals properly performed). Throughout the Mediterranean, the relationship between living creatures and the natural environment was integral and reciprocal.

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NOTES

1 Length prohibits broader focus on the numerous other Mesopotamian cultures, such as the Hurrians and Phoenicians, the extant source literature for which is not abundant. Also omitted from this discussion is Egypt, which poses the opposite problem: the source material is so abundant, and so different from that of its ancient Near Eastern neighbors, that space precludes a fair treatment of both.

2 The Hebrew word *šāmayīm* ("heavens") is a fixed dual form, but there is no evidence that the ancient Israelites understood there to be more than one level of heaven. Other Mesopotamian cultures, however, recognized three or even seven different levels of heaven (Walton 2006, 168).

3 All Hebrew translations are by Robin McCall.

CHAPTER 19

The Failure of Evolutionary Thinking in Antiquity

Devin Henry

1. Introduction

When Darwin wrote the *Origin of Species*, Creationism was the dominant view, even among scientists.[1] According to this view, each species of living thing is characterized by an immutable form created by God and transmitted from one individual to the next in the act of reproduction. Although minor variation between individuals may exist, deep permanent changes were not possible. Creationists took the fact that species cannot successfully interbreed as empirical evidence for the existence of real species boundaries: God had implanted in each individual a mechanism designed to prevent species from being altered by natural causes and thereby disrupting His divine plan. Darwinism (understood here as the theory articulated and defended in the *Origin*) changed all this. We can divide Darwin's theory into two main theses. The first is the basic idea of descent with modification. In chapters 5–13 of the *Origin*, Darwin presented a wealth of evidence showing beyond a reasonable doubt that biological species are not immutable but evolve over time. The other part of Darwin's theory is the claim that natural selection is the primary mechanism responsible for evolutionary change (*Origin* chapters 1–4). Evolution by natural selection, as Darwin understood it, can be seen as a consequence of four conditions (compare *Origin* 1859, 4–5):

1) Variation
2) Struggle for existence
3) Differential fitness
4) Heritability

In the first place, there must be variation within a population, which provides the raw material for selection. Without variation there can be no selection. Second, there must

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be a struggle for existence. Darwin argued that the conditions of life are such that, in every generation, more individuals are born than can possibly survive, given limited resources. This generates competition between individuals for resources, including competition for mates. Third, for selection to act on a population, some variations must give their possessor a competitive advantage, which increases its chances of surviving and reproducing relative to other individuals in the population. (Selection is blind to ecologically neutral traits.) Finally, in order for evolution to result, those favorable variations must be heritable. If some individuals vary from others in ways that give them an edge in the struggle for existence, but those variations are not heritable, then no evolutionary change will occur. Inheritance is necessary to ensure that those advantageous traits are preserved in future generations.

Darwinism incorporates several other ideas. (1) Evolution by natural selection is an adaptive process capable of fitting a population to its environment. (2) Natural selection is capable of producing diversity so that the number of different kinds of organism increases over time, resulting in a branching "tree of life." Most importantly, selection is capable of generating new species, owing to what Darwin called "The Principle of the Divergence of Character" (*Origin* IV.111–126). (3) All life on earth can be traced back to some unknown ancestor(s) in the remote past (the theory of common descent). (4) Evolution is a gradual process that requires a large amount of time; no evolutionary changes occur instantaneously over a few generations (gradualism). "*Natura non facit sultum*," Darwin said (*Origin* 1859, 194). (5) The individual organism is the unit of selection, not groups of organisms. Individuals, not groups, are locked in a continuous struggle for existence and natural selection favors variations that give those individuals an edge in that struggle.

The intellectual history of evolutionary theory really does not begin in earnest until the late seventeenth/early eighteenth century.[2] Prior to that, the idea that species might have evolved over time was not a serious possibility for most naturalists and philosophers. There is certainly no substantive debate in antiquity about evolution in the modern sense. There were really only two competing explanations for how living things came to have the parts they do: design or blind chance. The ancient Greek Atomists, for example, taught that all composite bodies, including living things, are generated through the random collision of atoms as they "rebel and move in the void" (Aristotle, *On Democritus* [= Simplicius *in DC* 295.9]). Plato and Aristotle both dismissed this possibility on the grounds that living things are too complex and well adapted to be products of chance. This eventually became the central premise in Galen's own argument from design (see below). That species forms might have gradually evolved over time by a process of natural selection was not seen as a plausible alternative. Of course, such a theory had been proposed by Empedocles in the fifth century BCE. But because his theory still relied heavily on chance, it was not taken seriously by any of the later ancient Greek or Roman thinkers.[3]

This raises a question about methodology. How should one go about writing an essay on evolution in the ancient world? The most common approach has been to offer a survey of the scattered remarks that appear significant when read in the context of later evolutionary thought. But it is difficult to see what we might learn from that exercise. For example, Aristotle's student Theophrastus has plenty to say about variation and modification in plants, both in nature and under domestication (e.g., *Inquiry into Plants* 2), which seem significant in light of the first two chapters of the *Origin*. But Theophrastus

was not thinking about evolution, and so any comparisons with Darwin would be superficial.[4] Instead, I shall concentrate on exploring the views of a few representative thinkers in detail. My aim is to investigate the reasons why evolutionary thinking failed to gain momentum in antiquity after its introduction by Empedocles.

2. Empedocles of Acragas

The only recognizable transmutation theory to survive from antiquity was developed by Empedocles in the fifth century BCE. Empedocles' cosmology posited four basic elements—earth, air, fire, and water—and two cosmic forces—Love and Strife (MATTER; MOTION AND ENERGY). Strife is an entropic force that causes things to separate, while Love is a magnetic force bringing them together. Empedocles thought that all of the diversity and change in the universe could be adequately explained in terms of a general theory of mixture in which a small number of basic materials combined and recombined in different ratios (*logoi*) under the periodic influence of Love and Strife. It is within this framework that he developed his transmutation theory of the origin of species.[5] Unfortunately, his account can only be reconstructed from fragments, the most important of which are the following:

> Empedocles held that the first generations of animals and plants were not complete but consisted of separate limbs not joined together. The second generation, arising from the joining of these limbs, were like creatures in dreams. The third was the generation of whole-natured forms. And the fourth arose no longer from the homogeneous substances, such as earth or water, but by interbreeding, in some cases as the result of the condensation of their nourishment, in other cases because the beauty of the females excited the sexual urge; and the various species of animals were distinguished by the quality of the mixture in them …. (TEGP 122, translated after KRS)

> Here sprang up many faces without necks, arms wandered without shoulders, unattached, and eyes strayed alone, in need of foreheads. (TEGP 118)

> Many creatures were born with faces and breasts on both sides, man-faced ox-progeny, while others again sprang forth as ox-headed offspring of man, creatures compounded partly of male, partly of the nature of female, and fitted with shadowy parts. (TEGP 121)

The details of Empedocles' theory are unclear, owing to the fragmentary nature of the evidence, making it difficult to piece together a coherent picture. But the basic idea is relatively straightforward.

Empedocles clearly envisioned some kind of evolutionary account for the origin of species. According to this theory, life evolved from simple inorganic materials (the four elements) through a combination of random variation and some kind of selection process (Aristotle, *Physics* 198b29–32). The primary forces that generate variation are Love and Strife. As Aristotle makes clear (e.g., *GC* 333a35–334a9), Empedocles treated these as blind mechanical forces ("blind" in the sense of not aiming at any specific outcome). Love is a cause of coming together *only*, not of coming together in *this* or *that* way, while Strife is a cause of dissociation *only*. Empedocles imagined Love generating variation by first bringing the elements together in random ways resulting in chance combinations (*TEGP* 119). For example, Empedocles tells us that flesh and bone were originally produced as the elements "happened to fall together" in different proportions "as each

chanced to meet another" under the influence of Love. The resulting "tissues" formed the basis for the first generation of living things to evolve.

As Love began to take hold of the universe, the "tissues" were brought together in different ways to form disembodied limbs (*TEGP* 118, 122). Of course, these were not limbs in the proper sense (they were not parts of whole organisms) but proto-organisms, rudimentary life-forms that enjoyed an independent existence of their own.[6] The next evolutionary change produced the biggest explosion of diversity. As the various "limbs" collided with one another, they produced a variety of complex organ systems ("the second generation, arising from the joining of these limbs"), which Empedocles describes as being "like creatures in a dream." There were organisms with "rolling gait and countless hands" (*TEGP* 120), others with "faces and breasts on both sides" as well as "man-faced ox-progeny" (*TEGP* 121). Somewhere along the line, Empedocles invokes what looks like a principle of natural selection, which Aristotle describes at *Physics* 198b29–32:

> Wherever, then, everything happened just as it would have if it had it come to be for the sake of something, those that were spontaneously organized in a useful way survived while those that were not perished and are still perishing just as Empedocles says of his man-faced ox-progeny.

The other details of Empedocles' full evolution story are murky. *TEGP* 122 mentions a third generation of "whole-natured forms" as well as a fourth generation (presumably the immediate ancestors of all contemporary species) that were capable of sexual reproduction. But it is unclear how these were both related to the previous generations. There are generally two ways of understanding Empedocles' account here.

Some read the fragments as positing a single continuous line of evolution from the elements to present-day species. Random mixtures of elements first threw up "tissues," which eventually combined to form disembodied "limbs" (the first generation of living things). The dreamlike creatures of the second generation later emerged as these "limbs" were fused together by Love. Contemporary species are descended from those advantageous fusions that out-survived and out-reproduced their more unprofitable counterparts. For example, Empedocles may have thought that modern sea urchins evolved from those creatures with "rolling gait and countless hands" (cf. Aristotle, *PA* 681a6–9), since that arrangement of limbs was better adapted for survival than other combinations. The whole-natured forms were intermediate between the dreamlike creatures and present-day species. By calling them "whole-natured" (*tōn holophuōn*), Empedocles presumably means that, at some point in their evolutionary history, living things transitioned from being mere collections of limbs randomly joined together by Love to the sorts of functionally integrated unities we see today. On this first reading, then, the evolutionary history of life on earth runs from (1) elements to (2) "tissues" to (3) disembodied "limbs" to (4) combinations of "limbs" to (5) whole-natured organisms, which eventually evolve sexual reproduction to become (6) present-day species.[7] Other scholars deny that there is one continuous evolutionary sequence and instead posit a break in Empedocles' zoogony between (4) and (5).[8] The first sequence culminated in the dreamlike creatures of the second generation, which immediately went extinct.[9] The second sequence began afresh when "the whole-natured forms" sprang up from the earth (*TEGP* 125) and then evolved into present-day species after acquiring sexual reproduction.

The fragmentary evidence is not sufficient to settle which of these two readings is correct. On the one hand, *TEGP* 125 does refer to whole-natured organisms that were spontaneously generated, like the earth-born race of Plato's *Statesman* (269b). This would have been consistent with traditional views about the origins of modern humans and non-human animals (cf. Aristotle, *GA* 726b28–30). On the other hand, Aristotle's remarks could be read as implying that some of the dreamlike creatures of the second generation evolved into present-day species. At the very least, he suggests that Empedocles' principle of selection was operating on the individuals of the second generation, and so we should expect them to have left descendants. Whichever of these two interpretations is correct, the more interesting philosophical question is whether or not Empedocles can be said to have anticipated Darwin's theory of evolution by natural selection, as traditionally assumed.

Empedocles certainly grasped the basic concept of natural selection. Darwin defined natural selection in the *Origin* as "the preservation of favourable variations and the elimination of unfavourable ones" (1859, 81). This is exactly what we find in Empedocles. On Empedocles' account, the second generation of dreamlike creatures arose as Love randomly joined together various limbs. Those forms that were "spontaneously organized in a suitable way" were preserved, while those that were not were eliminated.

But there are good reasons to resist the conclusion that Empedocles anticipated *Darwin's* theory of evolution by natural selection (as traditionally assumed). First, Darwinian selection is an intergenerational process that depends on the inheritance of beneficial variations. While Empedocles' "dream-like" creatures exhibited differential fitness, there is a question as to whether or not they were reproductively viable. For example, *Physics* 198b29–32 says that some of these creatures survived; it does not say they survived *and reproduced* (Sorabji 1980, 177). If this is right, then Empedocles' brand of one-off selection (which occurs within a single generation only) would not be sufficient to count as Darwinian selection (cf. Dawkins 1986, chapter 3). I do not take this objection to be decisive. The fact that Aristotle only mentions survival does not necessarily mean individuals in the second generation were not reproductively viable. By saying those fusions that were spontaneously organized in a suitable way "survived," Aristotle could mean (a) those particular organisms survived for a single generation or (b) the lineage itself survived for several generations. None of the extant fragments helps us to decide between these alternatives.

Let us grant that, on Empedocles' theory, the history of life forms a continuous trajectory from simple inorganic materials (the four elements unmixed) all the way to contemporary species. Let us also grant that life evolved owing to a combination of random variation and some kind of intergenerational selective process. Still, this is not enough to conclude that Empedocles anticipated Darwin's theory of evolution. Empedocles' principle of natural selection is not Darwinian for at least two important reasons. First, none of the fragments mentions anything like the Malthusian principle of geometric increase (that many more individuals are born each generation than can possibly survive given limited environmental resources) or the struggle for existence that such conditions give rise to. This was a crucial step in Darwin's argument.[10] Second, and more importantly, Empedocles assigned only a negative role to his principle of selection, whereas Darwinian selection is a creative force capable of building organs through the accumulation of favorable variations over time (stepwise cumulative selection).

To see how natural selection can build complex adaptations, imagine an ancestral population of sightless organisms (Dawkins 1986). One day a mutation arises that generates a patch of photoreceptor cells on the heads of a small number of individuals, which allows them to detect shadows. While not a huge improvement, it is enough to give those individuals a slight advantage in the struggle for existence. If the mutation is heritable, then natural selection will preserve that new variation in the next generation. Over time, the trait will spread through the population as light-detecting individuals will tend to leave more offspring than their blind conspecifics. Eventually, the population evolves as the proportion of light detectors increases relative to the blind variants, which are driven to extinction. Those new light-sensitive cells now provide the basis for further modification. Imagine a few thousand generations later the gene that controls the growth of those photoreceptors again mutates, causing an overproduction of cells. This expands the area, allowing in more light. This again gives its possessors an edge in the struggle for existence, causing the new mutation to spread through the population as individuals with the new expanded patches outcompete their original sighted ancestors, again causing a change in the relative frequency of the two variants (evolution). Next, imagine that several thousands of years later another mutation causes the expanded patch of skin to bend inward, forming a shallow cavity. These new organisms can not only detect light and dark, they can also sense the direction of an object. This would give those organisms a tremendous advantage over their conspecifics in the struggle for existence, again leading to an evolutionary change in the population, and so forth, until eventually we arrive at something like the complex vertebrate eye. In this way, natural selection is able to build up complex organs piece by piece through the gradual *accumulation* of small (yet random) modifications of pre-existing traits over hundreds of thousands of generations.

By contrast, the production of new forms in Empedocles' system is entirely the result of chance. At each stage of evolution, new forms are created through chance collisions of simpler bodies brought together under the influence of Love, a blind mechanical force that combines things wholly at random. Selection's role in this process is limited to removing those complex fusions that happened to be combined in ways that are not ecologically viable (see further, Sorabji 1980). On Empedocles' account, then, each generation of new forms is produced in a single step by randomly combining the bodies of the previous generation ("saltation"). There is no suggestion of any stepwise accumulation of slight variations over thousands of generation (no gradual cumulative selection). To use an analogy from Dawkins, Empedoclean evolution works like a hurricane blowing through a junk yard and randomly combining parts of a plane. When the dust settles, we are left mostly with clusters of parts that cannot fly, but also some working planes. The principle of selection is merely responsible for removing those unprofitable combinations from the junk yard and leaving the viable ones behind.

Aside from Empedocles, there were no other recognizable theories of transmutation in antiquity, and certainly no recognition of the mechanism of natural selection. Although Empedocles did not manage to achieve the sophistication of Darwin's theory, his idea that life evolved from simple inorganic materials through a combination of random variation and some kind of selective process was clearly ahead of its time. Unfortunately, his ideas failed to gain momentum and were eventually eclipsed by the static worldview characteristic of Platonism and Aristotelianism.

3. Plato

There is little in Plato that even remotely resembles evolutionary thinking. On the contrary, Plato is seen as the forefather of modern Creationism. At *Philebus* 28d–29a (Plato's), Socrates argues that the *cosmos* is an ordered whole and that only reason and intelligence could be the cause of such complexity. This commitment forms the basis of the Creationism articulated and defended in the *Timaeus* (Henry 2013, 226–229). There, Plato sets out his two-world view, which divides reality into "that which always is and has no becoming" (the world of the Forms) and "that which comes to be but never is" (the sensible world) (*Timaeus* 28ab). The world of being is "grasped by thought together with an account, and is unchanging," while the world of becoming (characterized by instability and constant flux) is "grasped by belief together with unreasoning sense perception." Plato establishes, first, that everything that comes into being is necessarily brought into being by the agency of some cause (since nothing comes to be without a cause) and, second, that everything that is produced is done so according to some model. The Demiurge (aka *Nous*) and the Forms satisfy these two requirements, respectively. This yields an account of creation according to which visible nature is the product of an Intelligent Designer who constructed things by looking to the Forms as his models: "This, then, is how it has come to be: it is a work of Craftsmanship (*technē*), modeled after that which is changeless [sc. the Forms] and is grasped by a rational account, that is, by wisdom." (29a)

At the core of Plato's account is a distinction between intelligence, which serves as the primary cause of order (following the *Philebus*), and material necessities, which function as "co-causes" (*sunaitia*) that are used by intelligence to execute its plans:

> All of these [material-level forces] are among the co-causes that are used in service to the god as he brings about the best possible form. But because they cool and heat, congeal and dissolve, and produce all other sorts of effects, they are thought by many to be, not co-causes, but <primary> causes. However, not one of these sorts of things is capable of possessing reason or understanding concerning anything. For, among the things that are, one must say that soul is the only thing that is suited to acquire understanding — and this is non-visible, whereas fire, water, earth, and air have all come to be as visible bodies. So it is necessary for the lover of understanding and knowledge to investigate first the causes found among those things that are naturally intelligent, and second all of those things that are set in motion by something else and set others in motion by necessity. Surely we, too, must do the same: we must state both kinds of cause, separating all of those causes that possess understanding and fashion what is beautiful and good, from those that produce only random and disorderly effects when deserted by intelligence. (Timaeus 46c7–e6)

For Plato, then, natural causes could never produce complex adaptations without the guidance of intelligence. Only things that possess intelligence are capable of producing "what is beautiful and good," whereas natural causes operating according to blind necessity "produce only random and disorderly effects."

4. Aristotle

Aristotle is more direct in his rejection of Empedocles' biological views. At *Physics* 198b10–29, he entertains Empedocles' theory as a possible rival to his own, which relies heavily on intrinsic goal-directed principles of change (or "natures"):

> We must first say why nature is among the causes that operate for the sake of something. … Here a problem arises: What is to prevent nature from acting, not for the sake of something and because it is better, but just as Zeus sends the rain, not so that the crops may grow, but of necessity? For what goes up must cool, and when cooled must become water and descend, while the growth of the grain results from this. Likewise if a man's crop is spoiled on the threshing floor, the rain did not fall for the sake of this (so that the crops might spoil); that just happened. So what is to prevent it being this way with the parts in nature, e.g., the teeth coming up from necessity—the front ones sharp and suited for tearing, the back ones broad and useful for grinding down food—since they did not come to be for the sake of that but rather it was just a coincidence? And similarly with all the other parts that are thought to be present for the sake of something.

Aristotle takes Empedocles' account to be an example of the sort of thinking expressed in this passage (*Physics* 198b29–32). As we have seen, Empedocles treats Love as a blind mechanical force that causes things to fuse together in no particular way. Most of the time these fusions are poorly adapted for survival and die out. But every once in a while, Love will throw up a combination of parts that happen to work together and the fusion survives. But that was purely coincidental, since Love does not act for the sake of creating well-adapted forms anymore than it does for the sake of creating poorly adapted ones. It is all a matter of chance.

Aristotle ultimately rejects Empedocles' account, not because its transmutation theory is antithetical to a world of changeless forms, but because it affords too great a role to chance in the process of development:

> It is impossible for it to be this way. For these [teeth] and all the other parts on nature come into being in the same way either always or for the most part while this is not the case with any of the products of luck or chance. … If, then, it is agreed that things are either the result of coincidence or exist for the sake of something, it follows that they must be for the sake of something. (*Physics* 198b34–199a5)

On Empedocles' theory, complex adaptations are the products of blind chance. But the development of the parts of living things is just too consistent to be the result of chance. Instead, the causal mechanisms that generate adaptations must themselves be under the teleological control of the organism's "nature" (*Physics* 199b13–18; cf. *PA* 641b23–28).

At first glance, Aristotle's objection appears to rest on a confusion between what Ernst Mayr (1988, 28) calls the *proximate* versus *ultimate* causes of species forms. The former refer to the underlying developmental mechanisms that are responsible for generating the particular individual, while the latter refer to the historical (evolutionary) causes that operate on the species itself over thousands of generations. Since the account to which Aristotle refers in *Physics* 198b29–32 concerns the evolutionary origins of species, not the embryological origins of particular members of species, it looks as though he is guilty of a kind of category mistake. But there is some evidence that Empedocles tried to apply his basic evolutionary principles to embryology (*GA* 722b6–20, 764b15–20) and that this is the target of Aristotle's criticism. According to that account, each embryo contains a set of tiny pre-formed parts derived from the parts of the parent organism (Embryology). As Aristotle understands the theory, those pre-formed parts are meant to resemble the proto-organisms that constitute the ancestors of modern species. And just

as those disembodied "limbs" fused together to form various complex organ systems, so too the tiny pre-formed limbs grow together during development to create a new individual (*GA* 722b6–20). Thus, at least as Aristotle understands him, Empedocles thought that embryology recapitulates zoogony (to adapt a famous expression). If this is right, then Aristotle may have felt justified in extrapolating from Empedocles' evolutionary account (including the role assigned to Love in the process) to his explanation of development.

Modern biology agrees with Aristotle's objection as it applies directly to Empedocles' theory of evolution (that it affords too great a role to chance in the process). This was the point made earlier, where it was noted that Empedocles makes chance the primary cause of adaptive evolution. On Empedocles' account, Love creates organic forms by randomly fusing together simpler elements. Any good "fit" that results between a particular fusion and its surrounding environment is thus purely coincidental (which is anathema to Darwinism). On this theory, selection is left to play only the negative role of culling those fusions that happen to be put together in ways that are not ecologically viable.

Aristotle no doubt opposed the idea of a transmutation of species. But it is worth noting that several features of his biology are actually conducive to an evolutionary worldview. I mention only three here.

(1) The inclusion of humans within animal nature. Aristotle certainly believed that the possession of intellect (or *nous*) constitutes a unique feature of the human essence not shared by other animals. But Aristotle's biology does not define humans exclusively in terms of this feature. The human species, like other animals, is defined by multiple differentiae (*PA* 643b9–644a11) including various features of its *bios* or "way of making a living," which is a single complex activity that incorporates a certain way of moving in space, a certain way of feeding, a certain way of reproducing, a certain way of sensing the world, and so forth (see, especially, *HA* 1.1–5). (Modern ecologists refer to this multi-dimensional description that relates the organism to its environment as its "ecological niche.") This had implications for the way Aristotle understood the boundary between human and non-human animals. He recognized that many dimensions of the human *bios* overlap with those of other animals. For example, humans are air-breathing land dwellers that give birth to live young, something they share in common with other mammals. Given this fact, it is doubtful that Aristotle conceived of the difference between humans and non-human animals as fundamentally a difference in kind. Instead, he seems to treat it as a difference in degree: humans share many features in common with other non-human animals; they simply realize those shared features to a greater degree of perfection. This is even true for some features of their moral character (Lennox 1999), which historically have been seen as separating humans from the rest of the animal kingdom. This is important because the biblical conception of humans as somehow separate from the rest of nature was a major barrier to accepting Darwin's claim that humans evolved from other animals (cf. Bowler 2009, 7).

(2) The elimination of design. While Aristotle often characterizes the productive activity of "nature" using the language of design (*PA* 645a9–11, 652a31; *GA* 730b24–33, 730b19–23, 731a24, 740b25–741a3, 743b20–25, 744b16–27, 778a4), his personification of nature can only be metaphorical. For there is little evidence that his biology relied on an intelligent designer. In *Physics* 2, Aristotle argues that each natural substance contains within itself principles of change and stability, which together constitute its "nature." He goes on to defend the view that nature in this sense is a goal-directed

efficient cause that acts "for the sake of something and because it is better" (198b17–18). And he explicitly contrasts natures with intelligence and craftsmanship as distinct kinds of moving causes (e.g., 192b8–34, 198a2–4, 199a20–28; cf. *GA* 735a2–4). Thus, Aristotle had no need to posit anything like Plato's Demiurge over-and-above the natures of particular natural substances. His natural teleology does not depend on intelligence as it does for Plato.

(3) The recognition of heritable variation. Perhaps the most overlooked feature of Aristotle's biology from an evolutionary perspective is his theory of heredity. In *GA* 4.3, Aristotle argues that an adequate theory of generation must explain a number of phenomena connected with heredity (767a36–b6). The bulk of his theory is devoted to articulating the causal mechanisms that explain how heritable variations are communicated from one generation to the next. According to his account, each organism's genetic material carries a set of "movements" (*kinēseis*), drawn from a corresponding set of "potentials" (*dynameis*) in the organism itself. Once inside the embryo, these movements generate copies of those potentials from which they were drawn, which trigger a sequence of changes that terminates in a new individual with a similar phenotype. The main consequence of Aristotle's theory is that it became possible to explain how variations within a species are maintained across generations (Henry 2006). This is important because that kind of heritable variation provides the raw material for natural selection.

Aristotle's theory of heredity also included the possibility of heritable mutations. At *GA* 768b10 (cf. 769b9–10), Aristotle tells us that disruptions in the normal pattern of inheritance result when the spermatic movements become "confused together." On one reading, these "confused" movements produce mutated potentials in the offspring's genetic nature. Those mutations would then be perpetuated, since there will be a new set of movements in the offspring's own *sperma* derived from those mutated potentials (in accordance with *GA* 767b35–768a2). The possibility of heritable mutation thus opened up theoretical space in Aristotle's account for a source of new variations, which could potentially lead to an evolution of species forms in the way Empedocles suggests.

Aristotle, of course, never took this step. Although his biology included a mechanism for generating and perpetuating heritable variations (the raw materials for natural selection), he failed to appreciate the evolutionary significance of this fact. To see why, consider Darwin's synopsis of natural selection:

> Let it be borne in mind in what an endless number of strange peculiarities our domestic productions, and, in a lesser degree, those under nature, vary; and how strong the hereditary tendency is. Under domestication, it may be truly said that the whole organisation becomes in some degree plastic. Let it be borne in mind how infinitely complex and close-fitting are the mutual relations of all organic beings to each other and to their physical conditions of life. Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life, should sometimes occur in the course of thousands of generations? If such do occur, can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and of procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favourable variations and the rejection of injurious variations, I call Natural Selection. Variations neither useful nor injurious would not be affected by natural selection, and would be left a fluctuating element, as perhaps we see in the species called polymorphic. (*Origin* 1859, 80–81)

While Aristotle recognized the importance of heritable variations between species members, in contrast to Empedocles, his emphasis was never on differential fitness. Rather, his main focus in *GA* 4.3 is on patterns of heredity as such—why offspring resemble their parents more than other members of the same species—and not on whether those heritable variations give their possessor an advantage over conspecifics. For one thing, though Aristotle's biology places great emphasis on what Darwin calls "the mutual relations of all organic beings to each other and to their physical conditions of life" (compare *HA* 1.1–5), he did not recognize (or at least said nothing about) the struggle for existence that those relations can generate, which is so important to Darwinian evolution. For another thing, Aristotle seems to have viewed most intraspecific variations as ecologically neutral: those traits that he thinks differ within a species tend not to make any functional contribution to the species' particular way of life (cf. *GA* 5). Thus, while Aristotle allowed for heritable variations between species members, he did not see the possibility of those variations increasing an individual's reproductive fitness relative to conspecifics. The main explanatory burden of his theory is simply to account for the maintenance of polymorphism in the form of family resemblances.

So why did Aristotle fail to see the evolutionary implications of his own biological views? What is the ultimate source of his blindness, if not outright resistance, to a transmutation of species? One place to look is a pair of arguments from *GC* 2.10 and *GA* 2.1. Like many philosophers in antiquity, Aristotle held the view that being is better than non-being so that the ideal universe would be one that contained only eternal substances that never passed out of existence. Thus, the universe would be completely filled up with being, with no traces of non-being. But since the actual universe contains a sublunary realm of material composites, and since all material composites must come to be and pass away (*GC* 335a32–b5), this state of affairs is not possible. The alternative, Aristotle reasons, is to have an everlasting cycle of generation that guarantees an endless supply of generated beings: "That way," he says, "existence would be most connected, because the fact that coming to be should itself come to be perpetually is the closest approximation it has to eternal being" (*GC* 336b25–35). In *GA* 2.1 Aristotle tries to apply this general argument to the specific case of biological generation in order to explain why sexes exist (731b24–732a3). Because there cannot be any eternal organisms in the sublunary world, insofar as they contain matter, the next best thing is to make their generation continuous. For having *eternal lineages* is the best possible way to maximize the amount of life in the world, given the constraints imposed on living things by their material natures. Eternal lineages would ensure that biological existence is most connected by leaving no existential gaps in the living world as it were. This, in turn, provides the final cause for the existence of sexes: males and females are present for the sake of this end, insofar as they constitute the first principles of generation.

But this argument does not commit Aristotle to the claim that what passes from one generation to the next is an immutable species form. What he says is that there will always be a continuous lineage of animals and plants (*GC* 731b35–732a1), which does not imply that any *particular species* of animal or plant must remain the same over time.[11] The continuity in question holds at a much higher level of generality, which leaves room for evolution (even if within fixed limits). Aristotle does say there will always be lineage of *humans*, which does seem to commit him to the view that at least one species is immutable. But he is not actually arguing for that claim here. Rather, he is making a more general conclusion about why animal species are divided into separate sexes (*GA* 731b24–732a10).

Instead, I would suggest that the primary impetus for Aristotle's anti-evolutionary views comes not in his biology, but from his epistemology. According to *Posterior Analytics*, knowledge in the strict sense (*epistēmē haplōs*)—the sense that is appropriate to science—is acquired through demonstration (*apodexis*). And the premises of a demonstration must be universal propositions that express necessary relations between natural kinds (1.2, 4), where "necessity" is understood in terms of what is eternal and incapable of being otherwise. It follows that there cannot be scientific knowledge of non-eternal truths:

> It is also clear that, if the premises of the syllogism are universal, then the conclusion of a demonstration of this kind (demonstration in the strict sense) must be eternal (*aidion*). Therefore there is no demonstration of things that pass out of existence nor is there knowledge of them in the strict sense but only in the incidental sense in which an attribute belongs to the subject not universally but only at a given time or under certain circumstances. (*Posterior Analytics* 75b21–26; cf. *Nicomachean Ethics* 6.3)

In this way, the formal requirements of Aristotelian science impose constraints on the objects of knowledge that seem to be incompatible with an evolutionary worldview. For Aristotle, the objects of scientific knowledge must be eternal and unchanging. So there could not be an Aristotelian science that took as its objects evolving populations that come into being and go extinct (cf. *Metaphysics* 7.15). Scientific knowledge of biological species is only possible if those species did not undergo any permanent changes in their essential nature.[12]

5. Galen

Aristotle's argument for teleology in *Physics* 2.8 laid the foundation for the first genuine design argument, formulated by Galen in the second century CE. Galen's *On the Usefulness of the Parts of Animals* can be read as an extended defense of Aristotle's argument supported by his extensive knowledge of animal anatomy. In Galen's version of the argument, however, the key premise that things come about either by coincidence or for the sake of something (*Physics* 199a3–5) becomes an opposition between the hypothesis of chance defended by the Epicureans and the hypothesis of design articulated in Plato's *Phaedo* and *Timaeus*.[13] The structure of Galen's argument is roughly:

1) The parts of living things perform functions that contribute to survival.
2) The ability of each part to perform its function depends on a precise structure. Any deviation from that structure, however slight, would destroy its ability to execute that function.
3) The perfect fit between structure and function is either a product of chance or intelligent design.
4) It is highly improbable that chance could be responsible for the perfect adaptations we observe in nature.
5) Therefore, such adaptations must be the product of intelligent design.

Galen builds his case for Premise 4 in stages, moving from the internal coordination of the features of a single part, to the coordination of the parts of the whole system, to the

fact that different species of animals with the same way of life possess these same adaptations. As the level of complexity increases, Galen argues, the possibility that blind mechanical forces (e.g., the random collision of atoms) are responsible for the fit between structure and function becomes increasingly small. Galen's example of teeth illustrates this general argument (*On the Usefulness of the Parts of Animals* 11.8, cf. 11.7).

When we examine the dentition of a carnivore, we can see that different kinds of teeth play different roles in mastication. And each tooth possesses its own unique set of characteristics optimally suited to its function. The different features of the molar, for instance, are all adjusted to one another in a way that allows them to execute the function of grinding. Change any one of those features and the function is destroyed. Even if we grant that each tooth might be the result of the random collisions of atoms, all the teeth must be coordinated in such a way that they work together to execute the overall function of mastication. There are an indefinite number of possible dental arrangements that carnivores might have had, but only one that results in a working system of teeth suited to its particular way of life: there must be sharp incisors in the front for biting, followed by a set of canines for gripping and tearing flesh, with flat molars at the back fitted with the precise topography needed to grind the food down before swallowing. Altering that set-up in any way, either by changing the shape and structure of any tooth or arranging them in a different order, would destroy the function for the sake of which that particular dentition arose. Finally, in order for mastication to contribute successfully to nutrition, the carnivore's teeth must be coordinated with its other organ systems, each of whose own viability is in turn dependent on the same delicate balance between structure and function. The probability that all of this is due to the random collision of atoms, Galen argues, is vanishingly small.

Galen's argument has the familiar ring of modern design arguments, which have their roots in Paley's famous watchmaker argument. Complex adaptations depend on a precise coordination between features that are all "adjusted" to one another in such a way that they work together to fulfill a specific biological need. Change any one of those features in any way, and the whole function is destroyed. This has come to be known as the "irreducible complexity" of certain biological systems.[14] That argument now strikes us as weak because we are used to viewing adaptations from a Darwinian perspective. Galen is surely right that it is unreasonable to suppose that something as complex as the vertebrate eye or the dentition of a carnivore, let alone an entire organism, might arise in a single step from the spontaneous collision of atoms swirling around the void. But Darwinian selection is not like that. It involves the gradual modification of pre-existing structures through the accumulation of random variations over thousands of generations, where each new variation is only a slight alteration in the pre-existing structure. And the chances of slight variations arising in the course of many generations that are also profitable is much less improbable than a single massive variation (which usually crashes the whole system). However, the central weakness of Galen's argument is the assumption that *any* adjustment to a part, however slight, would destroy its ability to function. This is empirically false: a survey of the number of variations, not only among carnivores as a class, but among the members of each species of carnivore, shows that there are multiple adjustments that could be made to carnivore dentition that would preserve the function of mastication.

6. Conclusion

Galen's argument helps draw attention to how small an impact evolutionary thinking had on Greek and Roman naturalists. To Galen, the only two options for explaining complex adaptations were intelligent design or blind chance. Even Aristotle, who rejected intelligent design, saw chance as the only alternative to his own brand of naturalistic teleology. That adaptations might have been gradually built up over time by a slow process of cumulative selection was not considered an option. The failure of evolutionary thinking to gain any traction in antiquity seems to come down to two factors. First, and most obvious, there was a serious lack of empirical evidence for evolution in antiquity. So Empedocles' theory would have been viewed as pure speculation. The best *available* (empirical) theory at that time was that species forms are immutable. The fact of evolution was accepted by science only after we had amassed a large body of empirical evidence to support it.[15] Some of the most important evidence was provided by fossils. While there is some suggestion that the ancients may have encountered fossils, even if they recognized them as such, isolated fossils viewed out of context would not have been enough to suggest an evolution of species.[16] What is needed is a proper *fossil record* that reveals different species existing in different rock strata, together with a theory that allows us to map the different the layers of rock onto different periods in the earth's history. Without this systematic fossil evidence, there was simply no impetus for pursuing the evolutionary hypothesis. Second, Empedocles himself had failed to appreciate the creative power of natural selection. As we have seen, even on his theory, well-adapted forms were seen as the products of blind mechanical forces that combined things entirely at random. That meant that any good fit that exists between organism and environment is entirely a coincidence. And few were willing to accept that.

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NOTES

1 I am grateful to my research assistant, Martin Vezer, for the excellent work of tracking down obscure passages and compiling an annotated bibliography of sources.

2 The first significant theory of transmutation was developed by French biologist Jean-Baptiste Lamarck (1744–1829), though Lamarck's contemporary, Comte de Buffon (1707–1788), also proposed a form of transmutation. See Mayr (1982, Part II), Grene and Depew (2004, Chapter 3), and Bowler (2009, Chapter 3).

3 The Epicureans seem to have invoked Empedocles' ideas (Lucretius 5.826–848), but evolutionary thinking did not form a major part of their system. They still saw chance as the only true alternative to design (e.g., Lucretius 2.166–183; cf. 4. 823–876).

4 Theophrastus also discusses what has come to be called "heterogony," the belief that the seeds of one species of plant can give rise to plants of another species (*Inquiry into Plants* 2.4). In the *Vestiges of the Natural History of Creation* (Chambers 1844), this was offered as a major piece of "evidence" for evolution. But Theophrastus' remarks are about different methods of propagation and have nothing to do with evolution (cf. Mayr 1982, 309).

5 *TEGP* 46. Cf. KRS 294. There is no scholarly consensus surrounding Empedocles' cosmic cycles (see O'Brien 1969). For convenience, I shall assume that the evolutionary processes that follow occurred during the reign of Love.

6 *TEGP* 122 tells us that these proto-organisms constituted the first generation of living things. Though obscure, *TEGP* 44 (lines 2–3, of the newly discovered Strasbourg fragments) also suggests that Empedocles considered these "limbs" to be living organisms. He says: "…at

one time through Love, we [sc. the elements] all came together into one as limbs, which have acquired bodies at the height of their flourishing life."

7 This interpretation goes at least as far back as Lucretius 5.855–860.

8 See O'Brien (1969, 196–200) for other interpretations that advocate a discontinuous sequence with a full break between the second and third generations.

9 See Sorabji (1980, 176–177), who argues that these organisms were incapable of reproduction and died off after one generation.

10 It is well known that A. R. Wallace had independently discovered natural selection. And both of these were part of his account (see *On the Tendency of Varieties to Depart Indefinitely from the Original Type*, 1858).

11 Aristotle actually seems to allow for differences in the degree to which individuals manage to replicate their forms (*On the Soul* 2.4.415b3–6), which is already implied by his theory of heredity.

12 It is a matter of great controversy whether or not Aristotle's biology conforms to the strict standards of knowledge developed in the *Analytics*. Indeed, it is a matter of scholarly debate whether or not those standards are in fact as strict as I have suggested here.

13 See, especially, *On the Usefulness of the Parts of Animals* 1.21, 6.12–13. By contrast, Aristotle explicitly argues that the natures of living things operate for the sake of an end but not through intelligence (*Physics* 2.8).

14 The fallacy of an appeal to so-called irreducible complexity to refute the explanatory power of natural selection has been well documented.

15 Today, science accepts that species have evolved over time on the basis of several lines of evidence, including the fossil records, the distribution of species around the globe (biogeography), embryological patterns, DNA evidence, the existence of homologies, and so forth, all of which converge on the theory of evolution. For an excellent discussion of the main lines of evidence, see Dawkins (2009) and Coyne (2009). While Empedocles seems to have appreciated that embryology might be related to the evolution of life on earth, this idea failed to gain any support beginning with Aristotle (see earlier text).

16 Mayor (2011) claims that the ancient Greeks and Romans collected, measured, displayed, and pondered the significance of fossils and that this formed the empirical basis for much of their mythology. I will leave the reader to judge the persuasiveness of Mayor's argument. However, if she is right, then it is puzzling why Aristotle—one of the most systematic and careful biologists the world has ever known and much of whose data is drawn from ordinary knowledge—never once mentions anything about observations of the bones of giant unknown animals. Even if we accept that the ancients encountered the fossilized remains of extinct species, including large vertebrates, there is no evidence that they recognized their evolutionary significance. For example, Xenophanes and Herodotus, writing in the fifth century BCE, apparently made passing remarks about fossilized shells. But neither of them saw this as evidence that species have evolved over time. Rather, both simply took them as evidence that the land in which they were found was once under water.

CHAPTER 20

Embryology

James Wilberding

1. Introduction

Two doxographical stretches of text from authors in late antiquity (pseudo-Plutarch, *Moralia* 5.904c–909b and Censorinus, *On the Birthday* 5–11) offer a particularly synoptic picture of the widespread attention embryology received in antiquity. Both reports document that embryology was of interest to physicians and philosophers. They refer by name to Alcmaeon, Anaxagoras, Aristotle, Democritus, Diogenes, Empedocles, Epicharmus, Epicurus, Hippon, Leucippus, Parmenides, Plato, Pythagoras and Pythagoreans, the Stoics, Strato, and Zeno of Citium. This shows that embryology was an area of sustained interest from the Presocratics until the Hellenistic period, and this list could easily be extended to include, for example, later Christian and Neoplatonic thinkers. The questions that these two authors include in their doxographies are also wide-ranging: What is the substance of the seed? Is the seed a body? Do females emit seed? How does conception take place? What determines the offspring's sex? Why do deformities occur? Why do females sometimes not succeed in conceiving? How do twins and triplets come to be? How is parental resemblance to be explained? Why does it sometimes happen that offspring resemble others and not the parents? Why are some females infertile and some men impotent? Why are mules sterile? Is the embryo an animal? How is the embryo nourished? What part is formed first in the womb? Why are seventh-month children viable? How long does the formation of animals in the womb take? To be sure, for the historian of embryology there are obvious limits to the value of these doxographies. Many important physicians, including Galen, are omitted entirely from these surveys, for example, and the views of those who are included are presented in a curt and superficial manner. Yet this list does provide us with a first glimpse of the broad scope of embryological interest. Needless to say, we cannot pursue all of these questions here, nor even all of the ancient authors who concerned themselves with embryology.

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2. Approaches to Empirical Research

Let us begin with a question that our two ancient doxographers did not think to pose, namely, how ancient embryologists approached their subject empirically. One of the problems intrinsic to human embryology, after all, is that the phenomena to be studied all occur in the hidden recesses of the womb. This inhibits systematic observation of the formation of the human embryo, which would require viewing an adequate sampling of human embryos and fetuses at set intervals from conception. Some of the phenomena regarding conception and the duration of pregnancy, for example, might have been ascertained by consulting with women about their own experiences, but such testimony can take one only so far, and it sometimes even takes one in the wrong direction (Dean-Jones 1994, 27–31; Nickel 1989, 16–17). If one Rabbinic source is to be believed, the Ptolemaic Queen Cleopatra overcame this obstacle in a particularly gruesome manner, by performing vivisections on convicted pregnant female slaves (Preuss 2004, 41; cf. Pliny, *NH* 19.86). There is, however, no evidence of an ancient Greek or Roman physician ever having carried out such an embryological research program. Even the dissection of human corpses was off-limits for virtually the entire history of ancient medicine, with the exception of a brief spell in Alexandria in the third century BCE (Anatomy and Physiology; Surgery). The Alexandrian physician Herophilus exploited this window to advance the understanding of human anatomy considerably (see below; Physicians and "Schools"). Herophilus' research program probably even included vivisection on human convicts (this might apply to Erasistratus of Ceos as well), but it is not clear that his embryology or reproductive anatomy profited directly from such work. The majority of ancient researchers, however, had to find alternative approaches to the empirical study of the embryo.

One such approach was to examine human embryos that had been aborted or miscarried, which Aristotle (*GA* 773a1–2) describes as happening frequently in his day. There is evidence of such practice, for example, in Aristotle (*HA* 583b9–28; *PA* 665b1–2; cf. Lloyd 1991, 179 note 55) and Galen (*On the Formation of the Fetus* 54.13–14 Nickel [4.653 Kühn], 66.7–15 Nickel [4.662–663 Kühn]; *On the Seed* 92.21–22 De Lacy [4.542 Kühn], 192.3–5 De Lacy [4.637 Kühn]), but the most celebrated example is found in the Hippocratic *On the Nature of the Child* 13 [7.488–492 Littré], in which the author recounts his experience of examining, though not dissecting (Lloyd 1991, 186), an embryo that was allegedly conceived only six days beforehand: "As a matter of fact I myself have seen an embryo which was aborted after remaining in the womb for six days. It is upon its nature, as I observed it then, that I base the rest of my inferences" (*On the Nature of the Child* 13.1 [7.488–490 Littré], trans. Lonie). What the author proceeds to describe looks like "someone had removed the shell from a raw egg." It was a round, red membrane with clots of blood on the outside and white fibers on the inside, and there appeared to be an umbilicus stretching from the seed at the center to the membrane, through which, the author inferred, the embryo received breath. We shall return later to the importance of this breath for the embryology of *On the Nature of the Child*. For now, we may simply note that whatever the author saw—and there has been much speculation—it cannot have been a six-day-old human embryo (Lonie 1981, 161). Nevertheless, the Hippocratic name bestowed enormous authority upon this account, and it was invoked as evidence for centuries to come.

A second, complementary strategy to empirical research in embryology involved working by analogy. The scope of this analogical method extended well past the borders of the animal kingdom. Over a quarter of the Hippocratic *On the Nature of the Child* is devoted to the developmental biology of plants, for example, because the author was convinced that "from beginning to end the process of growth in plants and in humans is exactly the same" (27.1 [7.528 Littré], trans. Lonie; cf. 22–27 [7.514–528 Littré]). Elsewhere, for example, the same Hippocratic author supported his thesis that developmental deformities in humans are often due to the constricting size of the mother's womb by comparison with cucumbers growing in jars that are likewise deformed (*On Generation* 9.3 [7.482 Littré]). As we shall see later, other important analogies were made even to areas outside of biology, but it was certainly the analogies with other animals that led to the most striking advancements in ancient embryology. With the exception of those physicians who programmatically rejected the value of dissection (e.g., Soranus, *Gynecology* 1.5 [1.3.37–45 Burguière et al.]), ancient physicians, even Herophilus, relied mainly on the dissection of animal fetuses and uteri to further their knowledge of embryological processes, the assumption being that there are fundamental parallels between the anatomy and development of humans and animals (Aristotle, *HA* 494b21–24; Galen, *On the Formation of the Fetus* 58.10–12 Nickel [4.655 Kühn]). There is ample evidence of such practice (e.g., *On the Nature of the Child* 31.2 [7.540 Littré]; Aristotle, *GA* 746a22), which was not limited to corpses. (Animal lovers are advised to steer clear of Galen's vivid instructions on binding and preparing a pregnant goat for vivisection [*On Anatomical Procedures* 12.6, not in Kühn].) The perceived similarities between the early stages of the human embryo and the hen's egg helped make the latter a popular object of study: the two most famous examples may be found in the Hippocratic *On the Nature of the Child* 29 [7.530] and Aristotle, *HA* 561a6–562a22. The Hippocratic author describes the procedure as setting up "twenty or more eggs" so as to allow for incubation, and opening one egg every day for examination. Interestingly, there is no evidence that Galen performed this experiment, perhaps because he believed that hens are too far removed from human beings for their developmental biology to be meaningfully transferred to that of humans. Instead, Galen directed his efforts at animals that he considered more analogous to humans, in particular goats, sheep, cows, horses, and donkeys. All of this work was used to draw inferences about a wide range of embryological issues in humans, including the order of the embryo's formation, the embryo's manner of nourishment and relation to its mother, and the point at which its life functions begin. Of course, all analogies have their limits, and even Galen's more selective research program led to some erroneous conclusions (Nickel 1989, 18–22).

A final variety of analogical reasoning brings us to the domain of embryological etiology, and this in turn takes us into the very heart of theoretical embryology. The embryology of the Hippocratic *On Generation* and *On the Nature of the Child*—two treatises composed by a single author, dating to around the end of the fifth century BCE (Joly 1970, 23; Lonie 1981, 71)—may serve as the first illustration of such reasoning, as it is the earliest comprehensive embryology that has come down to us in its entirety. Yet two of the starting points of the Hippocratic theory require some preliminary exposition, as they are both issues that pertain to the larger history of ancient embryology.

3. Male and Female Seeds

The first of these issues concerns the author's understanding of the male and female contributions to reproduction. Today, we understand the process of human development to begin with the fertilization of a female oocyte or egg by the male seed or spermatozoon. This overlaps with ancient embryology to the extent that ancient theorists universally envisioned the male's contribution as a seed. (Whether the seed should be described as a *zōon*—literally a "living thing" or an "animal"—was debated.) But it was only in the nineteenth century that the female mammalian ovum was first described (though it had been the object of earlier speculation), and it is entirely absent from ancient embryological theory. What the female contribution amounted to, however, was a matter of a long-running controversy in antiquity. Our Hippocratic author maintains that it is also a seed (*On Generation* 4.1 [7.474 Littré]; *On the Nature of the Child* 12.1 [7.486 Littré]; *On the Sacred Disease* 4 32.1 [7.542 Littré]). The alternative was to say that it was something inferior to a seed, usually amounting to some form of nourishment. Both views found their advocates, both predating this treatise and well afterward. The widespread acceptance of the one-seed theory and its far-reaching cultural and social implications are made vivid in Aeschylus, *Eumenides* 657–666, where Apollo employs it to defend Orestes against the charge of matricide: "The mother of what is called her child is not its parent, but only the nurse of the newly implanted germ (*kuēma*). The begetter is the parent, whereas she, as a stranger for a stranger, doth but preserve the sprout" (trans. Smyth; cf. Euripides, *Orestes* 551–556). Presocratic defenders of the one-seed theory include Anaxagoras (DK 59A107, but cf. Censorinus, *On the Birthday* 5.4, 6.8) and Diogenes of Apollonia (*TEGP* 36, 40). Aristotle argues for it at length in *GA* (726a30–731b14), and it is subsequently adopted by the Stoics and all of the Neoplatonists. The two-seed theory was advanced by numerous philosophers, including Pythagoreans (see Zhmud 2012, 374–380), Alcmaeon (DK 24A13–14), Parmenides (*TEGP* 54, 57), Empedocles (*TEGP* 146, 147, 126), Democritus (*TEGP* 93, 94), and Epicurus (pseudo-Plutarch, *Moralia* 905b–c), but it is particularly well represented among ancient physicians, notably by other Hippocratic authors (*On the Diseases of Women* 1.8 [8.34–38 Littré]; *On Regimen* 27 [6.500 Littré]), Diocles (fragment 42a/b van der Eijk) and the author (not Aristotle, presumably a third-century physician) of *History of Animals* Book 10 (see *HA* 634b29–38, 636b36–39). The most thorough surviving argument for the two-seed theory was made by Galen in his *On the Seed* (2.1 [4.593–651 Kühn]). Not all ancient embryologists can be neatly placed in either camp. Herophilus, for example, held that there is a female seed but, on the basis of purported anatomical evidence, he argued that the female seed does not contribute to the constitution of the embryo because it is conducted to the bladder and from there simply expelled (T60 von Staden), and this view is taken over by Soranus (*Gynecology* 1.12 [1.4.96–98 Burguière et al.]) and perhaps anticipated by Hippon (DK 38A13).

Each view faces at least one major obstacle. The one-seed theorists must provide some explanation of maternal resemblance, and the two-seed theorists must explain the impossibility of parthenogenesis. Hippocrates, for his part, seeks to support the two-seed theory by considerations relating to maternal resemblance (*On Generation* 8 [7.480–482 Littré]) and to the pleasure that the female experiences during coitus, with said pleasure being explained by the discharge of seminal fluid (Lonie 1981, 120–121).

Galen later buttresses these arguments with anatomical observations, e.g., the female testicles (today we would say "ovaries" in light of their egg-producing function, but the ancients used the same term *didymoi* for the male and the female; the anatomical discovery of the female testicles is credited to Herophilus [T60 von Staden]) contain seed, especially when the female is in a sexually excited state. He also made observations of a less invasive nature, for example, that there is evidence of spermatic discharge by females in sleep and disease, often accompanied by pleasure (Nickel 1989, 40–43).

4. The Origin of the Seed

The second issue pertaining to the larger history of embryology concerns the corporeal origin of the seed. Our Hippocratic author subscribes to a form of pangenesis, according to which the seed derives from the entire body. One of the supposed strengths of this view is its ability to account for parental resemblance: the offspring's resemblance to a parent with respect to any given part can be explained by tracing the origin of that part back to the respective parent's part. As Aristotle points out, the pangenesis doctrine contains a fundamental ambiguity that turns on one's understanding of the "entire body" from which the seed derives (*GA* 722a16–b3). Our author sees it as deriving from the homoiomerous parts—the four humors as well as the "soft" and "hard" parts (*On Generation* 3 [7.474 Littré]; cf. Lesky 1951, 1301–1304), but different conceptions of the source parts led other theorists to somewhat different varieties of pangenesis, as can be seen in, for example, Anaxagoras (*TEGP* 28), Democritus (*TEGP* 90, 319), and Epicurus (*Letter to Herodotus* 38, 66). Although Michael of Ephesus is a late and unreliable source, some appreciation of the possible scope of pangenesis theories can be won by comparing this Hippocratic account to his account of Democritean pangenesis, according to which each seed consists of microscopic anhomoiomerous parts such as heart and head (in *GA* 167.13–19; on Democritus' embryology, see Morel 2008). According to the earliest documented theory of spermatogenesis, however, the seed derives not from the entire body but from the brain and the marrow. This is the so-called encephalo-myelogenetic theory, and the surviving evidence allows us to attribute this theory above all to the Pythagorean school, in particular, to Alcmaeon (DK 24A13), Hippon (DK 38A12–13), and an unnamed Pythagorean in Diogenes Laërtius 8.28. The original motivation behind the identification of the brain and marrow is obscure and might well be a case of eastern influence. Be that as it may, while the encephalo-myelogenetic theory ultimately gave way to pangenesis, it did not disappear entirely. It is still on full display in Plato's *Timaeus* (73b–74b) and Diocles (fragment 41a/b van der Eijk), and traces of it can also be found alongside pangenesis, not without some tension, in the Hippocratic corpus (*On Generation* 1.2 [7.470 Littré]; cf. Lonie 1981, 101–103), as well as in subsequent non-pangenetic embryologies, for example, Aristotle (e.g., *GA* 747a17–18). By the time Aristotle wrote his *GA*, encephalo-myelogenesis appears to have no longer been a serious contender in the discussion of spermatogenesis. Aristotle focuses all of his efforts on refuting pangenesis (*GA* 1.17–18). In its place, Aristotle develops the hematogenetic theory, which has the seed deriving from the concoction of blood, a theory which already appears to have been advanced by a few Presocratics, namely, Parmenides (*TEGP* 54) and Diogenes of Apollonia (*TEGP* 34, 36). The hematogenetic theory was subsequently further developed by Herophilus, Erasistratus, and Galen, among

others. Herophilus (von Staden 1989, 288–296) and Galen (e.g., *On the Usefulness of the Parts* 14.10 [4.183–188 Kühn], *On the Seed* 1.12–14 [4.555–563 Kühn]), in particular, buttressed the hematogenetic theory with anatomical observations. Unlike pangenesis, which has a ready explanation for parental resemblance, hematogeneticists must supplement their theory with some account of how concocted blood can account for hereditary features.

5. Conception and Embryological Etiology

Let us now return to the embryology of the Hippocratic *On Generation* and *On the Nature of the Child* and its use of analogy as a model of causation. As we have just seen, this author envisions two seeds, one from the male and one from the female, each deriving from the entire body. Conception occurs when these two seeds are mixed together, leading to the process of formation. The driving force of embryonic formation is *pneuma* (here, ordinary "air" or "breath" as opposed to some more divine or teleological conception of "spirit", as is made clear by his comparison to the burning of freshly cut wood). Here, hot air is expelled and cold air is drawn in, giving rise to an eddy (*On the Nature of the Child* 12 [7.486–488 Littré]), and embryogenesis is supposed to proceed along similar causal lines. Since the seeds already contain all of the important parts of a human being, the formation of offspring can then be explained by appeal to two principles: predomination and like going to like. The author strikingly illustrates the central role of the latter in formation by appeal to an analogy to the non-biological physical world:

> Now the formation of each of these parts occurs through respiration—that is to say, they become filled with air and separate, according to their various affinities. Suppose you were to tie a bladder on to the end of a pipe, and insert through the pipe earth, sand, and fine filings of lead. Now pour in water, and blow through the pipe. First all of the ingredients will be thoroughly mixed up with the water, but after you have blown for a time, the lead will move towards the lead, the sand towards the sand, and the earth towards the earth. Now allow the ingredients to dry out and examine them by cutting the bladder: you will find that like ingredients have gone to join like. Now the seed, or rather the flesh, is separated into members by precisely the same process, with like going to like. (*On the Nature of the Child* 17.3–4 [7.498 Littré], trans. Lonie)

The specifics of maternal and paternal resemblance are then to be accounted for by appeal to a quantitative theory of predomination that is correlated to the offspring's parts: a given part resembles that parent whose seed provided a greater quantity of that part (*On Generation* 8 [7.480–482 Littré]). This theory bears unmistakable similarities to various Presocratic physical theories, and questions of the direction and extent of influence have been much discussed, but the major point I would like to emphasize here is that this author's understanding of the etiology of embryogenesis has been determined by applying a broader model of causation in the physical world to the case of embryogenesis.

A second point that deserves some attention concerns the female's integration into this causal model. A student surveying the landscape of ancient embryology for the first time is likely to be struck by the recurring instances of androcentricism. This is

most blatantly on view in the one-seed theories, but it is also deeply entrenched in the two-seed theories. Our Hippocratic author, for example, distinguishes between androgenetic and gynecogenetic seeds in terms of their quality: the seeds that produce males are "strong" (*iskhuros*) while the seeds that produce females are "weak" (*asthenes*). Nevertheless, the account he offers of the respective causal contributions by the father and the mother is more balanced than much of what one finds in subsequent theories. (The notable exception of the Neoplatonists will be discussed later.) This is due to his innovative doctrine of sexual bi-potency, according to which each parent is capable of supplying both androgenetic and gynecogenetic seed. Thus, even though the gynecogenetic seed is assumed to be weaker, the seed that the mother contributes is generally on a par with that of the father. In this way, the sex of the offspring may be determined as a function of the quality (weak or strong) of each parent's seed, with cases of differing qualities being determined by the quantity of the respective seeds (*On Generation* 6–8 [7.478–482 Littré]; a comparable theory is developed in the Hippocratic *On Regimen* 27–30 [6.500–506 Littré]). One of the virtues of this approach is its ability to accommodate secondary sexual characteristics into its theory of heredity. That is to say, this theory can account for a male offspring having a chin like his mother's while allowing for this chin to get hairier than his mother's as he gets older.

By contrast, the etiological balance in Aristotle's embryology is clearly skewed toward the father, and this is owed in large part to another application of analogical reasoning. As we saw earlier, Aristotle argues at length against pangenesis and the female seed, developing instead a one-seed hematogenetic theory. This theory is inextricably embedded in his broader physical theory of the four causes, and the key to understanding Aristotle's embryology lies in seeing how the male seed is related to these four causes. In cases of biological reproduction, Aristotle identifies the formal and final causes, because the complete human being is the goal of human reproduction; he connects both of these to the efficient cause (*Physics* 198a25–27; cf. *GA* 715a8–9) and situates them as a power (*dynamis*) in the male seed. Importantly, this power is no mere potentiality but already involves actual motion, making it an actual efficient cause (*GA* 730b19–21). Only the material cause is separated from these three, being identified with the menstrual blood provided by the mother: "The male provides the form and the principle of the movement, the female provides the body, in other words, the material" (*GA* 729a9–11, trans. Peck). This strong divorce of the material cause from the other three requires some comment. After all, given that the male seed itself evidently includes a fluid, material substrate, it would have been reasonable to assume that this material becomes part of the material constitution of the embryo. Aristotle not only denies this; he places great emphasis on the point. And, although he does supply some empirical evidence from which he thinks this division may be inferred, his main reason for refusing to classify the male seed as among the *material* causes of the embryo is drawn from an analogy to production in the crafts. The craftsman is responsible for imparting the shape to matter via the movement of his hands and tools, whereas the matter does not come from the craftsman but is already there, supplied from another source (*GA* 729b9–21, 730b4–32).

This fundamental framework of Aristotle's embryology then suggests that if everything goes according to plan, the offspring should turn out to be male—the spit and image of the father—since the father is the supplier of the offspring's form. This does indeed seem to be Aristotle's view insofar as he describes the female offspring as "a deformity, as it were" (*hōsper anapērian*: *GA* 775a15–16; cf. 767b8–9). Nevertheless, Aristotle

shows himself to be aware of the full spectrum of hereditary possibilities and develops a sophisticated response to this challenge (*GA* 4.3), though there are some questions as to whether this response is best viewed as a precision or a revision of the fundamental framework. This response begins by acknowledging that although the mother's *menses* is not a seed, it is still seminal; like the male seed, it is concocted from blood, but owing to the female's colder nature, it is not fully concocted and thus does not contain within itself an efficient cause of embryogenesis (e.g., *GA* 728a25–26, 774a2–3). Then it posits powers (*dynameis*) in both the male seed and the female menses, corresponding not only to their own features and parts but also to those of their ancestors, and through a complex process of domination (*krasis*) and relapse (*lusis*), these powers determine the ultimate appearance and sex of the offspring, thus achieving the goal of human reproduction (see, e.g., Cooper 1988 and Henry 2006).

That biological reproduction for Aristotle has a goal to achieve at all also bears emphasis. As we have just seen, Hippocratic embryology makes do without any goal-directed principles; the embryo's parts simply fall into place, as it were, by the forces of necessity. Aristotle saw this absence of teleological principles as a major failing of his Presocratic predecessors, and although he never criticizes Hippocratic embryology specifically on this count (though cf. *GA* 736b29–737a1, 740b12–18), his criticisms of Anaxagoras and Empedocles (*Physics* 2.8) paint a clear enough picture of his disdain for this approach to natural philosophy. This brings us to another fundamental issue in the history of ancient embryology, sometimes considered under the rubric of "mechanism" versus "vitalism" (e.g., Lonie 1981, 150–152), though both of these terms can have unwanted connotations. Aristotle is hardly alone in his battle against the so-called mechanists. Centuries later, we find the physician-philosopher Galen still engaged in the same battle, this time primarily against the physicians Erasistratus and Asclepiades, and distinguishing himself as one of the most vocal critics of the mechanistic approach to human physiology (see especially *On the Natural Faculties, On the Usefulness of the Parts*).

Galen's work also serves as a fine example of how ancient two-seed theories typically remained under the androcentric spell. Galen dedicated a considerable amount of attention to embryological questions, with several surviving works devoted entirely to embryology (notably *On the Seed*, *On the Formation of the Fetus*, *On the Anatomy of the Uterus, On the Seven-Month Child*) and many other works engaging with embryological issues on a more selective basis (especially *On the Usefulness of the Parts* 6 [3.409–515 Kühn], 14–15 [4.142–262 Kühn]; *On Anatomical Procedures* 12–13 [not in Kühn]; *On the Natural Faculties* 1.5–6 [2.10–15 Kühn], 2.3 [2.80–88 Kühn]; *On the Doctrines of Hippocrates and Plato* 2 [5.211–284 Kühn], 6 [5.505–585 Kühn]). To be sure, Galen makes major adjustments to received views on the male and female contributions. He attacks not only Herophilus' belief that the female seed is simply expelled and plays no causal role in reproduction but especially the strict Aristotelian division between the material and the other three causes. He insists that both the male and female seed contribute both form and matter, and this seminal matter plays an important role in his theory of embryogenesis. For it allows him to distinguish between spermatogenetic and hematogenetic body parts, with the former being generated out of seminal matter and the latter out of blood (menses). This Galenic distinction left an enduring mark on the history of embryology and was not without consequences for medical practice, since on this view any part designated as spermatogenetic (e.g., bones and nerves) cannot be

regenerated if lost or removed by surgery (Nickel 1989, 83–90). Like Hippocrates, Galen envisions conception as the successful mixing together of male and female seeds (*On the Seed* 146.14–20 De Lacy [4.595–596 Kühn]), but like Aristotle he understands seed to result from the concoction of blood (see Lesky 1951, 181) and the female nature to be colder than the male's (*On the Seed* 176.13 De Lacy [4.624 Kühn] and see De Lacy's note *ad* 86.24–25). In this way, he arrives at a two-seed theory that is not as far removed from Aristotle's as one might expect. There is a female seed, but it is qualitatively and quantitatively inferior to the male seed (*On the Seed* 1.7 [4.535–539 Kühn], 2.4 [4.620–625 Kühn]; *On the Usefulness of the Parts* 14.6 [4.158–165 Kühn]). Moreover, this is reinforced by some of Galen's statements about the causes of embryogenesis, which he explains in terms of this theory of natural powers. This begins with the powers of attraction and transformation—drawing in and assimilating the nourishing blood—and culminates with the activity of the formative (*diaplastikē*) power, which he describes as "active" (*drastikē*), "artistic" (*technikē*), and "creative" (*dēmiourgikē*) and which he appears to locate in the male seed (*On the Usefulness of the Parts* 14.5 [4.156–158 Kühn]; *On the Natural Faculties* 2.3 [2.80–88 Kühn]; *On the Preservation of Health* 1.2 [6.3–7 Kühn]; cf. Nickel 1989, 42–49). All of this, however, must be understood against the background of *On the Formation of the Fetus* 104.15–106.13 Nickel [4.700–702 Kühn], where Galen explains that he cannot be certain of the agent ultimately responsible for the embryo's formation.

This survey of embryological etiology may be concluded with a brief look at the Neoplatonists. These thinkers have traditionally been omitted in histories of embryology because they were seen as metaphysicians with little interest and limited aptitude for empirical science, especially the biological sciences, and—to be fair—there is some justification for this assessment. For example, they were part of a robust Aristotelian commentary tradition, yet they never commentated on any of Aristotle's biological writings. That said, there is one Neoplatonic treatise devoted entirely to embryological issues, Porphyry's *To Gaurus On How Embryos are Ensouled (Ad Gaur.)*, and a good deal of embryological material scattered throughout other works. Perhaps more to the point, in contrast to the philosophers and physicians discussed earlier, here we find no evidence of original empirical research or experimentation. In this regard, Neoplatonic excursions into embryology are comparable to those of the church fathers (e.g., Augustine, Lactantius, Nemesius, and Tertullian); their interest was focused on a different set of questions revolving primarily around the origin of the soul and the role of higher powers in the natural world, as is already evident in the title of Porphyry's treatise. Nevertheless, the Neoplatonists have earned their place in the history of embryology thanks to their distinctively active understanding of the female's role in reproduction. Like our Hippocratic author and Aristotle, the Neoplatonists also bring their own preconceived ideas about causation to embryology, and when they apply their causal model, drawn from the metaphysics of procession and reversion, to embryology, what results is a new variation on the one-seed theory. It begins with the familiar assumption of a male seed that contains form-principles corresponding to all of the parts, but unlike Aristotle and Galen, the Neoplatonists refuse to see the male seed as an actual efficient cause. Rather, this seed lacks actual motion (Porphyry, *Ad Gaur.* 14.3 [54.12–14 Kalbfleisch]), and all of its form-principles are in a state of potentiality and must be led to actuality by an external agent who possesses these principles in actuality, and this agent is usually identified with the mother, for example:

> What is imperfect is generated from what is perfect, and what is in a state of potentiality from what is in a state of actuality. For a human being generates a seed, as the father does, and again generates a human being from a seed, as the mother does. For everything in a state of potentiality must be led to a state of actuality by something that is in a state of actuality. (Simplicius, *On Aristotle's Categories* 244.1–4; cf. Proclus, *On Plato's Parmenides* 792.7–18 Steel; Asclepius, *On Aristotle's Metaphysics* 404.12–29; Philoponus, *On Aristotle's On the Soul* 306.2–8)

6. "Preformation" and "Epigenesis"

The manner of the embryo's formation was also of great interest to ancient embryologists. The disagreement surrounding preformationism, which holds that the body of the offspring exists preformed in the seed, and epigenesis, according to which the offspring's parts are formed successively after conception, sets out one of the major dividing lines in theories of formation. Although "preformationism" and "epigenesis" are terms drawn from the more recent history of embryology, ancient embryologists were aware of the conceptual alternatives. Aristotle lucidly articulates the alternatives: "How, then, are the other parts formed? Either they are all formed simultaneously—heart, lung, liver, eye, and the rest of them—or successively" (*GA* 734a16–18), and he, for his part, thinks that empirical observation is sufficient to refute preformationism: if all of the parts were already present in a microscopic state and gestation simply consisted in growing larger, then the largest parts (e.g., the lungs) would be the first ones to become visible, but this is not the case (*GA* 734a20–25).

It is helpful to distinguish between different varieties of preformationism that result from different theories of spermatogenesis. In its most striking form, which we may refer to as homuncular preformationism, the seed already contains the microscopic offspring in a unified organic state. This theory, which would seem to be incompatible with two-seed theories, is on clear display in the passages by Aeschylus and Euripides cited earlier, but it is far from clear that homuncular preformationism was advanced by any embryologists in antiquity. It has been attributed by some scholars (e.g., Lesky 1951, 72) to Democritus on the basis of his description of reproduction as "a mild apoplexy; for a man issues from man and is torn away, separated by a sort of blow" (*TEGP* 319, trans. Taylor), but this interpretation does not sit well with the precious little else we know about Democritus' embryology (cf. especially *TEGP* 93, 94, 96–98; Morel 2008). Plato has also been categorized as an homuncular preformationist (e.g., Taylor 1928, 640), partly on the basis of his description of conception as the sowing of "living things that are too small to see and unformed" (*Timaeus* 91d2–3) and partly under the influence of Michael of Ephesus' far-fetched exegesis of Platonic embryology (*On GA* 25.20–31, 33.19–34.6). But this is an unlikely interpretation of Plato's admittedly obscure remarks on embryology and is, in any case, difficult to square with his encephalo-myelogenetic theory. Weaker varieties of preformationism result from requiring only the offspring's parts to exist in a preformed state, and these weaker varieties are more obviously compatible with two-seed theories.

Since preformationism in this weaker sense follows necessarily from pangenesis, we may once again distinguish between homoiomerous and anhomoiomerous preformationism, depending on which parts are thought to be preformed. Thus, the theory

examined earlier in the Hippocratic *On Generation* and *On the Nature of the Child* may, for example, be characterized as homoiomerous preformationism, yet insofar as the offspring's anhomoiomerous parts do not appear to exist in a preformed state in the seeds, this theory may also be classified as epigenetic (see *On the Nature of the Child* 17.2 [7.498 Littré]). On balance, it may be said that epigenesis was the more widely accepted approach in antiquity—it found the support not only of Aristotle but also Diocles, Galen, the Stoics, and others—though this still left ample room for disagreement about the details of formation.

From our perspective, perhaps one of the most surprising of such disagreements concerns whether the child born in the eighth month is viable, and if not, why it is not. This is not simply addressing the dangers of premature births. Rather, there was a widely held belief that there was not a single period of gestation for human beings. Children born in the seventh month survived, as did those born in the ninth (or tenth or even eleventh) month, but those born in the eighth month generally perished (e.g., Hippocratic *On the Eight-Month Child* [*passim*]; Aristotle, *HA* 584a35–b25, *GA* 772b6–12; cf. Hanson 1987).Yet there is also some evidence that this view was not universally held; for example, Herophilus is reported to have rejected the possibility of the seven-month period as resulting from a mistaken guess about the date of conception (T198 von Staden).

Another major disagreement concerns the exact sequence in which the offspring's parts are formed, and in particular which part was thought to be formed first, as is also attested by the list of aforementioned doxographical questions. The various proposed parts show how closely this line of questioning is tied to psychological views regarding the soul's seat or seats in the body. It should come as no surprise, for example, that some encephalo-myelogenecists thought that the brain was the first part to be formed, for example, Alcmaeon (DK 24A13) and Hippon (DK 38A15), and it is probably no coincidence that both Alcmaeon and Hippon maintained that the soul has its seat in the brain (DK 24A8, 38A3). Aristotle, by contrast, maintains that the heart is the primary seat of the mortal soul (*PA* 666a10–13; *Parva Naturalia* [*Short Treatises on Nature*] 465a4–6, 469a5–12; *On the Motion of Animals* 703b23–24; *GA* 743b25–26), and this certainly figures into his view that the heart is the first organ formed. This is not to say that Aristotle provides no empirical evidence for this view; he claims that his view is borne out by the examination of sanguineous animals during the earliest stage of their development, and here he presumably has his dissections of chick eggs in mind (*PA* 665a33–b2; *HA* 561a11–13; *GA* 734a23–25; *Parva Naturalia* 468b28–31). This theory receives further support from his physiology: the development of all parts requires that nourishment (blood) be supplied, and the heart is the source of blood and of the blood vessels that convey it; hence, the heart is a prerequisite for the generation of the other parts (*GA* 740a4–24). Likewise, Chrysippus and other Stoics, who maintained that the soul has its primary seat in the heart, also have the heart being generated first (*SVF* 2.761, 737, 879–881, 3.29; cf. Gourinat 2008, 70–71).

Galen relates that he also held this view early on in his career but then rejected it in favor of taking the liver to be the first part formed (*On the Formation of the Fetus* 66.19–32 Nickel [4.663–664 Kühn]; *On My Own Opinions* 90.18–94.17 Nutton [not in Kühn]). Galen, too, claims that empirical observation supports this revision: after thirty days, the liver, heart, and brain can all be observed in miscarriages and animal dissections, but the liver is largest, which suggests to him that it must have been

formed first (*On the Formation of the Fetus* 64.25–66.11 Nickel [4.662–663 Kühn]; 15.6 [4.241–246 Kühn]). Indeed, he even goes so far as to surmise that the famous Hippocratic description of the six-day embryo contains a description of the liver, even if that author did not recognize it as such (*On the Formation of the Fetus* 66.5–7 Nickel [4.662 Kühn]). This revision must be understood in light of Galen's physiology and psychology. Unlike Aristotle's, Galen's physiology distinguishes between the arteries and veins, whose principles are the heart and liver, respectively. Thus, while Galen agrees with Aristotle that the source of blood and its conduits must be formed first, this points Galen to the liver rather than the heart. Moreover, in terms of his psychology, Galen subscribes to the Platonic tripartite theory of the soul. And he locates the appetitive part in the liver, the spirited in the heart, and the rational in the brain: it is the appetitive soul that is responsible for the activities of formation and growth. Hence, its seat, the liver, should have generative priority over the others (see Nickel 1989, 74–79).

Not all embryologists agreed that any one organ had priority over the others. Some preferred to think of all the parts being formed simultaneously (e.g., Hippocratic *On Regimen* 26 [6.498 Littré]; cf. John of Alexandria, *On Hippocrates' On the Nature of the Child* 158.22–162.6 Bell et al.), and this, too, is sometimes connected to views on soul and animation. Porphyry, for example, argues that no organ is formed until birth. For a completed organ would require a power of the soul (e.g., the eye would require sight), and thus allowing any organ, including the liver, heart, and brain, to be formed before birth would be incompatible with his position that animation occurs only at birth (*Ad Gaur.* 13.6 [53.7–17 Kalbfleisch]).

7. Animation

Considerations such as these allow one to see how the issue of the embryo's animation came to be part and parcel of ancient embryology. The Hippocratic embryology of *On Generation* and *On the Nature of the Child* is a notable exception, insofar as the notions of the soul and animation do not even appear here (cf. Hippocratic *On Regimen* 27–30 [6.500–506 Littré]). This, however, did not stop later embryologists from drawing inferences on the author's behalf based on some of his remarks. Yet, for later embryologists, determining the life status of the embryo or fetus—there is no terminological distinction in Greek that maps neatly onto our own—became an issue of increasing importance, often articulated in terms of whether the embryo is an "animal" (*zōon*), as in our list of aforementioned doxographical questions. Some theorists denied embryos and fetuses the life status of animals completely, classifying them rather as vegetative life-forms for the entire period of gestation, for example, the Stoics (*SVF* 2.804–806) and Porphyry (*Ad Gaur.* [*passim*]). Others were more charitable. The view that the rational human soul was present already at conception is much more common among early Christians, though it is not entirely absent from non-Christian circles (e.g., Numenius, *apud* Porphyry *Ad Gaur.* 2.2 [34.23–26 Kalbfleisch]; [Galen] *Ad animal sit* [*passim*]; cf. Scholten 2005).

More typically, the alternative to the vegetative theory involved granting that at some determinate point during the period of gestation, the embryo acquires the powers of sensation and motion, which together elevate it from the status of mere plant. Porphyry reports (*Ad Gaur.* 2.2 [35.3–10 Kalbfleisch]) that this moment was sometimes identi-

fied as the so-called moment of first-formation, which *On the Nature of the Child* specifies as 30 days for male embryos and 42 days for females (18.1 [7.500 Littré]; cf. *On Nutriment* 42 [9.112–116 Littré]), or as the moment of first movement, which was frequently specified as three months for males and four for females (*On the Nature of the Child* 21.1 [7.510 Littré]; cf., e.g., Diocles, fragment 47 van der Eijk). Aristotle and Galen both offer examples of gradual animation. Upon conception, the embryo first achieves vegetative status, and then acquires the powers of sensation and movement only later (Aristotle, *GA* 2.3; *HA* 7.3; *Politics* 1335b24–25; cf. Schütrumpf *ad loc.*; Galen, *On the Seed* 1.9 [4.542–46 Kühn]; *On the Formation of the Fetus* 62.25–78.11 Nickel [4.660–674 Kühn]; and see Nickel 1989, 23–26 and 79–80). The rational soul that is constitutive of human beings adds yet another layer of complexity. Aristotle famously describes it as coming "from outside" (*GA* 736b27–28) as opposed to emerging from the powers in the seed like the rest of the soul, but he does not say *when* this is supposed to happen (cf. Balme 1990). It looks at times as if Galen is willing to extend an emergentist approach to the rational soul by identifying the rational soul with the *krasis* of its seat, the brain (e.g., *The Faculties of the Soul follow the Mixtures of the Body (QAM)* 38.1–2 Mueller [4.775 Kühn]), in which case the rational soul would be present with the complete formation of the brain, but elsewhere he claims to be unable to decide between emergentism and traditional Platonic dualism (e.g., *On the Formation of the Fetus* 104.12–14 Nickel [4.700 Kühn], and see Nickel 2001, 170-03).

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FURTHER READING

Essential reading among the numerous surviving primary sources: The Hippocratic *On Generation*, *On the Nature of the Child,* and *Diseases 4* (Lonie); Aristotle *On the Generation of Animals* (Peck); Galen *On the Seed* (De Lacy) and *On the Formation of the Fetus* (Nickel's German translation, or Singer's English translation). Newcomers to the history of embryology might begin with the classic *A History of Embryology* (A. H. Needham 1959. 2nd edition. Cambridge: Cambridge University Press), though its examination of ancient embryology is brief. For a more thorough introduction to ancient embryology with a particular focus on heredity, Lesky 1951 remains unsurpassed. M.-H. Congourdeau's *L'embryon et son âme dans les sources grecques* (2007. Paris: Association des amis du Centre d'histoire et civilisation de Byzance) is a helpful resource for finding material (including in the biblical traditions) relating to the embryo's animation, even if the analysis is often thin. C. C. Bien (1997. *Erklärungen zur Entstehung von Mißbildungen im physiologischen und medizinischen Schriftum der Antike.* Stuttgart: Steiner) offers a valuable overview on teratology in antiquity, which could not be addressed in the chapter. Lonie's introduction and commentary (1981) is also an excellent resource on Presocratic embryology more generally and is highly recommended. L. Brisson et al. *Porphyre: Sur la manière dont l'embryon reçoit l'âme* (2012, Paris: J. Vrin) also offers introductory chapters on the embryological theories of several major figures and schools, and nicely complements the selection of more specialized studies in Brisson and Solère 2008.

PART V

Healing and the Human Body

CHAPTER 21

Anatomy and Physiology

Julius Rocca

1. Introduction

Dissecting a body for the specific purpose of acquiring empirical knowledge about its structure and function is to perform anatomy. Insofar as the body was human, dissection was also regarded in Western antiquity as a revolutionary act. *Tomos*, the root form of *anatomē*, also carries the connotation "sharp," implying a degree of exactness to the act of "cutting" (*temnein*). Acts of cutting in antiquity were predominately associated with animal sacrifice and war—sacred and profane acts of penetrating violence—and the methodology behind subverting these actions for epistemic reasons was never uncontested. The evidential credentials and scientific validity of dissection, however, were frequently called into question, as was the role and status of anatomy and physiology within the wider framework of medical principles and practices. Beginning with Aristotle and the early Hellenistic period, one can point to increasingly sophisticated discoveries and enabling techniques, culminating in the anatomical expositions of Galen, which formed the high watermark of anatomical science in antiquity. But even Galen had to argue, repeatedly and forcefully, for anatomy's epistemological place in the medical and philosophical arena. For even if basic anatomical data (however obtained and interpreted) were accepted as approximately valid, this did not necessarily bolster its scientific status. Although what is revealed by dissection often makes possible a determination of the function of a particular structure, physiology was perforce a more speculative science, critically dependent on the explanatory power of analogical reasoning.

The earliest Greek philosophers, the Presocratics, known as enquirers into nature (*physis*), were the first *physiologists* in the literal and restricted sense of the word. When Aristotle discusses *physiologoi*, he refers to this aspect of their work (*PA* 640b5, 641a15–647a10). Rather than use the term "physiology," Greek medicine postulated the

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"effect" (*ergon*) of a structure on other parts, sought to account for its "activity" (*energeia*), noted whether it was subject to "change" (*kinēsis*), and thus defined its "use" (*chreia*). Tying these terms together was the notion that each discrete bodily structure, quality, or element possessed a capacity or inherent power (sometimes reciprocal) known as its *dynamis*. Ancient thought conceived of anatomy and physiology as fundamentally interconnected (Galen divides anatomy into the study of structure and function). "Physiology" will be used here as a convenient placeholder. And we shall examine the key themes—medical, philosophical, and cultural—that made it possible to classify anatomical investigation, however ephemerally, as an epistemic undertaking in its own right.

2. Babylonian and Egyptian Initiatives

Anatomical knowledge in ancient Mediterranean societies was largely gleaned from accidents and battle wounds, and it was mostly limited to what could be observed on the surface of the body (Edelstein 1967, 251). Internal anatomical knowledge was obtained from animals butchered for food consumption and by sacrifice, and Babylonian internal anatomical vocabulary was based on sacrifice (Geller 2007). The first known attempt to textually organize anatomical material, the Egyptian Edwin Smith Papyrus, a seventeenth-century BCE redaction of an earlier work (Breasted 1930), lists 48 cases of head and neck trauma sustained in accidents and war, arranged in terms of diagnosis, treatment and prognosis, and incorporating some anatomical information. They record that damage to the brain (*ais*, "viscera of the skull"), is sometimes fatal. But for Egyptians, in common with other Mediterranean societies, the organ and font of life was the heart (*ib*, *haty*). The brain, unlike the heart, was discarded at the beginning of the mummification process. Gloss A of the Smith Papyrus states the heart's "pulsation is in every member." Ebers Papyrus (circa 1550 BCE) maintains that knowledge of the heart and its movements constitutes the "beginning of the physician's secret" (Ebbell 1937, 14). Egyptian mummification must have yielded some information on internal anatomy, though how much is a matter of dispute. Although physicians (and embalmers) were priests of diametrically opposed gods, there was no taboo on disturbing the dead—which was so prominent a feature in Greek and Roman culture—but the mainstay of Egyptian anatomical knowledge was derived from animals. Egyptian medicine elaborated on 315 anatomical terms, and many "which are applied to humans are written or determined with signs which depict the corresponding part of an animal's anatomy" (Walker 1996, 259). Neither muscles nor nerves were individually named. No absolute distinction was made between blood vessels, nerves, tendons, ducts, and other passages, being labeled with the generic *met*, "vessel." But their contents were usually specified, ranging from blood, air, semen, urine, and supernatural entities (Nunn 1996, 44). Aristotle's contention was that, since blooded animals have a heart and blood is fluid, necessity dictates there must be a "vessel" (*aggeion*) to contain it (*PA* 665b10–15). Nature constructed blood vessels for this purpose. Egyptian medicine many not have construed this in such teleological terms, but the need for containing and conveying bodily fluids is an argument they would have recognized.

3. The Presocratics and Plato

Presocratic natural philosophers evinced an interest in the structure and function of the body, although none produced a dedicated work on the subject. Alcmaeon of Croton (circa 490–430 BCE) is controversially said to have been the first to dissect the human eye, to verify the optic nerve's connection to the brain, and to elucidate its cognitive and perceptive roles, although any of his dissections would have strictly involved animals. It is possible that Alcmaeon speculated on the structure that links the eye and brain, but he would not have necessarily regarded it as a nerve, since that knowledge—gained in part by human dissection—was a Hellenistic innovation (Lloyd 1975).

Anaxagoras describes three sets of contrary qualities: "wet and dry," "hot and cold," and "bright and dark." Also present in this pre-cosmic grouping are earth and myriads of seeds (*spermata*) (*TEGP* 13). The relationship between these qualities and elements is not specified, nor is it clear if the seeds are biological. But the notion of primary qualities—wet, dry, hot, cold—was an important feature of early Greek philosophy (Lloyd 1964) and would prove deeply influential, for example, to account for the basic components of the body. These qualities are first specifically articulated for living things in the Hippocratic *On the Nature of Man* chapter 3 (circa 430–370 BCE), which states that at death the body's components return to that from which they were composed: "wet to wet, dry to dry, hot to hot and cold to cold." Earlier, Empedocles posited four elements or roots (*rhizōmata*) of all things: fire, air, water, and earth (*TEGP* 26–29), "which henceforth become the most basic components of nature until the modern age" (Graham 2010, 423). Empedocles' other physiological claims consisted of an account of respiration by analogy to the workings of a clepsydra (*TEGP* 127), and the claim that blood around the heart was responsible for cognition (*TEGP* 163). Visual perception was based on elemental effluences from the eye (*TEGP* 151) by comparison with a lantern (*TEGP* 152, 153, 155, 158).

On the Nature of Man, chapter 4, begins by stating that the body of man contains blood, phlegm, yellow bile, and black bile (the word *chymos*, "humor," however, is not used), which comprise the nature (*physis*) of the body. Health is due to their correct proportion, and disease is ascribed to their deficit or excess. This notion of a physiological necessity for an internal equilibrium or "equal rule" (*isonomia*) among the body's "powers" (*dynameis*) goes back to Alcmaeon, who regarded disease as caused by a "dominance" (*monarchia*) of one of the powers (DK 24 B4). The humoral concept, derived from Empedocles, and the explicit link between the Presocratic qualities of hot, cold, dry, and wet, is set out in the Hippocratic *Affections* (circa 400 BCE), which maintains that all diseases are caused by bile and phlegm when either becomes "too wet, too dry, too hot, or too cold" (chapter 1). The early-fourth-century BCE physician, Philistion of Locri, assigned each of the four qualities to the Empedoclean elements (Jones 1947, 81). Greek and Roman therapeutics consisted largely of attempts to restore this physiological balance, whether expressed in terms of humors, elements, or qualities.

Plato also took up elemental physiology. In the *Timaeus* (82a–b), the body is said to be composed of earth, fire, air, and water. Disorders are caused by an excess or deficiency of any of these "elements," or their presence in a part of the body unsuited to them. The physiological importance of air is also noted. The function of the lungs is to provide the body with essential breath: when phlegm impedes the breath, several pathological

conditions result (84d–85b). It is almost conventional to contrast Plato's knowledge of anatomy and physiology unfavorably with Aristotle's. But Plato's aim is not to provide a detailed anatomical account of the human body but instead to use general anatomical descriptions and functional explanations to provide a framework for his tripartite theory of the soul. Its reasoned or rational part (immortal and divine) is housed in the head (44d–45b), the spirited or courageous part in the chest, and that part concerned with natural desires in the region between the diaphragm and umbilicus, not, as later assumed, in the liver (69e–72d). The spirited and desiderative parts of the soul are mortal. This tripartite physiological/psychological model would prove greatly influential, receiving its most sophisticated anatomical elaboration in Galen.

For Plato, teleology serves anatomy. The heart is both the source of blood and the origin of the blood vessels (*qua* veins: the distinction—functional as well as anatomical—between artery and vein is yet to be made). When anger causes the heart to throb, the surrounding lungs, soft, bloodless, and sponge-like, cool and give relief to the heart (70c–d). This feature, like the construction of the rest of the body, was designed by the lesser gods, acting on behalf of the Demiurge. Plato makes use of anatomical and physiological concepts selected from physicians and natural philosophers in order to help frame philosophical concepts. Anatomy and physiology were entirely subservient to philosophy. His most famous pupil would be the one to partially reverse this distinction.

4. The Hippocratics and Aristotle

Physiological theories were mined and progressively elaborated from natural philosophy. Anatomical knowledge in the Classical period, by contrast, was neither developed nor systematized. The Hippocratic Corpus offers a set of general bodily schematics "conditioned by supposed routes and conduits of fluids in motion" (Craik 2001, 104). Fluids coursed through vessels (*phlēbes*) to bodily structures, and organs were interconnected by *neura* (here ligaments as well as nerves). Texts such as *Anatomy* and *Places in Man* (Craik 1998a, 1998b) reveal a rudimentary knowledge of structure, representative of the corpus as a whole (*The Heart*, with its detailed anatomy, is Hellenistic: Lonie 1973). Yet *Anatomy* gives a reasonable account of topographic anatomy, and its brief descriptions of the liver (an organ not mentioned in *Places in Man*) and lungs (regarded as a single structure) show some awareness of human material, even if dependent on animal models. *Epidemics II* (chapter 4) depicts, albeit gnomically, an anatomy of blood vessels based on animal dissection. But this is presented in order to establish the validity of humoral doctrine rather than as epistemology for its own sake (Langholf 1990, 145–149). The author of *Joints* evinces a desire to pursue human dissections, albeit necessarily as thought experiments (Edelstein 1967, 255). After an overview of the body's cavities, vessels, sinews, bones, and joints, *The Art* (chapter 11) states that these "obscure" structures can only be visualized with "the eye of the mind."

Aristotle, whose significance in the history of Greek anatomical science cannot be overestimated, employed his mind's eye to understand those obscure structures. Aristotle is the first thinker to provide a detailed epistemological methodology as well as a justification that the examination of living things be considered part of a philosophical program (Lloyd 1996). This is a revolutionary accomplishment, since "an investigation of the natural world so organized was unprecedented in Ancient Greece" (Lennox 2012, 288). Approximately one-quarter of the extant Aristotelian corpus is devoted

to biological science. It is an approach that is groundbreaking in several ways. First is the acknowledgment that dissection is an unpleasant task which generates considerable disgust (*HA* 645a29–31). In sacrificial rites, priests may have viewed such matters with impunity, but Aristotle, in addressing those who would investigate the world of living things, is implying that what may be unpleasant is necessary for epistemic purposes. This is no armchair anatomy. One must also be prepared to temper one's dislike when examining animals that are aesthetically unappealing, since even here Nature "gives immeasurable delights" (644b8–10). For Aristotle, the natural world reveals something of "the marvelous" (*ti thaumaston*, 644b19). Second, Aristotle's intention in examining the biological world is classificatory, based on location (land, air, sea), blooded or bloodless, warm- or cold-blooded, and what shared (and unique) characteristics structure and function reveals (Zoology). Third, while Aristotle's predecessors studied nature, they did so neither to his extent nor with the aim of making such an investigation part of their philosophy. They failed either to observe properly (hence their mistakes regarding the vasculature) or to dissect adequately and with a correct methodology (*HA* 511b10–24). It is this emphasis on method that sets Aristotle apart from all his predecessors. In addition to works on comparative biology, Aristotle wrote a text on dissection and an epitome (both lost). The salient features of Aristotle's anatomical research are as follows. First, the heart is prioritized. Not only is it the central organ in blooded animals, but it is also the principle of life and of an animal's nature (*GA* 739b35–740a5; 741b15–21). The first organ to develop, the heart, was also the source (*archē*) of blood vessels (Aristotle did not differentiate between arteries and veins). Blood is the body's nutriment, and the heart is the center of vital heat (that the body required an innate source of heat in order to live was a physiological axiom in Greek medical thought: Solmsen 1957). Aristotle developed this concept by having vital heat act on the blood in the heart to produce an innate form of air, *connate pneuma*, which, conveyed in the vasculature, is responsible for the modalities of sensation. Hence, Aristotle's focus on the heart and his emphasis on the correct understanding of the vessels through methodological dissection, a point on which he criticizes three of his predecessors: the physicians Syennesis and Polybus, and the philosopher Diogenes of Apollonia (*HA* 511b10–513a15). In contrast, Aristotle regarded the brain as wet and cold and essentially bloodless (but for all his criticism of those who failed to dissect correctly, Aristotle appears not to have determined the gross vasculature of the brain and their relation to the vessels of the neck and thorax). The brain's frigid nature was nevertheless essential as it played a key role in the body's thermo-regulation.

Blood vessels (*phlēbes*) not only contained blood. They were also thought to contain a form of air called *pneuma*. That air is an essential component of the life force in conjunction with the soul (or as personifying both) has a long and culturally diverse history and plays a crucial role in Greek medical and philosophical thought (Lloyd 2007). As noted earlier, air (*qua aēr*) was postulated as one of the four elements. The Hippocratic *Breaths* uses terms such as *pneuma*, *physa*, and *aēr*, which—varyingly posited as internal and external—are said to account for health and disease. Aristotle's use of *pneuma* can be seen as reflecting the importance of air as a basic physiological requirement for life. Among the Presocratics, Anaximenes held that air (*aēr*, *pneuma*) was the life principle and soul (*psychē*: *TEGP* 8; Matter). Diogenes of Apollonia postulated *aēr* (equated with soul and intellect) as being conveyed through the body by the vasculature (DK 64 A19, 20; B6). The Hippocratic *The Sacred Disease* posits that blood vessels admit external air

to cool the body and to pass it (air) to the brain, allowing for intelligence and motion (chapter 10). Here then are two principal themes in Greek physiological thought: a system of vessels (*phlebēs*), channels, or passages (*poroi*) linking the outside air with the body, and air being used to account for cognition, motion, and sensation. These notions would be further refined in the Hellenistic period. That air or *pneuma* was also regarded by some as soul would also be adapted and developed.

5. Hellenistic Initiatives: Human Dissection and Vivisection

"For it is a fact that the inner parts of man are largely unknown, and in consequence we must needs rely on examination of the inner parts of other animals whose nature is in any way similar to that of man" (*HA* 494b21–24). Aristotle underscores a blunt fact: scientific understanding of the human body is perforce established by comparative means, a testimony to the power of analogy's "heuristic and didactic functions" (Lloyd 1966, 397). Human dissection *and* vivisection were performed only once in antiquity, in Hellenistic Alexandria, in circumstances that will now be examined.

Broadly speaking, animal dissection, as a branch of the investigation of nature, involves no violation of cultural norms (although it was often regarded as a lamentable departure from mainstream philosophy). Dissection of a human body is quite different. The corpse (*nekros*) is a source of pollution (*miasma*). Contact with a dead body, as Euripides (*Iphigeneia in Tauris* 380–384) reminds, renders one impure (*musaros*). This interdicts communication with the gods, which is only restored by purification rites (for example, at Delos during the plague of 426–425 BCE: Thucydides 3.104). How a corpse was treated "remained one of the means by which men could hurt, humiliate, or honour one another, express contempt or respect" (Parker 1983, 46). Achilles' treatment of Hector's body, whom he addresses as "corpse" (*nekron*) is a paradigmatic example of disrespect. Antigone's defiance of Creon's edict that Polynices remain unburied accords with the notion that the corpse of a defeated enemy merits the respect of burial (in contrast, executed criminals were subject to *ataphia*, "want of burial"). In Statius' *Thebaid*, the Thebans defile the dead, "disregarding their moral obligation to respect the bodies of their enemies" (Parkes 2011, 88). The Roman perspective was similar; for although "a corpse could be abused, mutilated and denied burial" (Hope 2000, 126), Pliny can remark that "to examine human entrails is deemed an act of impiety (*nefas*)" (*NH* 28.2). For the Roman, a dead body was likewise a source of pollution. Undertakers (and executioners) were by extension tainted. Undertakers established a community outside the city walls, where the executioner (*carnifex*, which also means "butcher") worked.

Thus, there existed powerful barriers, social as well as psychic, that had to be crossed before a human corpse could be dissected, an act that "simply lay beyond any culturally accepted limit" (von Staden 1992, 225). Yet crossing this boundary occurred in the early Hellenistic period. The newly minted city of Alexandria possessed an equally new Ptolemaic dynasty anxious to highlight and reinforce its status. Patronage was one means, exemplified by the creation of the Museum and Library (Fraser 1972, 312–335). This research complex formed part of the strategy of Ptolemy I Soter and Ptolemy II Philadelphus to make Alexandria the leading center for arts and sciences. In the natural sciences, the influence of Aristotle's school was noteworthy (Demetrius of Phaleron, student of Aristotle's successor Theophrastus, was mentor to Ptolemy I). Aristotelian

research methodology found fertile ground in Alexandria. Herophilus of Chalcedon and his younger coeval Erasistratus of Ceos used it to place anatomy and physiology on a scientific basis. Although animals probably comprised the bulk of their experimental subjects, they nevertheless took the radical step of not only systematically dissecting human beings, but also, in a "ghastly innovation" (Fraser 1972, 349), of vivisecting them. The Roman medical encyclopedist Cornelius Celsus (preface 23–26), although not defending either practice, advances a utilitarian defense, stating that it is not cruel (*neque esse crudele*) for a few criminals to be executed in this way, since future cures (*remedia*) might be found. The condemned may thus be regarded in sacrificial terms as offerings that contributed to the general good. Pliny, while not naming either Alexandrian physician, remarks that the Egyptian kings ordered postmortem dissections in order to better understand certain disease processes (*NH* 19.26). The third-century CE Patristic Tertullian refers to Herophilus as a butcher (*lanius*; note the implied invidious comparison to an executioner) who "cut up adults" (*maiorum prosector*; *de Anima* 25). Several explanations have been offered to account for this practice (von Staden 1989, 1–31, 138–153, 187–189). Alexandria was a new city on the boundary between Greek and non-Greek, and Hellenic customs were not expected to be rigorously enforced. Moreover, the victims selected were criminals and, therefore, outside the *polis* by their actions. Such condemned bodies (alive or dead) were open to abuse, but here the violence is more selective and deliberate, carried out by physicians for epistemic, not punitive, purposes. There is no evidence that those condemned to death in this way were selected on the basis of their *being* Egyptian. Although class distinctions did exist in Ptolemaic Alexandria, there is little to support the notion that Egyptians under Ptolemaic rule were a suppressed people (Samuel 1983, 105–117). The key factor in allowing the cutting open of the body is patronage. The early Ptolemies placed scholarship and scientific practices under royal sponsorship (and protection), which bolstered the status of the new regime. Galen goes as far to state that patronage was obligatory if research into the human body were to be carried out (*Antidotes* 14.2 Kühn). The new Ptolemaic dynasty also wished to be seen as recognizably Egyptian, and preparation of the body for the afterlife, which involved violating the integrity of the corpse, was an Egyptian cultural norm. An Egyptian pharaoh could relax the prohibition on dissection and, by extension, on the vivisection of those who were condemned to death. A Greek autarch could not as easily go against the cultural constraints of the *polis*.

Herophilus' interest in the structure and function of the body owed much to one of his teachers, Praxagoras of Cos, who postulated eleven humors whose deficit or excess were responsible for disease. His *Anatomy* has not survived, but, likely influenced by Aristotle, Praxagoras maintained that the heart, not the brain, was the principle hegemonic organ (Steckerl 1958, fragments 7–9). The brain was considered an excrescence of the spinal cord. Praxagoras appears to have been the first to distinguish formally between artery and vein. The heart is the source of the arteries whose distal terminations become nerves. The arteries, whose pulsation is stated to be independent of the heartbeat, contain *pneuma*, which, when transmitted to the "nerves," is responsible for voluntary motion. The veins, by contrast, have their origin in the liver and contain the body's nutriment, blood. This type of source distinction between artery and vein is also found in the Hippocratic *Nutriment* (circa 400 BCE), which states that the "root" (*rhizōsis*) of the veins is the liver, the arteries the heart. They convey blood, *pneuma*, and heat to all

parts of the body (chapter 31). The development of these anatomical and physiological themes was a hallmark of the Hellenistic era.

Only fragments of Herophilus' work survive (conveniently collected in von Staden 1989), although Galen, our chief source, probably had access to the complete collection. Herophilus' *Anatomy* seems to have been a comprehensive work, examining the brain and nerves, liver and abdominal organs, the reproductive system, and the heart and the vasculature. Herophilus was not the first to have composed an anatomical text. The fourth-century BCE physician, Diocles of Carystus, regarded in antiquity as second only to Hippocrates, is said by Galen to have composed the first manual of anatomy, which appears to have been general in scope although with some discussion of the female reproductive system (van der Eijk 2000, fragments 17–24; GYNECOLOGY). Herophilus' *Anatomy* represented a significant advance. There was for the first time an accurate description of the human liver. Herophilus' work on its vascular system, especially that of the portal vein and its relationship to the veins of the intestine, was exemplary. His name for the first part of the small intestine, the duodenum (*dodekadactylon*, "twelve finger [lengths]"), is retained today. Erasistratus completed his study of the heart valves. Advancing Praxagoras' work on the vascular system, Herophilus grounded the difference between artery and vein on anatomical grounds (arteries having a wall six times the diameter of veins), but maintained that the arteries carried both blood *and pneuma*, the veins only blood. In gynecology, Herophilus provided an accurate account of the vasculature of the reproductive organs, and his description of the uterus and its ligaments—and his assertion that it was an organ like any other—countered the prevalent Hippocratic notion that the uterus was mobile to the extent that it could affix itself to other organs (Dean-Jones 1994, 69–77). More tellingly, Plato (*Timaeus* 91b–d) described the uterus as a living being, which, if not impregnated, courses through the body with deleterious effects. The notion of the so-called "wandering womb" would much later be systematically applied by a willful misreading of the ancient evidence, to the "construction of hysteria" (King 1998, 214; GYNECOLOGY). Herophilean anatomical evidence notwithstanding, in antiquity the prevalent view remained that, on structural, functional, and teleological grounds, female bodies were not only different but also inherently inferior to those of males (Mayhew 2004; Nielsen 2008).

Arguably Herophilus' most distinguished work involved the brain and nerves. Although Aristotle had noted that the brain consisted of the larger cerebrum and smaller cerebellum, Herophilus went much further, dissecting deep within the brain to reveal four cavities or ventricles, whose physiological role would prove of lasting significance. In the ventricles, Herophilus noted small vascular complexes resembling the fetal choroid, terming them *choroid plexuses.* According to Galen, Herophilus regarded the fourth ventricle as the most important from the point of view of hegemonic control of the body's movement. Herophilus also described part of the venous sinuses of the brain (the *torcular Herophili*), and the *retiform plexus*, a net of small arteries at the base of the brain found in several animals, but not in man (implying that Herophilus' use of human specimens was less extensive than we might think). Galen would give a crucial physiological role to this plexus. Although Herophilus did not absolutely distinguish between nerves and tendons, he nevertheless differentiated nerves into sensory and motor components. To do so would have demanded meticulous, repeated vivisection (animal or human). *Pneuma* was made to account for nervous action. Herophilus, like Praxagoras, maintained that *pneuma* and blood were present in the arteries, and it

is possible that Herophilus envisaged the arterial system as involved in nervous action since it was a carrier for *pneuma*.

Erasistratus' work survives only in fragments (collected in Garofalo 1988), and Galen is our principal source. Erasistratus followed Herophilus' scientific methodology and in some ways "displays marked advances upon that of his predecessor" (Longrigg 1993, 205). The structure and function of the heart valves were thoroughly delineated (even to Galen's satisfaction). Erasistratus envisaged the heart as possessing a sort of pumping capacity (and he may have drawn inspiration from his Alexandrian contemporary, the mathematician Ctesibius, although Erasistratus is said to have used the analogy of a smithy's bellows: c.f., Hydrostatics and Pneumatics in Antiquity). However, there is no evidence to suggest that Erasistratus (or anyone else) thought in terms of a circulatory system. Blood moved, but the vasculature was a distributive system, likened to a series of irrigation channels, supplying nutritive blood. There was no proto-Harvey who could "see beyond the analogies they employed in their physiological systems" (Lonie 1964, 426). For Erasistratus, blood was present only in the veins; arteries conveyed *pneuma*. According to Erasistratus, arterial pulsation is due to the presence of *pneuma*. To the observed fact that blood is seen to flow when an artery is pierced, Erasistratus invoked the principle of matter being "attracted to that which is being emptied" (*pros to kenoumenon akolouthia*): it is *pneuma* that escapes, and the presence of blood is due to its passing from the vein to the affected artery (through alleged openings between the two vessels) to fill the void left by the escaping *pneuma*.

Erasistratus advanced Herophilus' work on the brain, especially the ventricular system. Galen states that Erasistratus wrote "most accurately" in this field, regarding the brain as the source of nerves and seeing them as outgrowths of the brain. According to Galen, Erasistratus originally thought that the nerves derived from the brain's meningeal coverings, but he later emended this view, although some sources attest to Erasistratus placing the body's control center (the *hegemonikon*) in the *dura mater* (the outer meningeal layer), and not, as Herophilus and Galen maintained, in the ventricles.

Erasistratus composed the first dedicated physiological work, *General Principles*. The structure of the body was based not on elements but on corpuscles and void, a notion taken from the Peripatetic Strato of Lampsacus (Hydrostatics and Pneumatics in Antiquity). Further, no organic distinction was made: all the body's tissues were composed of a similar substance, a triple interweaving (*triplokia ton angeiōn*) of artery, vein, and nerve. The body operates in a mechanistic fashion, based on the aforementioned principle of matter being "attracted to that which is being emptied." Erasistratus here reveals a debt not only to Strato's conception of *horror vacui*, but also to Hellenistic engineering theories encapsulated by Hero's *Pneumatica*. Thus, the reason that air is drawn into the lungs, according to Erasistratus, is because the temporary void within the lungs occurring after exhalation must be filled. Mechanical principles are applied to digestion: tearing, grinding, and pressure account for the processing of food into nutriment. There is thus no need for principles of attraction or of any form of qualitative or elaborative change to account for digestion or any other physiological operation.

Erasistratus' conception of the body as fundamentally a corpuscular or particulate mechanism whose interactions accounted for health and disease would prove influential. Although particulate theories can be traced to the atomism of Democritus and Epicurus, the medical implications of such a theory were explored by Erasistratus and later by Asclepiades of Bithynia (*fl.* circa 120–90 BCE). Asclepiades also rejected elemental/

humoral physiology in favor of a corpuscular theory in which the body is comprised of units of "jointless masses" (Polito 2006). The Asclepiadean body was comprised of aggregates of such masses, interspersed with channels or pores (*poroi*). Galen attacks this theory since not only did it imply chaos and disavowed purpose in nature, but also because such a system had little need for anatomical study (the Methodist medical sect would make of this a virtue). Such theories recall earlier conceptualizations: "For 'Homer', as for later Greeks, man was both a unified whole and an aggregate of discrete parts … determined in each case by the needs and emphasis of the particular context" (Renehan 1979, 280).

Pneuma played a critical role in Erasistratean physiology, and his deployment of it would become a template for Galen's physiology. In Erasistratus' system, *pneuma* in the lungs entered the left ventricle of the heart via the pulmonary vein, where it was converted to vital *pneuma* (*pneuma zōtikon*). Some of this then traveled in the arteries (which for Erasistratus contain only *pneuma*) to the ventricles of the brain, which further changed it into psychic *pneuma* (*pneuma psuchikon*). This type of *pneuma* now had access to the nerves and was responsible for sensation and voluntary motion. This is almost identical to Galen's own system, but for Galen pneumatic changes were due to *qualitative* elaboration. In keeping with his mechanistic physiology, Erasistratean *pneuma* was subject only to successive *quantitative* changes. Nevertheless, the groundbreaking studies on the brain and the nerves by Herophilus and Erasistratus made Galen's work as an experimental anatomist possible.

6. Codification of Anatomical Knowledge

After Herophilus and Erasistratus, anatomical research effectively ceased for the next four centuries. There is no single reason for this cessation, but the place of anatomical science was always privileged and precarious. Increasing attention was devoted to the systematization and codification of medical knowledge in the post-Herophilean/Erasistratean period, as well as on developments in medical therapeutics. Herophilus and Erasistratus had quarried much material concerning the structure and function of the body, and time was required to process and assimilate it. In this codifying atmosphere, experimental activity also largely ceased (von Staden 1975, 192).

An Alexandrian climate that had allowed work on practical medical matters now interdicted human dissection and vivisection. The umbra of patronage cast by the first two Ptolemies had permitted the taboo on the handling of the human body to be lifted. But this was as radical as it was temporary, and later rulers "withdrew their patronage from an activity which, instead of winning renown, was now bringing their regime into disrepute" (Longrigg 1993, 219). Coupled with this was a movement away from the Aristotelian notion of the importance of anatomical knowledge for its own sake. In a period where the practical side of medicine was being increasingly addressed, questions were raised regarding the epistemological worth of anatomical science. This change of intellectual priorities was encapsulated by medical sectarianism (see also Physicians and "Schools"). The impact of Herophilus and Erasistratus had led to the establishment of eponymous "sects" (*haireseis*). The Empirics, founded by a former Herophilean, Philinus of Cos (*fl.* 280–220 BCE), denied dissection's epistemic validity, deeming it a fruitless study into hidden causes. Empirics maintained that the act of dissection produced

changes in the part being investigated, and knowledge derived from such a practice was therefore useless (Celsus, preface 40–43). Celsus' interest in anatomy led to his formulating, however incomplete, a Latin anatomical nomenclature (von Staden 2010). For medical Empirics, the only worthwhile anatomical knowledge was derived from occasional examination of living persons, a practice Galen labeled the "anatomy of happenstance." Such investigation into the human body as sanctioned by the Empiricists—for example, by Heraclides of Tarentum (*fl.* 95–55 BCE)—was geared primarily to improving surgical techniques.

Medical Methodism, which originated in the first century BCE under the influence of Themison, coalesced as a distinctive sect under Thessalus of Tralles (*fl.* 20–70 CE). The Methodists did not go as far as the Empirics in their explicit denial of anatomical epistemology: they were prepared to use knowledge derived from dissection, but with the knowledge that this would also provide a rhetorical advantage over an opponent. The Methodist physician Soranus, whose *Gynecology* "represented ancient gynecological and obstetrical practice at its height" (Temkin 1956, xxv), encapsulates this limiting epistemology.

It is not until the beginning of the second century CE that the status of anatomy as a science began to recover. The text on anatomical nomenclature by Rufus of Ephesus (*fl.* 70–100 CE) is one such indication. Rufus "considered anatomy to be a fundamental medical subject" (Nutton 2008, 756–757). This recovery was due in significant measure to a renewed focus on Greek learning (*paideia*) by the Second Sophistic (Swain 1996). This movement encouraged public exhibitions in anatomy and physiology, where Galen excelled (Mattern 2008, 7–11; von Staden 1997). These demonstrations also sought to offer empirical proof of certain philosophical tenets. For example, in showing that the nerves have their ultimate origin in the brain and by interrupting the course of their distribution in various ways on living animals, Galen demonstrated their function with a view to establishing that the brain is the controlling center (*hegemonikon*) of the body. Embedded within a wider philosophical perspective, investigations into the body held an attraction for a Second Sophistic target audience of *pepaideumenoi*.

The early second century CE also saw other doctors pursuing anatomical investigation. Some retraced the work of Herophilus and Erasistratus. Galen makes reference to anonymous doctors who clearly had a detailed knowledge of the brain (Rocca 2003, 136–137, 149–151). Several of Galen's teachers were also influential. Galen's first instructor in anatomy was Satyrus, whose demonstrations Galen attended in Pergamon. Quintus, whom Galen refers to as having the "greatest skill in anatomy," taught Satyrus. Lycus of Macedon, another pupil of Quintus, wrote an anatomical text, and Galen composed a (lost) abridgment of it to highlight its supposed flaws. Lycus also seems to have investigated the brain and the nerves. In Smyrna, Galen attended lectures by Pelops, whose *Anatomy* he respected. Pelops' *Introduction to Hippocrates* discussed the muscles, the liver, vasculature, the brain, and nerves.

There is an Alexandrian link in this anatomical revival. According to Galen, Numisianus, Pelops' teacher, was pre-eminent in Alexandria (where he himself spent four years: Nutton 1993), a city whose continuing anatomical importance is reinforced and commended by Galen as the only place to study human osteology. Of all his immediate predecessors, Galen holds Marinus of Alexandria in highest regard. Galen praises him for having "recovered" (*anaktēsamenos*) the study of anatomy after it had fallen into neglect. Marinus, in common with Herophilus and Erasistratus, seems to have been a

source for Galen's epistemic methodology. In *On My Own Books*, Galen devotes more space to Marinus than to any other physician or philosopher. Galen states that he had composed a (lost) summary of Marinus' twenty-volume *Anatomy* (the question of the *hegemonikon* of the body comprised one volume). Not only does Galen praise (*epainos*) Marinus, but he also refers to him as "most excellent" (*kratistos*). Only Hippocrates, Galen's medical ideal, merits similar encomia (Rocca 2003, 42–46).

7. Galen

Galen of Pergamon consolidated anatomical science in antiquity, and anatomy formed the epistemological core of his medical and philosophical world. Space permits only a summary of his achievements in anatomy and physiology (Rocca 2008; Debru 2008). The most important to note are the degree of indebtedness to certain of his predecessors and the furthering of their knowledge. Galen combined Aristotelian methodology with the anatomical investigations of Herophilus and Erasistratus. Galen's anatomy was based on animal models, with the assumption that comparison between animal and human bodies was epistemologically valid (Rocca 2003, 67–76). Galen presents a fourfold justification for anatomical study: epistemic, in the Aristotelian pursuit of knowledge for its own sake; teleologic, in demonstrating Nature's purpose in structure and function; empiric, in accounting for physical and psychic actions; and practical, in enabling surgical proficiency. In setting the hallmark of the competent physician, Galen also used anatomical knowledge ideologically. Since Hippocrates is Galen's paradigm for the ideal physician, it was then necessary for Galen that anatomy, like other parts of medicine, be traced to its supposed Hippocratic origins (Smith 1979). Galen therefore brackets Hippocrates, together with Herophilus and several others, as one cognizant of the "science of the body" (von Staden 1989, fragment 37). A further measure of this approach is illustrated by Galen's vehement attacks on Empiricists and Methodists, who, as noted earlier, regarded comprehensive anatomical knowledge as neither necessary nor relevant to medical practice.

In addition to Galen's principal anatomical work (Singer 1956; Duckworth 1962), there were texts on osteology, nerves, blood vessels, muscles, respiration, the female reproductive tract, the production of sperm, and embryology. Lost anatomical works, which dealt with dissection, vivisection, and anatomical epistemology, as well as epitomes and criticisms of anatomical predecessors, all testify to Galen's range and depth. Extant physiological texts include *On the Use of the Parts of the Body*, an extensive account of functional anatomy from a teleological perspective (May 1968). *On the Natural Faculties* is a comprehensive polemic on Erasistratean and Asclepiadean mechanistic and corpuscular theories.

Galen's anatomical and physiological priorities were the brain and the nerves. The brain was the *hegemonikon* of the body. To prove this, Galen devoted enormous effort in dissection and vivisection. His account of the effects of cutting into the nerve roots of the spinal cord is as accurate as his other investigations into the nerves. Galen accorded functional priority to the brain's ventricles, significantly expanding the work of Herophilus and Erasistratus. The ventricles were made the final stage in a set of qualitative elaborations of *pneuma*. In this scheme, modeled after Erasistratus', inspired air is altered by the lungs to a "*pneuma*-like" substance, which passes through a vascular connection to the left ventricle of the heart. There, with assistance from the heart's vital heat and venous

blood from the right ventricle, a further concoction occurs, creating vital *pneuma*. The indispensability of the vasculature is highlighted in the next step in the elaborative process. The vital *pneuma* passes to the retiform arterial plexus at the base of the brain (not present in man, but found in some animals dissected by Galen). Here, and in the vascular system (the choroid plexus) in the ventricles of the brain, vital *pneuma* enters its final elaboration, becoming physic *pneuma*, Galen's "first instrument" of the rational soul. In a remarkable series of vivisection experiments, Galen also sought to prove that the ventricles of the brain could elaborate psychic *pneuma* from the outside air via a supposed connection—which he believed he had shown by dissection—between the anterior ventricles and the olfactory system (Rocca 2003, 119–132). Psychic *pneuma* is said to account for vision by a communication between the anterior ventricles and the optic tract. Passing from the fourth ventricle, psychic *pneuma* enters the spinal cord through its central canal, and hence to the nerves via their alleged central cavities. Galen never completely resolved how psychic *pneuma* operates in effecting motion and sensation, and in one of his last works he is remarkably candid on this epistemological *aporia* (Nutton 2011). However, the later systematizing movement known as *Galenism* eradicated all uncertainty (Temkin 1973). Galenism also validated the existence of natural *pneuma*. Galen's physiological system has no need for it, and Galen admits this when he states that if it does exist, then it should be confined (*not* elaborated) to the liver and veins. This important qualification was dropped, and Galenism recast natural *pneuma* into a functioning part of a fully tripartite pneumatic physiological system of immense philosophical and medical longevity (Rocca 2012).

8. Conclusion

The history of anatomy in antiquity shows a developing epistemology subject to judgment. Despite Galen's assertion that anatomy could be traced to Hippocratic origins, the fact remains that scientific knowledge of the body was in essence a Hellenistic endeavor facilitated by Aristotelian methodology, and therefore a relatively late acquisition. Its subsequent progress was neither steady nor unchallenged. Medical sects such as Empiricists and Methodists denied anatomy's empirical value. Nor did anatomical knowledge lead invariably to better patient care. Since no formal qualification for a doctor existed in antiquity, lack of anatomical knowledge never precluded medical practice. During the Second Sophistic, anatomy was admired for its epistemic rigor but only by an elite group of litterateurs, philosophers, and doctors who could perceive it in Aristotelian terms as a branch of philosophy. Impressive experiments performed on isolated structures such as nerves and blood vessels did assist in better comprehension of how those structures appeared to operate, but physiology—whether interpreted in terms of elements, humors, or corpuscles—remained in antiquity part of a broader, speculative discourse.

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CHAPTER 22

Gynecology

Lauren Caldwell

1. Greek and Roman Gynecological Theory

It was the epic poet Hesiod in the eighth century BCE who first articulated the idea that women were their own "race" distinct from that of men (*Theogony* 590–593). This distinction made sense on some level, as the mature female body did have physical qualities and functions that differed from those of the male body. In the fifth century BCE, the Hippocratic physicians picked up on this notion of female difference and began to combine it with the concept of nature (Greek *physis*) that was developed in the writings of the so-called Presocratic philosophers in the sixth and fifth centuries CE. What emerged was the first rough version of what we know now as the field of gynecology, as the Hippocratics offered naturalistic explanations for aspects of health particular to the female body, including menstruation, pregnancy, and childbirth. These explanations were based on a conceptual model that presented the body as made up of four fluids or humors: blood, phlegm, yellow bile, and black bile (*Nature of Man* 4; ANATOMY AND PHYSIOLOGY; PHYSICIANS AND "SCHOOLS"). Moving through channels in the body, the humors needed to achieve a balance and modulated flow to ensure good health. Excess or deficiency of any of the four humors, or blockage of their proper passage, caused illness; such potential problems pertained to both the female and male body.

However, according to the Hippocratic model, women faced a challenge to their health that men did not, in that their bodies by nature tended toward imbalance: in particular, female bodies were inclined to be overly moist. For example, in one treatise about embryology, the mature woman's body is described as containing "more fluid than that of a man" (*Nature of the Child* 15). The female body was also understood to be prone to a blockage of channels through which humors were supposed to flow freely. These dangers of moisture and blockage were linked to the maturation process, likely to become acute beginning at puberty. For example, the Hippocratic author of *Diseases*

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of Young Girls, a text that addresses female puberty, describes menarche as an extremely perilous time for health. An excess of fluid could weigh down the female body starting at puberty when blood began to accumulate in the body and attempted to find an exit. According to this model, if the first menstruation did not occur at the proper time, a buildup of blood resulted, and the physical and emotional symptoms that follow were severe: girls were thought to be inclined to suffer from seizures and even to attempt suicide. As the *Diseases of Young Girls* suggests, the Hippocratic writers viewed menstruation as the primary way in which the healthy female body self-regulated by eliminating fluid on a regular basis.

While it advances a conceptual model of female physiology, the *Diseases of Young Girls* also illustrates another crucial aspect of Hippocratic theory, namely, its reliance on and reinforcement of traditional gender-based social norms and expectations. In this treatise, which focuses on girls of marriageable age, a causal link is drawn between pregnancy within marriage and female health. The author of *Diseases of Young Girls* is noteworthy for making this suggestion the culmination of his text, after the dramatic description of a girl's symptoms:

> When she is recovering her senses, the women dedicate to Artemis many other things and especially expensive female clothing at the orders of the goddess's priests. But the women are being deceived. Relief from this comes when there is no obstruction to the flow of blood. I urge, then, that whenever young girls suffer this kind of malady they should marry as quickly as possible. If they become pregnant, they become healthy. (trans. Flemming and Hanson 1998, 251–252)

How, according to the Hippocratics, did pregnancy and childbirth aid the female body's health and regulatory processes? It appears that birth was thought to help open the network of vessels throughout the body from which blood flowed into the womb, and the fetus directly aided in this process by beating his way out of the mother's body. As a consequence, says the author of *Diseases of Women* (*DW*) 1.1, "the uterus becomes more open because the baby is moving through it, causing injury and pain" (Dean-Jones 1994, 62–63). The proper channel through the body was the *hodos* or path, envisioned as a channel running internally from the nose and mouth down to the vagina (*DW* 2.137). As Helen King has observed (1998, 58–59), this model of the *hodos* accounts not only for the ideas about childbirth as clearing a way through the body, but also for the separate contention, found in the Hippocratic *Aphorisms* (5.33), that nosebleed could provide relief for a women whose menstrual blood was blocked.

Pregnancy also was thought to solve the perceived problem of the womb's tendency to wander in the body. According the Hippocratic view, the womb was not anchored in the body and could move about in a way that caused illness. When either not weighed down by a fetus, or when overly dry, the womb was thought to migrate to other parts of the body. The results of this movement could be disastrous for a woman's health, as the womb could place pressure on other organs. And, if it migrated so far as the throat, it could even fatally suffocate her (*DW* 2).

The notion of the wandering womb quickly moved beyond the confines of medical writings and exerted influence on other writers. In his account of the creation of the human body in the *Timaeus*, for example, Plato depicts the womb as a wild and unpredictable animal with a will that serves to provoke women to act on sexual desire

(91a–d). Although the *Timaeus* is a philosophical text, it finds common ground with the Hippocratic *Diseases of Young Girls* in considering uterine problems as a cross between the social and the medical and in prescribing male intervention as a cure. According to Plato, the womb blocks a woman's respiratory passages and causes "additional illnesses" until she engages in sexual intercourse and becomes pregnant. Moreover, in keeping with Plato's larger objective, Hippocratic ideas about controlling the womb are imbued with larger cosmic significance in the *Timaeus*: with pregnancy and childbirth, Plato emphasizes, the propagation of the human species, which is part of the natural order, is ensured. Shortly afterward, Aristotle adopted the Hippocratic idea of the womb as a feature of the female body that may have need of male intervention to be stabilized; he claims that a prolapsed uterus can be remedied by pregnancy (*HA* 582b22–26). Elsewhere, Aristotle's model presents the female reproductive system as an inversion of the male (*HA* 493b2–6).

While the traditional picture of the female as untamed and in need of control might have been difficult to keep entirely separate from medical thought, nevertheless a key part of the explanation for the Hippocratic model of the female body and its functions is found in the fact that Classical Greek physicians did not perform dissection of the human body (see further Anatomy and Physiology; Surgery; Physicians and "Schools"). In developing a model of female anatomy and physiology, these authors instead relied on observation of external symptoms and signs, including the fluids excreted by the body, and on analogies, such as the comparison of female flesh to absorbent wool and male flesh to tightly woven fabric (*DW* 1.1). With Aristotle's *History of Animals* came a systematic investigation into comparative anatomy, but still no human dissection, in keeping with cultural norms. It was only beginning in the third century BCE, when Hellenistic physicians at the Museum in Alexandria began to use human cadavers in their research (Anatomy and Physiology; Physicians and "Schools"; Surgery), that the Hippocratic model of female reproductive health was modified. The work of the Hellenistic researcher Herophilus was transformative in showing, among other things, that the womb is anchored in the body (Flemming 2000, 233).

Herophilus' texts survive only in fragments, leaving us with a regrettable gap in our understanding of this important moment in the development of gynecological theory, but his discoveries left their mark and influenced subsequent generations of physicians. The development of the medical profession also affected the understanding of women's health. By the first century CE, the flourishing of medical sects (Physicians and "Schools") in the Roman Empire provided the opportunity for physicians to debate issues in women's health and to provide alternative frameworks for interpretation. The *Gynecology* of Soranus of Ephesus, from the early second century CE, illustrates the growth and change of the profession and the impact it had on the practice of medicine. Most notably, Soranus' understanding of the female body, built on the ideas of Methodism, imported ideas from the Hippocratic writers about the womb and accommodated new discoveries by Herophilus. For example, Soranus provides a detailed description of the womb that appears to be derived from cadaver dissection, noting that it is connected "by thin membranes" to the bladder (*Gynecology* 1.8). He does, however, retain the notion that the womb can cause suffocation of the patient who has experienced "multiple miscarriages, premature birth, long widowhood, menstrual blockage, or the end of the age of childbearing or the swelling of the uterus" (*Gynecology* 3.27), while

simultaneously rejecting Hippocratic treatments and Plato's depiction of the womb as an animal (*Gynecology* 3.29).

Apart from providing these anatomical descriptions that reflected technical progress, Soranus is noteworthy for expressing in a direct way his dissent from the Hippocratic viewpoint that female reproductive health was assisted by marriage and pregnancy. He contended that permanent virginity was healthful for women (*Gynecology* 1.30–32), as pregnancy and childbirth depleted the body, and he rejected the idea that there was a moment in the maturation process when abstinence from sexual intercourse suddenly began to harm female health. This perspective is valuable, as it demonstrates that physicians conceived of women's illness and its causes in different ways. This development is also underscored by the writings of Rufus of Ephesus, Soranus' contemporary, who stayed closer to the Hippocratic understanding of female reproductive health, drawing a link between maturation and pathology. Rufus notes that puberty is a time when the female body is notoriously fragile, and he cites the familiar image of blood's accumulation in the body as causing fevers and headache.

The differing theoretical models of Soranus and Rufus attest to the fact that there was no consensus on how the female body functioned, despite the intellectual advances of Herophilus and his fellow researchers at Alexandria several centuries earlier. The persistence of traditional gender-based social expectations for women, as much as obstacles to understanding anatomy and physiology, influenced gynecological theory and also shaped the content and emphasis of prescriptions for health. One must imagine that readers who picked up these texts faced a difficult challenge in deciding which model to follow and trust in understanding their own health.

2. Greek and Roman Gynecological Prescriptions

For practicing physicians, the purpose of gaining a theoretical understanding was to improve their ability to diagnose and treat illness. As the *Diseases of Young Girls* and *Diseases of Women* attest, there was plenty of interest, from the fifth century BCE onward, in developing therapies keyed to the reproductive and menstrual ailments of women. Yet from the Classical Greek to the Imperial Roman period, prescriptions about women simultaneously address legitimate health concerns and reinforce gender-based social expectations. Physicians offered prescriptions for these therapies in an effort to cure health problems, but in doing so, they operated within the context of cultural norms and values that influenced the conduct of patients and of physicians themselves. For female patients, for example, expectations for demure behavior could lead to a lack of effective communication, or even silence, with the male physician: the author of *Diseases of Women* cites women's modesty, inexperience, and ignorance as an impediment to effective treatments (1.62). As for pressures on the conduct of physicians themselves, as Susan Mattern (1999) has shown for the Roman Empire, the financial support of local aristocrats was critical for the career advancement of physicians at a time when there were no large-scale institutions or external credentialing shoring up the profession.

When the ability of physicians to sustain a livelihood depended on the patronage of male clients in whose households many female patients resided, the conflict of interest could become acute. Prescriptions for women's health reveal, sometimes explicitly, an awareness of the social expectations placed on women, particularly those of marriageable

age. As noted earlier, these prescriptions focus on female patients starting at puberty, when menarche along with the timing of marriage, sexual initiation, and pregnancy became pressing concerns. The youthful female patient is envisioned not as an ethical subject capable of taking care of her own health, but as a passive figure whose family members, supervising her care, will make decisions for her.

In the *Diseases of Young Girls*, for example, the Hippocratic writer not only describes the ailments suffered by girls whose menarche is delayed, as noted earlier. He also offers recommendations for treating this ailment, and this cure is socially based. As he notes succinctly, "If they get married and become pregnant, they are cured." Although seemingly relevant to his discussion, the risks of early pregnancy and childbearing are not addressed by this writer. He seems, as Helen King has noted, to be content to promote a short interval between physical and social maturation and to affirm its health benefits. Truncating the time span between menarche and marriage conveniently was healthful even as it helped to ensure the virginity of brides, a valuable attribute on the marriage market. The same emphasis is revealed in *Diseases of Women,* a text that is preoccupied with menstrual problems and not reluctant to recommend interventionist therapies for the opening and closing of the womb at the proper time, and for halting the wayward movement of the womb. Fumigation was prescribed for attracting the womb back to its appropriate position: the patient sat over a vessel that emitted pleasant vapors, and sniffed unpleasant vapors through her nose at the same time. This would bring the womb back to its proper seat, pulling it down from the chest (*DW* 1.13).

Too little survives of Hellenistic medical writings to draw conclusions about attitudes, but in Roman Imperial gynecological writings, it is possible to detect a questioning of the assumptions about the health made by the Hippocratics. In Rufus' *Regimen for Young Girls*, for example, the physician rejects the notion that girls must marry and have children starting at the age of menarche, that is, around age fourteen. Pregnancy and childbirth in the early teenage years, he counters, is extremely unhealthy. It is better to have girls wait until age eighteen:

> Hesiod has composed for a woman, "Let a woman be mature four years, and let her be married on the fifth," and for a man, "Neither much short of nor much over thirty, this is the time for marriage." Hesiod is especially eager that a girl marry around age eighteen, but if it occurs to a person that this is too late, one could reasonably respond, "Sure, as things are now." If that person reflects on the old way of life, though, and how it used to be the case that females toiled equally with males, he or she would no longer think that a girl of that age was marrying late. (*Regimen for Young Girls* 18.3)

Soranus' *Gynecology* takes up similar concerns about the unhealthfulness of pregnancy, as we saw earlier, but nevertheless Soranus retreats from his own view in prescribing behaviors. Most notably, he acknowledges that girls do usually get married, and he urges that they should remain virgins only until "around the fourteenth year," which he cites as the usual age of menarche (*Gynecology* 1.10). He then quickly proceeds to offer advice to men who are seeking fertility in their prospective brides, offering a description of the age and physical characteristics that would indicate suitability for childbearing. In offering these recommendations that convey a "relentlessly reproductive message" (Flemming 2000, 237) to his readership, Soranus falls back on public health or the greater good as the reason for abandoning this recommendation for permanent celibacy. He notes that

the purpose of the human race is to reproduce, and so individuals, both male and female, must participate in fulfilling that larger purpose. As an argument, this must have struck even some of Soranus' contemporary readers as strained. In explicitly and implicitly acknowledging the issue of death in childbirth, however, Soranus shows that he is not unaware of the costs to women's individual well-being.

3. Greek and Roman Practitioners of Gynecology and Obstetrics

Who was practicing women's medicine in the ancient world? Certainly medicine was not unchanged from the Classical Greek world to the Roman Empire, but one consistent feature of the medical profession is that physicians throughout antiquity were mostly male and were trained as generalists who treated both male and female patients. A treatise such as the Hippocratic *Epidemics* offers case histories for adult patients of both genders. The illnesses recorded for women are usually those related to or resulting from pregnancy or childbirth. In accordance with Greek custom, women are referred to by their relationship with men rather than by their own names, as, for example, in the cases of the "wife of Philinus" and "daughter of Telebulus" in *Epidemics* I. Both women suffered illness followed by death within a week or two after childbirth. While *Epidemics* profiles female patients, however, it says nothing about female practitioners, and the author appears to be a male practitioner attending to men and women.

From a range of other later, mostly Roman sources, however, we learn that there were specialists in women's health, including midwives (Latin *obstetrices*; Greek *maiai*) and female doctors (*maiaiatrai*). Soranus' *Gynecology* attests to the prevalence of successful midwives and the profession of midwifery in the Roman Empire. He goes so far as to offer a set of criteria for selecting and training a competent midwife (*maia*), implying, if not a problem with the quality of care by midwives, then at least a perceived need among those hiring midwives to know what the professional standards were, for, in Soranus' view, there was a tendency among his peers to be too lenient in training unsuitable persons (*Gynecology* 1.3). To that end, Soranus emphasizes that midwives must be literate and somewhat educated in the theoretical as well as technical aspects of the art, and also physically robust (*Gynecology* 1.3). From these guidelines, we receive some broader insight into the growth of the medical profession in the Empire and perhaps also into the demand for female practitioners, as Soranus shows himself to be interested in broadening, rather than limiting, the group of potential applicants. For example, Soranus notes that while a midwife needs to be calm, supportive, and sympathetic, she need not have given birth herself, as some of his fellow physicians had apparently claimed (*Gynecology* 1.4). It appears he views such a prerequisite as arbitrary and as needlessly excluding potentially qualified practitioners.

Funerary inscriptions mentioning midwives survive from across the Roman Empire and attest to the presence of midwives in large cities as well as smaller towns. These inscriptions offer few details about the lives and practices of midwives, although they do provide valuable indicators of social status. It is from inscriptions such as that of Primilla, a practicing midwife at Rome in the second century CE, that we can glean the few details that survive (Flemming 2007, 259). Most of these women are commemorated by their husbands, and their epitaphs stress their wifely virtue more than their professional

competence. More surprising, given the impression from many of our sources that the medical profession was male dominated, are the suggestions from some Roman Imperial evidence that women occasionally attained a level of theoretical knowledge along with technical skill. As Rebecca Flemming has shown (2007, 260), female medical practitioners were sometimes commemorated in terms comparable to those of their male colleagues. For example, in a funerary stele from Imperial Rome, the freedwoman Naevia Clara is praised as a "physician and scholar" (Latin *medica philologa*) and as the wife of a fellow physician.

This epigraphic evidence for the existence of caregivers raises questions about how they interacted with patients. From Rufus' *Regimen for Young Girls* (see above), the reader gets the strong sense that adolescent girls, at least, were perceived as needing others to guide and supervise their care. Adult women were likely seen as somewhat more able to help themselves, and no doubt many of them sought out the advice and assistance of female family members or friends who had no medical training in addition to doctors. With no surviving writings from women themselves reflecting on their feelings or their efforts to obtain care, moreover, what can we learn about how girls and women consulted with doctors or midwives? A few texts address this issue, albeit indirectly. *Diseases of Women* 1.62, cited earlier, comments on the problems faced by practitioners in eliciting the kind of reporting from their patients that was needed in order to ensure an effective outcome for the patient. Male practitioners, especially, who relied on communication from their female patients about sensitive ailments or intimate areas of the body, could be at a disadvantage. As *Diseases of Women* suggests, these practitioners were aware of their patients' tendency to code or self-censor their responses out of concerns about modesty. Occasionally, a practitioner could use the customary silence of a woman about illness as an opportunity to showcase his own intuition and investigative diagnostic skills. Such is true in a case history described by the second-century CE physician Galen in *On Prognosis* 1.6. Galen's brief account of a woman suffering from psychological symptoms highlights that he needs no verbal account from his female patient; as he tells it, he is able to diagnose her lovesickness simply by detecting her racing pulse when she is in the presence of the male dancer she desires. In this interaction, Galen was able to circumvent the concern about the modesty of female patients expressed by the Hippocratic author and use it to his professional advantage.

One potential way around this problem of shame or modesty was to assign the caregiving role in matters of reproductive health to women. If women did achieve the status and education of a *medica*, or physician, as in the case of Naevia Clara, then women patients might have been able to entrust themselves to the care of women not only for pregnancy, labor, and delivery, but also for other ailments.

4. Religious and Magical Approaches to Women's Medicine

The gynecological writings of the Greek and Roman physicians were aimed at a literate and educated audience, which by all indications was primarily comprised of men who were interested in the health of women in their charge. But what about the women who decided on their own not to seek the advice of secular physicians for their care? What about those women who did not have access to a physician? Several groups of evidence, including temple inscriptions and magical spells on papyrus, attest to the willingness of

women to seek out religious and magical cures, and they offer a glimpse of the varied modes of healing women may have employed.

It should be emphasized, first, that rational and non-rational sources for cures did not necessarily run counter to each other; both could be sought by individuals and seen as complementary (see also Healing Shrines; Magic, Curses, and Healing). We lack an extensive first-hand patient account by a woman to compare to the health journal kept by Aelius Aristides, a second-century Roman orator and hypochondriac, but Aelius' account makes clear that physicians were part of his vision for his health care, although he preferred to follow the instructions of Asclepius, and the same was likely true for elite women as well. This was not only due to economic advantage, which allowed aristocrats to seek out care from many sources; it was also more broadly attributable to the lived reality of sickness and cure in the Greco-Roman world, wherein, irrespective of the patient's socio-economic status, she was confronted with uncertainty and risk in seeking out care. As Helen King has noted (1998, 106), in regard to attitudes toward secular medical practices and religious or magical healing practices, the "ancient perception of the two sectors as clear alternatives is most unlikely to have been universally the case." The evidence we have for these non-rational approaches to health and healing ranges widely, but taken together, it attests to the popularity of these methods and the efforts made by women to seek them out for both acute and chronic ailments.

For those who lived close enough to a shrine, or could afford the trip, one option was to seek treatment from the Greco-Roman god of healing, Asclepius. A ritual at one of the temples of Asclepius, for example at Epidaurus or on the Tiber Island in Rome, involved the supplicant's sleeping in the sanctuary (*abaton*) and receiving a curative dream from the god. Upon waking, the patient might find herself cured; or, if the dream had presented a suggestion that needed to be interpreted, then she could find priests of the god who were prepared to provide such service for a small payment. From the temple at Epidaurus survive several dozen healing inscriptions, *iamata*, in which patients attest to the efficacy of the cures they received in the temple. A pattern emerges from the *iamata* in which female patients seek out cures for chronic and difficult ailments, and these include gynecological or reproductive problems, such as infertility. Of the forty-three legible *iamata* that survive on two large tablets from Epidaurus, ten involve female suppliants, and six of these cases involve either pregnancy or infertility. The two pregnancies recorded in the *iamata* are both exceedingly long and result in miraculous cures:

> Cleo was with child for five years. After she had been pregnant for five years, she came as a suppliant to the god and slept in the *abaton*. As soon as she left it and got outside the temple precincts, she bore a son who, immediately after birth, washed himself at the fountain and walked about with his mother. In return for this favor she inscribed on her offering: "Admirable is not the greatness of the tablet, but the Divinity, in that Cleo carried the burden in her womb for five years, until she slept in the Temple and he made her sound." (T. 423, Edelstein and Edelstein 1998, 229)

The other inscriptions from the temple of Epidaurus are similarly simple and brief: the description of a woman's ailment is followed by confirmation that she had contact with the divinity and received a divine cure. The account sometimes concludes, like Cleo's, with direct expression of gratitude toward the god and description of the dedication provided. Notably, in these accounts, the focus is on celebrating the suppliant's direct

relationship with the god and his supernatural powers; the intermediary role of priests or temple wardens is rarely, if ever, mentioned. This highlights that, while they were undoubtedly authoritative in their own right (not least as dream interpreters and managers of the content of the dedicatory inscriptions), the priests' role was overshadowed by the contact of the suppliant with the god. The priests are not described in the narratives as having medical training which informs their interpretations, nor are they depicted as explaining the causes of a worshipper's illness. Asclepius maintains sole control over whether relief is provided from the ailment, a power illustrated in the case of one skeptical female suppliant. Relief is not forthcoming until she pledges to provide a gift of silver to the god to atone for her previous lack of trust (T. 423, Edelstein and Edelstein 1998, 230). The power and capricious nature of the god is thus highlighted, rather than systematic investigation into the cause of disease or an ethical relationship of "do no harm" akin to what was outlined in the Hippocratic *Oath*.

Charms, incantations, and spells provided another potential avenue for female patients. The surviving record of healing events that involved magical methods is scant, but those spells extant on papyrus from Roman Egypt suggest that the focus was, again, on achieving a desired outcome for the person seeking a cure rather than on understanding the underlying cause of the ailment. While this was undoubtedly an approach that relied heavily on the patient's belief, rather than on acceptance of a reasoned argument or explanation, it is nevertheless possible to imagine that practitioners of magic would have contended against skeptics that their approach was no less successful for women than the therapies prescribed by secular physicians. It is also possible that the magical or folk remedies were no less popular than were naturalistic approaches. Indeed, the survival of spells involving the uterus confirms that folk understandings of women's medicine persisted in the Roman Empire centuries after the Alexandrian anatomical discovery that the womb was held fast in the body, and it also counters the notion that there was a dramatic "turning point" in the treatment of women brought about by naturalistic explanations and treatments of disease. In the collection of *Greek Magical Papyri*, for example, there survives a spell (third century CE, from an Egyptian village) designed to prevent the ascent of the womb:

> Against the ascent of the womb. "I conjure you, womb—by him who set up his power over the Abyss, before there was heaven or earth or sea or light or darkness, by him who created the angels, of whom, first of all, Amichamchou and Chouchao Cheroei Oueiacho Odou Proseionges, and by him who sits over the cherubim, raising up the throne that is his own—that you sit back down in your seat and neither lean toward the right part of the ribs nor toward the left part of the ribs, that you not bite into the heart like a dog, but stand firm and remain in your own place, gnawing on nothing, as long as I conjure you by the one who in the beginning made the heaven and the earth and all the things in it. Alleluia. Amen.' Write this on a small strip of tin and wrap it in seven colors." (trans. Rowlandson 1998, 340)

Like temple healing, magic offered the female patient the opportunity to harness supernatural power for her health and provided therapy for an intimate problem without the discomfort or risk of physically invasive therapy. However, unlike Asclepius narratives, charms and spells are limited to being instructional; and while they do suggest that steps be followed in sequence, they stop short of confirming a successful outcome. Moreover, as this spell suggests, the act of conjuring the womb displays features that

temple dream-therapy does not, including the written component, which assumes literacy, and the lack of differentiation between the practitioner and patient, with the patient potentially serving as the practitioner (Gordon 1995, 373). Here, the elements of the spell, including direct address of the womb, invocation of divinities, and firm instructions, serve as the prescription. What this approach to women's reproductive health lacked in precise observations, it made up for in its brash assertiveness, which could have its own appeal and might not seem very different from Galen's reliance on the pulse. As the jurist Ulpian wrote in the early third century CE, Roman law might have prohibited magical practices, but people still sought them out and considered them effective (*Digest* 50.13.1.3). Even Galen, as part of his criticism of magic and magical remedies, conceded that such approaches did have the ability to convince the patient that the practitioner had the power to work wonders (*On Prognosis* 1). Ultimately, doctors, midwives, priests, and sorcerers could find common ground in the fact that they all hoped that their female patients would find their therapies effective.

5. Conclusion

Overall, patients in the Greco-Roman world, male or female, lived within a harsh reality in which reliable cures were often unavailable. Female patients encountered medical risks that male patients did not, most notably owing to the high rate of maternal mortality and the fact that normal maturational events, most notably puberty, were traditionally pathologized by Greco-Roman physicians. Whether women sought out secular physicians and "rational" theories and treatments for their ailments, or whether they pursued religious or magical avenues for finding a cure, the interactions between female patients and their practitioners in the Greco-Roman world required trust and belief on the part of the patient that the service they were seeking, and, in many cases, paying for, would provide them with relief from pain or illness.

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CHAPTER 23

Surgery

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Translated by Todd Black

1. Introduction

In his treatise *On Medicine*, the Roman encyclopedist A. Cornelius Celsus states that Hippocrates of Cos laid the foundations of the art of medicine by separating it from philosophy. The art itself became subdivided:

> During the same times the Art of Medicine was divided into three parts: one being that which cures through diet, another through medicaments, and the third by the hand. The Greeks termed the first *diaitētikē*, the second *pharmakeutikē*, the third *cheirourgia*. (preface 9: trans. Spencer)

This canonical definition does not tell us much about pathological states, nor does it rely on anatomical devices. Focusing on therapeutics, it demonstrates a more practical approach. The significance of the Greek word *cheirourgia* is explicit: surgery is the art or skill that requires the use of manual intervention for effecting cures. In that sense, it is the human response to disease or wounds, since animals can know how to cure or protect themselves only by changing their regimen or using natural remedies (see Boehm and Luccioni 2008). Such a response, which involves rather elaborate gestures and the use of tools, has a long history. Archeology shows signs of medical attention as early as prehistoric times (broken limbs that were set, dislocated joints, skulls showing signs of trepanation, etc.). Nonetheless, not every manual intervention on a body had a therapeutic aim: trepanation, for example, was often linked to ritual practice. Furthermore, as Nutton points out, medicine itself is "something over and beyond mere healing, as the possession of a specific body of learning, theoretical and practical, that might be used to treat the sick" (1996, 53).

The earliest Greek literary example of surgery comes from Homer's *Iliad*, where Machaon, son of Asclepius, stands as a prototypical surgeon: with his brother Podalirius,

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he is depicted as the "doctor" of the Achaean army that besieges Troy; he is responsible for healing several warriors, including Telephus, Menelaus, and even Philoctetes, finally cured of the severe and painful ulcer caused by Heracles' arrow. In the *Aeneid*, Vergil follows Homer's model by depicting Iapyx as healing the wound that Turnus inflicted on Aeneas (12.391–404). This episode is famously illustrated on a painting from Pompeii which accurately depicts a basic surgical instrument (Figure 23.1). These epic references remind us that, for over two thousand years, battlefields have been the initial and main arena for surgeons to practice their art.



Figure 23.1 Aeneas is healed by the surgeon Iapyx (Pompeii, House of Siricus, National Archeological Museum of Naples, inv. 9009). (*Source:* akg-images/Erich Lessing.)

2. The First Literary Sources

The Hippocratic treatises are the first testimonies to a surgical science in ancient Greece. Among the sixty-two works attributed to Hippocrates that have come down to us, seven texts deal specifically with surgical procedures. The authenticity and dating of those writings has been long debated. Nevertheless, scholars agree that several of these treatises might be the work of Hippocrates himself or his students. The Hippocratic surgical titles include the following:

- *On Fractures* (*De Fracturis*: 3.337–563 Littré).
- *On Joints* (*De Articulis*: 4.1–327 Littré): Showing a rather good knowledge of bones and the skeleton; also the first text to distinguish between veins and arteries.
- *On Head Wounds* (*De Capitis Vulneribus*: 3.150–261 Littré).
- *Ulcers* (*De Ulceribus*: 6.398–434 Littré).
- *Hemorrhoids* (*De Haemorrhoidibus*: 6.434–445 Littré).
- *On the Surgery* (*De Officina Medici*: 3.262–335 Littré): General procedures related to various operations and bandaging.
- *Mochlicon* (*Mochlikon* = *Vectiarius*, 4.328–397 Littré): The title refers to a specific lever dedicated to the reduction of luxations; the treatise itself is a summary of *On Fractures* and *On Joints*.
- *Anatomy* (*De Anatome* 8.536–541 Littré).
- *On Fistulas* (*De Fistulis* 6.446–561 Littré).
- *On Wounds by Projectiles*: Quoted by ancient sources but not extant.

These treatises describe various surgical procedures and testify to the fact that surgery was already a complex craft even before it was committed to writing. Their first merit is to supplement a teaching that had previously relied on oral transmission with the enduring record of a written account. As we will see later, they also introduce strong ethical principles and draw the limits of the art itself.

These treatises give an extended vision of the various interventions surgeons could have practiced around the fifth century BCE. The surgeon's main activity seems to have been the reduction of fractures and dislocated joints. There can be no doubt that such interventions were responses to common situations, as it remains today. We therefore know that contemporary surgeons were able to practice the following operations: trepanation, incisions, cauterization, draining of abscesses, amputation of gangrenous limbs, resection of hemorrhoids and anal fistula, resection of external tumors, and curing of empyema by thoracic paracentesis. Though opening the thorax was sometimes practiced, texts show that it remained exceptional. As we can conclude from non-surgical treatises (e.g., *The Nature of Man* 11.1–6), removing blood was a normal and even frequent procedure.

Other contemporary writers are known for their surgical works, such as Diocles of Carystus, whom Galen credited with the first book on dissection (of animals) (*Anatomical Procedures* 2.280–282 Kühn; fragments 17, 24; see van der Eijk 2000–2001). In his zoological treatises, Aristotle himself referred several times to a book that he had written, entitled *Dissections*, which contained figures and drawings of dissected animals (see Kollesch 1997, 370). Diocles is also quoted by ancient sources for writings on *Gynecology*, *Bandaging*, *Treatments*, *Surgery*, and *Affection*, *Cause and Treatment*. In surgery,

he can be credited with the introduction of a special spoon-shaped instrument for the removal of arrowheads from a wound (fragment 167).

3. The Alexandrian Revolution and Egyptian Myth

Numerous historical texts indicate that the foundation of the Museum of Alexandria under the Ptolemaic dynasty facilitated a more in-depth study of the sciences in general and of medicine in particular. Throughout the course of the third century BCE, four exceptional doctors stand out: Praxagoras of Cos and his disciple Herophilus of Chalcedon, and Chrysippus of Cnidus and his student Erasistratus of Ceos, who had practiced in Antioch before settling in Alexandria. These four noteworthy figures orchestrated a veritable epistemological revolution. They were responsible for the *translatio studii* from the most prestigious ancient centers of medicine to the new intellectual hub of the Mediterranean world, Alexandria. The Museum, significantly, was the first place where experiments in dissection were conducted for the purpose of broader anatomical knowledge. Such experiments and their unique historical context are explored by Celsus:

> Moreover, as pains, and also various kinds of diseases, arise in the more internal parts, they hold that no one, who is ignorant about the parts themselves, can apply remedies for these; hence it becomes necessary to lay open the bodies of the dead and to scrutinize their viscera and intestines. They hold that Herophilus and Erasistratus did this in the best way by far, when they led open men while alive—criminals received out of prison from the kings—and while these were still breathing, observed parts which beforehand nature had concealed, their position, color, shape, size, arrangement, hardness, softness, smoothness, relation, processes and depressions of each, and whether any part is inserted into or received into another. (preface 23–24: trans. Spencer)

Even today, this highly scrutinized text elicits surprise and controversy with regard to institutional human vivisection. A few centuries later, the use of human bodies for scientific observation was still considered problematic since Galen advised his students to open tombs, clandestinely, in order to practice autopsies (*Anatomical Procedures* 1.2, 2.220–222 Kühn). Galen also recommended traveling to Alexandria, where one could observe human skeletons. This short period of tolerance was doubtless due to a political power which privileged scientific inquiry over moral standards concerning the human body. It lasted only a few decades during the second half of the third century BCE before a return to a more conservative attitude.

Although the writings of these Alexandrian doctors and surgeons are lost, indirect sources abound, making it possible to identify their principal contributions to the study of the human body and improvements in surgical techniques. According to Vegetti (1995), the research of Herophilus and Erasistratus made it possible to open the "black box" which was the human body. Indeed, despite their wealth of information, the Hippocratic writings on precise knowledge of internal medicine remained limited. The Alexandrian school seems to have placed the study of anatomy at the very heart of science and medicine. The risk was that, as Vegetti notes, the clinical practice of medicine, which was the pillar of the Hippocratic tradition, would be replaced by a more theoretical approach. Erasistratus (fragment 32 von Staden) himself drew a distinction between anatomo-physiology (etiology), which is considered as absolute knowledge

(*epistēmonikon*), and clinical practice (semiotics, therapeutics), which is seen as a probable approximation (*stochastikon*).

Herophilus' major contribution was his description of the nervous system as the organ responsible for senses and motor skills. This breakthrough should have put an end to cardio-centrism, a theory advocated by his own mentor Praxagoras and by Aristotle. But, as the Stoics made it their own, the theory survived and was never really abandoned. Above all, as the first to provide a thorough description of the circulatory system, Herophilus laid the foundations for what would become a canonical distinction between the flow of blood through veins and that of *pneuma* through arteries.

Following in Herophilus' footsteps, Erasistratus theorized a holistic approach to internal movement through the body (blood, psychic, and animal *pneuma*) and their corresponding conduits (veins, arteries, nerves, etc.). Although this approach was obviously borrowed from teleological dogma, it nevertheless attempted to reconcile theory and observation.

Unfortunately, a number of original texts describing the significant advances made possible by that research have been lost, known only through later redactions. However, rare texts like the commentary on the Hippocratic *On Joints* by Apollonius of Citium make it possible to evaluate the contributions made in that period. Apollonius was known to have practiced at the court of Ptolemy XII Auletes of Cyprus around 90 BCE. His commentary goes far beyond the Hippocratic Corpus on, for example, thigh dislocation, by providing drawings and diagrams, as we see in the Nicetas manuscript (circa 900 CE, University of Bologna, Ms. 3632).

A few remarks should be made with regard to the Alexandrian "revolution" and the long-held thesis of the Egyptian heritage of the Greek surgical art. Some have tried to locate the cradle of surgical knowledge in Pharaonic Egypt, whence it could have been passed down to the Greeks. Indeed, there is no lack of documentation which credits the Egyptian experts with breakthroughs in the knowledge of the internal parts of the body.

Celsus (7.3) provided a list of famous surgeons, all from Alexandria: Philoxenus (credited with several books), Gorgias, Sostratus, Hero, two Apollonii, and Hamonnius. Homer was the first to speak of Egypt as the land of the race of Paion, where everyone knew the art of healing (*Odyssey* 4.219–232). The first ethnographic account dedicated to Egypt, in Herodotus' *Histories*, suggests a country where knowledge and practice of medicine were highly advanced. Moreover, Herodotus described medical practitioners who specialized according to body part (2.84). Of course, this division between areas of competence can be interpreted in different ways. It can reveal a lack of theory just as easily as it might indicate a high degree of technical skill. Some have pointed to traditional funeral rites to support the thesis that the Egyptians had particularly advanced knowledge of anatomy which could well have been transmitted to the Greeks. Modern scholars often refer to embalming techniques as proof of an anatomical science that the Egyptians were the first to master. Dissections practiced in Alexandria could therefore be situated in a long tradition of human autopsies (but see Nutton 2013, 132, who argues that there is no definitive evidence that the Egyptian practice of cutting into the body served any purpose beyond ritual burial).

We know that, as a general rule, the Greeks turned to Egypt when in search of their origins. Plato himself promoted the idea that science and knowledge originated from Egypt. For example, according to the myth of Theuth, writing, mathematics, geometry, and astronomy were all invented by the Egyptians (*Phaedrus* 274c1). In addition to the

myth of Atlantis, the *Critias* (113a–b) recounts the tale of Solon, one of the seven Greek sages who received knowledge from the Egyptian priests.

It is hardly surprising, then, that the Greeks regarded Egyptian civilization as a model for art and science. Nevertheless, it is clear that the authors referring to this tradition rarely mention medicine in favor of other forms of knowledge. Thus, given what is known of ancient Egyptian medicine, it is not possible to uphold the thesis that this tradition was necessarily the basis for the first Greek theoreticians. In fact, nothing allows us to link the Hippocratic tradition directly to Egyptian tradition. The rapid advances in the art of surgery in Alexandria can only be explained within a specific political and cultural context. It was in this context that scholars were able to engage in medical research. There is no doubt that the model for the Museum was the work of Aristotle and his system of classification. It is therefore in Greek thought that the discoveries of Herophilus and Erasistratus are to be found. It must not be forgotten that Aristotle himself was a biologist and zoologist who practiced dissection and direct observation. The very scientific framework of the Alexandrian school was a direct descendant of his philosophy of theoretical speculation coupled with practical experimentation.

4. Surgery in Roman Times: Celsus' Latin Encyclopedia

We have already noted that no direct Hellenistic literary sources survive. Celsus' *On Medicine* is, in fact, the first significant text dealing with the art of medicine since Hippocrates, and it stands as one of the four fundamental medical collections preserved from Greco-Roman antiquity, along with the works of the Hippocratic Corpus, Galen, and Caelius Aurelianus.

Scholars now agree that Celsus was not a practitioner, but a scholar who sought to transmit a scientific and technical body of knowledge to his contemporaries in the first decades of the first century CE. The only extant vestige of a much larger encyclopedic work dedicated to a body of knowledge comprising agriculture, military matters, rhetoric, and philosophy, *On Medicine* signifies a deep and direct reading of medical texts (see also SCIENTIFIC ENCYCLOPEDIAS). Celsus' eight books represent the first concrete and direct documentation of Hellenistic medical advances. The practices and knowledge found in Celsus can therefore be placed in the context of those transmitted by the Hippocratic Corpus. The author's technical lexicon bespeaks these advances highly since it introduces a multitude of Greek terms related to surgical techniques and instruments not found in the Hippocratic texts. Books 7 and 8 deal specifically with surgery.

Following a brief history of surgery and a definition of what it is to be a surgeon, Celsus describes a series of surgical and therapeutic techniques for diverse pathologies (book 7). Book 8 begins with a detailed description of the human skeleton, from head to heel (*a capite ad calcem*) according to the canonical order of ancient medical treatises. It then proceeds to detail specific bone-related pathologies (fractures, cavities, gangrene, etc.) as well as the instruments used for treating the bones affected by them.

The pathologies and Celsus' recommended treatments suggest a wide-ranging course of surgical experience, knowledge, and treatments. In book 7, Celsus addresses contusions; abscesses; fistulas; extraction of projectiles; protuberances on the head; affections of the eyes and ears; mutilation of lips, ears, and nose; afflictions of the mouth and teeth; inflammations of the throat and tonsils; malformation of the tongue and lips; bronchial tumors; umbilical hernias; wounded or perforated intestines; inguinal hernias; genital

hernias; surgery of the penis and infibulation; bladder stones; genital cancer; embryotomy and abortion; genital warts and hemorrhoids; varicose veins; surgery of fingers; and gangrene of the limbs. In book 8, he describes fractures (head, nose, ear, jaw, clavicle, ribs, chest, arms, femur, leg, and fingers); dislocations (jaw bones, head, spinal cord, chest, elbow, hand, fingers, femur, knees, heel, sole, and toes); and dislocations caused by disease ("without a wound").

A number of the aforelisted conditions and operations were already addressed by the Hippocratic texts. But, more surprisingly, Celsus advocated that the surgeon not hesitate to operate on internal organs, which received little textual attention before him. Moreover, Celsus also gave special attention to skin conditions and external growths. Such obsessive attention to physical deformity and imperfections is rather uncommon in ancient medical texts, but the use of plastic surgery for aesthetic ends is hardly a modern invention. It should also be noted that superficial operations were less life-threatening than those which involved opening the body. One could assume that physicians were solicited more for the former than the latter. Finally, as with the Hippocratic Corpus, Celsus devoted an entire book to fractures and dislocations, which were likely the most common areas of surgical intervention.

On the basis of this synthesis, Greco-Roman surgery can be divided into three parts:

- Operational: Treatment of wounds, ulcers, tumors, etc., and plastic surgery.
- Mechanical: Fractures and dislocations, representing the oldest field of intervention for the surgeon.
- Obstetrics and treatment of gynecological infections: By far the most crucial in the context of a society where infant mortality and death during childbirth were common.

It is because of this medical encyclopedia that we have a trace of famous doctors who would have otherwise been long forgotten. As an example, Celsus praised Philoxenus, a surgeon who practiced in Egypt, perhaps around 100 BCE, and whose multi-book treatise on surgery was "careful and comprehensive" (7 preface 3).

5. The Galenic Corpus

Given the importance of Galen's writings, one might expect his texts to contain a wealth of information about surgical knowledge. Surprisingly, this vast corpus does not deal with our topic. Generally speaking, Galen returned to a more ancient practice which pays little attention to the Hellenistic advances in surgery, focusing instead on the foundational texts of medicine in order to establish himself as their legitimate heir. He thus presented himself as the second founding father of ancient medicine after his model, Hippocrates. Nevertheless, Galen's work is in no way devoid of innovations and original theories, but surgery is not its main focus.

Of the nearly 140 treatises which can be attributed Galen, only a handful deal directly with surgery:

- *Concerning the Method of Curing through Venesection* (*De Curandi Ratione per Venae Sectionem:* 11.250–316 Kühn).
- *A Commentary on Hippocrates about Fractures* (*In Hippocratis de Fracturis Commentarii III*: 18B.318–628 Kühn).

- *On the Therapeutic Method* (*de Methodo Medendi*: 10.1–1021 Kühn): Only two books of this immense treatise (13–14) evince the practice of surgery.
- *Introduction to Medicine* (*Introductio sive Medicus*: 14.674–797 Kühn): Gives a description of common operations, but its authenticity remains dubious.

Nevertheless, mentions of surgical acts can be found in this otherwise rich body of texts. It is most surprising to note that, compared to the Hippocratic Corpus, which devotes numerous chapters to surgery, the Galenic Corpus does not consider surgery as a distinct field within the art of medicine. The crucial question of surgery as a specialty in its own right will be addressed later.

Galen, however, was a specialist of anatomy; he made regular and extensive use of dissection on animals, especially monkeys, given their close resemblance to humans (e.g., *Anatomical Procedures* 6.1, 2.537 Kühn). Several of his treatises are a testimony to his exceptional skills in anatomy. Given Galen's careful study of the anatomy of internal organs, it is clear that his disinterest in surgery is not attributable to ignorance. It would seem, then, that his approach to dissection was purely theoretical. Dissection, thus, is to be distinguished from surgery, whose aim is therapeutic, since the act of cutting into a body is not in itself an act of surgery.

6. Later Compilations

After Galen, there were no innovations in medical science. The knowledge and practices of the past were simply summarized, translated, and compiled. For example, Oribasius, the personal physician of the emperor Julian (ruled 361–363 CE), compiled a *Medical Collections* which brought together various sources of information concerning the practice of medicine. Surgery, however, plays a minor role in his text. In the first half of the fifth century, the works of the Greek physician and gynecological writer Soranus of Ephesus—who himself described a number of surgical remedies for female maladies in book 4, including surgical abortion (4.3) and the removal of uterine fibroids (4.14)—were translated and partly adapted by Caelius Aurelianus, whose important treatise, *On Acute and Chronic Diseases*, contains numerous descriptions of therapeutic acts, including surgery. Owing to the remarkable accuracy of his content, Caelius Aurelianus has thus been traditionally considered one of the great physicians of antiquity. Nevertheless, like Galen, no noteworthy innovation can be attributed to his work.

7. Surgery as Craft

The question of the existence of an art of surgery as such cannot be ignored. Modern medicine considers surgery as a distinct field, different from other forms of therapeutics. However, was this also the case in ancient Greece and Rome? To what degree did the physicians and practitioners of antiquity specialize? Were they generalists who were more or less specialized according to their areas of expertise? Or were their domains clearly defined? The Hippocratic tradition eschewed specialized medicine. According to Herodotus, this trait distinguished the Greek doctor, who did not concentrate on specialized forms of medicine, from the Egyptian doctor, who did (2.84). We have already seen that Galen had little interest in surgery, in part owing to his devotion to a unified conception

of medicine as practiced by Hippocrates. Like his model, Galen was opposed to a fragmented approach. He believed that privileging one aspect over another, be it gymnastics, diet, pharmacology, or surgery, would jeopardize a holistic approach to human health. For him, the specialist was not a good doctor.

Surgery as such could also have been perceived negatively because of its invasive nature. Frequently cited is Archagathus, a successful physician in Rome in the third century BCE, who was granted citizenship and endowed with a publicly financed dispensary. Despite his early success, because of the invasive violence of his methods, he quickly fell out of favor and received the nickname *carnifex*—butcher or executioner. This resulted in the utter disdain of the (professional) art of medicine in Rome (Pliny, *NH* 29.12–14). The same hesitation can also be found in Galen, since for him a surgeon who removes what exists naturally and tampers with the natural evacuative functions of the body could only be wrong. For Galen, only that which does not exist naturally should be removed; kidney stones, for example, and tumors. However, in the case of the latter, surgery should not be the first course of action, since early treatment of a tumor allows the body to discharge it naturally with the help of certain medicines and diets. In modern terms, Galen might be seen as a practitioner of alternative medicine, using surgery as a last recourse. As we will see, in spite of the technical knowledge acquired over generations by practitioners, surgery remained a potentially dangerous and painful experience.

Nevertheless, Celsus paints a more positive picture of the surgeon. A surgeon should be young with a firm hand and not be prone to trembling (7.4). Generally speaking, such considerations are simply common sense, but they may also indicate a practice that was preferably entrusted to young doctors in full possession of their physical faculties. Even today, many patients might have similar reactions, which is not to say that there should be rules forbidding older doctors from practicing surgery. Technical and theoretical knowledge is important, but the surgeon must also possess dexterity and precision. In any case, no clear distinction between surgery and medicine can be found in Greco-Roman antiquity—contrary to what can be observed in subsequent historical periods, when surgeons were considered inferior to the physicians who practiced under the aegis of official schools.[1] The respect of a code of ethics is doubtless what gives more depth to the practice of surgery within the Hippocratic tradition.

8. Ethical Questions

The well-being of the patient is at the very heart of the Hippocratic texts. The Hippocratic ethos imposes upon the practitioner a code of deontology, wherein the proscribed therapy is carried out within a framework that is both socially and morally acceptable. The main principles of an ethical code of medicine can be observed in the Hippocratic *Oath*. Once again, Herodotus' comparison between Greece and Egypt is quite revealing. Herodotus mentions the treatment that Darius received from Democedes, noting that it was a gentler, Greek method compared to the medicine practiced by the Egyptians (3.130). Just as in the case of Archagathus, the acts of cutting and burning were perceived as a kind of violence on the part of the surgeon. From this perspective, all moral considerations aside, the rules governing good medical practices must have been established early on. Had this not been the case, the practitioner would have run the risk of facing massive rejection.

The precise descriptions of the first surgical acts were concerned not only with various techniques—for example, the use of trepanation to treat head wounds—but also with methods employed to treat dislocations and fractures by respecting the natural position of body parts and avoiding procedures that were unnecessarily risky. In the first chapter of *On Fractures*, the physician (Hippocrates) recommends avoiding audacious and dangerous treatments. Similar recommendations are found throughout the corpus. For example, in *Epidemics* (1.5), one finds the following suggestion "As far as diseases are concerned, one may keep in mind these two principles: help or do not harm." This principle clearly seeks to deter the physician from excessive interventionism which could result in the need for a more violent and painful operation, making matters far worse and less efficient.

One essential fact which characterized the act of surgery until only recently must not be forgotten: surgery was carried out without anesthesia. Thus, the surgeon was fully aware of the pain his patient had to endure. It is for this reason that, over time, the practitioner acquired the necessary skills to alleviate pain. The Hippocratic *On Joints* describes the use of a winch to control the amount of applied force, in order to avoid excessive violence. Likewise, frequently mentioned are leather cushions, underscoring the desire for patient comfort during operations. And, if the patient had to be immobilized, it was essential that restraint be done in such a way that was least uncomfortable. Above and beyond any sense of compassion, the surgeon knows that an operation carried out on a cooperative patient has a far greater chance of success.

9. Tools and Techniques

Our sources for surgical tools and techniques are both textual and archaeological.

Celsus' descriptions are rich with details about the techniques and procedures. His vivid description of a cataract operation (7.7.14) underscores the importance of the high level of competency, knowledge, and skill of the Greco-Roman surgeon. After describing the causes and different types of cataracts, Celsus advised on which types are operable (cataracts in the very young or the elderly are not conducive to treatment), as well as on the patient's pre-operative behavior (the patient should eat moderately, drinking only water, and should fast the previous day). The actual operation is then described in detail. In a light room, the patient should face the light while an assistant "holds the head from behind … for vision can be destroyed permanently by a slight movement." The actual procedure is depicted in stunning detail:

> Further the left eye should be operated on with the right hand, and the right eye with the left hand. Thereupon a needle is to be taken pointed enough to penetrate, yet not too fine; and this is to be inserted straight through the two outer tunics at a point intermediate between the pupil of the eye and the angle adjacent to the temple, away from the middle of the cataract, in such a way that no vein is wounded. The needle should not, however, be entered timidly, for it passes into the empty space; and when this is reached even a man of moderate experience cannot be mistaken, for there is then no resistance to pressure. When the spot is reached, the needle is to be sloped against the suffusion itself and should gently rotate there and little by little guide it below the region of the pupil; when the cataract has passed below the pupil, it is pressed upon most firmly in order that it may settle below. If it sticks there, the cure is accomplished; if it returns to some extent, it is to be cut up with the

> same needle and separated into several pieces, which can be the more easily stowed away singly, and form smaller obstacles to vision. After this the needle is drawn straight out; and soft wool soaked in white of egg is to be put on, and above this something to check inflammation, and then bandages. (trans. Spencer)

After the operation, the patient is instructed to rest and to treat the eye with "soothing medicaments," drinking only water for several days, and abstaining from solid food until the inflammation subsides. Celsus also described the use of ligatures to avoid hemorrhaging during a hernia operation, a procedure, handed down by the Alexandrian school, that made the surgery less dangerous (7.19.8). Moreover, throughout book 7, Celsus cited the use of sutures made of metallic hooks, and he presented the main Hellenistic surgical advances. The contributions of book 8 are minimal compared with the Hippocratic O*n Fractures*, *On Joints*, and *On Head Wounds*. As noted earlier, Galen was ambiguous regarding surgery, preferring Hippocratic techniques over more recent ones, and the procedures he detailed are generally far from innovative. First, Galen recommended amputating a limb at the joint instead of sawing into the healthy part of the bone (the same recommendation can be found in Celsus: 7.33). Second, Galen advised using pressure and not ligature to stop bleeding (see McVaugh 1995).

The complex field of surgery was transmitted neither by Galen nor Celsus, who was virtually unknown in the Middle Ages, but instead by Paul of Aegina in his seven-volume medical handbook, *Epitome*, specifically book 6. Like Galen, Paul placed surgery within the larger framework of the general practice of medicine. Much of the *Epitome's* content is already present in Celsus, and, like Celsus, Paul divided his text in two parts: surgery and the treatment of fractures and dislocations. In the *Epitome*, cautery stands out as a broadly used method, not only to prevent chronic dislocations (with the use of a Hippocratic technique) or to treat empyema but also to stimulate bedsores, which were believed to aid liver, spleen, and stomach functions. The use of cautery was also prescribed against dropsy. The *Epitome* was translated into Arabic in the ninth century and became a medical reference in the Muslim world (see also Translation and Transmission of Ancient Scientific Texts).

Archaeology has brought to light highly crafted instruments that corroborate our textual evidence. Many instruments, furthermore, bear a striking resemblance to their modern counterparts, simplifying their identification. Even today, ancient surgical tools are admired for the quality and precision of their workmanship (Figure 23.2). Among the ancient instruments are rough-edged forceps, used to grasp kidney or gallstones through an incision; needles for pulling back the lens during cataract surgery; and vaginal dilatators, often mentioned in texts on gynecology and obstetrics. In addition, numerous instruments for general surgical use have come to light: bistouries (surgical knives with long, narrow blades), scalpels, hooks, forceps, probes, spoons, scissors, saws, catheters, and specula, all of which made up the surgeon's arsenal as described in texts (see further Jackson 1994).

A significant number of surgical tools has also been discovered at Roman sites. Such tools were almost always found together ("the surgeon's bag") and are scattered throughout the Empire. The discoveries of medical tools are especially plentiful in legionary garrisons, particularly along the frontiers. Dioscorides and Scribonius Largus are two famous doctor-surgeons who traveled with the Roman army: Scribonius



Figure 23.2 Surgical tools found in Pompeii (National Archeological Museum of Naples, inv. 11141). (*Source:* Hulton Archive/Stringer/Getty Images.)

Largus may have been a private physician (Nutton 2013, 175), and Dioscorides enigmatically referred to living a "soldier's life" (Nutton, 2013, 178; Greek and Roman Botany; Pharmacy). In fact, the battlefield with its share of wounds and mutilations was a kind of giant laboratory which made advances in surgery possible. The same can be said of veterinary medicine, especially concerning the treatment of horses, which were widely used in the Roman army (Cam 2007; see also Animal Husbandry), as well as the gladiatorial schools, where Galen learned much about anatomy (see Physicians and "Schools").

10. Conclusion

The first medical corpus, attributed to Hippocrates, had established surgery as one of many specialized fields of medicine. It is therefore impossible to dissociate it from the body of knowledge which made up the practice of ancient medicine as a whole. Surgery, however, was not the only means of intervention. The science of pharmacology also played a vital role alongside the practice of surgery in the treatment of wounds, skin disorders, etc.

A careful reading of the texts reveals the hesitancy of some authors to turn to surgery, a last resort when all other methods of treatment have proved ineffective. Both the surgeon

and the patient must have given considerable thought to the matter when faced with an act that could be dangerous, painful, and cruel. For Galen, these reservations were mostly theoretical and dogmatic, and his engagement with the field of surgery was distant. Galen cannot be considered a major source of surgical knowledge, which explains why, during the Middle Ages, medicine and surgery were regarded as separate fields, the latter relegated to the status of a bloodletting barber, in no way comparable to the honorable profession of physician.

Generally speaking, like pharmacology, ancient surgery is an area that required a high degree of experience and practice. The supporting theories and etiology were of lesser importance. Surgery seemed little concerned with the arguments and debates that opposed, sometimes virulently, different schools and currents of thought even if some physicians expressed hesitation to engage in its practice. Whether it was to treat a fracture or an abscess, all physicians, regardless of philosophical or ideological position, were required to practice surgical acts to alleviate pain and prescribe appropriate treatment. Given the absence of anesthesia and antiseptics, patients must have at least been reassured that their bodies and afflictions were not seen as a laboratory to prove or disprove differing views since, even if practiced by an experienced physician, the surgical act remained dangerous and traumatic.

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NOTES

1 One must keep in mind that during the Middle Ages, in the universities, medicine was taught through reading Galen's works. Celsus' *On Medicine*, our main source on surgery, was almost unknown.

CHAPTER 24

Physicians and "Schools"

Molly Jones-Lewis

1. The Ancient Physician

It may be safe to say that healing is among the oldest professions. Certainly, we see evidence of healing and healers from the earliest surviving Mediterranean literary evidence, principally from Egypt and the Levant. But our information about their beliefs and practices in the Greek-speaking world is limited before the fifth century BCE. Our knowledge of trade in the Bronze Age suggests that medicinal items were imported and exported along with other valuable goods around the Mediterranean basin (PHARMACY), and the Greek word for "physician" (*iatros*) appears in Linear B as *i-ja-te*. In later records, Homer includes Podalirius and Machaon, the sons of Asclepius, among the soldiers fighting for the Greeks at Troy, and he mentions their battlefield medicine in passing (*Iliad* 2.731–733, 4.192–218). The *Odyssey* suggests early connections between Greek and Egyptian healers when Helen's *nepenthe* comes from that land (4.219–232), and the image of the herb *moly* used to counteract Circe's *pharmaka* (10.287–290) indicates that there was an understanding of medicinal plants, broadly understood (Nutton 2013, 37–40). The migrations of the Dark and Archaic periods exposed Greek traditional medicine to the ideas of their Egyptian and Mesopotamian neighbors, and the foundations of Greek peripatetic (and therefore cosmopolitan) medicine were laid.

Although it is clear to modern scholars that healing professions were an old and common part of ancient Mediterranean society, their practices, beliefs, and social roles are obscured by wide gaps in the source material. Papyri, material remains, and inscriptions certainly form an important part of the evidence for medicine as it was practiced rather than described in texts, and they form a growing body of evidence as advances are made

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in archaeology (Nutton 2013, 11–12). Only a limited amount of medical literature survives, and texts represent physicians of the upper class disproportionately over the types of unlettered practitioners who served the majority of patients. Added to that is the nature of the transmission of medical texts and the "long shadow" cast by Galen, whose theories and writings triumphed in the Middle Ages as the definitive texts of Western medicine. Original texts were generally not copied, because Galen's work was considered more thorough and more modern, and Galen's habit of informing his reader of the failings of his predecessors and competitors convinced many a scribe not to bother preserving the texts dismissed by Galen. The greatest exception is the Hippocratic Corpus, which survives because *this* was the collection of texts that Galen admired and cited often. Galen urged his pupils to value the Hippocratic texts, and so the scribes diligently followed his directions (Nutton 2013, 13–15).

The exceptions to the Galenic rule largely comprise those texts for which Galen provides no substitute. Dioscorides of Anazarbus' systematic work on pharmacy, for instance, seems to have been a better reference work for the practicing physician than its competition, ensuring its survival (Roman and Greek Botany; Pharmacy). Similarly, we still have most of Soranus of Ephesus' *Gynecology,* the most complete work written by a member of the Methodist school to have survived Galen's savage attacks. Soranus gives a thorough and helpful account of practical obstetrics and gynecology whose usefulness saved it from going the way of other treatises that became redundant under Galen. Likewise, the language of the text plays a role in how it was or was not preserved. Works in Latin were kept in the west as the use of Greek began to wane. So we have Scribonius Largus' *Compositiones* (*Compounding Recipes*) for both its language and wide-ranging directions for compounded medications that supplement Dioscorides' simpler approach to pharmacy. We also have Celsus' *De Medicina* (*On Medicine*), which preserves accounts of Alexandrian medicine in clear enough detail for later physicians to have used it for reference, although Celsus himself was probably not a physician.

Finally, there are works on the natural sciences (Pliny the Elder's *Natural History* chief among them: Scientific Encyclopedias) that preserve extra medical information alongside geology, geography, ethnography, and the like, and also bits and pieces of information tossed in as asides from non-scientific literature. And yet, medical texts were preserved in far better number and range than other ancient genres; large amounts of Galen and Hippocratic texts, as well as these other smaller works, survive where many others have been lost. The fact that even our more triumphant cases of textual survival offer such a fragmentary view of ancient lives is a telling commentary on the daunting task facing a modern scholar of ancient medicine.

"Hippocrates"

The Hippocratic Corpus represents a collection of texts written by a variety of authors over a span of time from the fifth to fourth centuries bce. It represents our best and earliest voice of a tradition of medicine that had already begun developing in the sixth century bce, if Herodotus' account of Democedes of Croton's peripatetic life during the Archaic period is indicative of how less famous physicians made their living (3.125, 129–137; Zhmud 2008a). A physician named Hippocrates did exist, but scholars now

generally agree that none of the works collected under his name were written by his pen. The texts represent the great range of theory and practice among physicians engaging in this rationalizing approach to the human body, but there is a unity of vision that sets aside supernatural explanations for disease in favor of the rational. And it preserves the collective experience of these scholar-physicians to work toward agreement about physical rather than supernatural explanations (Jouanna 1999, xi–xii). Prognosis, or the ability to predict the course of a disease, a key interest of these physicians, is a focal point in several treatises of the Corpus and the theme of the Hippocratic *Prognostics*. If a patient's disease followed the course predicted by the physician, then, regardless of the outcome, the physician would have proved his competence by showing his knowledge. Likewise, prognosis allowed physicians to choose whom they would and would not treat. This element of Hippocratic medicine—avoiding intervention in hopeless or difficult cases—is one of the most foreign to modern medical thought, but it served an important function in a world where medicine was still very much a developing discipline. It protected patients from a doctor's unnecessary experimentation and intervention, and it also protected the physician from losing his reputation owing to too many deaths (Amundsen 1996).

The physicians of the fifth and fourth centuries BCE represented in the written record are primarily, but not exclusively, men, and they tend to come from middling levels of society. There is some evidence that slaves treated slaves and freeborn treated freeborn, but there is also evidence that this social barrier could be broken if the circumstances warranted. Likewise, there is reason to believe that women practicing medicine might be called on to treat male patients, though the details of when, how, and why this happened are fragmentary. The most certain evidence suggests at least that a male slave could be subject to the services of a female physician (Nutton 2013, 101–102; Flemming 2000, 383–391). *Maiai* (female specialists in obstetrics and gynecology) seem to have lived in a world parallel to that of their male contemporaries, and they may have steadily lost prestige and patients as educated male physicians began taking an interest in women's healthcare. However, they remained for many women a primary source of medical treatment and advice, and they are well represented among the range of those practicing medicine. The gynecological treatises of the Hippocratic Corpus may provide some insight into the largely traditional, separate, and oral practices of the *maiai*, though opinions differ on the degree to which the presumably male author misunderstood and distorted the information he received from his sources (King 1998, 172–187).

Finally, the Corpus makes reference to a range of magical and religious approaches to healing, almost always with sharp criticism. It was this traditional and supernatural approach to the body that the Hippocratics used as a foil for their own approach, but there is compelling evidence that the opposition was not nearly as vitriolic as the authors of *On Ancient Medicine* and *The Sacred Disease* would have their readers believe. Physicians were closely involved with the ritual treatments at shrines of Asclepius and other healing gods, and these shrines seem to have served as local centers for medical training and exchange of ideas. Many medical practitioners began their careers with offerings to patron gods; and others, like the author of *Dreams/Epidemics IV*, included dream interpretation as a supplement to Hippocratic-style diagnostic and prognostic techniques.

Art versus Technē

The dirty and often taboo activities required of physicians were considered beneath the dignity of the wealthy and powerful, for the most part, and medicine was ranked firmly among the trades (*techmai*), although intellectual physicians of the fifth century BCE would argue often and convincingly that it also was a part of intellectual inquiry or philosophy. The author of the Hippocratic *Ancient Medicine* goes so far as to assert that medicine ought to inform natural philosophy, and not the other way around (Nutton 2013, 51). This debate continued to lie at the center of Western concepts of medicine, being as it was composed of both physical work (*techmē*) and active engagement with creative mental processes (*philosophia*). Those who studied the medicine of the elite were required to combine rigorous intellectual activity with manual skill and trade knowledge; though medicine's prestige had risen significantly, it still remained an outlier among the educated professions owing to its unavoidable engagement with the body and the body's fluids, odors, and the unpredictability of disease and death. There seems to have been early and vigorous engagement with philosophy, at least among the elite physicians producing written texts, and medical knowledge was widespread enough that a theory of conception became the key argument in Orestes' trial (*Eumenides* 657–666). Medicine's working relationship with philosophy and philosophers was, however, a close one from at least the fifth century onward, and we often find doctors borrowing concepts from movements in philosophy, and natural philosophers using medicine to extrapolate larger models of the workings of the *cosmos*. It is no accident that Plato's *Symposium* includes a physician among the guests discussing the nature of love (Eryximachus: 186a–189d).

During this early period (and indeed for the majority of physicians in antiquity), the practice of medicine was firmly based in the context of apprenticed trade, though there are suggestions that features of an older family-based tradition of medicine were being used as the model for the relationship of teacher to student (Nutton 2013, 70). Once trained, a physician had several options for pursuing his practice, and his choice may have depended on the degree to which he was attached to his community, his financial means, and his interest in producing scholarship recording his discoveries and patient notes. Peripatetic physicians were hired, supported, and paid by the community to treat that community's illnesses, though the degree of support and expectations seems to have varied wildly. Some could be expected to treat only the poor for free, others used sliding scales, and still others were required to treat only government workers and soldiers. There is reason to believe that many of these physicians were transient, working a few years (or months) in one city, then moving to the next (Nutton 2013, 87–88). Others settled and practiced both privately and publicly in the same place all their lives, while still others had only private practices. The public doctor continued to feature in civic politics well into late antiquity, and, by the time of the compilation of the *Digest of Law* under Justinian, there was a well-developed set of laws and regulations meant to protect and regulate those who practiced public healthcare (Mommsen and Krueger 1985; Below 1953).

The texts of the Hippocratic Corpus give momentary insight into the activities of these physicians, particularly in the *Epidemics*, which preserve case histories describing a wide range of illnesses suffered by members from varied levels of society. For peripatetic physicians in particular, theories about drugs and the weather's effects on the body were

key in coping with wild variations among populations in the Mediterranean in terms of disease, available treatments, and even temperament (as in *Airs, Waters, Places*). Still other texts (e.g., *On the Sacred Disease*) promoted rational medicine over other, more popular alternatives, and they were intended to show the public what rational medicine could offer. The overwhelming concern with argumentation and positioning of medicine as an art and profession speaks eloquently to the task of a doctor whose position requires that he often quickly win over strangers to the support of rationalism under life-or-death circumstances (Jouanna 1999, 75–111).

Asclepiadic "Physicians"

This need for promoting philosophical trends in medicine is best understood against the variety of more traditional approaches to healing. In particular, the cult of Asclepius drew large crowds to various shrines for a cure that relied on ritualistic dream interpretation to diagnose and cure illnesses (Healing Shrines). Other gods, likewise, had their petitioners, and medical authors refer to their magical competitors with dismay and irritation. It is reasonable to claim that many physicians, if the term is broadly understood, were not philosophical but instead treated their patients with a blend of religion, magic, and orally transmitted tradition. Some may have gone further to blend the newer rational techniques and beliefs with older systems. There is some evidence that physicians trained in Hippocratic approaches still employed complementary techniques from religious healing. Indeed, physicians were among those making offerings to Asclepius and courting his favor. Despite the pains Hippocratic physicians took to differentiate themselves from older forms of medicine, it is anachronistic to draw hard lines between medicine, religion, and magic in antiquity (Edelstein and Edelstein 1945; Magic, Curses, and Healing).

The Greek Physician after Alexander

With the rise of the Hellenistic kingdoms in Alexander's wake came some of the most productive advances in medical knowledge. It is, then, unfortunate that none of the many treatises from this high point survive; what we know, we know from later sources. However, medical advances were fueled by the wealth and power of Hellenistic kings as well as competition among them for academic supremacy together with military and politically created centers of learning where researching physicians had access to funding and facilities unknown to their Hippocratic predecessors. Alexandria, in particular, drew great minds to the Museum. Physicians working there were freed from taboos against human dissection owing to the liberal attitude of the Ptolemies and the differing attitudes of native Egyptians to the human corpse (Nutton 2013, 130–132; Scarborough 1976). The lucky few who were given support at Alexandria, the Seleucid courts, Pergamon, or other rival kingdoms were free to learn, write, and publish on any number of topics. There was an explosion in anatomical and pharmaceutical knowledge as well as more practical techniques for surgery and diagnostic procedures. These centers also became magnets for students. Although such centers had existed earlier in Cos and Chios, those had not the support of wealthy monarchs or access to the impressive libraries kept for the use of scholars in residence. Indeed, scholars of all disciplines mingled and shared ideas, thus creating a synergy that allowed medical research to break still further

from its roots in vocational trade-based education. Patients, too, were in large supply, allowing physicians who had formerly traveled to increase their knowledge to stay in one place. This era gave us Herophilus and Erasistratus, both pioneers in anatomy and surgery whose publications are quoted widely in later sources. Likewise, Mithradatic sponsorship in Pontus produced a range of authors commenting on drug lore, including Crateuas, whose work is quoted in both lay and professional treatises in the centuries following (Scarborough 2012; Jacques 2008).

It is this environment in which governments recognized the value of both medical services and research that Rome came of age and then to power. The assumption that power is projected not only by means of force but also by domination of intellectual capital continued to form the cornerstone of imperialism in the Mediterranean for years to come, and this assumption is to be credited for directing the course of Western medicine as both a practice of technique and a frontier of innovation. The research physician (as differentiated from a physician practicing for trade profits) became a recognized sort of doctor revered as key in the profession (Flemming 2003). Such physicians were hardly pure researchers; their duties in exchange for patronage included treating (and occasionally poisoning) the king, his family, and favorites, according to anecdotes passed down by historians with great relish (Pharmacy). Then, as now, no physician enjoyed funding independent of oversight and service obligations.

Physicians at Rome

Little is known about the practice of medicine in Rome prior to the introduction of Greek rationalizing medicine. Indeed, the fact that Alcmaon of Croton pursued his research in Magna Graecia (Southern Italy) suggests that Greek philosophical ideas about the nature and functioning of the human body were known to the Romans very early on. The Romans, however, had a narrative that sharply distinguished an older and, to their minds, more purely Roman kind of medicine from the sort of medicine practiced by the Greeks who lived among them (Nutton 2013, 164–168; Zhmud 2008b).

As with many aspects of Roman life, healthcare revolved around the system of patronage headed by the *pater familias* (male head of a family), who was responsible for tending to the sick within the *familia*, including slaves and, perhaps, farm animals as well. Our best source for this approach to medicine is found in Cato the Elder's *On Agriculture*, which preserves information about the practicalities of running a Roman farming estate and includes medical treatments alongside animal husbandry and crop care (Thibodeau 2008; Greek and Roman Agriculture; Scientific Encyclopedias). Cato, if we are to take his letter quoted in Pliny (*NH* 29.14) at face value, was staunchly opposed to the kind of medicine practiced by Greek doctors and believed that they were actively plotting to kill their Roman patients. The actual text of *On Agriculture*, though, reads much less xenophobically. Cato recommends imported remedies alongside native Italian cures (3, 6, 8, 158–159), and he cheerfully offers Pythagoras as an authority supporting his own use of cabbage as a cure-all (157).

Although Greek-trained physicians were the norm by the first century bce, elements of the Roman ideal of the *pater familias* physician remained throughout the Imperial period. The patron had a legal obligation to provide care to his slaves and freedmen, often filled by owning a slave physician. Likewise, law required that a patron offer legal protection for both patients and physicians under his authority (*Digest* 38.1.2, 18, 21).

It seems that many Roman patrons included Greek medicine in their education so they could act as informed consumers of the medical marketplace. There is no better example of this than Aulus Cornelius Celsus, whose writings on medicine survive, in part owing to their detailed summary of diet, pharmacy, and surgery (Stok 2008).

Celsus remains an intriguing figure about whom little is known beyond what survives from a much larger work on various topics that were considered necessary for a proper Roman education. The work suggests that he might have been able to perform some of the procedures he describes in minute detail, but it is more likely that his knowledge was used to evaluate and choose physicians for hire. There are suggestions of other upper-class Romans turning to the practice of medicine for hire, though. Pliny (*NH* 29.17) claims that "very few Romans have tried their hands at medicine, and those immediately became deserters to the Greeks," implying that at least *some* "Romans" practiced professionally. We know of Scribonius Largus, a Sicilian, actively practicing at the court of Claudius and writing his pharmaceutical treatise in Latin (Scarborough 2008b). Be that as it may, the written Greek tradition quickly trumped native Roman medical practices among the wealthier classes, and the language of medical publication for medical professionals was, for the most part, Greek. The line between Greek and Roman was blurry at best, but it was defended wholeheartedly during the Imperial period by both self-identifying "Greeks" and self-identifying "Romans" when it came to the subject of medicine (Kaimio 1979; Pliny, *NH* 29.17–18).

Galen

Much of what came during the previous five centuries continued throughout the Roman Empire. Peripatetic physicians still sought public appointments, well-heeled professionals carried out research under patronage both public and private, and Greek-educated elites controlled the authorship of medical texts. Here, the source problem becomes most pronounced because the vast majority of the surviving works were written by Galen, who was himself a player in a highly competitive marketplace vying over patronage, patients, and (presumably) the vast sums of money a successful physician could earn. This becomes a particularly challenging issue when examining the Methodists, whose success made them Galen's prime competition. Much of what we know of this sect comes to us from the one-sided bias of Galen's self-promotional treatises and Soranus of Ephesus' surviving works, primarily concerned with gynecology. Galen also mentions physicians who incorporate magic and divination into their regimens, but we have only scattered *testimonia* from those healers who continued to integrate traditional magic and religion with medical practice. Beyond all this, we have fragmentary knowledge of the *obstetrices* or *maiai* who practiced in abundance among a female clientele, and none of their own treatises. Galen's loud voice shouts too clearly over his competition to the point that one must listen hard to hear anything but his version of the Imperial Roman physician.

The majority of physicians practicing among the Roman Imperial elite did so under Greek names and with Greek as their primary language. It is this sort of physician whose life is best represented by Galen's career. He was born into a family with enough money to afford travel and tuition under mentors at the Asclepeion in his native Pergamon, then later under various masters in the eastern Mediterranean, culminating with study in Alexandria. He then returned to Pergamon to fulfill a public appointment as physician to the Pergamene gladiators, and he proceeded from there to Rome (Nutton 1973).

It is from Galen that we also get our clearest picture of the environment in which these physicians competed over the wealthiest patients, often very publicly. His works describe sickbeds where several physicians debated for their turn to attempt to cure patients while onlookers watched to see which physician's prognosis and treatment proved correct. It seems Galen also used animal vivisection as a vehicle for self-promotion, engaging in the competitive philosophy that was flourishing among the rhetoricians of the Second Sophistic movement. Galen took pains at every turn to use his technical writing to promote his own legend while attacking the reputation of his stiffest competition. He was so effective a combatant that the then-popular Methodist school of medicine can hardly be reconstructed through the cloud of vitriol (von Staden 1995; Gleason 2009). Galen relates at least one instance in which a competitor, Martianus, attempted to slander Galen with accusations that his ability to predict the course of disease came from divination rather than medical skill. It seems that Galen's mentor Quintus was driven out of the city of Rome by (according to Galen) the slander of other physicians (Keyser 2008a). To practice medicine among the Roman elite was a competitive rhetorical business with high stakes (*On Prognosis* 1.9–10).

It was not enough simply to defeat other physicians in order to practice in Rome. A patron was needed to support the cost of business and to promote the aspiring physician among his circle of friends and allies. A patron could also protect a practicing physician under attack from litigious patients and competing doctors. Galen's skills seem to have been promoted at various times by assorted patrons whose importance increased along with Galen's profile, including the emperors Marcus Aurelius and Septimius Severus. Galen's move to Rome was cushioned in large part by his network of friends who were able to provide him with opportunities to impress consuls and intimates of the emperor. Imperial recognition did not come without a cost. Galen speaks about one incident in which he fled Rome in secret because he feared that his powerful friends would not allow him to return home (*On Prognosis* 9.3–10). The sincerity of Galen's fear is questionable, but this outlines the very real control a powerful patron could exercise over physicians working under his sponsorship.

At the same time, Galen had his own students for whose benefit some his works seem to have been written, and he in turn was part of a network of physicians who had shared a master during their own training. The bond between teacher and pupil in these situations could function as another form of patronage, since the reputation of the master gave the pupil legitimacy in the eyes of potential clients. It is likely no accident that Galen names Quintus in the treatises aimed at "educating" the general public to promote his own reputation over that of his competitors.

Social Status

Not all freeborn doctors were fortunate enough to be independently wealthy. For the less fortunate, there was always the option of the legions, where an aspiring physician (*medicus*) could learn a great deal while traveling abroad and encountering a steady supply of patients suffering from both trauma and the illnesses that could plague an encampment. A particularly lucky *medicus* could be stationed at one of the military hospitals where supplies, training, and patients all came courtesy of the Roman government.

The custom of Roman generals traveling with their own physicians led to a structure of organized medicine in which the general's patronage of his legions included healthcare (Nutton 2013, 174–190). In the prologue to his *Peri Hyles Iatrikes* (*On Medical Material*), Dioscorides writes of having lived a "soldier's life," a phrase whose meaning has been hotly contested but may allude to the research possibilities that awaited a physician willing to cooperate with the Roman military to gain support for travel and research (Scarborough and Nutton 1982; see also Greek and Roman Botany). The legions made use of *valetudinaria*, an early form of military hospital, combining a fixed work environment with a steady stream of patients suffering a wide variety of ailments and the support of like-minded colleagues. Such a physician could be either under a general's patronage (as Galen was to Marcus Aurelius), attached to a particular legion, or even a soldier who used his time in the legions to gain a medical education (Cruse 2004, 94–105).

It is more than likely that most physicians in the Roman world were owned at one time by other physicians. The *Digest of Roman Law* gives us the clearest picture of such practitioners and their lives and struggles, which had little to do with the world of rhetorical competition and slander that Galen's peers endured. For the enslaved or freedman physician, training was often given either by the owner-physician or by a physician contracted by the owner to provide training. Once ready, the slave physician would practice under orders of his master on his own *familia* or the *familiae* of his owner's friends, and he seems to have had little say over what patients he took. In some instances, this might have been an exceedingly unpleasant sort of practice. We hear of Nero (ruled 54–68 ce), for instance, sending physicians to assist with the suicides of those whose deaths he had ordered (Tacitus, *Annals* 6.38.4, 16.35.2; Below 1953).

However, there were certain advantages to being an enslaved physician, primarily the financial and legal support the owner was required to provide. This may have been an onerous burden, because the law also provided for agreements in which a slave would gain his freedom early, then use his greater independence to pay his owner his purchase price. The law indicates that such relationships were fraught with disputes over who was responsible for providing the cost of equipment and medications, and the degree to which a former owner could control his freedman physician. In one instance, the law addresses a case in which a former owner with a thriving medical practice prevented his freedmen from competing with him by requiring them to act as his assistants even when their assistance was unnecessary. The owner would have several qualified physicians doing menial, unskilled tasks. The freedmen complained, and it seems the judge ruled in their favor, except when former owners (now patrons) actually needed additional trained assistants (*Digest* 38.1.26). One can only imagine that other physicians were less lucky and lived out their lives waiting for the day their former owner's death released them from his control.

The arrangement was not entirely uneven for the freedman. A former owner, as patron, was obliged to promote that physician's practice and to recommend patients. Likewise, he would provide legal defense and could also be asked to defray costs (*Digest* 4.1.9, 14.5.1, 33.3.1.10.3, 38.1.25.4). There were protections, on the books at least, against burdensome duties for the freedman (*Digest* 37.14.2, 37.14.18, 37.15.11). Such physicians were well cushioned against many of the troubles plaguing those practicing without the formal tie of an owner or ex-owner/patron.

2. "Schools" of Medicine

One of the features that most separates ancient medicine and medical practice from modern is the fact that, although there was much similarity among the treatments and pharmacy of ancient physicians, there was little agreement between groups of physicians about the basic principles on which the body functioned, let alone between individual physicians subscribing to the same schools of thought. As was the case with ancient philosophy, so too in ancient medicine there were sharp disagreements over the rules by which the *cosmos*, and therefore the human body, functioned. There was even disagreement as to the degree of rationality that could be applied to the practice of medicine. Many practitioners embraced a view that combined to some degree magical and religious thinking alongside the tenets of philosophical medicine.

Certain ways of thinking gathered enough adherents and educational structures to become coherent schools of medical thought, while others came and went with the rise and fall of a founder and his students. Still more doctors practiced under principles that never survived in the written medical tradition; it is certain that there are many "lost" schools of medicine whose popularity did not reach medical redactors. Even with schools like the Methodists, who practiced in great numbers with great success during the first centuries CE, little is known because of the overwhelming success of Galen and his interpretation of Dogmatic doctrine. Earlier schools, likewise, became absorbed and re-interpreted by later authors, the original works seldom surviving.

"Hippocratic School"

Nonetheless, there are some schools whose names are still known, and whose doctrines were pivotal in shaping the western way of viewing and interpreting the body in disease and health. Within the Hippocratic Corpus, there are signs of early theoretical differences and disagreement among authors regarding the body. Scholars during the early twentieth century made much of the supposed differences between "Coan" and "Cnidian" approaches to the body, but current scholarship is in relative agreement that these differences have been magnified by the lens of later years in which schools of medicine were more pronounced (Nutton 2013, 74). It is perhaps better to see the writers of the Hippocratic Corpus engaged in the formation of their own "school" inasmuch as they often disagree with the traditional and often magical medicine of contemporary practitioners. The Hippocratics differentiate themselves by insisting that nature is a law-abiding entity, and that the human body obeys the same basic rules as the rest of nature. This view of the body owes much to humoral theory, though there was still some disagreement over how many humors there were, and what those humors might have been. Nevertheless, it seems that the Hippocratic tradition, following the same natural philosophy found in Aristotle, sought a balance of body fluids which, in turn, represented the bodily manifestations of the four elements of nature. The task of the Hippocratic physician was to restore the balance of these humors by means of diet, exercise, pharmacy, surgery, and environmental control. This last, at least, is the clearest way wherein theories of the body connected to theories of the natural world. Location, humidity, weather, and temperature all were factors that had profound effects on the body and personality. Hippocratic theory, then, was a holistic view of the human

being as intimately and inextricably related to its natural environment, and its rational approaches were heavily dependent on a theory that applied the rules of the *cosmos* to the treatment of illness (Nutton 2013, 53–86).

The Cult of Asclepius

This is contrasted somewhat with, though not inherently opposed to, the sort of medicine practiced at the shrines of Asclepius, where dream therapy and (perhaps) altered states dependent on the use of drugs were used to treat the illnesses of pilgrims (Healing Shrines). Mainstream doctors subscribing to many schools of medicine seem to have used these shrines as training grounds, sites to ply their trade, and vehicles for sharing medical techniques among colleagues from other regions of the Mediterranean. Asclepian medicine, if one could class it as a "school" (the ancients did not seem to do so), incorporated ritual, medicine, and miracles into a form of treatment that many patients relied on in direct competition with healing from other schools of thought. The persistent popularity of Asclepius probably derives from the fact that his cult, unlike rationalized schools of medicine, validated the magical thinking of patients without directly questioning the role of rational medicine and healers. It is the most notable example of other magical and religious schools of medical thought that continued to be used to treat, diagnose, and support patients undergoing illness and injury (Nutton 2013, 104–115; Edelstein and Edelstein 1945).

Empiricists and Dogmatists

With the advent of the Hellenistic world and the widening control of the eastern Mediterranean by Greek-speaking cultures, there came vast strides in medical research and thought. During this period, a split occurred in medical thought hinging on the degree to which theory should be used to drive medical practice, and the balance of ethical practice against the drive to expand medical knowledge by means of dissection and vivisection. This split centered around the "unseen causes" of disease and the degree to which beliefs about them were useful to medical practice. These "unseen causes" refer primarily to the range of theories attempting to explain the origins of disease in the human body that drove fevers, chills, infection, and a host of other illnesses which contemporary medical research was able to explain only theoretically through humors, or *pneuma*. The two conflicting sides included the Empiricists, who rejected any theoretical explanations for disease and relied instead on a series of experience-proven practices, and the Dogmatists, who embraced theoretical underpinnings that, they felt, explained the reasons why treatments worked and suggested future avenues of study (Celsus, preface; Nutton 2013, 116–141). The Dogmatists had to their name a further splinter-school in the Pneumatists, about whom little is known other than that they accorded a greater role to "*Pneuma*" in their etiology of disease than did the humor-based Dogmatists (Jackson 1988, 30–31).

It is possible that practicing physicians usually fell along a spectrum between these two poles, and it is absurd to imagine a practicing doctor completely blind to his own experience or who never once tried to think of connections between two patients exhibiting similar symptoms. Our best sources for this feud are Roman laymen (Pliny and

Celsus), who perhaps exaggerate the differences for the sake of clarity. These two levels of privileging experience over theory or theory over experience, however, led to key differences in the way doctors treated patients and educated their students. A Dogmatic approach would include a hefty dose of philosophy and reading as well as dissection of animals and, occasionally, humans to gain a thorough knowledge of anatomy (Celsus, preface 23). These physicians may have been much more likely to engage in surgery and prescribe medication according to what humoral effect they were attempting to achieve.

Empiricists, on the other hand, would expose students to patients with a range of illnesses and encourage learning through doing. They relied on a tradition of treatments that bore more of a resemblance to the sort of medicine practiced outside the circles of academic medicine inasmuch as remedies and techniques were passed from teacher to student, but also included the acquisition of anatomical knowledge by observing while operating, then learning from each patient and refining techniques on subsequent cases. The Empiricists also seem to have considered dissection and vivisection unnecessary and cruel while not providing useful information. How could one know that the dead body on the slab was anything like the live organism had been before death and knives distorted it (Celsus, preface 40–43)? Moreover, anatomical knowledge beyond a certain point could be clinically useless in a world before reliable sterile surgery, transfusions, and ventilators were available to support major surgical efforts. According to the Empiricists, the Dogmatic insistence on cleaving to an unprovable theory for "hidden causes" could lead to patients being treated by rule, ignoring the facts particular to an individual patient's unique situation. Although the Dogmatists and their approach eventually provided most of the advances key to modern medicine, within the context of the ancient world the Empiricists may well have had the ethical upper hand. Certainly, when operating under humoral theory, even the best Dogmatist could very well have ignored common sense in order to make each patient fit neatly into an ultimately incorrect theoretical paradigm. Dogmatists may have given us anatomy, but the Empiricists laid the foundation of bias-free medical research.

Roman Initiatives

The first century BCE ushered in a change in the political and cultural landscape. As Rome came of age and began first to participate, then dominate, the political and military sphere of the Mediterranean, the system of Greek medicine likewise changed and adapted to new realities. Rome's early experiences in hiring public physicians was a disaster. Invited to live in Rome, Archagathus of Sparta was given public housing and funding to support his practice. He turned out to be so fond of surgery and cautery that he was nicknamed "*Carnifex*" ("The Butcher"). The Roman public was decidedly unimpressed (Pliny, *NH* 29.12–13; Keyser 2008b). In general, Roman public opinion was divided when it came to the legacy of their Greek-speaking neighbors. At times, they enthusiastically followed the pattern of earlier conquests by absorbing Greek ideas and knowledge, and at other times they withdrew in horror, feeling that they were losing their identity in the flood of Hellenistic culture and ideas. At least some of this objection was linguistic. Greek-language scholarship had become institutionalized to the point that it would be impractical to absorb it by translation, though attempts were made. The use of Greek, however, was strongly established in the east and on the Italian peninsula itself, and it was far easier and efficient simply to be a Roman who spoke and

read Greek than to insist that the vast fount of Greek literature be translated into Latin (Kaimio 1979).

Methodists

Into this environment of both fascination and mistrust of Greek scholarship came Asclepiades of Bithynia, a teacher of rhetoric who saw potential where others saw risk (Scarborough 2008a). He invented a new theory of the body that depended on a model of motion and balanced flow rather than the humoral theories in vogue among the Dogmatists. While authors of the Hippocratic Corpus at times seem to integrate ideas of flow with humors (Nutton 2013, 72–73), Asclepiades eschewed a differentiation of body fluids, claiming instead that health and disease depended on the motion of small clumps of matter moving through the pores (Vallance 1990, 1–5). His student Themison further modified this theory into a system whereby all diseases could be understood through their common characteristics: either the flow of particles was constricted, in flux, or some mixture of the two states. These commonalities (*koinotēs*) were the hallmark of Methodist theory and allowed this new school of medicine to differentiate itself from the long legacy of Hippocratic doctrine behind the Dogmatists and Empiricists and to sell itself to a new medical market of patients distrustful of Greek-speaking physicians, but who still felt that a proper physician should be "Greek." Asclepiades is mentioned in Latin medical writings often and favorably, and those who followed him used that positive publicity to promote treatments that were gentler than those used by their competition and, therefore, less threatening to a cagey public.

The Methodists introduced the idea of passive exercise, promoting the rocking motion of hammocks and sedan chairs to induce a more balanced motion of particles through the pores. They also made liberal use of the baths and massage, and they decried treatments that were, in their minds, unnecessarily harsh and harmful (Nutton 2013, 191–206; Tecusan 2004, 1–36). This is not to say that Methodism was without its flaws. It was a highly theoretical approach to medicine that used vast generalizations and downplayed the importance of anatomical knowledge, and there are indications that some Methodists came to their practice without much education or training. If Galen is to be believed (*On the Therapeutic Method* 1.1; Scarborough 2008cc), Thessalus of Tralles claimed to train his students in a mere six months, and the market was flooded with physicians who had not the faintest idea of what they were doing, using the Methodist label to sell their services.

Indeed, Galen's dismissive remarks about Methodists have cast a long, dark shadow over the sect that has been only recently dispelled somewhat by scholarship re-examining the few pieces of Methodist writings that yet survive. Primary among these is Soranus' *Gynecology*, which shows a Methodist author who, far from being ignorant of developments in other branches of medicine, was well-read in the literature of past ages and actively engaged in using experience to question and dispute ideas that had gone unchallenged among both Empiricists and Dogmatists. While he affirmed the Methodist antipathy to dissection, he showed that he himself was not ignorant of it, proving that far from being lazy or unknowledgeable, he was a thoughtful participant in the ethical and theoretical debates of his age (1.14). Likewise, he made several corrective observations critical of the Dogmatists' tendency to overlook the evidence that, far from enhancing a woman's health, menstruation, childbirth, and breastfeeding are more likely

to detract from it. Finally, the charge that Methodists were poor surgeons is refuted by the measures recorded to intervene in difficult childbirth, many of which require steady hands and the practiced use of surgical instruments. It is likely that future studies of the Methodists will do much to rehabilitate these powerful and prominent physicians from the rubbish heap where Galen placed them for so many years.

"Galenism"

This finally brings us to Galen, whose eclectic brand of Dogmatism spawned its own school, often called "Galenism." Through a combination of hard work, good patronage, and tireless publication, Galen and his own particular interpretation of the Hippocratic tradition became ascendant in Western medicine. The political turmoil following the collapse of the Severan dynasty made medical publication much more difficult than it had been during the orderly years of Galen's lifetime. When the dust cleared, Galen's many volumes and convincing works of self-promotion ensured that his ideas were taken seriously and treated as the final word in medical knowledge. Galen was not alone on the reading lists of Byzantine, Islamic, and Medieval medical students, but he dominated in volume and personality, and as an authority on all matters medical he was unquestioned in large part until the Renaissance (The Reception of Greco-Roman Science in the Renaissance: Assimilation(s), Transformation(s), Rejection, Hybridization).

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CHAPTER 25

Pharmacy

Molly Jones-Lewis

1. Introduction

Pharmacy—the deliberate use of substances to affect the body—is one of the first sciences, perhaps as old as human beings. It is also one of the most difficult to reconstruct in modern scholarship because the materials used are fragile and, until recently, could not be studied directly, but only through educated guesswork based on texts that predate standardized names for plant species. In recent years, the use of mass spectroscopy and DNA analysis has vastly expanded the potential for studying the physical residue adhering to the durable tools of pharmacy. Such techniques have been used to find evidence of pharmacologically active ingredients in wines and perfumes dating to Minoan Crete (Martlew 2002; McGovern 2003), though such tests do not definitively prove that these products were intended specifically for medicinal use. Similarly, studies of ancient fermented foods suggest that beer (and perhaps other products) contained enough tetracycline to have therapeutic effects, but it is unclear the degree to which this was a deliberate goal of beer making or a happy side effect (Nelson et al. 2010).

Recently, such techniques have been brought to bear on tablets found in the Relitto del Pozzino shipwreck. Sealed in a tin container found with other vials and physician's tools, these disk-shaped compounds were very likely meant to be used for medicinal purposes (Figure 25.1). DNA sequencing of the plant materials conducted through the *Institute for the Preservation of Medical Traditions* at the Smithsonian and presented at the *Fourth International Symposium on Biomolecular Archaeology* in Copenhagen revealed that these pills contained material from simple garden plants, namely, carrot, radish, parsley, celery, wild onion, and cabbage. Yarrow and hibiscus also were detected (preliminary results in Touwaide and Fleischer 2010). However, a subsequent physicochemical analysis in 2013 revealed that zinc compounds (notably samsonite) made up

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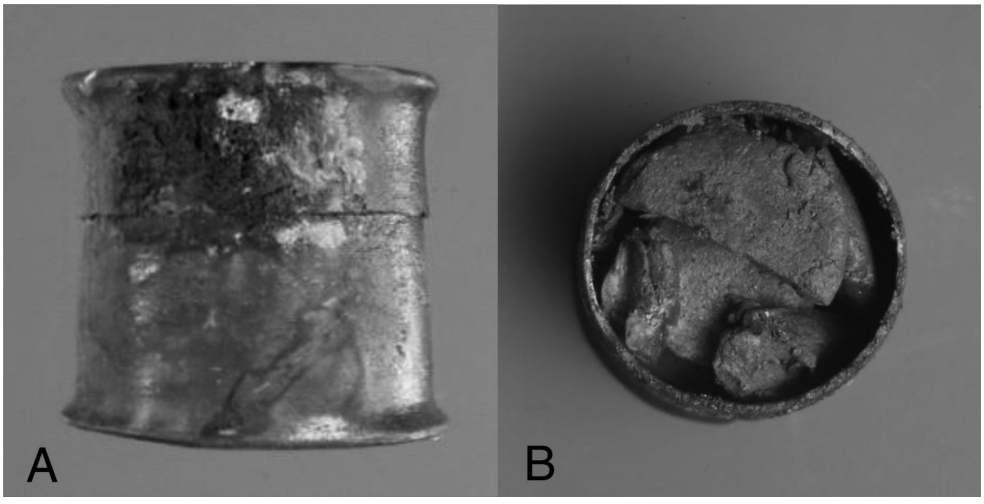


Figure 25.1 Tin pyxis (A) and its contents (B) from the Relitto del Pozzino shipwreck (140–120 BCE). [*Source:* © PNAS. doi: 10.1073/pnas.1216776110 (Medical Xpress).]

most of the tablet along with a smaller portion of hematite, ingredients mentioned in ancient treatments for eye and skin infections. Oils, starches, and beeswax may have been included as binding agents, while pine resin could act as binder, preservative, and antiseptic. Those starches show signs of having been cooked, suggesting that heat was used to process the finished product—techniques and ingredients in keeping with those described by ancient pharmaceutical authors. The plant ingredients found by Touwaide and Fleischer form only a small part of the compound. It is likely that these tablets were *collyria* for ophthalmic use (Giachi et al. 2013). This one find furnishes evidence that actual ancient medicines resembled the descriptions we find in the literary record, and it supports the idea that most remedies were made from local ingredients, and then processed for use by physicians. This analysis of the Pozzino tablets also illustrates the benefits of using multiple methods of analysis that are informed by the substantial written and artistic tradition; future advances in our understanding of ancient remedies depend on the judicious use of all techniques at our disposal.

Pharmacy is peculiar among the ancient sciences as never having been completely divorced from its roots in folklore, even at its most recognizably "rational." The word itself derives directly from the Greek *pharmakon*, which refers to any substance (including magical talismans; MAGIC, CURSES, AND HEALING) thought to be able to alter the body for good or ill. The word encompasses both drugs and poisons. In many ways, it is an appropriate semantic range for a world in which the difference between an effective drug and a poison was dosage, and dosage was difficult to control with the accuracy available to a modern druggist. Likewise, the seemingly magical way in which drugs acted on the body and mind kept mystery as part of the word and its variants.

The related word *pharmakos* in many ways underlines the ambiguous mixture of the rational and magical in the semantic range of *pharmak-*. It refers to a scapegoat: human or animal, symbolically imbued with the *miasma* ("pollution") of a community, and then driven off to remove whatever taint was causing the community's misfortune

(Scarborough 2010 I.146–148). Magical thought and rationalizing theory co-existed closely in the practice of pharmacy, and even the rationalizing authors have difficulty removing the mystery from the art (e.g., Pliny, *NH* 28.10–13). Unlike surgery, which works on the physical and observable body, medicine operates in a way invisible to the ancient eye. The ancients knew that certain substances had invisible powers, and such a thing is difficult to completely rationalize. Even Galen, arguably the most rationalizing of the Greek medical authors, relied on reasoning with magical elements when faced with the puzzle of why drugs work (Keyser 1997).

All kinds of substances from animal, vegetable, and mineral sources were used in treating and preventing disease. Discussions of ancient pharmacy involve some specialized vocabulary since many of the processes central to ancient drugs have ceased to be a part of modern life and language. For our purposes, we adopt the following conventions: the term "simple" is used to refer to a single ingredient; *materia medica* rather than "herbs" or "drugs" is used to refer the class of items used for medical purposes; and *pharmakon* is used to refer to a treatment processed and ready to be used on patients, though in ancient Greek the term also refers to individual ingredients.

One of the sharpest differences between modern concepts of pharmacy and ancient is the distinction we now place between dietetics and pharmacy (Nutrition). In antiquity, diet and food were the first step in a regimen of treatment. The difference between a meal and a medicine would often be in the quantity and choice of ingredients and in a physician's involvement in the process. Many food items were also used to treat specific illnesses as part of a prescription diet or as a delivery system to buffer the effects of a harsh medicine on the stomach. As treatment progressed, increasingly harsher drugs would be applied (e.g., Scribonius, preface). We will concentrate on the harsher end of this food–drug spectrum, but ancient authors integrated dietary information alongside drug compounding recipes.

Unlike modern pharmacy, which relies on a single (sometimes multiple) isolated chemical compounded with "inactive ingredients" and prescribed to achieve a specific effect, ancient pharmacy recognized that any one simple could have multiple effects on the body (Riddle 1985; Scarborough 2010, x–xii). There were no "inactive ingredients" in a compounded *pharmakon*—the base oil of an ointment was just as carefully chosen for its curative properties as were the simples mixed into it (e.g., Dioscorides 2.73–101). Certainly, there was extensive processing of plants from the field to the medicine box, but nothing like the laboratory processing that allows us to ensure standardized dosages. Instead, attention was given to the cultivation, harvesting, and preservation of *materia medica* at the right times and using the correct methods for achieving the desired potency (Dioscorides, preface 6–9). Pharmacy was, first and foremost, an activity and profession requiring a vast and careful knowledge of nature, and most of it seems to have been disseminated via oral communication and hands-on training (Scarborough 2010, viii–ix).

Pharmacy shows up in the earliest Mediterranean literature, embedded in cuneiform tablets (Geller 2010; Scurlock 2006; Scurlock and Andersen 2005), in Egyptian medical texts like the Ebers and Edwin Smith Papyri, and in Minoan art and Linear B records (Scarborough 2012a, 4–5). Early non-medical literature likewise includes pharmacological information: Gilgamesh's thorny plant is plucked so that the hero can regain his youth (*Gilgamesh* tablet XI, column vi). In Greek literature, the same is true. The Homeric tradition, for instance, includes two plotlines that hinge on the

use of *pharmaka*. Helen, when hosting Telemachus in Sparta, uses the *pharmakon* "*nepenthes*" mixed in wine to dull emotional pain (*Odyssey* 4.220–221). Circe's transformation of the sailors is accomplished by means of drugs mixed into food and wine (*Odyssey* 10.212–236), and Odysseus employs the *moly* given by Hermes with unspecified instructions for use as an antidote (10.308–309, Scarborough 2010 I.139–142). We continue to see drugs mentioned casually in subsequent literature with the assumption that a wide audience would know what was meant when certain pharmaceutical plants were named. When Aristophanes mentions pennyroyal in the *Lysistrata* (89), he does not need to explain that it is a contraceptive; the audience understands the joke because the audience is as familiar with the effects of the drug as a modern audience would be with the birth-control pill (Scarborough 2010, VI 74). Be that as it may, before the Hellenistic period, pharmacy existed as a part of life rather than as a written tradition, and so it remained long after the advent of written handbooks.

2. Pharmaceutical Writings

With the rapid expansion of boundaries and opportunities for trade following in Alexander's wake, a far greater array of medical items came available. In this period there begins a flourishing of written sciences in all fields. But in the case of doctors practicing pharmacy in the far-flung corners of the Hellenistic kingdoms and colonies, a written resource listing all known *pharmaka* and their properties must have been particularly welcome. The development of pharmaceutical manuals rightly begins with Theophrastus' *Inquiry into Plants* and *On the Causes of Plants*, which in the course of recording contemporary plant lore preserves a great deal of pharmaceutical information (Greek and Roman Botany). Such information also appears to a lesser extent in his *On Stones*. Theophrastus' contribution laid the groundwork for a badly needed standardized way of naming plants, animals, and minerals as well as of organizing their properties in a systematic fashion. It is a start rather than an end; wild variations in nomenclature continued to plague subsequent authors on pharmacy, and differing models of natural philosophy meant that pharmaceutical authors differed sharply on how and why various drugs worked. Nevertheless, Theophrastus proved a much needed touchstone of authority amid a babble of differing voices, and his work continued to be quoted in later works directed specifically at medical practitioners (Scarborough 2010, IV; Sollenberger 2008).

Roughly contemporary with Theophrastus, the authors of the Hippocratic Corpus were also beginning to think critically about how theory could be used to explain the actions of drugs. Within the Corpus, there are preserved some of the first recipes for compound medications, though these recipes are in many respects less specific than those that came later. They represent what Totelin (2009, 18–19) calls "*haute medicine*" of the Classical period; a medicine in which foreign ingredients were used in costly mixtures to effect (presumably) better cures. Debate has focused on these recipes also because they appear primarily but not exclusively in gynecological texts, hinting at the elusive specter of orally transmitted "women's" medicine that seems so often lacking in the surviving written record (Totelin 2009, 21–47).

During the third through first centuries BCE, many authors, whose names we know, wrote on pharmacy, but as with many scientific traditions, these authors ceased to be copied and preserved when newer, more complete works became available. Crateuas the root-cutter, the most notable among them, was a physician to Mithradates VI of Pontus

and is quoted by name frequently by both Dioscorides and Pliny the Elder (Jacques 2008a). Toxicology seems to have been of great interest to pharmaceutical research of the period, very likely because the royal Hellenistic patrons sponsoring the research had a vested interest in avoiding assassination by such means. Andreas (d. 217 BCE), a physician to Ptolemy IV, wrote on such topics (Irby-Massie 2008), as did Nicander of Colophon (150–110 BCE), whose patron was Attalus III of Pergamon. Nicander's surviving works are the *Theriaka* and *Alexipharmaka*, two poems about toxicology, venomous bites, and antidotes based on the earlier work of the medical author Apollodorus (Jacques 2008b, Scarborough 2010, V–VI).

Rome, like other cultures of the ancient Mediterranean, had its own culture of pharmacy predating the Greek written tradition, and the Romans were by and large more comfortable with pharmacy than with more invasive aspects of medicine and medical treatment. Our best literary source for the period is Cato the Elder, although he is writing well after the Romans became familiar with Greek scholarship and treatments, including, for example, wormwood from Pontus alongside native remedies. *De Agri Cultura* (*On Agriculture*) is not aimed primarily at healing, but rather it gives advice to the Roman landowner on how to manage a farming estate properly. The pharmaceutical information is meant not for a physician, but for the conscientious *pater familias* to whose care the slaves and animals were given. It combines magic alongside plant cures, though not many of them, and is notable for the way it illustrates the abiding connection between farming lore and pharmacy (Thibodeau 2008).

The scholarship of pharmacy seems to have flourished under the *Pax Romana*, perhaps owing partly to the fact that our surviving sources (Dioscorides, Scribonius, and Pliny the Elder) cite their contemporary sources quite heavily. Be that as it may, the relative peace and prosperity of the shipping lanes and trade routes of the Mediterranean of the first century CE made it necessary and practical for authorities to write newer, more complete handbooks on the medications now more widely available to the various corners of the empire. Most notable among this group are Sextius Niger, Julius Bassus, Petronios Musa, and Antonius Musa.

During the first century CE, Dioscorides of Anazarbus composed *Peri Hyles Iatrikes* (*Concerning Materia Medica*), a text that became the authoritative compendium to *materia medica* well into the Enlightenment and still in use into the nineteenth century (trans. Beck 2005). It was so influential in its day that it was translated into Latin and survived in the western European intellectual tradition, where other surviving works composed in Greek fell out of use only to resurface in the Renaissance. Dioscorides himself is a shadowy figure known mainly from his own prologue, which includes the enigmatic claim that he has lead "a soldier's life" (Greek and Roman Botany). His organizational scheme groups *materia medica* by six major classes (aromatics, animal derivatives, grains, herbs, wines, and minerals), an order he claims more appropriate for a reference work than an alphabetical listing. An ancient physician would welcome a grouping that made it easy to compare and substitute similar ingredients without having to look each one up by name. However, later editions tended to reorganize the entries alphabetically, suggestive of the limitations of the original approach within a medical system that did not agree as to how drugs or the body work. The fact that his work survives, where other acclaimed contemporary sources have not, speaks to the quality and completeness of his work. The text almost certainly was accompanied by illustrations; the Anicia Codex (Figure 25.2), our earliest manuscript (dated 512 CE), is beautifully illuminated with full color (Riddle 1985, 168–217).



Figure 25.2 A folio from the Anicia Dioscorides showing an illustration of asphodel (*Asphodelus ramosus*). The red label near the root is the original, and subsequent owners have written in alternate names in various languages. The roots, leaves, stems, buds, and blossoms in various stages of bloom are all included in the picture, and the explanatory text is fitted around the large color illustration. Collins, M., *Medieval Herbals: The Illustrative Traditions* (2000), pp. 39–50; figures 2–10; color plates I–II. Brubaker, L., "Vienna Dioskorides and Anicia Juliana," Byzantine Garden Culture (2002), 189–214; figures 1–24. (*Source:* Science & Society Picture Library/Getty Images.)

Dioscorides' place in the medical establishment is also in question. He does not mention what his own profession was, but he dedicates his work to his teacher Areius of Tarsus, who was himself a physician and author on compounding pharmacy (Scarborough

2008a). Dioscorides' use of other authors' works makes him an academic rather than a pure *rhizotomos* (root-cutter), though, considering Crateuas, scholarly credentials and membership among the traveling herb-masters were not necessarily mutually exclusive. It is highly unlikely that Dioscorides himself observed every plant he describes growing in the wild; the descriptions owe too much to the work of earlier authors, and, had he done completely original research, he almost certainly would have run out of money and had little time to compile his intricately organized work. Riddle's suggestion that Dioscorides be viewed as an academic physician of some independent means balancing a clinical practice with sponsored research (and possibly military service) is probably the best sense than can be made from the scant details that Dioscorides himself provides (Riddle 1985: 1–24; Scarborough and Nutton 1982).

Roughly contemporary with Dioscorides is Scribonius Largus, a Sicilian active at the court of Claudius (43–54 CE). His *Compositiones* or "Compounding Recipes" is arranged in a less novel fashion than Dioscorides', moving with cures from head to heel, antidotes, and general (mostly topical) remedies. Scribonius Largus' work very likely survives owing to its practical focus and the fact that it is written in Latin, unusual for a technical manual in an international discipline whose common tongue was Greek. Scribonius' position at the court of Claudius may account for the choice. He dedicates the work to the prominent Imperial freedman Callistus and mentions, between recipes, his own role in the British campaign (*Compounding Recipes* 163) and his knowledge of the Augusta's (probably Antonia Minor) favorite throat remedy (*Compounding Recipes* 50). In the pro-Latin environment of the Julio-Claudian courts, the choice to publish in a format easily readable by Latin speakers might have ingratiated him with those who, like Pliny (*NH* 29.11–17), distrusted Greek scholarship even though they were perfectly familiar with the language. Whatever the reason, Scribonius' recipes survived where many other such handbooks did not, and we have a much better knowledge of the actual processing and administration of drugs because of it (Scarborough 2008b).

Again, within the latter half of the first century CE, Pliny's *Naturalis Historia* contains, among its many, many items of interest to scholars of ancient science, an extensive (if somewhat haphazard) listing of *materia medica* and a few recipes (see also Scientific Encyclopedias). Some of the remedies, such as the brassiere he recommends wearing to cure headaches, come with his personal recommendation, illustrating the degree to which pharmacy was not the sole purview of the professional but was rather a necessary life skill. Much as the modern Westerner purchases aspirin for a headache or, if ambitious, grows her own St. John's Wort to stave off depression, Pliny himself would have taken his own simple remedies before resorting to a professional to mix something more complicated. Indeed, Pliny gives us insight into the mind of a consumer frustrated over the rising costs of healthcare in Rome when he decries complicated medical recipes as a marketing gimmick invented to drive up costs and keep pharmacists employed (*NH* 29.21–24). The vast scale and scope of the *NH* made it a key resource in the Medieval Latin West, and, fortunately, scholars have from it the observations of the educated consumer to balance the professional advice coming from Scribonius and Dioscorides (Murphy 2008, Scarborough 2010 IX).

Soranus of Ephesus is notable for many reasons, but his preservation of gynecological recipes is certainly one of the most important. From his *Gynekeia*, we have preparations to treat various conditions and also information on the preparation and use of contraceptive and abortifacient recipes beyond the simples listed in Dioscorides and Pliny.

Galen likewise preserves additional information on the principles of clinical pharmacology in various treatises, emphasizing the necessity of matching the patient's condition to the dosing amount and method. Both Soranus and Galen model the approaches of their own schools of medicine (Methodist and Eclectic Dogmatist, respectively: see PHYSICIANS AND "SCHOOLS"), and their works, therefore, provide two different approaches to the clinical application of pharmacy and drug lore. Soranus is concerned with the effects of drugs on the flow of bodily fluids and functions, while Galen focuses on the mixture of powers in the drug versus the existing mixture of humors in the patient (Van der Eijk 1997, 39–48; Scarborough 2008cc).

In the early Middle Ages, many additional works of pharmacy were produced, reliant (as are all works of formal medical literature) on earlier authors, primarily those listed earlier. Detailed discussion is beyond our scope, but worthy of special mention are Oribasius of Pergamon (circa 325–400 CE), Aëtius of Amida (circa 500–50 CE), Alexander of Tralles (circa 550–605 CE), and Paul of Aegina (circa 590–640 CE).

3. Drug Trade

The drug trade is difficult to tease out from the myriad other trades of the ancient Mediterranean basin because many of the items traded were not exported as drugs alone, but as perfumes, foods, cosmetics, and pigments. We rely primarily on archaeological evidence to supplement the patchy written records, and recent developments in underwater archaeology and chemical analysis promise to expand greatly what we now know. Certainly the Mycenaean era saw traffic circulating often and regularly between Greece, Egypt, the Near East, and the Baltic (Scarborough 2012a). The development of written Greek-language medicine comes out of Cos, Cnidus, and Ionia, and the exotic ingredients of the Hippocratic Corpus reflect a focus on Eastern trade (Totelin 2009, 141–194). This focus ossified somewhat in the written record, privileging and promoting Eastern (defined broadly) ingredients over those imported from the west. This trend weakened to some extent in Roman sources, where more readily available items from Spain, Britain, and Gaul became part of the trade of empire, but still the legacy of these Hellenistic pharmaceutical authors lingers in references to "Egyptian" and "Pontic" *materia medica*.

As Rome normalized the large-scale shipping of even homely items such as wine and grain, so did it become more usual to include formerly exotic items in pharmaceutical recipes. The degree to which such items were available to the average citizen of the city of Rome (let alone the provinces) is, however, debatable; even Pliny discusses issues of mislabeling in the marketplace (*NH* 29.24, where Indian cinnabar is replaced with "red lead"). With so many items in the record easily obtained from local agricultural sources, it seems prudent to assume that, for the most part, local remedies were used by most people over and above expensive imports. Early results from new analyses of material evidence tends to support this conclusion (Giachi et al. 2013).

There were other pressing reasons to prefer locally sourced *materia medica* for reliable clinical results. The necessary processing required to transport plant material from, say, Pontus, to Rome would have rendered perishable *materia medica* such as plants and animal parts difficult to identify as genuine. Moreover, transit time and poor storage conditions would have reduced the active chemicals in the plant as breakdown occurred. Herbs are particularly sensitive to degradation over time, still a problem in the commercial

production of herbal remedies for the modern alternative medicine market. All of this further assumes honest producers, gatherers, importers, and vendors. Evidence suggests that such traders, knowing they could charge more for exotic *materia medica* from the far corners of the empire and that their buyers would have few if any ways to tell that a bit of plant material was or was not authentic Pontic wormwood, played on the public's willingness to pay more for drugs with foreign names, and they sold all sorts of fraudulent cargo to gullible customers. Dioscorides may give the impression that one could simply visit the neighborhood *pharmakolopes* (drug seller) to pick up some genuine myrrh, but the reality was likely far from that ideal (Nutton 1985).

4. Folklore

Pharmacy was in large part a traditional art based on experience and lore passed down within local cultures. Evidence for this appears even in the work of pharmaceutical authors. Pliny mentions the illiterate "*pagani*" of the Italian countryside, lamenting the fact that their knowledge is inaccessible because it is not written (*NH* 25.16), and Scribonius Largus tells of a stomach remedy bought from a little old lady (*Compounding Recipes* 122). The use of private gardens to grow common remedies is well documented in the archaeological record, particularly in Pompeii (Jashemski 1999), and anecdotal evidence also supports the notion that the ancients grew and compounded *pharmaka* as casually as a modern person would pick up cough syrup from the local drugstore. Likewise, there was a culture of lore, some of it magical, that supported the drug culture of various ancient Mediterranean settlements. As early as Homer and as late as Pliny, magic and the supernatural were major parts of the average person's use of medication (Magic, Curses, and Healing). Furthermore, items that modern consumers might not recognize as "pharmaceutical" can be considered as part of the culture of pharmacy in antiquity. Votive offerings meant to treat illness were commonplace (Healing Shrines), and amulets could be worn as contraceptive devices or prophylactics against a variety of ailments (Cruse 2004, 107–140). Outside of professional medical writing, such "magic" measures are happily married to things the modern eye would recognize as pharmacy (eg., *NH* 28.5).

5. Practitioners

For this reason, the kind of rationalizing academic pharmacy relying on imported *materia medica* and elaborate theories of the body (or astrology, for that matter) represents the minority experience of the elite able to afford the services of specialists and their expensive wares (Pliny, *NH* 29.7–9, 21–22). Those with more modest means would grow a basic stock and rely on common recipes learned from family and friends, moving on to the services of a *rhizotomos* when something stronger was needed. These root-cutters appear as sources in pharmaceutical writing, and some of them seem to have been involved in medical research themselves: Crateuas, in particular, was known as the "Root-cutter" rather than "physician." The primary trade of the *rhizotomoi* was the gathering and preliminary processing of stronger drugs, the roots of which were occasionally so toxic that special measures were needed to protect the gatherer from poisoning. Our sources speak of *rhizotomoi* averting their faces from the fumes while gathering certain plants and

gathering others by night, or naked, or while using a specific chant to ward off blindness (Scarborough 2010, I; Magic, Curses, and Healing). Some of this activity could be the work of authors with overactive imaginations, but it seems clear that in order to preserve trade secrets and market share, *rhizotomoi* made sure that the art of gathering wild herbs remained specialized and beyond the reach of the average working person or physician.

Alongside these was a business in retail pharmacy serving both the public and physicians in the cities, as evidenced by the laws that regulate their responsibilities when selling more toxic *materia medica* (e.g., *Digest* 48.8.3.2–3). Because the gathering, processing, and storage of compounded remedies was so time consuming, it seems that physicians would often rely on a trusted *pharmakolopes* instead of doing the labor themselves, much as is the case with modern pharmacy. This approach, however, could be perilous for the physician who relied on the wrong *pharmakolopes*. In his prologue, Dioscorides warns the unwary consumer about the variable quality of drugs and the necessity of knowing when, where, and how they were gathered (*preface* 6–9). In his listings of *materia medica*, he also offers ways of identifying items in their dried or processed form to help urban physicians know what it is that they are buying (cf. 2.82.5 for sugar crystals), and he gives various alternate names and places of origin for plants, information more useful in a marketplace than in the field. Such vigilance against cheating *pharmakopolai* speaks volumes for the general quality of product in the medical marketplace, even at the height of Rome's ability to import such items (Nutton 1985).

One cannot discuss the profession of ancient pharmacy without mentioning those who combined magic and exoticism along with their cures (Magic, Curses, and Healing). Such traveling salesmen of magico-pharmacy were among the chief competitors with physicians of the Hippocratic Corpus, and the author of *Sacred Disease* is particularly acerbic in his remarks against their practices (2–4). Be that as it may, this sort of pharmacy flourished and co-existed with rationalizing medicine. The market for drugs was so active that an edge was needed: a way for a medical practitioner to cut through the noise of other purveyors of goods and convince a wealthy customer to buy his services (Scarborough 2010, I). Consequently, some groups used ethnicity and ritualistic showmanship along with a medical specialization to succeed in a competitive medical marketplace. Two such groups stand out in particular: the Italian Marsi, and the North-African Psylloi. Both tribes used and promoted a notion that their physical bodies were natural antitoxins capable of treating the bites of venomous creatures. And they seem to have enjoyed a reasonably good reputation, even among rationalizing physicians (Nutton 1985).

6. Compounding Pharmaceuticals

Without a doubt some physicians did their own compounding on occasion and to differing extents, but it is likely that the components were purchased rather than gathered. It would simply have been too time consuming to sustain a full medical practice *and* grow each and every item in a basic pharmaceutical cabinet.

A startling array of items were used in ancient *pharmaka* from excrement to honey and herbs to metal oxides. We now recognize most of these as having medical properties. The gathering, processing, and dosing of *pharmaka* was time consuming in the extreme and accounted for the early division between specialists in pharmacy among all sorts of medical schools and approaches.

The primary tools of the trade were the same as those used for cooking (Cooking and Baking Technology), and the recipes likewise look much like the recipes for food. This began with the gathering process, in which freshly dug plant parts were chosen for varying dosages and effects; root, stem, or leaves would sometimes be the appropriate plant part for the intended remedy. These items would be grown or gathered wild, depending on the circumstances and place, then either processed fresh into a *pharmakon* intended for immediate consumption or dried/preserved for later use. Drying was the easiest way to preserve most plants for later cooking in water, oils, ointments, and the like, and it need not always involve the whole plant. The juice of a succulent could be pressed and dried into powder, for instance, or put into a stabilizing agent like honey or wine. Such a process allowed for the crude extraction of the most potent part of the plant and also for a durable stock that could be used in later compounding.

Also used in the preparation of animal *materia medica* were drying as well as steaming and preservation in oil. Lizards, frogs, snakes, and the like could be used fresh or, at times, smoked dry, then ground or flaked into medications. Animal parts like the castoreum-containing anal glands of the beaver were removed and sold separately by importers or hunters, and the same was true of insect parts. One animal ingredient deserves particular attention: blister beetles, including the cantharis and Spanish Fly (Pliny, *NH* 29.93–96; Dioscorides 2.61; *Digest* 48.8.3.2–3). As the name suggests, these beetles produce cantharadin, an irritant toxic to the skin, still used as a component in preparations to remove warts and tattoos. In antiquity, it was also used as an aphrodisiac to disastrous effect; ingested, it can cause priapism, but it can also kill a patient horribly. This substance perhaps accounts for the connection made in antiquity between aphrodisiacs and poisons. In order to prepare them, a jar would be completely filled, the mouth tied with a layer of cloth, then the vessel up-ended over a vinegar steam, killing the beetles and dry-pickling them. Thus preserved, they could be ground into ointments using either the whole beetle, or just the wings. It was agreed that the heads ought to be removed entirely, and indeed there is a greater concentration of cantharadin in the wings than other parts of the body (Scarborough 1977).

7. Administration

Drugs were delivered to the body by a variety of routes. Medication taken orally could be drunk as tea, sucked as a lozenge, painted onto the throat as sticky salve, or rolled into a pill. Wine mixtures were a common method of taking medicinal substances, and the large amount of space devoted to the varying powers of different wine varietals and mixes in Dioscorides well illustrates the close connection between brewing and the crafting of medicine (5.1–73; Oil and Wine Production; Culinary and Medicinal Uses of Oil and Wine). Honey-based drinks were also used ubiquitously, both alone and with other ingredients; *hydromel* (a honey–water mixture, fermented, Pliny, *NH* 14.113) and its cousin *oxymel* (honey–water–vinegar–salt *NH* 14.114) were often included in regimens for the ill, and the anti-microbial properties of both honey, vinegar, and the products of light fermentation would have aided the action of other ingredients while hydrating the body with safer drinking fluid. In a time before intravenous fluids, dehydration with fever and/or diarrhea was a real concern to the management of acute and chronic illnesses, and the soothing properties of honey combined with its dense, cheap

calories would have been of life-saving value, as would the flora from the fermentation process.

Oral medications have their limits, both in absorption and access. An illness with severe vomiting keeps the drug from reaching the bloodstream at all, and some treatments absorb better when the drug seeps through the mucus membranes of the anus and vagina. To this end, vaginal and anal suppositories were used much more frequently than in modern medicine, where intravenous delivery puts medications directly into the bloodstream. Recipes for suppositories and pessaries abound, as did uses for douches and enemas. Not surprisingly, gynecology relied heavily on the pessary as a method of treatment and for prophylaxis against pregnancy. The recipes for contraceptives often are made with a wax or oil base that would have melted to form a spermicidal barrier, and even the infamous crocodile dung, with its alkalinity, might have proved relatively effective as a spermicide (e.g., Soranus 1.60–65; see Riddle 1997, 35–63).

Topical salves in a variety of bases were key to the success of wound treatment and the resolution of dermatological complaints. Honey, a common ingredient in such salves and plasters, is still used in modern medicine for its effective antimicrobial action. Not only does it clean wounds and treat infections, but it is antiseptic *and* moisturizing. Honey will not dry out burns or cuts, and it does not sting like salts and alcohol. It mixes well in water and oil-based medications, and it is cheap and easy to acquire locally. This does not mean that it did not have its luxury side; Attic (Athenian) honey was highly prized well into the second century CE (Dioscorides 2.82), and varietals from Pontus, especially those made from flowering wormwood, were known to be toxic in large doses and (to ancient minds) therefore useful in smaller doses (Pliny, *NH* 21.74, 77, 83, 29.97, 32.43). Metal ash and its by-products also were frequently included, as were a variety of volcanic minerals (Dioscorides 5.74–162). Though there can be heavy metal toxicity if too much is used, copper, silver, and even arsenic and lead can and do reliably clear up a range of infections

Washes too were used to irrigate wounds and sores, and they were as likely to be made with oil as with water or vinegar. Many of these were antiseptic to a certain degree. Wound care was one of the better-developed medical arts of antiquity. In addition to this, physicians would deliberately culture "good" pus whose bacillus was relatively harmless to the patient and kept other bacteria from invading the wound (Prag 1990). Mupirocin, a culture of pseudomonas fluorescens, is used in modern medicine for just that purpose. There is more debate about the various wet-grain plasters and the infamous "scrapings from the bath" which consisted of dust, skin, sweat, and oil recovered from the floors of public baths. Riddle (1985, 49–54) suggests that such items might have contained cultures of penicillium or other primitive antibiotic cultures, and there is some reason to take such arguments seriously (cf. Nelson et al. 2010).

Collyrium, a term for eyewashes, was made more solidly than other salves, pressed into dried bars, and stamped with identifying information (see also WINE AND OIL PRODUCTION). A physician could then cut or scrape from that stamped bar to remix the salve for use on the spot, a convenience to the traveling practitioner away from a full set of compounding equipment. The prevalence of eye complaints and specialists who made their living treating them doubtless accounts for the way in which these particular drugs were prepared and stored; not only are infections of the eye subject to serious complications, but they also tend to be very contagious, as anyone who has had pinkeye can attest. A remedy that could be brought along on house calls or kept in a family's

medicine box, then mixed as needed, would be a necessary part of ancient communal life (Cruse 2004).

One of the drug delivery systems that seems most alien to modern pharmacy is the practice of fumigation. Smoke inhalation is a quick and efficient way to introduce chemicals into the bloodstream; the practice of smoking relies on this very phenomenon. However, instead of using direct inhalation from a pipe, ancient fumigation was more like the burning of incense, possibly involving steam as well. Fumigation as a medical practice is best attested in gynecological treatments. Burning *pharmaka* were set under the patient, who would either wrap herself in cloth or make use of some other device to funnel the smoke into her genitals (King 1993, 20–22). Such treatments did not end in antiquity; fumigation tents for the delivery of mercury and arsenic were used well into the 1800s as a treatment for syphilis (Hayden 2003).

As for the instruments used to mix and apply these drugs, we find mortars and pestles as well as ceramic pots. When the time came to apply a medicine prepared for later use, it could be reconstituted with water or oil, depending on the intended use, and possibly cooked in one of the pouring spoons we find in medical tool collections. These spoons with their broad bases and pouring lips suggest that, much as modern users of street drugs will "cook" their dose over a flame, so too did ancient people cook up their doses on the spot. Small spatula probes were used to mix, and then apply, medications to the skin; this had the useful effect of preventing skin-to-skin contact with open sores, though it is unclear that this was recognized as a benefit (Bliquez 2015, 118–122, 125–138). *Cannulae* (small tubes) could be secured in wounds to allow for simultaneous closing and drainage through plasters and dressings (Bliquez 2015, 224).

Douches and enemas were administered by a variety of methods. A simple gravity-fed assembly of a funnel or bladder connected to a brass tube could be used, and when more force was needed to propel liquid, a kind of large-bore syringe was used. To apply powdered medications, hollow tubes could be filled with the *pharmakon*, and then applied by blowing from the other end. Any opening (vagina, anus, urethra/bladder, ears, nose, or mouth) could be cleaned and medicated by such means, and the practice is returning to greater popularity with the use of neti pots to clean, clear, and medicate the nasal sinuses with saline solution (Bliquez 2015, 208–17, 229). In antiquity, this could go too far; in some cases, a bellows-type apparatus could be used to inject liquids, and rather infamously to cure *hysterike pnix* by inflating the vagina and uterus with air. Soranus dismisses such treatments outright, and he is quite correct to do so; forcing air into the vagina and uterus can and does cause death by air embolism (3.29, *CMG* 4.112.18–23).

8. Alexipharmaka (Antidotes) and Anesthesia

Theriacs or broad-spectrum antidotes (also called *Alexipharmaka*) deserve a special mention. These compounds became a major part of high-end drugs aimed at the wealthy and powerful, who felt (with some cause) that they could be the target of poisoners. The archetypal paranoid king Mithradates VI of Pontus, who sponsored Crateuas' research and allegedly performed his own experiments on human subjects, was also said to have immunized himself to poison by taking increasingly large amounts over a period of time. So successful were his efforts that, according to Appian (*Mithradetes* 111), he was unable to use poison to commit suicide when Pompey closed in on him. Instead, he had to resort to death by sword. This legend (a rather far-fetched one, unless Mithradates

excluded heavy metals from his daily intake) gave a name to a subset of "theriac" medications taken as treatment or prophylaxis for the bites of stinging animals and insects. *Mithradatium* came to be used to refer to a great number of recipes, each claiming to have been invented by the notorious king and providing a surefire defense against the arts of poisoners (Totelin 2004). Antidotes in general and *Mithradatia* in particular formed the most expensive, exotic, and ostentatious of all drugs, catering as it did only to those wealthy and powerful enough to need fear poison. Included in their number is Marcus Aurelius, whose use of theriac is well documented by his physician Galen (Scarborough 2004).

One of the most frequent assertions about premodern medicine is that there were no effective means of anesthetizing patients. While it is true that much more reliable methods are available now at considerably lower risk, it is not true that the ancients were lacking in a variety of methods to induce sleep and control pain. Dioscorides lists twenty alkaloid-rich analgesics, narcotics, and poisons, and he groups them together (4.63–83). Notable among these is *Papaver sominiferum* or the opium poppy, which even now is the plant from which modern opiates and street drugs both are derived. The ancients knew of its anodyne powers as well as its effectiveness as a depressant, and they most certainly knew that too much could cause death (Scarborough 2010, VII). Mandrake is now better known for its place in magic and folklore, but it got that reputation owing to its chemical makeup of hyoscyamine, scopolamine, and atropine; prepared carefully, it is a powerful anesthetic and hypnotic. Datura plants (Thornapple and its relatives) are likewise prevalent in ancient anesthesia (Scarborough 2012b, Ellis 1946).

9. Conclusions

How effective was ancient pharmacy? It is a question often asked and difficult to answer (for a summary of recent discussions, see Totelin 2009, 219–224). Surely the ancients would claim that it was effective. In many respects, it can be said that healthcare *with* pharmacy—any pharmacy—will do better than without, especially as concerns wound care. The degree to which the placebo effect functioned in some of these treatments, however, is and will be under debate for years to come. Modern pharmacy has, in large part, eschewed scientific studies of herbal medicine, and those that exist (for instance, those used in Riddle's work) rely on animal studies rather than human (King 1998, 132–56). Modern herbalists work in large part in systems separate from the modern pharmacy embraced by institutional academia, and this engenders skepticism from scholars.

Certainly traditional medicine does not entirely come out of aether and sympathetic magic; many of the common drugs and *materia medica* contain active chemicals and have an effect of some kind on the body. One must, however, also consider the degree to which modern pharmacy still has variable degrees of success in treatment; different patients respond to the same drug differently, and one person's penicillin is another person's anaphylactic shock. Some patients respond well to a medication that has little effect on others. It sounds much like the observations of the ancient physicians who warned that the patient is also a variable in the application of a drug. In a modern pharmacy where drugs are farmed remotely, processed in factories, compounded, and shipped to pharmacists who then fill prescriptions written by medical doctors, as many patterns from antiquity are preserved as are rejected.

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FURTHER READING

Scarborough 2010 is a collection of essays arranged in an order designed to provide in-depth discussion of key authors and issues in Greco-Roman pharmacy, and his recent article on fish glue joins these as a thorough exploration of the compounding of isinglass (rendered from Caspian sturgeons) with mineral, animal, and herbal components to create a strong surgical glue: Scarborough, J. 2015. "Fish Glue (Grk. ἰχθυοκόλλα) in Hellenistic and Roman Medicine and Pharmacology." *CPh* 110 (1): 54–65. Forthcoming in 2016, Paul Keyser and John Scarborough's *Oxford Handbook of Science and Medicine in Classical Antiquity* will contain updated articles on various topics of interest, particularly biographical information on pharmaceutical authors.

Totelin 2009 not only provides translations of the collected Hippocratic recipes, but details much about the drug trade during the fifth and fourth centuries bce and is a good read for those interested in the pharmacy of the period. Likewise, anyone interested in a serious study of ancient pharmacy would be well served by Beck, L. Y. 2005. *Dioscorides. De Materia Medica*. Altertumswissenschaftliche Texte und Studien 38. Hildesheim: Olms-Weidmann. Beck's edition includes extensive notes and suggested identifications for the *materia medica* listed.

Medical abortion and contraception in the ancient world were common and as socially complex issues as they still remain. Kapparis, K. A. 2002. *Abortion in the Ancient World*. London: Duckworth. Covers the topic in all its aspects deftly and completely in a way that is accessible to the general public without losing scholarly rigor.

Tzedakis, Y., H. Martlew, and M. K. Jones, 2008. *Archaeology Meets Science: Biomolecular Investigations in Bronze Age Greece: The Primary Scientific Evidence, 1997–2003.* Oxford: Oxbow Books. A valuable starting point for those interested in the ways that modern science is contributing to our knowledge of ancient pharmacy.

CHAPTER 26

Magic, Curses, and Healing

Andrew D. Gregory

1. Polytheistic Context

The links between religion, eschatology, and magic are often strong. While it may seem obvious that the ancient Greeks were polytheistic for a large part of their pre-Christian history, this is important because Christianity has had a strong and distinctive attitude to magic which still in some ways pervades modern western ideas. The classical Christian view is that humans are not themselves able to work magic in the sense of generating breaches of the laws of nature. If a human accomplishes something considered to be beyond nature, either God is working a miracle through that person, or that person is in league with the devil. On this view there can be no white wizards or white witches. There are miracles, or there is black magic. It is important to recognize then that in other cultures there is the view that humans are able to work magic unaided and for good purposes.

2. Natural Magic

In the modern West, magic is often characterized in two ways: "conjuring" or supernatural. When it is not really "magic," but rather conjuring in some guise, magic can, in fact, be explained through the "magician's" skill, by physical science, and social psychology. On the other hand, there can be a claim that it is "real" magic, and the supernatural or the paranormal are involved. It is important to recognize another possibility, which does not come easily to modern western thinking, that of natural magic. There was a strong natural magic movement in the Renaissance. Giambattista della Porta, in his *Natural Magic* (1558), says:

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> There are two sorts of magic; the one infamous and unhappy, because it has to do with foul spirits, and consists of enchantments and wicked curiosity, and this is called sorcery, an art which all learned and good men detest … the other magic is natural, which all excellent wise men embrace, and worship with great applause. (cf. Cornelius Agrippa, *Three Books Concerning Occult Philosophy* [1531]; Marsilio Ficino, *Three Books on Life* [1489], etc.)

Elsewhere he says:

> I never writ here nor elsewhere, what is not contain'd within the bounds of Nature. (1598, Preface)

Why is this important for Greek and Roman magic? Historically, the border between magic/non-magic was much fuzzier than for us. Further, what is considered magic undergoes historical shifts. Some phenomena which we consider magical were considered natural, or natural magic. Galen, for instance, was happy with the natural role of some amulets in healing (so Rufus, Fragment 90, believed amulets had natural effects, and Galen believed one amulet in particular had a natural effect: Lloyd 1979, 42–43). Some phenomena which we understand as natural were once deemed magical. Magnetism, at one point considered an occult subject and part of natural magic, is now part of mainstream physics (see, e.g., the list of subjects treated in della Porta's *Natural Magic*). A key idea for magic was sympathetic interaction, the classic statement of which is by the anthropologist Frazer (1917, 52):

> First, that like produces like, or that an effect resembles its cause; and second, that things which have once been in contact with each other continue to act on each other at a distance after the physical contact has been severed.

Sympathy was used widely in Renaissance natural magic and in ancient Greece as a natural means of interaction. To quote Plotinus:

> How is there magic? By sympathy, and that naturally there is a sympathy between like things and an antipathy between unlike things. (*Enneads* 4.4.40)

Magic in antiquity did not require a universal belief in what we would term the supernatural, although some versions did have such a belief. The terminology "laws of nature" was not used until the seventeenth century; thus, we avoid it here.

3. Extended World

One important concept for understanding magic is the idea of participation in an extended world. Some people believe that they live in a world which is richer in hidden powers, spirits, and other entities than our modern western conception of the world. These people then participate in this world, employing what we would call magic, in order to access, manipulate, or petition this extended realm. Lévy-Bruhl (1979, 327) says:

> The things that a man has used, the clothes he has worn, his weapons, ornaments, are part of him, *are* his very self, just like his saliva, nail-parings, hair, excreta, although to a lesser

> extent. Something has been communicated to them by him which, as it were, a continuance of his individuality, and in a mystic sense these objects are henceforth inseparable from him.

Some believe that the dead have not definitively left us, but live an afterlife, perhaps still near us in spirit form, perhaps in another place. It may be possible for us to travel in spirit to the other place or for the dead, usually residing elsewhere, to come among us. Again, with this worldview one might employ magic in order to participate in it.

4. The Historiography of Magic

There has been considerable change in how magic has been treated both in itself and in relation to religion and science. We have moved beyond hierarchical developmental views typical of the nineteenth century, which stated that for humans first there was magic, then there was religion, and then there was science in ascending order of human intellectual achievement, each view superseding its predecessor. Nor do we view magic as failed science or the supposition of ideal connections for real ones, but often more fruitfully as a system of beliefs embedded in a specific social context (Tylor 1871; Frazer 1917). In the early and middle parts of the twentieth century, enormously important anthropological work has also been done on tribal magical beliefs, showing that they are coherent, often empirically based, and that tribes have means of navigating these magical beliefs and the worldview concomitant with them (Canon 1942; Lévi-Strauss 1963; Lévy-Bruhl 1979; see also Horton 1967, 1993). While they did not employ western rationality, their means of navigation are effective within their belief systems. This has been important in breaking down the idea that all magical belief is simply irrational. Further, we must be careful in our use of terms like rational or irrational in this sort of context. "Irrational" ambiguously straddles the dividing line between "lacking reason" and "not conforming to the canons of (modern western) rationality." The latter does not entail the former. "Irrational" is also often taken as pejorative and frequently interpreted as "completely irrational."

There has also been a move away from a bipolar characterization of magic and science, with no interaction or overlap, toward more complex models, paralleling developments in the historiography of science and religion (e.g., Fauvel 1989). So, for example, attempts to see science as rational, empirical, and progressive as opposed to irrational, metaphysical, static magic have broken down with the realization that magic was highly varied and could have interesting intellectual bases. The positivist rejection of magic tended to blur many fine distinctions between types of magic.

Greek Historiography

There has also been an important shift in attitudes to magic and rationality in ancient Greece. In *The Greeks and the Irrational*, Dodds did much to break down the idea that ancient Greek beliefs were generally rational. Dodds (1951, viii) posed a key question:

> Why should we attribute to the ancient Greeks an immunity from "primitive" modes of thought which we do not find in any society open to our direct observation?

Indeed, there is no reason to exempt the ancient Greeks from such beliefs, and Dodds had gathered a large amount of evidence in support of his view. There are two aspects

of Dodds' approach. Firstly, that the Greek populace continued to have magical beliefs even though there was a supposed move away from such thought among the early philosophers. Second, that the presumed rejection of magic and the "irrational" by early philosophers allied with the idea that what exists is entirely natural was not as clear-cut as is often thought.

5. What Is Magic?

Readers may be expecting a definition of magic, but none will be forthcoming. Recent scholarship has come to doubt whether it is possible to give a single, comprehensive definition of magic (Collins 2008, 2). There are two reasons for this. First, any attempt to give an ahistorical, exhaustive definition of magic will be problematic as magic occurs in many different ways in many different social and religious contexts. Attempts to capture the commonalities are likely to be vacuous and, since magic changes significantly over time, anachronistic when applied to the Greeks and Romans. Modern western conceptions of magic, based on a Christian heritage, would be hugely misleading in a Greek or Roman context. Second, there is no unanimous Greek or Roman definition of magic, which meant different things to different people in ancient Greece and Rome. I agree with Collins (2003, 17) that "it has always been easier to define ancient magic by contrasts than in its essence."

It is also difficult in a Greek and Roman context to make any sharp division between religion and science. In what follows, I will look at Greek and Roman terms for magic/magicians and try to contrast magical views with those of the natural philosophers. The lack of precise definitions and demarcations is in some ways a little problematic but typical of magic in many cultures and time periods. I appreciate in particular that some philosophers will find this frustrating—define magic they will say, so we know precisely what it is. However, not only is that not easy (which should not stop us), it is not, as generations of magic scholars have found, helpful, either philosophically or historically.

6. Greek and Roman Words

The usual Greek term for a magician is *magos*, derived from the Persian *magu*, priest. What the *magos* does is termed *mageia*, and there is also the adjective *magikos*. A second group of terms is *goētos* (sorcerer, wizard, juggler, cheat) and *goēteia* (witchcraft or jugglery). These terms may have derived from *goos*, someone who lamented for the dead, a *goētos* then dealing with the dead. However, certainly in later usage, these groups of terms are largely synonymous. Neither term on its own tells us much about what Greek magicians did. In the existing sources, the terms are usually used derogatively, indicating a fraud or scoundrel. That may well say something about the status of magicians, at least among intellectuals, but one must always have reservations here about which sources have survived and whether magic and magicians had a better reputation among the populace. There is also the important term *pharmaka*, which usually means medicine, cure, or remedy in the orthodox sense, but in some contexts also having the sense of enchanted potion, charm, or spell (see Pharmacy).

7. Homer and Hesiod

The works of Homer and Hesiod provide an important reference point and intellectual framework for many ancient Greeks. While Homer and Hesiod were aware of some regularities in nature (see Lloyd 1991, 419), their gods were capricious, capable of intervening in human affairs and nature. Xenophanes' criticism that the gods of Homer and Hesiod are guilty of "theft, adultery, and deceiving each other" can hardly be denied (*TEGP* 29; cf. 30). So one might think of the repeating motif in Homer's *Odyssey*, where a ship is hit by lightning that was generated by a spiteful Zeus, a phenomenon which would not have occurred otherwise (e.g., 5.128; 7.249; 12.387, 415; 14.305; 22.330). In Hesiod's *Theogony*, Zeus employs his weapons of thunder, lightning, and thunderbolt against the Titans (690–712, 853–868). The classic contrast to this view is Anaximander, who gives natural explanations for all of these phenomena:

> Concerning thunder, lightning, thunderbolts, hurricanes and typhoons.
>
> Anaximander said that these come about because of wind. Whenever it is enclosed in a thick cloud and then forcibly breaks out, due to its fineness and lightness, then the bursting makes the noise, and the rent against the blackness of the cloud is the lightning flash. (*TEGP* 30)

In Homer we find intervention in the mental processes of humans as well. Dodds (1951, 10–11) comments that

> The most characteristic feature of the *Odyssey* is the way in which its personages ascribe all sorts of mental (as well as physical) events to the intervention of a nameless and indeterminate daemon of "god" or "gods." These vaguely conceived beings can inspire courage at a crisis or take away a man's understanding just as the gods do in the *Iliad*.

The most famous example of this is in the *Iliad*, where Agamemnon, forced to return his own concubine, steals Achilles' lover and blames Zeus and the Erinyes for taking away his understanding (19.86–89; see Dodds 1951, 2–3; cf. Vlastos 1973, 13 for a discussion of Dodds on *atē*).

It should be evident that both Homer and Hesiod had extended worlds which would support the use of magic. While in Homer, although the dead do not live about us, the underworld is accessible under certain circumstances. So Odysseus in *Odyssey* 11.25–33 manages to summon the dead by digging a trench, around which he pours libations of milk, honey, wine, and water and sprinkles barley meal. He slaughters two sheep and allows their blood to run into the trench. In Hesiod's *Works and Days* 100–126, the first humans are the golden people who, after their death, live on as good spirits on the face of the earth, watching over mortals. Dreams are seen as important and prophetic and are often sent by gods.

On some more specific instances of magic or divine intervention, in both Homer and Hesiod, diseases are caused by the gods, the plague in the opening passage of the *Iliad* and Pandora's box in *Works and Days*. The *Iliad* begins:

> Sing, goddess, the wrath of Achilles Peleus' son, the ruinous wrath that brought on the Achaians woes innumerable, and hurled down into Hades many strong souls of heroes, and gave their bodies to be a prey to dogs and all winged fowls; and so the counsel of Zeus wrought out its accomplishment from the day when first strife parted Atreides king of men and noble Achilles. Who among the gods set the twain at strife and variance? Apollo, the son of Leto and of Zeus; for he in anger at the king sent a sore plague upon the host, so that the folk began to perish, because Atreides had done dishonour to Chryses the priest. (1.1–12, trans. Leaf et al.)

While in Hesiod's *Works and Days* we get:

> But for those who practice violence and cruel deeds far-seeing Zeus, the son of Cronos, ordains a punishment. Often even a whole city suffers for a bad man who sins and devises presumptuous deeds, and the son of Cronos lays great trouble upon the people, famine and plague together, so that the men perish away, and their women do not bear children, and their houses become few, through the contriving of Olympian Zeus. (238–245, trans. West; cp. 69–104, where Pandora and her famous box, full of diseases, are sent by Zeus as a punishment.)

There could be magical healing too, as in *Odyssey* 19.455–458, where Odysseus tells the tale of a boar-hunting accident in his youth and the treatment for a gore wound: the flow of blood was staunched by the singing of an incantation. In *Odyssey* 10.229–242, Circe uses drugs and a wand to transform men into pigs. The classic contrast to this is the Hippocratic insistence that all diseases have natural origins, and all diseases have natural cures.

In terms of magical practices, verses from Homer were used as healing incantations for a wide range of maladies (Collins 2008, 104–131), and the general use of incantations in healing was widespread. The idea of personal purification was also seen as important in combating disease. Those claiming foresight were also commonplace, as were people claiming to be able to interpret prophetic dreams. Ritual, diet, and prayer were employed in attempts to bring on such dreams (Kingsley 1995, 281–288; Healing Shrines).

8. Binding Magic and Curses

A common form of magic in ancient Greece and Rome was that of binding, particularly the binding curse (Graf 1997, 118–174; Dickie 2001, 17–18; Collins 2008, 64–103; Ogden 2009, 227–244). In Greek this was known as a *katadesmos*, a "binding down," whose Roman variant was *tabella defixionis*, an "enchanted tablet." Sixteen to seventeen hundred of these binding curses survive, from around the first part of the fifth century BCE through to the Roman era. Most were written in Greek, but we have many in Latin as well. There are precedents from other earlier cultures, notably the Egyptians.

Typically, these binding curses were in one of two forms. The binding spell could be written on wax or a piece of broken pot, but most frequently on thin lead. The lead was then rolled up and pierced with a nail. Some hair or scrap of clothing from the target might be included with the curse (see §3 above, for Lévi-Bruhl quote). Alternatively, one might use a doll, loosely resembling the person at whom the spell was aimed, made of fabric or wax, or perhaps clay such that the limbs could be bound. These dolls too

might have nails put through them. Although these are sometimes referred to as "voodoo dolls," there are many important differences from the voodoo religion. In addition to the symbolic binding of the body, the binding curse could also mention parts of the target's body to be bound, such as the hands, feet, and mouth.

The language for the binding spell was relatively standard, and the binding was often, though not always, thought to require the aid of divinities for it to work. So Greek binding spells would begin with "I bind," and would then call upon a deity and mention the names of the people to be bound. The nature of the curses varied widely, from attempts to make an opposing litigant perform badly in court to curses against thieves or others who had seemingly wronged the curser, or with whom the cursor had some business, love, or sporting rivalry. The curses could be phrased conditionally or indefinitely (if x does this, whoever stole from me). From differences in the quality of the handwriting, grammar, syntax, and spelling, it would seem that the use of binding magic was widespread.

Some curse tablets simply name those cursed, indicating perhaps that there was an oral or performative part of the ritual, that the nature of the curses was well known, or that the cursing was a general one. The names of those cursed were often written backward. We are not entirely sure why this occurred (though certainly this should be dissociated from modern demonic ideas: reciting the Lord's prayer backward, etc.), and there were non-magical precedents on Greek vases, for example. Certainly in the Roman period, curse tablets had been prepared in advance for the curser simply to write in the name of the cursed. Binding magic often involved inflicting some form of ill health upon the target. Sometimes the curses entailed piercing body parts, perhaps also symbolized by piercing the rolled lead or a doll with nails. An example of a legal curse (reverse side) reads "I bind (*katadesmeuo*) my opponent in court Dion and Grancios" (Ogden 2009, 211). The first side of this curse is interesting in terms of belief and paranoia:

> If anyone put a binding spell on me, be it man or woman, slave or free, alien or citizen, from my household or from outside it, be it out of envy toward my work or my actions, if anyone put a binding spell on me before Hermes, be it Hermes *Eriounos* or Hermes Restrainer or Hermes Trickster, or before some other power, I bind in return all my enemies. (Ogden 2009, 211)

Not all binding magic involved curses. Some was amorous, intended to gain the target's affection or sexual favor. Though used primarily by men, this sort of magic was also used by women. Wishes here could vary considerably, and they need to be contextualized according to contemporary sexual mores. Binding magic could also aim to force the target to do something, and some of this magic could be quite malicious (Collins 2008, 88–92). An example of erotic magic in this context reads:

> (I bind) Aristocydes and the women who show off to him. He is never to marry/have sex with another woman or with a girl/boy. (Ogden 2009, 228)

Binding magic was also used to attempt to help the dead. Typically binding magic and curses were placed in wells, or somewhere appropriate to the curse, such as on the graves of those who had died young or violently, whose spirits were thought to be restless on account of the injustice of their death (cf. Vergil, *Aeneid* 6.426–449). Here again we see the idea of an "extended" society including the dead and the gods invoked in the curses.

It is worth noting that the differences of these magical practices from Greek and Roman religion and prayer were far less apparent than with modern Christianity. The relation of human to non-omnipotent gods is distinct, as is the nature of some modes of prayer.

9. Disease

In the ancient world, disease was often thought to be caused by the gods or some magical action, and it was also considered curable by the appeasement of the gods, purification, or magical action. The Babylonians believed that all diseases were so caused, and we have already seen the view of Homer and Hesiod. An important text in relation to magic and healing is the Hippocratic *On the Sacred Disease*, which discusses epilepsy, often taken as a clear case of possession or the intervention of the gods. The Babylonian view was that

> If epilepsy falls once upon a person or falls many times, it is as the result of possession by a demon or a departed spirit.[1]

On the Sacred Disease sets out to demonstrate that the causes of the sacred disease are no different from any other disease. The work opens thus:

> Concerning the disease which is called "sacred." In my view it is no more divine or sacred than any other disease, but has a nature and a definite cause. Men have called it divine due to their inexperience and great wonder, it being unlike other diseases. (1.1–3; cf. 5.1–4)

There is an attack on magical practitioners throughout:

> In my opinion the first men to consider this disease to be sacred were like those we now call mages, purifiers, vagabonds, and quacks. These people claim for themselves great piety and much knowledge. They used the divine as a cloak, having no treatment or anything useful to offer, and in order that their lack of knowledge should not be evident, they called this condition sacred. (2.1–4)

The final lines of the book are as follows:

> Anyone who knows how to produce in men dryness or wetness, cold or heat by means of regimen, can cure this disease as well, if he can distinguish the due times for treatment, without needing purifications or magic. (21.1–26)

Epilepsy and Goats

Goats were believed to suffer from the sacred disease as well, and the magicians and purifiers forbade any association with goats or their produces. *On the Sacred Disease* says:

> They have instituted a mode of treatment which is safe for themselves, namely, by applying purifications and incantations, and enforcing abstinence from baths and many articles of food which are unwholesome to men in diseases … And they forbid to have a black robe, because black is expressive of death; and to sleep on a goat's skin, or to wear it, and to put

> one foot upon another, or one hand upon another; for all these things are held to be hindrances to the cure. (4.21–35)

The author also relates an interesting experiment:

> This is best seen with cattle who are attacked by the disease, especially goats. They are most commonly seized. If you cut open the head you will find that the brain is wet, full of fluid and foul smelling, so clearly one recognizes that it is not a god which is harming the body, but the disease. So too with humans. (14.11–19)

Denied the possibility of human postmortem dissection, the Hippocratics did what to them would have seemed the next best thing: they dissected goats which appeared to be suffering from epilepsy.

10. General Attack?

On the Sacred Disease launches a general attack on magic and magicians, and is important as the first known text to do so (Lloyd 1979, 19–27). Individual magicians had been attacked as incompetent, but not magic as a whole. Epilepsy has a natural cause, and so do *all* other diseases. That magical intervention does not work here is not an individual case or owing to an incompetent practitioner of magic; the whole practice is entirely unfounded. *On the Sacred Disease* (4.10–16) also says:

> If a human by magic and sacrifice can bring down the moon, eclipse the sun, make storm and good weather, I will not call these things divine, but human, since the ability of the god is overpowered and enslaved by the knowledge of humans. (cf. 5.1–4)

This is interesting once more for its breadth of attack on magical claims and practices. The Hippocratic author continues thus:

> But perhaps this is not true and these men, being in need of a living, fashioned and embellished many tales of all types, about many things and about this disease in particular, placing the blame for each form of this condition on some god. (4.16–21)

There has been some debate as to whether the Hippocratic rejection of magic was principled, or whether it was more of an ad hominem attack on rivals in the healing market (cf. Nutton 2013, 65). The generality of the attack would suggest that it was a matter of principle, though one should also be aware that the author of *On the Sacred Disease* (21.4–7) does not dismiss the divine entirely:

> Therefore there is no need to distinguish this disease from others or consider it more divine, for they are all divine and all human.

Whether the divine is something apart from the natural, that is whether they held some form of pantheism, is then a key question for the Hippocratics. Whether they rejected all magical practices, or perhaps more pertinently, whether they rejected everything that they believed to be a magical practice is a further key question.

11. Macrocosm and Microcosm

A second important text in relation to magic and healing is the Hippocratic *On Regimen*. 1.10 tells us:

> In a word, everything was arranged in the body by fire, in a manner suitable to itself, in imitation of the whole, small to large and large to small. The belly is the largest, a reservoir for water, both dry and moist, giving to all and taking from all, with the power of the sea, nourishing creatures suited to it, killing those not suited. Water, cold and moist, is arranged around this, a passage for cold breath and warm breath, an imitation of the earth, which alters everything which falls to it. Consuming and increasing it scatters fine water and aethereal creative fire, the visible and the invisible, separating from that which has been set together, in which things are brought into a state of clarity, each according to its destined role. In this fire made for itself three circuits bounded by each other internally and externally. Those towards the hold of the moist have the power of the moon, while those towards the outer circuits, towards the surrounding mass, have the power of the stars and those in the middle are bound internally and externally. The hottest and strongest fire, which controls all things, manages everything according to nature, it is imperceptible to sight or touch. In this are soul, mind, understanding, growth, change, diminution, separation, sleep, waking. This steers all things though all both here and there and is never still.

This is one of our earliest texts to invoke the macrocosm/microcosm relationship which became very influential in later magical thinking. One can also find Democritus (*TEGP* 193) saying that "Man is a small *cosmos* (*anthropos mikros cosmos*)." The macrocosm/microcosm analogy could involve some magical thinking, though this was not necessary. One might simply understand the *cosmos* as a large organism, or the body as a small *cosmos*, or one might believe that some form of sympathy or other magical relation existed between the two. It might also be the case that a benevolent creator/organizer (whether an element, principle, or god/Demiurge) might set up both the *cosmos* and the body so that they might relate as macrocosm and microcosm. Plato and Aristotle both employed macrocosm/microcosm analogies. The Hippocratics would seem to employ the third option here, and it is important to note that everything happens according to nature (*kata phusin*). The Hippocratics used their macrocosm/microcosm analogy for diagnosis by means of dreams. If patients dreamed of the stars in a disordered fashion, then their afflictions were close to the surface of the body; if they dreamed of the moon, afflictions were more internal, etc. Divination by means of dreams was taken seriously in ancient Greece. In *On Divination by Way of Dreams*, Aristotle asks:

> Are then some dreams causes, and others signs, for example of what occurs in the body? At all events, even reputable doctors say that one should pay close attention to dreams. (463a 3–6, trans. Hankinson)

Aristotle gives a natural account of the origins of some true dreams, for example, those of thunder caused by our faint hearing of thunder during our sleep (*On Divination by Way of Dreams* 1). Aristotle also says:

> Most [so-called prophetic] dreams are, however, to be classed as mere coincidences. (1, trans. Beare)

Aristotle is generally skeptical:

> All those whose physical temperament is, as it were, garrulous and excitable, see sights of all descriptions; for, inasmuch as they experience many movements of every kind, they just chance to have visions resembling objective facts, their luck in these matters being merely like that of persons who play at even and odd. For the principle which is expressed in the gambler's maxim: "If you make many throws your luck must change," holds in their case also. (2, trans. Beare)

12. Prognosis and Prophesy

The Hippocratics were concerned with the relation of their art of prognosis with *mantikē*, prophesy, divination, or foresight. There were official *manteis* (diviners, seers, prophets) who worked with temples or armies, for example, and also unofficial itinerant *manteis* who worked for whoever would pay for their services. A similar division existed among the *kathartai*, the cleansers or purifiers, who might seek to heal either by spiritual or more physical methods.

Again, whether the objection is in principle or ad hominem in a crowded healing marketplace is open to question. Prognosis was important for the Hippocratics. *Prognostics* 1 begins:

> It appears to me a most excellent thing for the physician to cultivate Prognosis; for by foreseeing and foretelling, in the presence of the sick, the present, the past, and the future, and explaining the omissions which patients have been guilty of, he will be the more readily believed to be acquainted with the circumstances of the sick; so that men will have confidence to intrust themselves to such a physician. And he will manage the cure best who has foreseen what is to happen from the present state of matters. (trans. Adams)

On Regimen in Acute Diseases 3 says:

> In this respect, they might say that the art of medicine resembles augury, since augurs hold that the same bird (omen) if seen on the left hand is good, but if on the right bad: and in divination by the inspection of entrails you will find similar differences; but certain diviners hold the very opposite of these opinions. (trans. Adams. The diviner in Homer, *Iliad* 1.62 is a watcher of birds)

The Hippocratic view in general is that prognoses be made on the basis of observation and precedent. *Prorrhetic* 2.2 says:

> I, however, will not indulge in this kind of prophecy; rather I record the things on the basis of which one must estimate which men will recover and which will die … I hope in these and other cases to make predictions which are more within human capabilities than those which are reported. (trans. Hankinson)

Whether their objections to magical healing are entirely principled or not, the Hippocratics form an important contrast to the various magical ideas about the etiology and treatment of disease.

13. Shamanism in Classical Antiquity?

A shaman is someone who employs an altered or transcendent state of consciousness (whether through drugs, dance, or meditation) to access a spiritual realm and interact with spiritual entities, who may well include the dead. Shamans use such encounters in various ways, to influence these spirits or to inform, heal, or practice divination. Whether there was shamanism in ancient Greece and Rome, and in particular whether Pythagoras was a shaman has been a matter of debate. Dodds (1951, 143–145) has argued he was, followed by Burkert (1972, 162–163) and Cornford (1952), and recently Kingsley (1994) has argued strongly for this view. Huffman (1999, 73) and Zhmud (2012, 207–238) have rejected the idea. Much depends here on whether one wants to assert that Pythagoras was indeed a shaman and so had all the characteristics of a shaman (or vice versa), or whether he could reasonably be likened to a shaman. Much also depends on the definition of a shaman and shamanism. Walsh (1989, 2) declares:

> The term itself comes from the word saman of the Tungus people of Siberia, meaning "one who is excited, moved, raised."

The *Oxford English Dictionary* offers this definition:

> A person regarded as having access to, and influence in, the world of good and evil spirits, especially among some peoples of northern Asia and North America. Typically such people enter a trance state during a ritual, and practise divination and healing. (cf. Shirokogoroff 1935, 269; Walsh 1989, 5)

More recently, discussions on the definition of shamanism have shifted in focus from the individual shamans to the cultures to which they belong. Jolly (2005) says:

> The following could perhaps serve as a definition: cultures that can be classified as shamanic are those which, as a minimum requirement, possess religious functionaries who draw on the powers in the natural world, including the powers of animals, and who mediate, usually in an altered state of consciousness, between the world of the living and that of the spirits including the spirits of the dead. (cf. Klein et al. 2005)

The legend surrounding Pythagoras is rich and odd. He was said to have been seen in two different places at exactly the same time, to have stood in a theater and revealed that one of his thighs was golden, and to have been addressed by the river Kosas, many people hearing this (Aristotle, fragment 191). He is also supposed to have prophesied the coming of a white, female bear, to have killed a dangerous snake by biting it, and to have prophesied to his followers approaching political strife (Aristotle, fragment 191). Recent scholarship has moved away from the idea of Pythagoras as an expert in mathematics, geometry, or harmonics, or as someone who believed there was a harmony of the celestial spheres. Rather, Pythagoras is seen as an advocate for a way of life based on stringent dietary regulations and strict self-discipline, and as an expert on the observance of religious ritual. There is, however, no reliable evidence that Pythagoras entered trances or ecstatic states in the manner of a shaman. Pythagoras believed in metempsychosis, that the soul moves to a new body, possibly an animal one, on the death of

the old body. It is not clear, unless Pythagoras believed that one could transcend this cycle, that there was a world of the dead with which human could communicate. The Pythagoreans, nonetheless, formed a broad church with a wide diversity of views on the soul, magic, and numerology.

A further question which involves the definition of shamanism is transmission or ubiquity. The more tightly one defines shamanism around the initial Tungus example, the more likely one is to require a route of transmission for shamanism. Kingsley (1994) has made such a case for a transmission from Siberia to ancient Greece, citing a path through ancient Iran. However, Zhmud (2012, 212–215) has now cast considerable doubt on Meuli's view of transmission via the Scythians on the Black Sea coast. Zhmud shows that it is highly doubtful that the Scythians were in any proper sense of the word shamanistic. It is also possible, however, to take the view that shamanism, given a looser and more inclusive definition, is a ubiquitous phenomenon, appearing in many unconnected cultures throughout the world and whose clearest expression (in the history of western anthropology) may be Siberian. If so, there is no need of a path of influence from Siberia to Greece (see Zhmud 2012, 210). KRS (229) argue as follows:

> It is doubtful how far a historical case can be made for an influence upon Archaic Greece from Central Asian shamanistic cultures, or to what extent an institution central to the life of politically primitive nomadic peoples could in any case illuminate the activities of a Greek sage in the more complex society of a rich and powerful city state.

This may be too dismissive of shamanism as a ubiquitous phenomenon and of Dodds' injunction that we cannot simply assume that the Greeks were immune to such practices.

Empedocles as a Shaman?

There is a further debate as to whether Empedocles was a shaman. Dodds (1951, 146) has claimed:

> Empedocles represents not a new but a very old type of personality, the shaman who combines the still undifferentiated functions of magician and naturalist, poet and philosopher, preacher, healer and public counsellor.

The passage which is critical to the debate is Empedocles *TEGP* 173, which says:

> All the remedies (*pharmaka*) which exist as a defence against evils and old age
> You will learn, as for you alone will I accomplish all these things
> You will stop the might of tireless winds which over the earth
> Sweep and destroy fields with their gusts
> Then again, if you wish, you will bring on the requiting winds
> You will produce from a black rainstorm seasonal drought
> for men, and out of a summer drought you will generate
> Tree nourishing streams that dwell in the aether
> and you will bring back from Hades the strength of a man who has died.

The last line here has led some commentators to compare Empedocles to a shaman (Dodds 1951; Kingsley 1995). However, I would disagree with Kingsley (1995, 41), who comments:

> There can be no possible justification for avoiding the literal meaning of this remarkable statement or trying to interpret it away allegorically.

It is possible to take this line literally, but given that Empedocles wrote in poetry and that other parts of his poem are clearly allegorical, we can at least consider other ways to interpret this line. Let us start with the magical interpretation. We might take *pharmaka* in the sense of a magical potion, "for you alone" as typical of privileged mage/adept relationships (Kingsley 1995, 221, note 13 for parallels with magical texts), weather working as magical (cf. Hippocratic *On the Sacred Disease* 4.10–16; see above, §9), and the last line as literal. One might also look to the ideas of divination, cunning art, and healing as we get in *TEGP* 174 (below). Communing with the spirits of the dead is one thing that a shaman does. However, there is no mention of any sort of altered or transcendent state of consciousness in Empedocles or of how such a state might be attained.

The alternative approach to *TEGP* 173 is to explain *pharmaka* simply as medical remedies, "to you alone" as poetic emphasis (it would be odd to advertise privileged knowledge in a poem open to all!), weather working as enhanced natural knowledge, and the final line as an allusion to resuscitation or aiding recovery from some near-death experience where someone's life force might be thought, poetically, to have departed for Hades. One might argue that this fragment begins and ends with something medical and mirrors the cyclical patterns and themes found elsewhere in Empedocles. Empedocles' extensive medical works are now lost (cf. *TEGP* 3, 5, 13, 14). Empedocles also gives a strong natural account of cosmogony, zoogony, and the cosmological cycle in general. One can argue that this allows an interpretation of this passage in natural terms. Curd has commented:

> In B111 (*TEGP* 173) Empedocles holds forth the promise of remarkable and seemingly supernatural skills, yet embeds this promise in the naturalistic account of the roots of all things, of the forces that combine and separate these roots and the consequent formation of the *kosmos* and living things. (2005, 13; cf. Longrigg 1993, 27)

TEGP 174 is also the subject of debate:

> O Friends, who live in the great city of the yellow Acragas,
> in the highest part of the city, caring for good deeds,
> I greet you. I am a divine god to you, no longer mortal
> I go around honoured by all, as is fitting
> crowned with ribbons and festive garlands
> I am revered by all I come upon as I arrive at flourishing towns,
> men and women. They follow me
> in countless numbers, asking for a short cut to cunning art (*kerdos*),
> some eager for divination, some for diseases
> of all kinds seeking to hear an oracle of healing,
> for too long having been pierced by pain.

Empedocles' claim to becoming a god has been much debated. Who can become a god? *TEGP* 210 says:

> In the end they are prophets (*manteis*) and minstrels and doctors and foremost men among those who dwell on earth, they then rise up as gods of highest honour.

I have translated *TEGP* 174 favorably for a magical interpretation. *Kerdos*, usually translated as "profit," can also have a sense of "cunning arts, wiles," which may fit with the references to divination and healing oracles. Of course, there are strategies for producing an interpretation of *TEGP* 174 which fits natural philosophy, based on alternative translations for some words and the idea that the key here is the crowd's perception of Empedocles.

14. Conclusion

Pythagoras and Empedocles make interesting cases in illustrating that it is not merely the Greek populace who are involved in questions concerning magic, but some of those who were considered natural philosophers as well. Empedocles is also interesting in that attempts have been made to marginalize *TEGP* 173. One commentator has denied it was genuinely Empedocles. Others, believing that Empedocles wrote two books, have tried to place it in "The Purifications" (*Katharmoi*) rather than in "Concerning Nature" (*Peri Physis*). They have then sought to privilege *Peri Physis* as the key work. Initially, when the first binding magic materials were found, there was doubt as to whether they were genuinely Greek materials. Magic and curses were an important part of Greek and Roman culture whether they fit into any idealized versions of those cultures or not. Both cultures also retained magical etiologies for disease and magical treatments for disease in competition with the Hippocratic tradition of natural etiology and treatment.

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NOTES

1 Tablet BM 47753, 25th or 26th tablet in a series known as *Sakikiu*, "all diseases," dated to the middle of the first Millennium BCE, trans. Wilson and Reynolds 1990. For the Christian view, Mark 9.14.

CHAPTER 27

Healing Shrines

Georgia Petridou

1. Introduction

"The merest schoolgirl, when she falls in love, has Shakespeare or Keats to speak her mind for her," Virginia Woolf (1930, 6–7) asserts in her well-known essay *On Being Ill*, "but let a sufferer try to describe a pain in his head to a doctor and language at once runs dry."[1] Perhaps this sort of ineffability of pain and anxiety caused by illness is partly responsible for the hundreds of thousands who continue to seek healing by religious means even nowadays, in an age when biomedicine and body-centered therapeutic methods prevail. Alternatively, the phenomenon of seeking medical treatment by a divine healer, pagan and Christian alike, could be explained by the deeper need of the individual for specialized treatment and personal one-on-one communication and interaction, a need that surfaces even more prominently in moments of extreme danger and personal crisis. One must not forget, however, that disease is not necessarily confined to the private realm. It is also of concern to the community, to the extent that the physical and psychological health of the individual is a prerequisite for a healthy and thriving community and for the perpetuation of its socio-political structures and cultural values.

In antiquity, the idea that gods granted health to the individual and the community, and that they were also able to deprive them of it, was widespread.[2] Indeed, the belief that an illness could be a form of divine punishment (*theodicy*) is widely attested in Greek and Roman literature, inscriptions, and archaeological findings. In Euripides' *Hippolytus* (141–144), the chorus wonders who among the gods is responsible for Phaedra's unusual behavior: is she possessed (*entheos*) by Pan, Hecate, the Corybantes, or the Mother of the gods? Phaedra herself, on the other hand, is convinced she has been afflicted by god-sent madness. In Sophocles' *Ajax* (172–186, 756–777), Athena is evidently behind

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Ajax's mental illness. In the Hippocratic *On the Sacred Disease* (1.11 Jouanna), the purifiers (*kathartae*) try to diagnose the divinity responsible for the disease: if the patient imitates a goat, or roars, or suffers from convulsions in the right side, then the mother of the gods is responsible. If he utters a loud cry and sounds like a horse, then Poseidon should be held accountable for the illness (see further, van der Eijk 2005, 48–60). Indigenous deities of Phrygia and Lydia are entreated as both the senders and averters of disease that has aggrieved their dedicants in local propitiatory inscriptions dated to the second and the third centuries CE.[3] Both in Epidaurus (*IG* IV^2 1,258) and Pergamon (*IvP* III, 161A), two of the best known cult centers of Asclepius (§3, below), the god was said to have chastised non-believers and those who did not pay their medical fee (*iatra*).[4]

2. Healing Deities and Their Shrines

From a methodological point of view, it is important to stress from the start that temple healing is a significant aspect of the history of medical thought and practice, and as such it deserves a place in a collective work that aims at examining the historical development of scientific thought and practice in Ancient Greece and Rome. Scholarly views framed in the nineteenth-century positivist duality of science versus religion and rational medicine versus irrational medicine, like those found in James Longrigg (1993), have now been abrogated as anachronistic and methodologically flawed. In fact, literary and epigraphic evidence, as well as archaeological findings, point to close correlation between secular and temple medicine, the latter aptly described by Parker (1983, 249 note 36) as "secular medicine … but with an injection of the supernatural."[5]

In particular, the upsurge of the so-called Hippocratic medicine (that is, the kind of medicine recognizing natural causes of disease, as opposed to supernatural explanations of illness and its symptoms) was concurrent with the rise of healing shrines, as far as we can judge from material evidence discovered in healing shrines in Attica and the environs, as surveyed by Gorrini (2005). This element by itself could be interpreted as indicating a symbiotic relationship between secular and "sacralized" healing practices. More significantly, a close reading and comparison of the texts of the so-called *Corpus Hippocraticum* and votive inscriptions found in the healing shrines of Attica would also soon reveal that the similarities between the two extend beyond the confines of chronological development and go well into the all-too-important area of scope and methodology. This synergy of secular and sacred doctors is not restricted to Attica and is even more evident in second-century CE authors who refer extensively to religious healing in temple contexts, such as Pausanias, Aristides, and Philostratus. As Horstmanshoff has put it very pertinently:

> Temple medicine is an integral part of ancient medicine. Medical history cannot only be written from the point of view of the physician, but should include the perspective of the patient, for whom an intellectual Hippocratic physician was not always the obvious choice. Inscriptions, papyri and a self-serving document like Aristides' "night book" bear testimony to that fact. There was no opposition or rivalry between temple medicine and Hippocratic medicine. The story that Hippocrates copied out the *iamata* at the temple of Asclepius in Cos (Str. 14.19, Pliny, *Nat.* 29.2.2), the presence of the gods as witnesses to

> the "Hippocratic Oath," and the attendance of physicians at the temples all point to a symbiotic relationship. (2004, 337–338)

Out of the many healing deities, most readers would be familiar with Asclepius and his well-known cult centers scattered all around the Greco-Roman world: Cos, Epidaurus, Corinth, and Pergamon. Asclepius came to be seen as "the healing god *par excellence*," as Nutton (2013, 104) puts it laconically. However, it is significant to note here that potentially every Greek deity was able to affect matters of human health negatively or positively. In Troizen, for instance, Pausanias (2.32.6) saw the temple of Pan Lyterios ("the one who releases from disease"). The people of Troizen were afflicted by a plague, and the god, manifesting himself to a sleeping magistrate, supplied a cure for the epidemic. In Tanagra, once again according to Pausanias (9.22.1–2), it was Hermes who averted a pestilence from the city by appearing as a youth and carrying a ram on his shoulders around the city walls; while in Aigialeia (Pausanias 2.7.7–8), Artemis and Apollo, entreated by the locals, came to the acropolis and saved the community from the deadly disease that had befallen them.

There is, however, a group of deities traditionally associated with both curative and preventive medicine, such as Apollo (with the cultic titles of Paion and Epikourios) and his son Asclepius, Heracles Alexikakos ("averter of evil"), Athena Hygeia (the personified virtue of Health), and, imported from the East, Sarapis, Isis, and Zeus Hypsistos, a major healing deity of later antiquity.[6] Their sanctuaries became the foci of pilgrimage for a great number of patients and their relatives, while in the Second Sophistic many of these temples catered to the eclectic taste of the contemporary socio-political elite, who visited these sanctuaries repeatedly in attempts to revive the glorious Classical past (especially in the Antonine era: Galli 2005). To think of these sanctuaries as modern hospitals would be to miss the point entirely. Mylonopoulos (2013) urges the reader to compare a patient's stay at the ancient Asklepieia to an extended visit to a spa, rather than a hospital. Indeed, these carefully designed architectural complexes, which have gained the admiration of modern hospital designers and architects (Barefoot 2005), could not be more different from our modern hospitals, resembling instead modern spa facilities and having as their focal point a sacred spring or fountain of sorts. Besides the temple and/or the temples of ancillary deities, ancient pilgrims (the literary and epigraphic sources refer to them occasionally as *hiketai* or *theoroi*) happened upon the *palaestra*, *abaton*, or *enkoimetērion* (where incubation, i.e., healing dreaming, was practiced), and often a gymnasium or stadium and a theater area.[7] Archaeological, literary, and epigraphic sources, as Melfi (2010) argues, attest to the existence of performative rites (e.g., processions, songs, mimetic dances, and dramatic re-enactments of divine myths, etc.) in the sanctuaries of Asclepius in Athens, Epidaurus, and Messene, at least during the Roman Imperial period. This is by itself a strong hint that the healing event in those sanctuaries went beyond somatic recovery and well into the holistic treatment of both the patient's body and mind. It is pain and illness that fragments the human body (this process of fragmentation is alluded to in the anatomical votives as Hughes 2008 and forthcoming argues), and it is up to the divine healer to reunite and heal this fragmented body and mind. But what exactly happened in those Asklepieia? How did Asclepius heal his patients?

3. Incubation: "The Medical Art Consists of Sacred Dream-Visions"

Aristophanes' *Plutus* (especially 698–747) along with Aelius Aristides' *Sacred Discourses* (*Orations* 47–52 Keil) and Plautus' *Curculio* (61–62, 216–222, 273—following a Greek original of the third century) are our three most extensive literary accounts of incubation in Asclepius' temples; while substantial epigraphic records come from the god's temples in Epidaurus, Athens, Rome, Pergamon, and Lebena (Nutton 2013, 110; Melfi 2007a, 2007b). In Epidaurus, in particular, we find lengthy accounts of the diagnostic and healing process followed there, which essentially amounts to detailed descriptions of the god's healing epiphanies. These are the celebrated Epidaurian *iamata* (Prêtre and Charlier 2009). As LiDonnici (1995, 40) rightly argues, it is naïve to treat those accounts as the creations of pious patients. They are mainly the product of the Epidaurian priesthood's careful collection, arrangement, and adaptation of a large variety of source material, which ranges from individual narrative and pictorial votives to oral tradition attached to temple features and state-sponsored inscriptions. The same holds true of the inscriptions from Lebena (Crete) and Rome.[8]

None of these literary or epigraphic sources provides us with an exhaustive description of a *paradigmatic* healing process, in the sense that they include elements that must have been particular to the time and the place the healing happened. Nonetheless, they all more or less describe a phenomenon called incubation ("healing sleep," derived from the Latin verb *incubare*; κατάκλισις [*kataklisis*] or ἐγκοίμησις [*enkoimēsis*] in Greek), briefly described as follows: the patient most commonly sleeps in a temple or other sacred precinct either to be healed by the healing deity on the spot, or to obtain a remedy for subsequent healing (see further, van Straten 1976). Incubation also occurs in caves and grottoes dedicated to various healing deities, such as Pan, the Nymphs, and the Anatolian god Men. The sleeping occurs either on beds of straw, or in some cases, like that of the Amphiaraos in Oropos (see §6), on the hide of a sacrificial animal (*LSCG* 69 with Lupu 2003). Both the healing and remedy for subsequent healing are administered in a dream-vision (ὄνειρος, ὄναρ, ἐνύπνιον, ὅραμα, φάσμα, φάνταsμα, ὀπτασία, ὅρασις, etc.).[9] Preliminary purification rites as well as sacrifices and offerings to specific deities prior to entering the *abaton* or *enkoimetērion* ensured the effectiveness of the incubation (see further, van Straten 1995, 69–71; Stafford 2008). In most cases, patients themselves sleep in the temple hoping to acquire a healing vision. However, to engage in incubation for the illness of others is also widely attested. This is, for instance, the case of Arata from Lacedaemon, who suffered from dropsy (IG IV^2, 1, #121–122, B21). Arata's mother slept in the temple of Asclepius in Epidaurus for her daughter's sake:[10]

> Arata of Lacedaemon, dropsy. For her sake, her mother slept here, while she remained in Lacedaemon, and she saw a dream. It seemed to her the god cut off the head of her daughter and hung the body neck downwards. After much fluid had run out, he untied the body and put the head back on the neck. Having seen this dream she returned to Lacedaemon and found on her arrival that her daughter was well and that she had seen the same dream. (trans., LiDonnici)

There is no decisive evidence about abstinence from certain kinds of food and drink, as rightly maintained by Edelstein and Edelstein (1998^2, 148–149), although in some

cases certain foods and sexual intercourse were regulated or avoided altogether. In a passage from Philostratus' *Life of Apollonius of Tuana* (1.9), we read about a young Assyrian man who made scornful remarks regarding not having received any healing visions, despite the fact that he came to the god's temple and practiced incubation. At the same time, though, he did not make any effort to curtail his luxurious and extravagant lifestyle. That was exactly why Asclepius did not visit the youth in his dreams: ἠμελεῖτο δὴ ὑπὸ τοῦ Ἀσκληπιοῦ διὰ ταῦτα, καὶ οὐδὲ ὄναρ αὐτῷ ἐφοίτα. Overhearing his criticism and revealing himself to the youth, the god advised him to befriend Apollonius and consult him on this matter. Apollonius reproached the young man for uttering blasphemous words and explained that the god reveals himself to those who crave healing (το ῖς γὰρ βουλομένοις δίδωσι), not to those who undermine their own health. Asclepius, the divine healer, seems to manifest himself only to those who make an active effort to improve their lifestyle and follow the prescribed regimen.

Nevertheless, the most frequent kind of criticism Asclepius received was related to the god's "multilocality": his absence at the moment of need from one specific sanctuary due to obligations to other patients at different healing locations. Indicative are, for instance, the complaints expressed by Themistius of Byzantium (*fl.* 340–385 CE) in the *Private Orations* entitled *On the Need to Give Thought* (*Oration* 27.333d with Penella 2000, 164–173). Reacting against the idea that Asclepius might not be present in the local temple and forcing the patient to travel to the more prestigious Asklepieion of Epidaurus, Themistius compelled Trikka to consult the god. By the same token, in one of the Epidaurian *iamata* (*IG* IV² 1, B23), we learn about a certain Aristagora, who, suffering from tapeworm, slept in Asclepius' sanctuary in Troizen but failed to encounter the god in her sleep because the god "was out of town" (οὐκ ἐπιδαμοῦντος) attending to his clientele at his temple in Epidaurus (ἀλλ᾽ ἐν Ἐπιδαύρῳ ἐόντος). Oblivious to the god's absence, Asclepius' sons proceeded with chopping off Aristagora's head. They would have failed to put it back had the god not returned from Epidaurus to Troizen (ὁ θεός ἵκων ἐξ Ἐπιδαύρου). When the god came back, he reattached the head, cut open her belly, removed the tapeworm, and stitched her up. This reference to the sons of Asclepius may well be to the secular doctors, collectively known as the *Asclepiadae*, who were associated with the temple (see Parker 1996, 177). If so, one may also argue that the passage neatly subordinates the prescriptive voice of fourth-century CE secular medicine to the authority of the divine healer. Similar delinquencies were not unknown even in Epidaurus, as we can conclude from Aelian's account of a woman, who, while suffering also from tapeworm, came to the god's temple to receive treatment (*On the Nature of Animals* 9.33). Just as in Aristagora's case in Troizen, the god happened to be absent (οὐ παρῆν ὁ θεός). In her dream, the god's overconfident helpers decapitated her, and one of them pulled out the tapeworm. He could not, however, re-attach her head, and the woman died. Once the god returned to Epidaurus, he put the woman's head back in its place and raised her from the dead!

Epiphanic revelations in the course of a dream prescribing appropriate remedies and courses of action are at the heart of Asclepian temple medicine, and they even epitomized the medical art per se according to Iamblichus: "Thus, in the temples of Asclepius diseases come to an end by means of divine dreams; and, because of the order of the nocturnal epiphanies, the medical art consists of sacred dream-visions" (*On the Mysteries* 3.3). To be sure, dreams used as diagnostic tools were not unique in the cult of Asclepius. On the contrary, dream diagnosis was known to and practiced by the author of the

Hippocratic *On Regimen* (cf. especially Book 4), Galen or pseudo-Galen (if we are to judge from his work *On Diagnosis from Dreams*) and Rufus, the Ephesian physician and contemporary of Galen (compare, for instance, the emphasis placed on diagnostic dreams and their interpretation in his *Medical Questions*), as rightly argued by Holowchack (2001, 382–399). What is unique in Asclepius' cult is that dreams become not simply the diagnostic but also the therapeutic means of treating an illness.

Occasionally, nonetheless, it is not clear at all whether the god appears in a dream or a waking vision. In these cases, the god is described as appearing "halfway between sleep and waking" (αὐτὸς ἥκοι καὶ μέσως ἔχειν ὕπνου καὶ ἐγρηγόρσεως), as, for instance, in the case of Aelius Aristides, who was seeking a remedy for his condition at the Pergameme Asklepieion (*Sacred Discourses* 48.32 Keil). To be fair, we do occasionally come across reports of Asclepius manifesting himself in waking reality, but, admittedly, these cases occur only very rarely. In Aristophanes' *Plutus* (633–747), for instance, Karion is not asleep when the god approaches him and the blind Pluto. Another instance of the god appearing in waking reality is that of Sostrata from Pherae (*IG* IV², 1, #121–122, B25, with Herzog 1931, 18). Having experienced a false pregnancy, Sostrata slept in the Epidaurian Asklepieion, yet without fruitful results. On her way home, the woman met a handsome man, who, after learning about her misfortunes, cut her belly wide open and set her free from the various creatures that she was carrying. When he had sewn up her stomach and made the woman well, Asclepius revealed his identity and ordered her to send his medical fee to Epidaurus.[11] This story, along with similar ones (originally from a votive relief?), must have been carefully and craftily reworked by the priestly personnel in their attempt to advertise the possibility that prima facie unsuccessful incubations may prove to be fruitful later on. This celebratory and simultaneously didactic feature is typical of the Epidaurian *iamata* (Dillon 1994).

4. Isis, Sarapis, and Hemithea

Temple medicine and incubation were also practiced in the temples of both Isis and Sarapis. In the third book of his *Sacred Discourses* (49.45–46 Keil), Aristeides gives the impression that he had frequented the temple of Isis in Smyrna much as he had done so in the case of other healing deities, and that, in fact, he believed that he enjoyed some kind of privileged relationship with the goddess. Diodorus of Sicily (1.25.2–5) attests to the popularity of Isis as a healing deity:

> For practically the entire inhabited world is their witness, in that it eagerly contributes to the honors of Isis because she manifests herself in healings. For standing above the sick in their sleep she gives them aid for their diseases and works remarkable cures upon them as they submit themselves to her.

The popularity of Sarapis as a healing deity, in particular, rose in the Hellenistic period, when his status rivaled that of Asclepius, and at least one relief depicts incubation performed in an *enkoimetērion* of Sarapis (van Straten 1981, 98 and figure 42). That sleeping in the temple of Sarapis resulted (or at least should result) in divinely inspired dreams, in which the god was expected to appear, is implied by Cicero: "It can be either Asclepius or Sarapis who is able to prescribe a treatment for health in sleep" (*an Aesculapius, an Serapis potest nobis praescribere per somnum curationem valetudinis*: *On Divination* 2.123;

see also Tacitus, *Histories* 4.84.5). From Diodorus (5.62–63), we also learn of Hemithea of Chersonesus, another healing deity who used to manifest herself in the sleep of patients practicing incubation in her temple. Hemithea's temple was so popular that during the Persian Wars her sanctuary was one of the very few that was not plundered.

5. Apollo Epikourios

While Asclepius appears more concerned with the health and illness of the individual, his father Apollo seems more concerned with the public aspect of health and disease. In the first hundred lines of the *Iliad*, Apollo—under the cult epithet Smintheos—is credited with both sending and averting a plague. In historical times, Apollo was again credited with causing and averting the plague that tormented Athens during the Peloponnesian War. The pestilence beleaguered the Athenians on and off for almost six years (430–426 BCE: Thucydides 2.47–55.1) and killed almost one third of the population. In the same fashion that the Achaeans in Troy tried to appease the god, having experienced the devastating results of his wrath, the Athenians tried to appease Apollo, this time by exhuming and removing all the burials from the god's birthplace, Delos. As Robert Parker (1983, 54–55) has shown, Greeks considered both birth and death as a source of ritual pollution (*miasma*), which required ritual purification (*catharsis*). In an attempt to eliminate the danger of a recurrent ritual pollution in the future, no births or deaths were to occur on the sacred ground from 426 BCE onward. The Athenians also revived the great Ionic festival, Delia, to commemorate their deliverance from the plague and Apollo's part in their *Soteria* (deliverance/preservation). Apollo was credited with averting the epidemic, and he was worshipped as Alexikakos. Enraged with the Milesians, Apollo punished them by sending a plague, averted by a certain Branchos, the mythical ancestor of the Branchidae. The tale became the foundation myth (*aition*) of Apollo's temple in Didyma (Callimachus, fragment 194.28–31; Burkert 1985, 147), while Apollo's averting of the plague of 430 became the *aition* for founding his temple in Bassae in Arcadia, where he was worshipped as Apollo Epikuorios, "the helper" (Pausanias 8.41.7–9; Burkert 1985, 147; Cooper 1996).

Healing remained one of Apollo's characteristic cult traits despite the fact that Asclepius dominated the medical scene of the fifth and fourth centuries. They functioned together in Epidaurus. It was to Apollo that the ailing person, garlanded with bay, offered preliminary sacrifices at the Epidaurian Asklepieion, while the sanctuary of Apollo Maleatas in Epidaurus enjoyed great popularity as well. It is also possible that the principal sanctuary of Epidaurus might have been initially dedicated to Apollo or jointly to Apollo and his son Asclepius. Asclepius remained dependent on Apollo to such an extent that the Epidaurian *iamata* are dedicated to both gods.

6. *Heros Iatros* and Amphiaraos

In addition, great popularity is attested for the cult of *Heros Iatros* (the hero physician). This figure was known under different names in different places: Amphilochos in Athens, Aristomachus in Marathon, and Oresinios in Eleusis; whereas in Rhamnous he was known as Aristomachus and later on as Amphiaraos (Parker 1996, 176–177; Nutton 2013, 10–09). In Oropos the cult of the hero doctor Amphiaraos became the leading healing cult, and it soon acquired Panhellenic status, attracting visitors from all over

the Greek-speaking world. The "grammar" of incubation practiced in his sanctuaries is demonstrated particularly well in votive reliefs such the famous votive of a patient called Archinos (Figure 27.1; see further, van Straten 1981, 63–146). Found in the sanctuary of Amphiaraos at Oropos and dated to circa 400–350 BCE, this marble relief is in the shape of a *naiskos* (small temple).[12] The inscription (*IG* VII 303) reads: "Archinos dedicated [this relief] to Amphiaraos."

This relief illustrates three different aspects of a medical encounter. In the first scene on the far left, shown in highest relief (an indication perhaps of its chronological priority), a bearded Amphiaraos leans on his staff and treats with a scalpel the right shoulder of a young man, in all probability Archinos himself. The young man occupies the middle part of the relief, here shown slightly smaller, frontal and prone on a bed, while a snake (a zoomorphic manifestation of Amphiaraos or perhaps one of the many sacred snakes inhabiting healing temples) treats his shoulder. Finally, on the right panel, the same young man appears again, standing up and raising his right hand in veneration. The panel on the tall base in the background (a dedicatory stele to Amphiaraos?) functions as a part for the whole of the healing temple where the events take place. Two apotropaic eyes are shown on the center of the cornice, above the relief.



Figure 27.1 Marble votive relief in the shape of a *naiskos* (small temple), found in the sanctuary of Amphiaraos at Oropos dated to circa 400–350 BCE, now in the National Museum of Athens (NM 3369). Dimensions: height 0.49 m., width 0.54 m (19.3″ × 21.25″). (*Source:* akg-images/Erich Lessing.)

The scene has been variously interpreted (Petrakos 1968; Petsalis-Diomidis 2006; Dignas 2007). According to van Straten (1981, 124–129, #16), the scene on the left (i.e., Amphiaraos in human form treating the patient in the manner of a secular physician by using a medical utensil) represents Archinos' dream, while the middle scene (Amphiaraos in a theriomorphic manifestation or a sacred snake in action) represents the same healing event, but this time from the point of view of bystanders. Finally, the third scene with the votive pinax on the pillar represents the worshipper Archinos expressing gratitude for the divine cure. More significantly, both the first and second scenes underline the intimate contact of patient with divine healer, a unique proximity with the divine which comes second only perhaps to the mystic union of the *mystēs* (the initiate in a mystery cult) and his god/goddess. Such an intimate physical interaction is generally expected between a patient and divine physician. Interacting with the healing deity via a dream and securing a treatment of sorts was the main goal for those who populated the temples of Asclepius, Amphiaraos, Hemithea, Isis, Sarapis, and other healing deities and heroes. Embarking on such a lengthy and expensive preparatory journey (both physical and mental) to seek the possibility of a medical encounter with the healing deity was merely the means to the ultimate aim: to experience a moment of extreme proximity with the divine, which would coincide with the moment that the healing deity finally appeared to diagnose and treat ailments (on the dangers of the theoric journey, Rutherford 1995).

7. Anatomical Votives and Specialist Healing Temples

One of the main criteria for characterizing deities as healers is the discovery of pertinent material evidence in their shrines: inscriptions, medical instruments, and funerary and honorary votives with explicit references to illness and healing and relevant architectural remains (likewise, relevant references in literature can support characterizing deities as healers). In Forsén's view, deities considered as paradigmatic healing deities ("Heilgottheiten"), and consequently the ones who receive the majority of anatomical votives, are Asclepius, *Heros Iatros*, Amphiaraos, Amynos, Apollo, Athena, Heracles, and Zeus in the cultic manifestations of Alexikakos, Soter ("Healer"), Hypsistos, Hypatos ("Supreme"), etc. Vikela (2006) offers an informative discussion of healing deities and their sanctuaries in Attica, but she goes too far in using anatomical votive offerings to distinguish between "genuine" and "not genuine" healing deities. On this view, for instance, Demeter may have received such dedications, but her sanctuary cannot be called a proper healing sanctuary, and Demeter herself is not true healing deity.[13]

But are these exactly anatomical votives? At the risk of sounding too simplistic, anatomical objects can be essentially defined as *ex-votos* in the shape of body parts (external and internal): hands, feet, ears, eyes, genitals, wombs, etc. (Figure 27.2; see further, Hughes forthcoming). To be precise, representations of internal organs are very rarely found in Greek healing sanctuaries. For example, only a heart (καρδία) and a bladder ([κ]ύστις) are mentioned in the inventories from the Athenian Asklepieion. Votives depicting internal organs, on the other hand, are mainly of Roman and Etruscan origins. These objects have been extensively examined and discussed by van Straten (1981, 111–112), Forsén (1996), Petsalis-Diomidis (2010), and, more recently, Hughes (2008 and forthcoming).[14] Anatomical votives were variably dedicated prior to the healing act or afterward. Thus they could function either as requests for a cure or as thank offerings.



Figure 27.2 Anatomical votives from the Athenian Asklepieion in the Archaeological Museum in Athens. (*Source:* © VPC Photo / Alamy.)

These objects underline the fragmentary character of such bodily parts, which were thus seen as isolated from the rest of the dedicator's body and via the act of dedication became the property of the petitioned healing deity and their sanctuary (Hughes 2008, forthcoming; Petsalis-Diomidis 2010, chapter 5). The patient's bodily parts became the loci of the divine conduct and healing, and these anatomical votive offerings became in turn the material evidence, if not for the act of healing itself, then certainly for the worshippers' steadfast expectation of it. It was pain and disease that fragmented the human body, and it was up to the divine healers to restore the human body to health and completeness, as the following extract from Aristides amply shows:

> But some, I mean both men and women, even attribute to the providence of the god the existence of the parts of their body, when their natural bodily parts have been destroyed; others list other things, some in oral accounts, some in declarations of their votive offerings. For us it is not only a part of the body, but it is the whole body which he has composed and put together and given as a gift, just as Prometheus of old is said to have fashioned man. (*An Address Regarding Asclepius* [*Oration* 42.7 Keil]; trans., Behr, modified)

Given that eye votives were the most frequently mentioned anatomical votive in the inventory from the Asklepieion at Athens (IG II^2 1532–1537, 1539), it is surprising how few of those eye-shaped votives were excavated in the Corinthian Asklepieion. Roebuck (1951, 114–115) understood this surplus of one kind of anatomical votive in one sanctuary and not in another as material evidence that different sanctuaries specialized in different kinds of illnesses. On this view, eye-related illnesses were the "specialization" of the Athenian Asklepieion but not of the Corinthian. van Straten (1981, 150) reacted strongly against this interpretation:

> However, we should bear in mind that these conclusions are only valid, if we assume that the known votive offerings from these sanctuaries form a representative collection. I doubt whether that is true. The striking predominance of eyes in Athens is incontestable, but their scarcity at Corinth is another matter. After all, out of the more than 150 Athenian dedications, only three really remain. All the other eyes were gold and silver votives that do not survive, but of which we happen to have an epigraphical record because the Athenians were rather given to inscribing all sorts of decrees and inventories on stone. For all we know, the Asclepieia of Corinth and Epidaurus may have been just as rich in gold and silver *týpoi*, which, like the Athenian ones, have left no tangible trace, and, unlike the Athenian ones, no epigraphical record either. That gold and silver votives indeed occurred there may perhaps be inferred from the gilded marble relief found at Epidaurus and the gilded terracottas from Corinth.

Jaeger (1988, 11) is also right when he begs for careful consideration of the perishable nature or extremely precious material from which some of these eye-shaped *ex-votos* were made before reaching rash conclusions: "Among the votives of the eye only material such as terracotta, stone, and metal is preserved."

This ritual practice of dedicating model parts out of metal, marble, and terracotta is not restricted to pagan healing deities. On the contrary, dedications of anatomical votives continue to swarm Italian Catholic and Greek Orthodox churches, like the Catholic churches at Santa Lucia (Cassell 1991) and Santa Maria, and the Orthodox churches of Agioi Anargyroi (Matthews 1969), Agia Thekla, and Agia Paraskeve (Merrifield 1987,

88; Hughes 2008, 218). It seems that the intervening centuries and the prevalence of biomedicine and body-centered healing practices have done very little to diminish hopes for that special extra care and attention that only divine healers can provide.

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FURTHER READING

For a general overview on health and disease in the ancient world, see King 2005. For a comprehensive analysis of the daily life in the healing sanctuaries, see Dignas 2007. Gary Ferngren's introduction to the 1998 reprint of the 1948 two-volume study by Emma and Ludwig Edelstein offers a useful overview of the evidence on the cult of Asclepius and the areas surveyed by the Edelsteins. The reader who seeks an exhaustive archaeological and historical study is referred to Riethmüller 2005. The material evidence collected from the Asklepieion of Athens is expertly collected and discussed in two books by Aleshire 1989, 1991. Benedum 1986 and Wickkiser 2008 offer an in-depth analysis of the political motives behind the introduction of the cult of Asclepius

in Attica. Individual healing sanctuaries have also received considerable amount of attention. Melfi 2007a expertly discusses the Asklepieion in Lebena; Petrakos 1968 is still the reference work for the Amphiareion in Oropos; while the reader interested in the Asklepieion of Corinth is referred to Roebuck 1951 and Wickkiser 2010. Petsalis-Diomidis 2010 offers an informative discussion of both the material evidence and the literary sources that throw light on the life of the ancient pilgrims at the Asklepieion of Pergamon. On the visual dynamic within the healing sanctuaries, see van Straten 1990, Petsalis-Diomidis 2005, and Mylonopoulos 2006. Finally, Montserrat 2005 offers an informative exposition of the some of the most well-known Christian healing cults.

NOTES

1 Virginia Woolf, *On Being Ill*, introduction by Hermione Lee (Ashfield, MA: Paris Press, 2002). The Hogarth Press published *On Being Ill* as an individual volume in 1930, but the work first appeared in 1926 in the *New Criterion*. I am indebted to the research program "Medicine of the Mind-Philosophy of the Body—Discourses of Health and Disease in the Ancient World" at Humboldt Universität zu Berlin and to its director Philip van der Eijk for his help and financial support. I am particularly grateful to Wolfgang Häfele for reading a draft of this paper and his help with the bibliographical references. I am also extremely grateful to the Lived Ancient Religion, ERC-funded project at Max-Weber-Kolleg, University of Erfurt, and to its director Jörg Rüpke and co-director Rubina Raja for allowing me to complete the final stages of this study.

2 Parker 1983, 234–256; Lloyd 2003, 12–13. In Christian healing culture, we find the comparable idea that disease can be caused by demons who occupy the patients' body and make them ill.

3 More on these inscriptions in Chaniotis (1995) and (2004). The corpus of the propitiatory inscriptions has been collected by G. Petzl.

4 On inscriptions commemorating or requesting relief from god-sent disease, see van Straten (1981, 101–103) and Parker (1983, 254–256).

5 Cf. Parker (1996, 184): "Divine healer though he was, Asclepius had the wisdom never to resist the developing secular 'art' of medicine. On the contrary, he appropriated it: not its substance perhaps but its symbols, its aura, its prestige. We already find various medicinal instruments listed in an early inventory of the Asklepieon in the Piraeus, and represented behind the god on Telemachus' monument; and the public physicians of Athens actually sacrificed twice annually in the hero's shrine. The truest explanation for the rise of Asclepius may be that he was, as it were, in partnership with Hippocrates." On the cooperation of secular and religious healing and their practitioners see also Holowchack (2001, 386) and Nutton (2013, 111–115). For an informative overview of the various methodological approaches in the study of ancient medicine and its place in the history of medicine as whole, see van der Eijk (2011).

6 On Heracles Alexikakos, see Kearns (1989, 14–15), and Parker (1996, 175, 186). On the cult of Hygeia and her association with Athena Hygeia, see Stafford (2005) and Leventi (2003). On the iconography of the goddess Hygeia, see Croissant, F., 1990 s.v. "Hygieia," in *LIMC* 5.554–572. Wild (1984) provides a comprehensive study of all the known sanctuaries of Isis and Sarapis in the Roman world.

7 Barefoot (2005) and Melfi (2010). Tholos buildings were also to be found in the larger complexes. On this and generally on the function of the various architectural features of the Asklepieia, see Markschies (2006), where the reader can also find a floor plan of the Epidaurian Asklepieion (figures 1, 2) as well as photos depicting the *abaton* and the *tholos* buildings in the Epidaurian Asklepieion.

8 Cf. also Chaniotis (1995, 323). Epidaurus: IG IV².1 121–122 (late fourth century BCE) = Edelstein and Edelstein (1945) vol. 1, #423, 424; cf. Herzog (1931); Chaniotis (1988) 19–23 T2 (with bibliography). Lebena (second century BCE): *I.Cret.* I xvii. 8–12 = Edelstein and Edelstein (1945) vol. 1, #426; cf. Chaniotis (1988) 51–52 T 2 (with bibliography). Rome (second/third century CE): *IGUR*148 = Edelstein and Edelstein (1945) vol. 1, #438; cf. Chaniotis (1988) 8 6 T 21 (with bibliography). On the deities who most commonly receive such anatomical votives, see Forsén 1996, 133–159.

9 More on the terminology of the dream-vision: Hanson (1980, 1407–1409) and Harris (2009). On incubation, see Herzog 1931, Kerenyi 1959, van Straten 1976, Hanson 1980, LiDonnici 1995, Edelstein and Edelstein 1998², Holowchak 2001, Lloyd 2003, and Nutton 2003, and Petsalis-Diomidis 2006, 2010.

10 Cf. also the so-called Imouthes Papyrus *POxy* 1381. See further, Hanson (1980) and Pearcy (1988).

11 On this inscription and the meaning of the term *iatra,* see Prêtre and Charlier (2009, 36–40, 76). On the medical fee of the physician and its impact on the patient–physician relationship in the Hippocratic corpus, see Ecca (2014). *Praecepta.* Edition, Übersetzung und Kommentar; and *eadem* (forthcoming) "The *mistharion* of the physician: A case of self-representation in *Praecepta*."

12 N. Kaltsas, *Sculpture in the National Archaeological Museum*, Athens (Los Angeles 2002) 209 #425.

13 Björn Forsén mentions health-related dedications made in honor of Demeter and Kore (1996, 142–144), but he considers them primarily as two goddesses who preside chiefly over womanhood and childbirth ("Geburts-und Frauengottheiten"). However, as I have argued elsewhere (Petridou 2013, 2016, although Demeter's iatric activity was not as prominent as some of the aforementioned healing deities, both literary and material evidence suggest that in certain contexts she must have been thought of as regulating eyesight and blindness.

14 Forsén (1996, 1) gives an informative account of the anatomical votives of the Greek-speaking world, defined as follows: "Gliederweihungen (auch als Körperteilvotive, Körperexvotos, Gliedmaßenvotive bezeichnet) sind Darstellungen menschlicher Körperteile, die Göttern mit heilenden Kräften geweiht wurden, als Bitte um Heilung oder als Dank für die Geqanesung des abgebildeten Gliedes." See also pages 9–27, where Forsén discusses material representations of bodily parts that should not be thought of as anatomical votives.

CHAPTER 28

Regimen and Athletic Training

Jason König

1. Introduction

The ancient athletic trainer is a rather shadowy figure. Trainers were an ever-present part of Greek gymnasium culture from the Classical period onward, but they rarely receive sustained attention in the ancient sources. It is also hard to generalize about them: there was considerable variation in their social and intellectual status; they also performed a range of functions, and laid claim to a wide range of skills.

2. *Paidotribēs*

The majority of trainers occupied themselves with teaching athletic technique. In the gymnasium, they were responsible for coaching boys and young men, especially those going through the *ephebeia*, a period of military and athletic training in the late teens, and a key feature of Greek civic life from its origins in fourth-century BCE Athens onward. Some were also involved in preparing athletes for competition in the agonistic festivals spread across the Mediterranean world, which proliferated especially in the Hellenistic and Roman periods. The word most often used in Classical texts for these coaching experts was *paidotribēs*, first attested in the mid-fifth century BCE (Antiphon 3.3.6; Aristophanes, *Clouds* 973–974). That word came to be used almost interchangeably with *aleiptēs* and *epistatēs*. All three terms—especially *epistatēs*—occur commonly in Hellenistic and Imperial inscriptions.

These men could command considerable respect, especially when they were associated with athletes who won prestigious victories. Trainers are conspicuous in Classical vase paintings on athletic topics, usually standing to one side holding a stick and watching their charges closely (although we must stress that it is often difficult to distinguish

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securely between *paidotribai* watching practice in the gymnasium and competition judges in the stadium; see Figure 28.1). The tradition of thanking trainers for their part in athletic victory dates back to the victory odes of Pindar and Bacchylides (e.g., Pindar, *Olympian* 8.54, *Nemean* 4.93, 6.65 for the trainer Melesias; Pindar, *Nemean* 5.48 and Bacchylides 13.190–198 for the trainer Menandros). These texts tend not to represent trainers as figures who apply a systematic, professionalized body of expertise, portraying them instead as companions and advisers to the aristocratic athletes whose victories they enabled, perhaps to avoid the impression that the athletic glory they celebrate was based on commercial transactions (Nicholson 2005, 119–210). Later it is common for victory inscriptions to acknowledge the help of trainers—a more prosaic continuation of the Pindaric motif (e.g., Pausanias 6.3.6 for a statue honoring a *paidotribēs* at Olympia). This statue base from Smyrna, for example, recording the successes of a second-century CE runner, is typical: "… M. Aur …, best of the Hellenes, first of runners, having won 66 sacred contests under the instruction of the trainer Areios (ὑπὸ ἀλείπτην Ἄρειον) the Alexandrian, son of Hermeios" (the opening of the inscription, and the full name of the athlete, have not survived: Robert 1937, 138–142). The key phrase ὑπὸ ἀλείπτην ("under the instruction of the trainer x"), or sometimes ὑπὸ παιδοτρίβην ορ ὑπὸ ἐπιστάτην, occurs over and over again in other inscriptions too (Robert 1974, 520–523). Clearly these trainers were sometimes highly educated. There is also evidence for trainers holding political office in their home cities and using rhetorical skills, for example in presenting requests for funding (*IEph.* 1416, 2005, fourth or third centuries BCE; see König 2005, 313–314). Some trainers clearly moved in intellectually elevated company. For example, Plutarch's *Sympotic Questions* includes one account of a symposium in Athens: "Pretty well all of our friends were present, and many other scholarly people in addition" (9.1.1, 736d), where one of the guests is an athletic trainer (*paidotribēs*: 9.15.1, 747a–b).



Figure 28.1 A trainer supervises boxers (red-figure kylix by the Foundry Painter, circa 490–480 BCE; British Museum E78). (*Source:* © The Trustees of the British Museum.)

However, other evidence suggests that the social and intellectual pretensions of the average *paidotribēs* may have been relatively modest. The passage from *Sympotic Questions* just quoted is oddly contradicted by another passage from Plutarch's *Precepts of Healthcare* (133b–d), where he criticizes the anti-intellectual conversation of *aleiptai* and *paidotribai* at dinner parties:

> But if they do not allow us to investigate or philosophize about anything else at dinner, or to read any of those things which have pleasurably alluring and sweet qualities as well as being beautiful and useful, we shall order them not to annoy us, but to go off to the gymnasium colonnades and the *palaistras* and talk about these things with their athletes, whom they have made as shiny and stone-like as the pillars of the gymnasium by tearing them from their books, and by accustoming them to spend their days in mockery and coarse joking. (133c–d)

Epigraphical evidence for staffing arrangements at publicly owned gymnasia suggests that *paidotribai* were often employed on relatively modest wages (König 2005, 309–312, with reference to *SIG*^{3} 577, 578).

It is also hard to clarify what the expertise of these men might have encompassed: there is little sign of attempts to systematize the expertise of the *paidotribēs* in writing. The only obvious exception is a surviving papyrus fragment of a treatise on wrestling, which, however, gives the impression of being functional, focused mainly on bare description of different wrestling moves:

> Stand to the side of your opponent and with your right arm take a headlock and fight it out. You take a hold around him. You get under his hold. You step through and fight it out. You underhook with your right arm. You wrap your arm around his, where he has taken the underhook, and attack the side with your left foot. You push away with your left hand. You force the hold and fight it out. You turn around. You fight it out with a grip on both sides. You throw your foot forward. You take a hold around his body. You step forward and force his head back. You face him and bend back and throw yourself into him, bracing your foot. (*POxy* 3.466, column ii; trans. Poliakoff 1986, 161–163)

That text is far removed in style from most other surviving technical or scientific treatises from the ancient world: there is no sign of the rhetorical embellishment and intellectual ambition usually associated with that genre. The *paidotribēs*, then, was a figure who tended to hover on the edge of the intellectual mainstream.

3. *Gymnastēs*

There was also a more medicalized and intellectually sophisticated strand of athletic training linked with the science of regimen which emerged in the fifth century BCE. Regimen, sometimes referred to as dietetics, was essentially preventative or preservative medicine employing a range of techniques—including diet, massage, and exercise—to maintain health (see also NUTRITION). Some writers and practitioners identified themselves by the term *gymnastēs* and the science of athletic training as *gymnastikē* (in contrast with *paidotribikē* for the expertise of the *paidotribēs*). Some of them seem to have used those skills at least partly to prepare athletes for competition, whereas others (as we shall see below) viewed them as applicable primarily to the day-to-day maintenance

of health. The use of the word *gymnastēs* is almost entirely confined to literary sources (used only rarely in documentary texts: König 2005, 306 for examples), another sign that this strand of athletic training was widely viewed as separate from the routine coaching of the *paidotribēs/aleiptēs/epistatēs*. Aristotle sums up the distinction in recommending that "the boys should be handed over to *gymnastikē* and *paidotribikē*, since the first produces a certain quality in the condition of the body, the second in its actions" (*Politics* 1338b).

Some of the earliest evidence for the emergence of the *gymnastai* comes from Plato, who seems quite ambivalent about the value of their contribution to training the human body. Plato mentions in particular two figures who seem to have been influential in cementing the place of the *gymnastēs* as an authority with an independent body of expertise: Ikkos of Tarentum and Herodikos of Selumbria (mentioned together at *Protagoras* 316d–e). Plato is scathing especially about Herodikos, most strikingly at *Republic* 406a–b, a passage which implies disapproval of the way in which the new science of *gymnastikē* could lead to excessively fussy self-attention:

> The former Asklepiads (i.e., physicians) did not use the current coddling system of medicine in treating illness before the time of Herodikos. Herodikos was a *paidotribēs* who became ill, and mixed *gymnastikē* with medicine, and in doing so wore away first and most of all himself, and then later many others.

Herodikos, he explains, was not able to cure his own illness but nevertheless managed to prolong his life into advanced old age by slavish observation of a fixed regimen. That passage is part of a wider discussion of the role of athletic training in the life of the city (*Republic* 3, 403c–412b) where Plato is clearly open to a positive role for athletic training, so long as it is used moderately and balanced with intellectual and musical education. Plato mentions the expertise of the *paidotribēs* in non-critical terms in other passages too, taking it, along with many other kinds of day-to-day expertise, as a point of comparison for the philosophical or rhetorical skills he is trying to define (e.g., *Gorgias* 452a–b). But he is nevertheless scathing in *Republic* Book 3 about some of the techniques used to train athletes for competition, which, he suggests, are inconsistent with the goal of maintaining health. At 404a, for example, Socrates suggests that the condition of athletes is

> a sleepy condition and dangerous for health: do you not see how these athletes sleep away their lives, and how they fall prey to great and violent diseases if they depart even a little from their prescribed regimen?

These concerns about the way in which gymnastic regimen can threaten the goal of maintaining a balanced bodily condition, rather than supporting it, as it should be, are reiterated in later centuries too.

4. The Hippocratic Corpus

Also crucial for our understanding of the early development of the *gymnastēs'* expertise is the Hippocratic Corpus, the body of medical writings, most dating probably from between 420 and 350 BCE, ascribed in antiquity to Hippocrates. Between them they give

an ambivalent image of the value of gymnastic training, partly, though perhaps not only, because of the varied authorship of the Corpus. *Ancient Medicine* 4, for example, offers a fairly positive assessment:

> Even today, those who give their attention to exercises and training are always making some additional discovery by the same method, investigating what foods and drinks a person will best overcome so as to become as strong as possible.

Some ancient writers even thought that Hippocrates had been the pupil of Herodikos (e.g., Soranus, *Life of Hippocrates* 2). Elsewhere, by contrast, as in Plato, we find signs of anxiety about the dangerous, unhealthy character of the athletic condition: for example, *Aphorisms* 1.3: "In athletes (*gymnastikoi*—literally "those involved in athletic training"), good condition which is at its highest pitch is dangerous."

The Hippocratic *On Regimen* falls halfway between these two extremes, embracing the power of exercise to improve the human constitution, but also keeping training for competition rather at arm's length. The author makes the importance of exercise clear right from the start, together with food, as one of two central planks of a healthy lifestyle:

> For food and exercise, while possessing opposite qualities, yet work together to produce health. For it is the nature of exercise to use up material, but of food and drink to make good deficiencies (*On Regimen* 1.2; trans. Jones 1931).

The key goal of regimen, as outlined in the rest of Book 1, is to maintain a harmonious bodily condition with the right combination of food and exercise, to maintain the correct balance between the two elements which the author calls "fire" (hot and dry) and "water" (wet and cold). For that reason, it is crucial to be aware of the difference between disparate constitutions: separate individuals will need different treatment to achieve this kind of balance, depending on the innate character of their bodies (e.g., see 1.2; also 3.67). Accordingly the author offers a systematic catalog of the differing effects of various kinds of exercise in 2.61–66—especially, but not exclusively, their capacity to moisten or dry, heat or cool—following on from an equivalent account of the effects of assorted food types in the first half of Book 2. Book 3 then offers examples of how to use these capacities of food and exercise to correct types of bodily imbalance (before turning finally to an account of the meaning of dreams in Book 4). The following passage is typical:

> Of running exercises, such as are not double [a reference to the *diaulos*, the event that involved two lengths of the track, i.e., roughly 400 m = 1312′ overall] and long, if increased gradually, have the power to heat, concoct and dissolve the flesh … Running in a cloak has the same power, but heating more rapidly it makes the body more moist but less tanned, because this is not cleansed by meeting the rush of pure air, but remains in the same air while it is exercised. So this kind of running is beneficial to those who have a dry body, to those who have excess of flesh they wish to reduce, and, because of the coldness of their bodies, to those who are getting on in years. The double course, with the body exposed to the air, dissolves the flesh less, but reduces the body more … Running in a circle dissolves the flesh least but reduces and contracts the flesh and the belly most, because, as it causes the most rapid respiration, it is quickest to draw the moisture to itself. (2.63)

There is no mention here of aptitude for competition: the focus is solely on using exercise, through a process of painstaking observation and calculation of bodily condition, to compensate for the body's natural deficiencies. That is not to say that the text is entirely hostile to the culture of the gymnasium; indeed, the author refers to gymnasium facilities regularly:

> Such a person is benefited by following a regimen inclining to water, and by avoiding excess, whether of food, drink or exercise, with exercises on the circular or double tracks, wrestling and all other forms of athletics, but he must in no case fall into excess. (1.35)

What he envisages here is gymnasium use by private individuals for moderate exercise aimed at maintaining their own health: the warning about excess acts as a reminder of how far removed this is from the coaching of competitive athletes.

5. Gymnastic Writing in the Hellenistic and Early Imperial Periods

The history of gymnastic writing over the 500 years or so following the Hippocratic *On Regimen* is hard to reconstruct. The epigraphical record allows us to trace the steady expansion of the athletic festival calendar in the early Hellenistic world, its slowing in the second and first centuries BCE, the explosion of new foundations in the two centuries following the reign of Augustus (27 BCE–14 CE), and the continued vitality of the *ephebeia* in the Greek-speaking cities of the eastern Mediterranean. From those same sources, we can see occasional, brief glimpses of *paidotribai* going about their work. But the evidence for writing on *gymnastikē* by the successors of Herodikos and Ikkos is very slim indeed. Much of our evidence comes from passing remarks in Galen (see §6 below) about his predecessors. Galen engages at length with the gymnastic writer Theon, who wrote extensively on different types of massage. He also mentions more briefly the *gymnastēs* Tryphon (criticized in passing, together with Theon, at *Thrasybulus* 47 [5.898 Kühn]). Neither of these two is securely datable. We also know, from surviving fragments and later testimonies, of work on regimen from the early Hellenistic period by authors who would have identified themselves not as *gymnastai* but as philosophers or doctors, for example by Diocles of Carystus, Mnesitheos of Athens, Praxagoras of Cos, Erasistratus of Ceos, and Dieuches; also fragments of Theophrastus' works *On Sweat* and *On Fatigue*. The first of those two works explicitly mentions the gymnastic writing of Diotimus as a source (*On Sweat* 11). Finally, we also have surviving extracts on the medical uses of different types of exercise from the work of Antyllus, a medical writer from the Imperial period roughly contemporary with Galen, preserved in the writings of Oribasius in the fourth century CE. These extracts cover events used within competition, for example, running and wrestling, but also non-competitive activities like horse riding, ball play and hoop rolling (*Medical Collections* 6.21–36, *CMG* 6.1.1.177–187; see König 2005, 280–281). It is clear from this evidence that investigation into the effects of exercise on health continued to attract a considerable amount of attention during the Hellenistic and early Imperial periods, but it is frustratingly difficult to reconstruct the main lines of development, or even to be clear about the full content of any of these works individually.

6. Galen

Galen, by contrast, is our single most detailed source for the use of athletic exercise in regimen. The dominance of his work over the later medical tradition may be one reason for the non-survival of other authors. Galen, who himself worked at the Pergamene gladiatorial school and so saw physical training first-hand, treats our topic in a number of different works. He offers on the whole a negative view of athletic trainers, criticizing them for failing to submit to the guiding hand of the philosophically informed medical expertise of which he claims to be a representative, and for exercising their athletes with a view to competition rather than health, in a way which damages the human body. Following closely in the footsteps of Hippocrates and Plato, Galen also offers an alternative vision of what a medically inspired use of athletic exercise should consist of.

The most vehement of those attacks comes in his *Protrepticus*, an exhortation to study the liberal arts, especially medicine, as contrasted with a series of false arts. The worst of those—Galen suggests in a tirade that lasts for more than half the work as it survives)—is athletics, which leads to a dangerous obsession with glory, and also damages the health of the human body (he makes similar points in his brief *Good Condition*). In the process, Galen aligns himself repeatedly with Hippocrates, in this case quoting the Hippocratic *Nutriment* 34 (now widely thought to be Hellenistic, and so much later than most of the other works in the Hippocratic Corpus: Jouanna 1999, 401):

> Their every activity contravenes the dictates of health. I would say, in fact, that athletics is the cultivation, not of health, but of disease. And I think Hippocrates is of this opinion too, as shown by his statement: "The athletic state is not natural; better the healthy condition." (*Protrepticus* 11[1.29 Kühn]; trans. Singer 1997)

And later:

> Often hollow spaces have developed around their eyes, and as their strength subsequently diminishes, these spaces fill with fluid. The teeth have been shaken up so much that when their power weakens a little, they tend to fall out. The joints which have been twisted become too weak for the exigencies of life, and wherever there has been a breakage or rupture, it readily reopens. In terms of the health of the body, then, it is clear that no other breed of men is as badly off as that of the athletes. (*Protrepticus* 11 [1.31 Kühn]; see Rosen 2010, 333 for an interesting discussion of the overlaps with the language of satire here.)

The *Protrepticus* is a deliberately provocative and sensationalistic attack. Galen's *Thrasybulus: Is Health a Part of Medicine or Gymnastics* is on the whole more measured. Its main subject is the question of how *gymnastikē* should be categorized in relation to medicine. Galen argues at length, drawing again on Hippocrates, and also on Plato, *Republic* Book 3, that the expertise of the *gymnastēs*, as an authority in the exercises of the gymnasium, should be viewed as just one tiny part of the half of medicine which is concerned with maintaining good condition (the other half being curative or therapeutic medicine), and so should be subordinate to the medical expert. Galen is arguing against an alternative view which takes the *gymnastēs* as the expert with primary responsibility for preserving the health of the body, and the doctor as responsible only for curing disease and injury. He reaches that conclusion only after a painstaking account of the

relationship between different branches of the medical art: the impression of relentless logical rigor in this section as elsewhere is a key part of his self-presentation as a reliable practitioner (Barton 1995, 133–168 for the importance of that impression in Galen's work generally). Even in this work, however, a more antagonistic tone sometimes surfaces, in a way which seems partly explained by the context of public debate between doctors and trainers, or at least between Galen himself and some of his gymnastic rivals. That context is referred to in the opening definition of the work's subject:

> The question before us is: does what is known as 'healthiness' come under medicine or under gymnastics? And you have desired to hear my opinion on this question, having yourself frequently been present at such disputes between doctors and gymnastic trainers. (*Thrasybulus* 2 [5.807 Kühn]; trans., Singer 1997)

We see a more vivid glimpse of public debate toward the end of the treatise, where Galen describes a hysterical attack by an ignorant *gymnastēs*:

> So this fellow screamed away, and in fact could not even be quiet for long enough to follow the discussion, while I calmly set to explaining matters to the assembled company. (*Thrasybulus* 46 [5.895 Kühn])

Having established the subordinate role of the *gymnastēs*, Galen then proceeds to reassert his own control over the art of medicalized regimen in another important work, *De Sanitate tuenda* (usually translated as *On the Preservation of Health*, or sometimes as *Hygiene*), which several times refers to the conclusions of the *Thrasybulus*, as if imagining a reader familiar with that earlier work (see *De Sanitate tuenda* 1.4 [6.12 Kühn]; 2.8[6.136 Kühn]). This text is the lengthiest and most complex account of the science of regimen surviving from Classical antiquity, and it wielded a major influence on the growth in interest in sporting activity in sixteenth- and seventeenth-century Europe (Brailsford 1969, 15, 18, 165), but it is still relatively neglected in modern scholarship.

De Sanitate tuenda opens in 1.1 with an account of the distinction between the two branches of medicine, the therapeutic and the "hygienic" or preservative (later, in 2.8 [6.135–136 Kühn]. Galen states his preference for the term *hygieinos* as the practitioner of the latter, criticizing those who instead use the term *gymnastēs*). He then outlines the continual tendency of the human constitution to deteriorate from perfect balance between hot, cold, moist, and dry (1.1 [6.2 Kühn]). And he defines correction and prevention of that deterioration as the primary goal of the science of *hygieinikē* (i.e., the expertise of the *hygieinos*). Up to that point, the development of the argument is closely reminiscent of the Hippocratic *On Regimen*. In 1.7, imagining a young child born with a balanced constitution, Galen shows how the science of "hygiene" or regimen would maintain that child's health through childhood and into adulthood. In the Hippocratic *On Regimen*, exercise strikingly plays a major role in that process, even from the very beginning of life: for example we hear that the child's nurse "should observe no little care as to her food, drink, sleep, sexual life, and exercise" (1.9, [6.45 Kühn], trans. Green 1951), so that the quality of her breast milk, which is directly dependent on the humoral balance of her blood, is not damaged. And in 1.10 (6.53–54 Kühn), we hear that moderate exercise is valuable even for young school-age children:

> When it is time for him to go to school, it is not necessary any longer to use constant baths, but it is sufficient, while he is learning sports, to exercise moderately before meals, and for the most part to go unwashed. But to over-exercise, as some trainers compel boys, is not good, for growth of the body is prevented by premature hardness, even if it has the usual internal impulse for growth.

Even at this young age, it seems, it is crucial to distinguish between valuable exercise for health and damaging exercise at the hands of trainers preparing athletes for competition (Aristotle makes similar criticisms of premature training for the young in *Politics* 1338b–1339a). Book 1 then ends (1.15) with a summary of what the trainer should be familiar with, listing four main areas: things to be administered (i.e., by absorption within the body, including food and drugs and air), things to be done (including massage, walking, riding, driving, exercise, sleep, wakefulness, sex), things to be applied to the outside of the body (including oil and dust in the gymnasium, which were thought to affect the humoral balance of the body), and things to be removed from the body (including sweat and other kinds of "excrement"). That categorization, noticeably more complicated than the division between food and exercise we find in the Hippocratic *On Regimen*, makes clear again—as in the *Thrasybulus*—that the exercises of the gymnasium are only one of many possible means of maintaining health.

Nevertheless, exercise does receive a great deal of attention in what follows, particularly in Book 2, which treats massage in the first half and exercise in the second, while also making it clear that they need to be considered together. In 2.2, for example, we hear that exercise should be defined as any kind of movement which changes respiration, and that it has two goals: "one for the evacuation of excrements, the other for the production of good condition in the firm parts of the body" (2.2 [6.87 Kühn]). It also facilitates the distribution of nutriments to the body, and it is therefore important to wait until well after eating to exercise, so that the material to be distributed has been digested. Not only that, but it is crucial to massage the body before exercise, Galen suggests (2.2 [6.89–91 Kühn]), among other things to prevent the pores from being blocked during exercise in a way which would impede the evacuation of "excrements." That initial summary is then followed by an exceptionally long attempt to categorize various different types of massage. Here Galen criticizes the *gymnastēs* Theon, who had written on that subject. From Galen's quotation and summary of Theon's work (e.g., see 2.3 [6.96–97 Kühn] for one quite lengthy quotation), it seems clear that Theon's work had considerable sophistication, and Galen expresses a degree of respect for him (2.4 [6.119 Kühn]), surprisingly, given Galen's usual views on *gymnastai* elsewhere. Nevertheless, Galen still makes clear the superiority of his own understanding, and of the Hippocratic writings on massage (which he accuses Theon of misunderstanding), advertising his own ability to subdivide the skills of massage in a more accurate and more complex fashion: essentially his criticism is that Theon omits a moderate variety of massage between the two extremes of soft and hard (see Barton 1995, 224–225, note 103).

In the second half of Book 2, Galen then offers a painstaking categorization of different types of exercise and their effects, with extensive subdivision of each category, offering, for example, a range of different "vigorous" exercise (2.9), and a range of varieties of "swift" exercise (2.10). Books 3 and 4 then deal in turn with "apotherapy" (i.e., treatment of the body after exercise is over), bathing, and different types of fatigue and their treatment. Finally, in Books 5 and 6, Galen turns to the treatment of constitutions

which are damaged in some way, by contrast with the imaginary subject with a balanced constitution in Book 1–4. He looks, for example, at how to treat the aged or those suffering from various diseases. In the process, exercise is mentioned repeatedly, as in the Hippocratic *On Regimen*, as one of several methods for restoring people to health, to be applied carefully, in different forms according to the particular needs of the individual patient. The opening lines of Book 3, for example, criticize those who have neglected individual difference:

> Of the physicians and gymnasts who have written about hygienic matters, some have made certain hypotheses common to all men, not considering at all the differences in kind of our bodies. Others have shown that we differ not a little from one another; but since it was not possible to reconcile all the differences, have purposely omitted them. But a few others, attempting to differentiate by sorts and kinds, have erred more than they rectified. But immediately in my first book I showed how many are all the forms of human bodies, and promised to write hygiene hypotheses individually for each. (3.1 [6.164–165 Kühn])

In making his recommendations, Galen repeatedly mentions the exercises of the gymnasium, and even the experience of athletes, but he also makes it clear that gymnasium exercise is only one type of many: for example, at 2.8 he gives equal weight to the kinds of exercise linked with work: "digging, rowing, plowing, pruning, burden-bearing, reaping, riding, fighting, walking, hunting, fishing …. house-building, bronze-working, ship-building, plough-making …" (2.8 [6.134 Kühn]). Once again, the exclusively athletic style of training for competition associated with the *gymnastēs* and the *paidotribēs* is kept very much at arm's length (see 3.2.168–169 for a passage which makes that distinction explicit). That is clear also in one of his other key works on the topic, *On Exercise with the Small Ball*, which gives a detailed account of the health benefits of ball play, which was viewed in the ancient world as unconnected with festival competition, although it was practiced regularly in *gymnasia* to judge by the evidence for ball-rooms (*sphairisteria*) in many gymnasium complexes.

7. Philostratus

The key authors we have examined so far—Plato, the Hippocratic authors, Galen—have much in common (even if Galen sometimes rather overstates the vehemence with which his two distinguished predecessors criticized athletics, and the degree to which their views match his own: see Smith 1979, 106–114; König 2005, 277–279). There is, however, one surviving work that makes a remarkable attempt to resist their conclusions, and to represent the training of athletes for competition as a serious and sophisticated science: that work is Philostratus' *Gymnasticus*, which dates probably from the 220s or 230s CE, several decades after Galen.

That goal is laid out clearly and ambitiously in the very opening lines of the text:

> Let us regard as types of wisdom, on the one hand, things like philosophy and skillful speech and engaging in poetry and music and geometry, and, by Zeus, astronomy, so long as it is not carried to excess. On the other hand, the organization of an army is a form of wisdom, and in addition things like the following: the whole of medicine and painting and modeling, and the various types of sculpting and gem-cutting and metal-engraving … As for athletic

> training, we assert that it is a form of wisdom, and one which is inferior to none of the other skills, which means that it can be summed up in treatise form for the benefit of those who wish to undertake training. (*Gymnasticus* 1)

Philostratus draws attention to the long tradition of gymnastic writing to authorize his claims about the intellectual respectability of *gymnastikē*. That opening is followed by an excursus on the history of athletics: historical contextualization is a standard feature in other works of this type which aim to defend or elevate particular bodies of expertise; this section also has much in common with the way in which celebration of athletic festival heritage plays a key role in his defense of the Greek tradition in Philostratus' other works. In *Gymnasticus* 14–16, Philostratus then addresses the issues of categorization treated by Galen in his *Thrasybulus* and elsewhere (it seems highly likely that he knows Galen's work and that the *Gymnasticus* is designed in part as a response to Galen's denigration of athletic training: see König 2005, 315–325):

> What, then, should one think about the art of athletic training? What else except to believe that it is a type of wisdom combining both the art of medicine and the art of the *paidotribēs*; it is more comprehensive than the latter, and a part of the former. The *paidotribēs* will demonstrate all the different types of wrestling move, giving instruction in good timing, in the degree of force to be used, in the limits to be observed in training, and in how one can defend oneself or defeat an opponent who is defending himself … But cleansing the humors and removing excess from the body and smoothing dried-up flesh, and fattening or transforming or warming some part of the body, all of these things belong to the wisdom of the trainer … Its relation to the art of medicine is as follows. Doctors cure the illnesses we refer to as catarrh and dropsy and consumption, and the various types of epilepsy, by prescribing irrigations or potions or dressings, whereas athletic training checks such conditions by the use of diet and massage. But if someone has a break or a flesh wound or clouding of the sight in his eyes or a dislocation of one of his limbs, then he needs to be taken to the doctor, for the art of the athletic trainer does not concern itself with problems of those kinds.

Here Philostratus reasserts the control of the *gymnastēs* over the whole of preventative medicine.

In the second half of the work, after a series of anecdotes about incidents where trainers have brought victory to their athletes by clever use of encouragement, Philostratus then turns to the physiological details of the science of *gymnastikē*, discussing among other things the way in which the trainer should be able to judge the suitability of athletes for particular events by visual inspection, and the way in which he should treat the bodies of athletes whose balance of humors is disturbed. A number of modern scholars have argued, probably rightly, that Philostratus is not an expert in training, on the grounds that he seems to make a number of mistakes (e.g., Poliakoff 1986, 143–147). Nevertheless, it is clear that the text represents a serious attempt to engage with and celebrate a complex body of expertise for a non-specialist audience.

One of the techniques Philostratus uses to convey the complexity of *gymnastikē*, much like Galen, is complex subdivision, linked with a highly Galenic insistence that the trainer needs to pay attention to individual differences between athletes. That is clearest in Philostratus' attack on the tetrad system, an inflexible system for training according to a fixed four-day cycle, also attacked by Galen (*Thrasybulus* 47). This culminates in an anecdote about a trainer whose insistence on following the tetrad system for an athlete

with a hangover led to the athlete's death. Indeed, Philostratus may well be drawing on Galen's work for some of his detail about the expertise the trainer needs, and he seems to be going out of his way to stress the compatibility of his own views with Galen's. For example, Philostratus criticizes the contemporary athletic trainers and suggests that they have been responsible for a decline:

> The training of our fathers' time produced athletes who were less impressive than these, but nevertheless remarkable and worthy of commemoration. But the kind of training which prevails today has so far changed the nature of athletes that the majority of people are irritated even by lovers of the gymnasium. I have decided to make clear the causes of this degeneration, and to contribute for trainers and their subjects alike everything I know … (*Gymnasticus* 1–2)

His criticism becomes even more vehement at *Gymnasticus* 44:

> When the situation changed, and when athletes became inexperienced in warfare, rather than combatants, and sluggish rather than energetic, soft rather than hardened, and when Sicilian gastronomy became popular, then the stadia became enfeebled, and all the more so since the art of flattery was introduced into athletic training.

That attack on the luxury of contemporary athletic trainers is, in fact, reminiscent of some of Galen's more vehement assaults on trainers in the *Protrepticus* and elsewhere. In some respects, then, Philostratus is happy to align himself with Galen's views. The key difference is that he takes a more optimistic view of the potential for athletic training to be a valuable profession in its own right standing independently of medicine.

There is also one respect in which Philostratus' contribution is unusual, going well beyond what we find in Galen, and that is in his treatment of traditions of physiognomical analysis. Ancient physiognomical writing too, like regimen, had a long prehistory, stretching back to Classical Greece. That earlier physiognomical tradition is concerned primarily with working out how physical appearance can give signs of moral character. There is a considerable amount of physiognomical writing surviving also from the Imperial period, most famously the work of Polemon (Barton 1995, 95–131; Swain 2007; Psychology and Physiognomics). Transitioning between the historical and physiological focus, Philostratus suggests that the trainer needs to have some understanding of physiognomy:

> Let him also take into consideration the whole art of physiognomy … The trainer, by contrast, needs to know these things well, being a sort of judge of the athlete's nature. Indeed he should know all the signs of character in the eyes, by which are revealed lazy people, impetuous people, and inactive people and those who are less capable of endurance and lacking in self-control. Some characteristics are associated with people who have black eyes, others with those who have bright, blue, or bloodshot eyes, others again with those whose eyes are yellow or flecked, prominent or sunken; for nature has signaled the seasons by the stars, and character by eyes. (*Gymnasticus* 25)

There he stresses, in conventional physiognomical fashion, the value of knowing about an athlete's character. Later, however, his concerns are rather different and more idiosyncratic: much of the second half of the *Gymnasticus* is taken up with an investigation

of how the outward appearance of an athlete reveals not so much his character, but rather his physical condition. Many passages in the second half of the work seem to envisage a situation where the trainer needs to be constantly on the alert for the hidden meaning of outward bodily signs which will affect his decisions about how a particular athlete needs to be trained. The following is a typical example:

> Those who come to the gymnasium straight after sex are exposed by a greater number of indicators when they train, for their strength is diminished and they are short of breath and lack daring in their attacks, and they fade in color in response to exertion, and they can be detected by signs of that sort; and when they strip, their hollow collar-bones give them away, their loose hips, the conspicuous outline of their ribs, and the coldness of their blood. These athletes, even if we dedicated ourselves to them, would have no chance of being crowned in any contest. The part beneath the eyes is weak, the beating of their hearts is weak, their perspiration is weak, their sleep, which controls digestion, is weak, and their eyes glance around in a wandering fashion and indicate their awareness of being loved. (*Gymnasticus* 48)

Elsewhere Philostratus extends the application of the physiognomical method further in a discussion of how outward appearance can be used to determine what kinds of events and techniques a particular athlete is most suited to. In 34, for example, we hear the following:

> The boxer should have large hands and well-built forearms, and upper arms which are not lacking in vigor, and strong shoulders, and a high neck. Thick wrists give a heavier punch; those which are less thick are flexible and punch with ease. Let him also be supported by well-built hips, for the forward projection of the hands drags the body downwards, unless it is supported on firm hips. I think that those who have bulky calves are not well-suited to any of the disciplines, but least of all to boxing. For these athletes will be slow to kick against the shins of their adversaries, and easily kicked in turn. The boxer should have calves which are straight and well proportioned, while the thighs should be well distanced and separate from each other. For the shape of the boxer is more suited to attack if his thighs do not come together.

And so on at great length for wrestling and other disciplines. In many cases, Philostratus uses the standard physiognomical techniques of argument from analogy, especially between humans and animals. For example, in 37 we read:

> Leonine athletes have well built chests and arms, but are lacking in the hind part of the body, while eagle-like athletes are similar to these in their appearance, but are thin in their groin region, like eagles when they stand up straight. Both of these categories display athletes who are daring and forceful and impetuous, but apt to lose heart when things go badly; and one should not be surprised at that, when one thinks about the nature of lions and eagles.

Those features of the text are unusual. There is some discussion in Galen's *De Sanitate tuenda* of the way in which the athletic body requires close observation (e.g., 2.12 [6.160–161 Kühn]); that is reminiscent of Galen's representation of his own virtuosic skills of visual diagnosis in other works. There is also occasional mention of how different body types are suited to different kinds of exercise (e.g., 5.10 [6.322 Kühn], translated as part of 5.3 by Green 1951, 196–197), although Galen's main concern is, of course,

the use of exercise for maintenance of health, rather than the allocation of athletes to the competitive events to which they are most suited. But there is nothing else in surviving ancient literature which offers anything like such a detailed account of these approaches. Philostratus may be innovating in this, or he may be drawing on lost treatises by trainers, and giving them a new prominence. Either way, it is clear that this adaptation of the terminology and logic of the discipline of ancient physiognomy for athletic purposes plays a major role in his project of giving a new prestige and intellectual respectability to the art of the athletic trainer. In that sense, Philostratus' treatise is a remarkable testimony to the continuing potential for *gymnastikē* to be envisaged as a complex and sophisticated science, despite the repeated attempts to marginalize it from Plato onward.

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FURTHER READING

See Lehmann 2009 for a useful overview of the development of athletic training in Classical Greek, and especially Athenian culture, up to the fourth century bce, but with mention of Hellenistic and Roman evidence too; also brief discussions in Pritchard 2003, especially 302–306, and Kyle 1987, especially 141–145: all three include useful surveys of key Platonic passages. For trainers in Pindar and Bacchylides, see Nicholson 2005, 119–210. For the Hippocratic writings on exercise and regimen, see Jouanna 1999, especially 166–168, 324–325 and 408–409.

For a survey of the educational and other functions of the gymnasium in the Greek cities of the Hellenistic period, see Gauthier 2010. On the Hellenistic fragments see (in German) Wöhrle 1990, 158–183, part of a broad survey of ancient traditions of writing about regimen/dietetics/preservative healthcare from Homer to Galen; also van der Eijk 2000–2001, especially 1.293–331 for translations of the most relevant fragments of Diocles; Fortenbaugh, Sharples, and Sollenberger 2002 for translation of Theophrastus' works on sweat and fatigue.

For Galen, König 2005, 254–300 surveys the key works in turn; also Smith 1979, 106–114 on Galen's opportunistic use of the Hippocratic heritage in *De Sanitate tuenda* and the *Thrasybulus*; van der Eijk 2008, 297–300 for useful brief introduction to Galen's approach to preservative medicine in *De Sanitate tuenda* and elsewhere; and Wöhrle 1990, 213–248 for a more detailed account. For translations of Galen into English, Singer 1997 for *Protrepticus*, *On Good Condition*, *Thrasybulus*, and *On Exercise with the Small Ball*; and Green 1951 for *De Sanitate tuenda*.

For Philostratus' *Gymnasticus*, König 2005, 301–344, surveys the epigraphical evidence for trainers in the Roman Empire; also König and Rusten (2014) for translation; König 2007 and 2009 for further analysis and contextualization. Also crucial is Jüthner's commentary (in German) 1909, including 3–131 for a long survey of earlier writing on regimen.

Other useful studies include Potter 2011, 137–168, who offers a vivid survey of what we know about trainers and training methods, with particular reference to Galen and Philostratus; and Golden 2008, 1–39, who focuses especially on the social status of trainers and their athletes.

CHAPTER 29

Epidemiology and Pathology

Efthymia Nikita, Anna Lagia, and Sevi Triantaphyllou

1. Introduction

Epidemiology, the science that investigates "the occurrence and distribution of health-related events, states, and processes in specified populations" (Porta 2014, 95), essentially started as a search for correlations between humans and their environment in terms of health and prosperity. The beginning of epidemiology is attributed to the Hippocratic *Airs, Waters, Places*, wherein the environment and the way of life, including the political system, is correlated with well-being (Merrill 2010, 24–25; Beckfield and Krieger 2009, 152). The Hippocratic School introduced the terms "epidemic" and "endemic" (deriving from *epidemeion* and *endemeion*, differentiating diseases that visit a community from those that reside there), and a series of principles that, to date, comprise the fundamental components of epidemiological thinking (Buck et al. 1988, 3). Since then and until the official establishment of epidemiology as a scientific field in the nineteenth century, a wealth of experience demonstrated the complexity and coalescence of factors from the ecological, social, and cultural environments that shape the health of an individual or a population (Susser and Bresnahan 2001).

Paleopathology investigates how these factors interacted and affected human conditions in the past through the analysis of ossified and mummified remains, parasite-containing coprolites, pollen, soils, and food remains, in addition to written sources and iconographic representations (Ortner 2003; Grauer 2012). Paleoepidemiology appraises disease experience at the population rather than at the individual level, investigating its prevalence with respect to chronology, cultural affiliation, sex, age at death, or socio-economic position (Boldsen and Milner 2012). While it shares the same objectives as epidemiology, its means are much more limited in accessing past populations (Waldron 2007). Key limiting factors include lack of correspondence between the range of possible diseases and those that leave their imprint on skeletal and mummified

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remains, the non-diagnostic value of many osseous lesions, and the selective mortality due to differential frailty in a population (Ortner 1988; Wood et al. 1992). Nonetheless, the employment of new analytical techniques encompassing genomic analyses of ancient pathogens and their hosts, paleohistology, paleoparasitology, and paleoimaging techniques, in addition to theoretical advances that emphasize population-level analysis and interdisciplinary investigations, have amplified the field's diagnostic potential.

Here we present aspects of pathology and epidemiology in antiquity: how disease was understood in the past on the basis of documentary and artistic sources together with osteoarchaeological evidence indicative of the range of pathologies thus far identified in the Greco-Roman world. Our aim is to provide a brief overview of the sources and scientific methods that make tangible the understanding of diseases in the past and their interaction with the environment—encompassing not only the ecological but also the social, economic, and political milieus.

2. Written Sources

The Greeks believed that disease emanated from divine wrath. A typical example can be found in the first book of the *Iliad*, where Homer describes how Apollo sent a plague upon the Greek army besieging Troy as punishment for Agamemnon's disrespectful attitude toward his priest (*Iliad* 1.46–53). Nevertheless, Homer exhibits some understanding of basic medical principles: for example, the vulnerable parts of the human body and the likely consequences of lesions for each vital organ (Grmek 1983). For example, Aeneas suffers a serious injury when a rock hits him on the hip, but he survives (*Iliad* 5.297–317, 431–470, 512–518). In contrast, head wounds are often fatal (e.g., *Iliad* 16.345–350), while those inflicting lethal trauma aim mostly for the throat, such as when Achilles kills Deucalion (*Iliad* 20.480–483). Hesiod similarly exhibits some knowledge of the impact of starvation and cold on the overall health of the individual (*Works and Days* 240–245, 496–499, 533–536); however, it is Zeus who sends famine and plague to the world (*Works and Days* 238–245).

A more rational approach to disease is found in Thucydides, who offers a detailed description of the symptoms of the fifth-century BCE Athenian plague. Thucydides realizes that the plague is contagious. He does not attribute the disease to divine intervention, but he does acknowledge that rational medicine is inadequate to deal with the plague (2.47–54, 58, 3.87).

In contrast, ancient tragedy primarily presents mental diseases, which are clearly the outcome of divine actions. The only case of a physical disease is presented in Sophocles' *Philoctetes*, where the eponymous hero suffers terrible anguish owing to a snake bite that has caused inflammation of his leg. In contrast, ancient comedy, represented primarily by Aristophanes, describes a wide range of diseases: fevers and inflammations (*Wasps* 276–278, 813), pustules (*Frogs* 236–237; *Ecclesiazusae* 1056–1057), burns (*Plutus* 535–536), deafness (*Horsemen* 43), and others. More importantly, the divine factor subsides in comedy, and more rational causes and treatments are foregrounded. For instance, a boil can be treated using a garlic ointment (*Wasps* 1170–1172), while reference is made to the public physicians, Pittalos and his students (*Acharnians* 1222–1223).

Undoubtedly, the most relevant Classical source on health and disease is the Hippocratic Corpus (PHYSICIANS AND "SCHOOLS"), which introduced the fundamental

concept of the observation of differences in the environment, human nature, and human behavior as the source of disparities in health and well-being among populations. Overall, Hippocratic medicine excelled in medical observation, but since dissections were not yet practiced, causal explanations were limited (Jouanna 1998). It is noteworthy that an imbalance among the *humors* that constitute the human body was credited as the causative factor behind all diseases. Nevertheless, given the diversity of Hippocratic authors, there are cases where the patients are advised to offer prayers to the gods (*On Regimen* 89, 90; see also Healing Shrines).

During the third century BCE, there is a remarkable increase in medical knowledge, as documented by later (Roman) sources. This medical progress can be attributed to four physicians, Praxagoras of Cos and his pupil Herophilus of Chalcedon, and Chrysippus of Cnidus and his pupil Erasistratus of Ceos. Herophilus advanced the knowledge of anatomy, the nervous system (Galen, *On the Usefulness of the Parts of the Body* 8.11, 9.6), vascular system (Galen, *On the Doctrines of Hippocrates and Plato* 6.5), liver (Oribasius, *Medical Collections* 24.25.1–6), eyes (Rufus, *On the Naming of the Parts of Man* 153), reproductive organs (Galen, *On the Semen* I.16), and sphygmology (Galen, *On Diagnosing the Pulses* 4.3). Erasistratus also made substantial contributions to anatomy (Galen, *On the Doctrines of Hippocrates and Plato* 6.6) and physiology (Galen, *On the Natural Faculties* 2.6; Anatomy and Physiology). Praxagoras introduced cardiocentrism, and he distinguished veins from arteries (fragments 30, 62, 72 Steckerl). Very little is known about Chryssipus, but he appears to have departed from Hippocratic medicine and possibly rejected humoral pathology (Longrigg 1998). Together with the Hippocratic Corpus, Galen, "the second founding father" of ancient medicine, is our most important textual source (see Physicians and "Schools").

Despite valuable information that can be extracted from written texts, serious limitations must be considered. First, the ancient terminology is often ambiguous. For instance, the Hippocratic terms *nephritis* and *splēnîtis* refer to pathological conditions that have nothing to do with the spleen or kidneys. In addition, the concepts expressed by some technical terms have been modified over the years. For example, *sciatica* (*iskhiás*) indicates hip pain in Hippocrates but neuralgia of the sciatic nerve for modern physicians (Grmek 1983). Moreover, symptoms described by ancient texts are often vaguely applicable to many diseases. Thus firm diagnosis is impossible: the symptoms of a certain disease may have changed over the centuries as a result of the evolution of different pathogens and the host's immune system (Phillips 1973).

3. Artistic Representations

Various deformities have been depicted in sculpture and pottery, many tentatively associated with specific diseases. For example, individuals with kyphosis ("slouching" or curvature of the spine) have often been interpreted as suffering from tuberculosis (Grmek 1983). In addition, several Hellenistic statuettes depict acromegaly, manifested as excessive growth of the extremities, projecting jaws, and oversized noses (e.g., Louvre Museum D 1176), while some faces have been identified as exhibiting signs of leprosy (National Archaeological Museum at Athens inv. no. 5871; Louvre E 17; Louvre E/D 1793, E144, E/D 1823; Hoggan 1893; Grmek 1983). Congenital conditions have also been identified in Greco-Roman art. A Hellenistic figurine apparently depicts an

individual suffering from Klippel–Feil syndrome (the congenital fusion of two or more cervical vertebrae; Louvre Museum D 1178), while a fourth-century BCE terracotta head from Corinth shows all the morphological characteristics of a unilateral cleft lip (Skoog 1969). Finally, Hellenistic terracotta children's heads seem to suggest thalassemia (Louvre Museum, inv. nos. E/D 564, E/D 1899–1905; Grmek 1983).

Common, artistic representations of violent injuries most often depict the moment just before impact. The attacker usually aims for the pharynx, aorta, heart, femoral arteries, or liver, suggesting that the artists had knowledge of which injuries are fatal. A typical example includes the attic kylix that shows Achilles killing Penthesileia by aiming for her throat (460 BCE; Munich, Staatliche Antikensammlungen Inv. 2688; Geroulanos and Bridler 1994).

As with written sources, only cautious paleopathological conclusions should be drawn on the basis of artistic representations. Serving several symbolic and aesthetic purposes, works of art may not always depict facts. In addition, an accurate diagnosis based on depicted symptoms is often difficult, while in many cases deformed figures, particularly those exhibiting facial deformities, may not have been diseased individuals but actors wearing theatrical masks (Grmek 1983).

4. Osteoarchaeological Evidence

Here we provide examples of the main pathological conditions that were investigated in the Greco-Roman world. Examples are drawn from the Mediterranean for the most part. Paleopathological research in this region has its roots in the late nineteenth and early twentieth century with the pioneering work of M. A. Ruffer, G. E. Smith, F. W. Jones, A. T. Sandison, E. Strouhal, D. Brothwell, and J. L. Angel on Egyptian mummies and skeletal collections (Buikstra and Roberts 2012). A multitude of other scholars have been working in diverse sites and chronological periods.

Developmental Disorders

Developmental disorders, known also as congenital abnormalities, derive from morphogenetic changes during embryonic and fetal life that may result in diverse alterations in the soft tissues, and osseous and dental structures. These alterations may have minimal or no impact on an individual's health, or they may lead to death (Barnes 2012). Socially, the deformities that certain developmental conditions may cause can lead to stigmatization even today (Strauss 1985). It is not surprising, therefore, that behavior in antiquity toward people with developmental disorders varied.

The killing of infants born with deformities has been widely discussed, and osteoarchaeological evidence from Hellenistic Greece lends some support to the occurrence of such practices. In a mid-second-century BCE well in the Athenian Agora, over 450 nonviable fetuses and perinatal infants are attested. Some of the infant remains were found to bear evidence of birth defects including cleft palates and stunted limbs, in addition to extensive endocranial infections and perimortem trauma. Thus the well may have been also used as an area of disposal of infants with birth defects (Liston 2007).

Other evidence, however, challenges such generalizations. A remarkable example concerns a 7–9-year-old child with characteristics of Down syndrome (fifth/sixth-century

CE Saint-Jean-des-Vignes, Saône-et-Loire, in Northeastern France). Mortuary practices do not distinguish its mode of burial from others in the same cemetery. This suggests that, at least at death, "this Down syndrome child was not treated differently than others in the community" (Rivollat et al. 2014, 13–14). Likewise, *osteogenesis imperfecta*, or "brittle bone disease" identified by Cope and Dupras (2011) in the skeleton of a fetus from the Romano-Byzantine period Kellis 2 cemetery (50–450 CE) in the Dakhleh Oasis, Egypt, offers evidence of attitudes toward rare congenital diseases in antiquity and corroborates the impression of a shift in burial practices in this period with the inclusion of individuals with disfigurements.

Most congenital anomalies, nevertheless, are asymptomatic and usually go unnoticed during life. Such cases are frequently observed in the archaeological record and may reveal information about consanguinity. For instance, the exceptionally high prevalence of *spina bifida occulta* in a Greco-Roman cemetery from Bahriyah Oasis in Egypt was explained by a high degree of endogamy (Hussien et al. 2009), while the occurrence of similar spinal malformations in a double burial of the Late Roman period in Corinth was attributed to close familial relations (Gejvall and Henschen 1968). Congenital conditions may also help appraise aspects of daily life such as pain, disability, and treatment. For example, the presence of unilateral aural atresia in an adult female skeleton from the Greek colonial site of Apollonia Pontica (fifth to third centuries BCE) is believed to have resulted in the loss of directional hearing and malformation of the external ear (Keenleyside 2011).

Metabolic Disorders

Metabolic disorders describe disturbances in the biochemical processes that control the synthesis and decomposition of chemical compounds in living cells (Kozłowski and Witas 2012). They have a wide range of causative mechanisms and, correspondingly, a broad range of expressions. Although paleopathology can access only a fragment of this range, it informs us that such conditions were common in antiquity. Because the etiology of these conditions is usually compound, and they tend to occur in clusters in nutritionally and environmentally stressed individuals or populations, their differentiation can be difficult.

Anemia

In the eastern Mediterranean, like many regions worldwide, one of the most frequently encountered groups of skeletal lesions in archaeological assemblages are cribra orbitalia (CO) (Figure 29.1) and porotic hyperostosis (PH). These are associated with anemias, a large complex of acquired and genetic conditions with diverse etiologies (Angel 1966). In contrast to other regions where genetic forms of anemia in prehistoric populations are largely unknown, in the eastern Mediterranean a complex of factors may be responsible for their development. Their differentiation has benefited from the application of scanning electron microscopy (Maat and Baig 1990), the systematic study of forensic cases (Hershkovitz et al. 1997; Lagia, Eliopoulos, and Manolis 2007), and the adoption of molecular techniques (Faerman et al. 2000; Filon et al. 1995). Many factors play a role in the development of acquired anemias, ranging from innate causes concerning increased iron demands during childhood, puberty, pregnancy, and nursing, to parasitic



Figure 29.1 Cribra orbitalia, 3–5-year-old child from the Classical cemetery of Laurion. Photo by author.

infestation and gastrointestinal disease resulting from social and cultural factors (Stuart-Macadam 1989; Walker et al. 2009; Piperata, Hubbe, and Schmeer 2014).

A study by Fairgrieve and Molto (2000) found that the majority of pre-Roman and Roman period crania from the Dakhleh Oasis exhibited CO. According to the authors, these lesions may be linked to folic acid deficiency and megaloblastic anemia as a result of weaning infants on goat's milk. Parasitic infestations, low bioavailability of iron in the diet, and genetic anemias were fairly common in Egypt and likely afflicted the samples under study. Keenleyside and Panayotova (2006) found that CO and, to a lesser degree, PH had affected a large proportion of a Greek population from Apollonia. The lack of any lesions suggestive of thalassemia led the authors to conclude that CO and PH were due to iron deficiency anemia resulting from a diet highly reliant on terrestrial C3 plants, food shortages due to crop failure, warfare, parasitic infections, prolonged breastfeeding, and weanling diarrhea. A recent study exploring the prevalence of CO and PH during the Classical, Hellenistic, and Imperial Roman periods in Athens observed their more consistent presence among women and their increase through time among men (Lagia 2014). In combination with a corresponding temporal reduction in the protein level assessed by carbon and nitrogen stable isotope analysis (Lagia, 2015), this evidence was taken to reflect a gradual decline in living standards, matching similar appraisals from other Roman provinces (e.g., Redfern and DeWitte 2011).

Scurvy, Rickets

Scurvy, a disease caused by vitamin C deficiency, is documented in populations when normal eating patterns are broken because of, for example, siege, famine, or prolonged military and seafaring campaigns (Mays 2014). Because vitamin C is present even in small quantities in fruits, vegetables, and dairy products, the occurrence of scurvy is difficult to interpret (Ortner and Eriksen 1997; Ortner et al. 2001), especially in temperate climates, and it is often attributed to cultural variables involving dietary or culinary practices. The presence of scurvy in Romano-British North Europe has been associated with breastfeeding and weaning practices (Redfern, Millard, and Hamlin 2012) and

with food shortages among the lower socio-economic strata (Brickley and Ives 2006). In Greece, lesions related to juvenile scurvy have been thus far recognized in periods when diet is generally poor: for example, Byzantine populations in Crete (Bourbou 2014).

Rickets is caused by deficiency of vitamin D (primarily produced by the skin during exposure to sunlight: Stuart-Macadam 1989). Generally observed in North European contexts, it has also been noted in regions with plentiful sunshine, such as in Bahrain (1000 BCE–CE 250: Littleton 1998) and in sixteenth-century CE Italy among children of aristocratic families (Giuffra et al. 2013). In both cases, rickets was attributed to cultural norms that kept children secluded during the early years. While the Medici children were able to reach the age of 6–7 years, in Bahrain no children with rickets older than 3 years were noted, suggesting that later exposure to sunlight repaired the lesions of those who survived.

In an attempt to evaluate the impact of Romanization at Durnovaria (Poundbury Camp, Dorset), Lewis (2010) found a high prevalence of lesions related to anemia, rickets, and scurvy. These suggest a high level of nutritional deficiencies believed to reflect a generally low standard of living in the urban environment.

Infectious Diseases

Infectious diseases have had a major impact on human history and biology given the dynamic relationship between the evolution of infectious agents and the immune response of individuals in host populations through time. A multitude of cultural and socio-economic conditions (population size, sanitation, and nutrition, among other factors) interact with environmental parameters (for example, temperature fluctuations, humidity, and water conditions) to allow pathogens to appear and evolve along with their vectors and hosts. While the list of infectious diseases that can afflict humans is extensive, only an estimated 5%–20% of diseases in the pre-antibiotic era leave their trace on human skeletal remains (Ortner 2008). For the skeleton to be affected, the infectious condition needs to be chronic, as with tuberculosis, leprosy, and syphilis—which have a propensity to produce characteristic skeletal lesions—or with infections with nonspecific characteristics, such as osteomyelitis, periostitis, and osteitis. The application of immunochemistry techniques and biomolecular research, despite requiring stringent protocols to secure authentication (Brandt, Weichmann, and Grupe 2002; Wilbur et al. 2009), have substantially broadened the range of identifiable diseases in the past.

Plague

Plagues have often been linked to major turning points in human history; the Mediterranean world offers several such examples. Osteoarchaeological evidence from a mass grave of the fifth century BCE in the Kerameikos cemetery in Athens revealed the burial of about 150 individuals believed to have been deposited synchronously in five successive layers. Scarce pottery remains point to circa 430 BCE, while experimental isolation of bacterial DNA from the dental pulp of a few individuals set typhoid fever as a likely candidate for the plague at Athens at the beginning of the Peloponnesian War (Papagrigorakis et al. 2006). Besides settling questions on authenticity (Shapiro, Rambaut, and Gilbert 2006), other lines of evidence may prove beneficial.

Respective investigations on the causes of two major pandemics (the sixth-century plague of Justinian, and the fourteenth-century Black Death) have invariably recognized *Yersinia pestis* as the causative agent (Drancourt et al. 1998; Harbeck et al. 2013). While replication of some of these results is pending, scholars inquire into the climatic and dietary conditions that may have contributed to the outbreak of the fourteenth-century plague (Antoine and Hillson 2002), while the scarcity of black rat bones from many sites in Northern Europe raises questions concerning its mode of transmission (Hufthammer and Walløe 2013).

Malaria

The occurrence of malaria, an infectious disease caused by parasites of the genus *Plasmodium* transmitted to humans by infected *Anopheline* mosquitos, is presumed in antiquity from descriptions in Hippocratic texts. The condition is believed to have been endemic in the Old World by 500 BCE although it must have been active in the region well before (Sallares, Bowman, and Anderung 2004). Attempts to identify antigens produced in response to malaria detect the disease in Egypt in very early periods (Bianucci et al. 2008). Other approaches, however, demonstrate its presence only later. A recent attempt to identify malaria—isolating the genome of *Plasmodium falciparum* in bone tissue samples from 91 Egyptian mummies of different periods—confirmed its presence in two cases only among the most recent specimens (1500–500 BCE: Nerlich et al. 2008).

A similar attempt to isolate aDNA of *Plasmodium falciparum* from 40 infant skeletons recovered from an abandoned villa in Lugnano in Taverina, Italy (450 CE) was successful in only one case (Sallares and Gomzi 2001). Taking into account phylogenetic relations among malaria strains and associated congenital blood disorders, Sallares, Bowman, and Anderung (2004, 321) interpret this find as evidence that falciparum malaria, and by inference its mosquito vector, "had attained their maximum geographical distribution in that region by mid-5th century AD." If we consider the possibility that other *Plasmodium* species were also present in antiquity, it seems possible, with current biomolecular techniques, to trace the history and spread of malaria and the role it has played in human history.

A recent attempt to recognize malaria on the basis of skeletal characteristics employed techniques of spatial epidemiology to appraise a correlation between CO in low-lying and fenland regions compared to non-marshy areas in England between 410 CE and 1050 CE (Gowland and Western 2012). The study built on rich medical and anthropological literature that noted a geographical association between the occurrence of malaria and genetic anemias (e.g., Livingstone 1957; Angel 1966).

Tuberculosis and Leprosy

Mycobacterial diseases have preoccupied paleopathological investigations because of their devastating impact on living conditions and their characteristic skeletal and soft tissue changes (Roberts and Buikstra 2003). Tuberculosis appears with certainty in the Neolithic era in the Mediterranean and North Europe but also from 700 CE in the New World. Leprosy may have been brought to the Mediterranean from India by Alexander the Great's returning armies, although no case of leprosy has been detected skeletally in India thus far (Stone et al. 2009). Ancient DNA retrieval techniques (Zink

et al. 2005) face the challenge of differentiating pathogens from the many forms of mycobacteria that live in soil and water (Wilbur et al. 2009). Phylogenetic analyses of the *Mycobacterium tuberculosis* complex have demonstrated that the human strain preceded that of other animals rather than vice versa, as believed until recently (Harper and Armelagos 2009).

Observation of the pathognomonic osseous lesions of both conditions in BCE centuries and more systematically in CE times has raised questions on the mode of transmission of these communicable diseases that are invariably linked to urbanization, overcrowding, and poverty (Roberts and Buikstra 2003). Tuberculosis is most clearly visible in the Medieval era, while leprosy is detectable starting from the Hellenistic and Roman periods (e.g., Zias 2002; Belcastro et al. 2005). Tuberculosis has been recently reported in the skeletal remains of a young adult male from a first-century CE necropolis near Rome (Canci et al. 2005), while childhood leprosy, perhaps the result of in utero infection, was identified in a Roman necropolis (second to third century CE) at Martellona (Rubini, Zaio, and Roberts 2012).

Treponematoses

Treponematoses (e.g., pinta, yaws, endemic and venereal syphilis) are believed by many to have originated in the New World and introduced to the Old World by Columbus' crews (Harper et al. 2011). Despite the number of cases of skeletal lesions compatible with treponematoses reported from Roman and Medieval sites (e.g., Mitchell 2003; Rissech et al. 2013), the evidence remains inconclusive, while the analysis of pathogenic aDNA has been thus far unsuccessful (Bowman and Brown 2005). Nevertheless, the recent identification of a pre-Columbian case of congenital syphilis in Anatolia (Erdal 2006), along with an increasing body of evidence on treponematoses in diverse European sites (Walker et al. 2014), suggests the intricacy of the evolution of this complex group of diseases (Cook and Powell 2012).

Tumors

The diagnosis of cancer in antiquity comprises one of the oldest fields of enquiry in paleopathology (Brothwell 2012). Egyptian and Greek medical documents provide references to tumor-like lesions, their treatment, and post-operative care, suggesting that the disease was well known in antiquity (Mukherjee 2010). However, despite the extensive analysis of thousands of osteological and mummified remains, the identification of cancer is rare in archaeological samples. By contrast, the identification of benign tumors seems more frequent. Recent identifications include a giant cell tumor in the tibia of a sub-adult from Roman Corinth examined radiographically (Fox 2005), as well as a form of rectal cancer, and a metastatic case (most likely from prostate cancer) in mummies of Ptolemaic Egypt diagnosed histologically, with digital radiography and computerized tomography (David and Zimmerman 2010; Prates et al. 2011). Most unusual has been the discovery of a calcified myoma (uterine fibroid) in a woman of the Late Roman period in Egypt (Strouhal and Jungwirth 1977) and an ossified ovary teratoma in the pelvic region of a 30–40-year-old woman of the same period from Catalonia (Armentano et al. 2012).

The rarity of malignant tumors is often explained by the lower life-span and the assumed reduced occurrence of carcinogens. Further limitations are imposed by preservation, diagnostic techniques, and pseudopathology (DeBoer, Van der Merwe, and Maat 2013). A rare epidemiological analysis of malignant tumors comparing their frequency in two cemeteries from Upper Egypt (3200–500 BCE) with that in a South German ossuary (CE 1400–1800) showed a similar occurrence between the two samples. This supports the view that lower life expectancy rather than environmental factors is responsible for the rarity of cancers (Nerlich et al. 2006). Binder et al. (2014), however, draw attention to the multitude of carcinogens that existed in antiquity, such as asbestos, indoor wood fires, and bitumen fumes exuded during waterproofing and embalming, in addition to infectious diseases, such as schistosomiasis, plaguing Egyptians and Nubians since 1500 BCE, and recognized today as a common cause of bladder cancer.

Trauma

Traumas comprise diverse forms of injuries on the human body that can result from accidents, violence, disease, therapeutic strategies, cultural practices, and many other causes (Judd and Redfern 2012). Epidemiological analyses identify shifting patterns of traumatic lesions temporally, while case studies of single or multiple injuries may offer valuable information on tolerance and medical care, but also on abuse, in antiquity. An unusual case of injury with a metal object penetrating the forehead of a young woman (early third century BCE) from the cemetery of the Kerameikos in Athens (Bisel 1990) suggests that the woman survived with this object visible on her face long enough for the bone to heal around the point of entry. Likewise, an adult with a healed comminuted fracture on the femur found in a late Roman collective grave from Akraifia in Boeotia chronicles a prolonged period of immobility that must have required sustained care for his survival (Vlachoyianni, Lagia, and Sabetai-Arditti 2008). Different stages of healing of multiple fractures on the skeleton of a 2–3-year-old child (50 BCE–450 CE) from Dakhleh Oasis in Egypt were analyzed using macroscopic, radiographic, and histologic techniques. The study claims this as the oldest case of child abuse from the osteoarchaeological record (Wheeler et al. 2013).

Trepanation, the surgical removal of a piece of bone from the cranium, is considered a special form of trauma that can result from ceremonial practices (see also SURGERY) or therapeutic practices intended to alleviate endocranial pressure (Capasso and Di Tota 1996). Repeatedly described in the Hippocratic Corpus, it exhibits a broad temporal and geographic distribution in the archaeological record. Fabbri et al. (2012) report on a trepanation from the Greek colony of Himera (Sicily) dating to the Classical age. SEM-EDS microanalysis revealed the traces left by the tool, subsequently identified as a Hippocratic *trypanon* or Latin *terebra*. Bourbou (2013) describes a case of trepanation on a young man at Chania in Crete found in a common grave at the rim of the main cemetery (fourth/third century BCE). On the basis of grave-finds, such as fetters, it appears that the area may have been used for the disposal of people living on the periphery of society. Bourbou acknowledges the difficulty of ascertaining whether this case of trepanation was an act of compassion offering relief from pain, or an act of fear or shame aimed to eliminate stigma from a disabled person.

Joint Disease

Joint diseases are among the most frequently encountered pathologies in human remains (Waldron 2012). Their age-progressive character probably explains their presence in almost every collection analyzed, starting from the earliest Archaic period in Egypt to Roman, Late Antique, and Medieval times across the Mediterranean (e.g., Capasso 2001; Rife 2012; Duday and Portat 2013). Joint diseases may be proliferative (osteoarthritis), resulting in new bone formation, or erosive (spondyloarthropathy), resulting in the loss of bone tissue, although in many cases a combination of the two processes occurs (Waldron 2008; Figure 29.2).



Figure 29.2 Severe degenerative changes in the distal epiphysis of the left humerus of an adult from the fourth century BCE Athens (Plateia Kotzia). Photo by author.

A recent study evaluated the presence of ankylosis in the hands and feet of the skeleton of a man buried in the catacombs of Saints Peter and Marcellinus in Rome (first–third centuries CE; Kacki et al. 2013). Exhaustive differential diagnosis using radiography suggested spondyloarthropathy as the possible etiology, and the condition apparently accompanied the man for a large part of his life, potentially restricting activity.

Another joint disease frequently encountered, and occasionally linked to increased longevity and obesity, is DISH (diffuse idiopathic skeletal hyperostosis). Producing characteristic lesions in the spine, this condition has been observed in eminent Classical/Roman-era burials in Athens (Angel 1945; Lagia 1999) and Hellenistic/Roman-era burials in Crete (Bourbou 2005).

In addition to providing information on health, osteoarthritis, the "archetypal proliferative joint disease" (Waldron 2008, 46), has also been viewed as an activity-related indicator although genetic, nutritional, and metabolic factors, as well as trauma, also affect the expression of this condition (Jurmain 2013). Hussien et al. (2009) examined spinal disease among Egyptians from Bahriyah Oasis (332–330 BCE). The prevalence of vertebral osteophytosis was found to be high, while Schmorl's nodes (herniation of the intervertebral disc) were also present in the sample along with one case of DISH. The relatively high frequency of vertebral osteophytosis in the cervical vertebrae was attributed to carrying heavy loads on the head, a common practice among Egyptians. In respect to the thoracic and lumbar vertebrae, the results of the study were tentatively attributed to agricultural activities, and wine and textile production.

Oral Health

The study of oral health allows the investigation of the standard of living through the examination of dietary habits, oral hygiene, and the use of teeth as tools (and therefore occupation), and also the general stress levels of a population (Lukacs 2012). As such, current studies inquire into the social, cultural, and environmental conditions that may differentiate subsistence and health regionally (Cohen and Crane-Kramer 2007).

Epidemiologic analyses in numerous sites around the Mediterranean have provided a wealth of data on dental health often analyzed in combination with diet modeled through bone chemistry. Keenleyside (2008) combined evidence on dietary status and dental stress on human skeletal remains from Apollonia Pontica and traced a diet rich in carbohydrates. Enamel hypoplasia, recorded in approximately one quarter of the sample, was attributed to nutritional stress and infectious agents. Indeed, stable isotopic data showed a predominance of C3 plants, suggesting potential nutritional deficiencies, while excavations revealed high-density occupation (Nedev and Panayotova 2003), which likely increased exposure to pathogens. Early weaning and using cereals and dairy products as a weaning food may have also contributed to the high frequency of enamel hypoplasia (Kwok 2007).

A study on sub-adults from the necropolis of Isola Sacra (second/third centuries CE) examined deciduous teeth for Wilson bands, that is, enamel defects due to external stressors. The high frequency of such bands in the sample was attributed to the use of nutritionally inadequate or unhygienically prepared supplementary foods during weaning (FitzGerald et al. 2006). A similar study based on a sample of adults, explored patterns of linear enamel hypoplasia in Greco-Roman Mendes, in Egypt. The relatively

low prevalence of the condition in the sample was interpreted as suggestive of well-nourished individuals in good health (Lovell and Whyte 1999).

5. Conclusion

The potential of the study of health and disease in past societies cannot be overstated, despite any methodological and interpretational limitations that the diverse lines of evidence, cultural and biological, may entail. Modern medicine and anthropology often impart a view on well-being that is defined by the absence of disease from an individual or a group (Levin and Browner 2005). Biocultural studies, focusing on contemporary populations and the determinants of health, propose resolutions to how health and well-being could be improved. Respective studies on past populations direct attention to the ability of humans to survive, despite many adversities and imbalances in the distribution of determinants of well-being. This cursory overview of pathologies detected in the Classical world elucidates dynamics in the development of what we recognize today as the highest standard of living thus far known in the western world.

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Grauer 2012. Presents a comprehensive and updated account on the evolution of paleopathology as a discipline, and the different pathological conditions that can be identified in skeletal remains.

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CHAPTER 30

Psychology and Physiognomics

Arnaud Zucker

1. Introduction

There is no more than a loose connection between the modern concept of "psychology" (unknown in antiquity) and the Ancient Greek study of *psychē*. Historical and conceptual factors account for their differences but also demand an understanding of Greek theories of the soul. On the one hand, some basic assumptions of modern psychology are completely foreign to the ancient interpretation: unconscious dimensions, constant psychic organization of the *Ego*, self-consciousness, and social behavioral adaptation. On the other hand, modern philosophical and medical notions of "*psychē*" differ significantly from ancient views, leading to serious misconceptions, particularly the Cartesian mind/body dichotomy. Ancient "psychology," in fact, is neither the science of the inner mind (the self and personal identity) nor the study of hidden mental processes. In truth, it has little to do with the investigation of psychic structures and processes. Ancient psychology is mainly the study of the physiology and dynamics of living beings. Moreover, it "did not regard 'study of the mind' as an autonomous subject with specific terms of reference" (Long 1973, 1). It is thus nearly impossible to render an adequate translation of the Greek word (or, for that matter of its Latin counterparts, "*animus*" and "*anima*"), which had a variety of uses, vis-à-vis our "soul" or "mind." Steeped in Christian and Cartesian traditions, these terms are both restrictive and inadequate (Snell 1953).

Let us first consider the most debated issues, precisely insofar as there was no consensus on the nature and properties of *psychē* and the terminology was unstable. A matter of philosophical and medical speculation, the topic also provided a persistent and "existential" focus of inquiry in literature. Indeed, psychology was not a discipline but rather a network of intertwined issues—like so much of ancient science—related to natural history, ethics, politics, metaphysics, and science: *psychē* and *cosmos*, *psychē* and living

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beings, *psychē* and passions and reason, *psychē* and the moral person, *psychē* and cognitive faculties … The core is what has been called the "mind-body problem," which for ancient authors was instead a "mind-body interaction." We first present the general conceptual and theoretical framework, especially in Aristotle's *De Anima* (*On the Soul*), the single most important ancient "psychological treatise." Next, we address some psychological (in the modern sense) questions and doctrines. Finally, we consider the theory of physiognomics, which logically extends from ancient "psychology."

2. Ontology and Physics

Nature of the Psychē

Psychē, which often simply means "life" (Heraclitus: *TEGP* 130), is the most distinctive "common factor" and general principle of life in all animated beings (see Aristotle, *On the Soul* 402a8). It occasionally applies to non-biological beings: the *cosmos* (Thales: *TEGP* 37; Plato, *Timaeus* 37d; Stoics: *SVF* 2.172, 633), celestial bodies (Aristotle, *On the Soul*), or even classical elements (Empedocles: *TEGP* 32). From the earliest Greek theories of natural philosophy, this dynamic principle is generally featured as a physical, elementary, and somehow material entity, thought to be both inherent in corporeal substance and transcendent from specific shapes. It was identified with one of the canonical elements (usually air or fire), and the later Epicureans and Stoics explicitly described it as material. In spite of the diversity of philosophical and medical doctrines, the *physical* conception, which determines the way philosophical systems are shaped (physics, biology, ethics, logic), is consistently viewed as "physical monism," with all bodies considered as unified structures. The concepts of "absolute soul," "infinite will," or "spirit detached from the body" would be utterly out of place in this context. Even for Plato, the more dualist of philosophers, personal *psychē* is *partly* detachable from the body only because he takes it to be immortal (*Phaedrus* 245c; cf. Thales: *TEGP* 34). Indeed, the *psychē's* immortality is generally a physical axiom (Aristotle excepted), and not at all spiritual or "metaphysical." Materialists (e.g., Democritus) deal with the problem in still another way: individual *psychē* is corporeal *and* eternal just as components of the body are; it is a fragment of the universal *psychē,* a constant mixture of elements pervading and irrigating the living body. In Homer, *psychē* is often mentioned in connection with death—including, at least once, the death of an animal (*Odyssey* 14.426; see Bremmer 1983, 126–128), an original (and probably allegorical) view. Leaving the body (a spatial and material object), *psychē* is described as a vaporous and lamenting echo or residue of the "person." Apart from the staunch support of Pythagoras, Empedocles, and Plato, usually in eschatological contexts, "metempsychosis" (better "metensomatosis:" the rather poetical idea that an individual *psychē* survives the death of one body to pass into another) is only marginally held in Greek thought.

Nonetheless, the essential feature of *psychē* is its physical, continuous, and coextensive relationship with the body, with ramifications for the whole sequence of anthropological sciences. The ancients never separated thought from corporeal existence: all emotions and states of mind are originally governed and produced by a physiological state or movement, where blood plays a prominent role. Moreover, *psychē* is located in the body, even though its location is disputed: the whole head (Democritus), between the eyebrows

(Strato), the whole breast (Parmenides, Epicurus), throughout the heart (Stoics), the arterial ventricle (Diogenes), blood (Empedocles), midriff, or between the heart and head (pseudo-Plutarch 899a–b).

A global and roughly regular system emerges from Homer, who neither explicitly associates *psychē* with the head nor uses a single term for "body" (Onians 1951, 95–115), to Galen, wherein intellectual faculties are located in the brain, passions and energy in the heart (thoracic organ), appetite or lust in the stomach (abdominal organ). Emotions and desires are usually relegated to the liver. The "psychic" topology in Greek and Latin texts, with its characteristic hesitation between a cardio-centric and encephalo-centric model, depends on the distinction of the "parts" or "functions" of such a complex entity. We note that psychological activities (sensitive, emotional, and intellectual) are explicitly anchored in parts of the body and sometimes associated with the canonical elements. Traditional questions consider the nature, abilities, and system of faculties (see Porphyry, *On the Faculties of the Soul*).

Plato: The Psychē Moralized

Plato presents a "psychological model," which proved extremely influential. Plato's binary or triadic diagram of *psychē* appears inspired by Homeric imagery and was expressed in mythological terms. In the *Timaeus*, Plato's anthropomorphic description of the creation of the world and living beings, the Demiurge sets intelligence in the *psychē*, and *psychē* in the body. Gods allotted to man two kinds of *psychē*: immortal, from the cosmic *psychē*; and mortal, whose origin is obscure and paradoxical in nature (*Timaeus* 69c–d; see Nature and the Divine).

Only interested in *human* psychology, Plato equates immortal and rational (*logistikon*) on the one hand, and mortal and irrational (*alogiston*: *Republic* 431a, 439d) on the other, laying the foundations of a conflict between two contradictory entities. While the *cosmos' psychē* is set in the middle of the world, human *psychē* is dispatched in two different places of the body: the rational (*genos*) in the head, and irrational in the thorax. Specifying the latter's location, Plato distinguishes two areas, above and below the diaphragm, corresponding to the good and bad parts of mortal *psychē*. This topology, hardly physiological, is rather an ethical conception, dominated by a moral program and reflecting the contemporary axiology of body parts. That Plato offers an allegorical representation of the soul as chariot (irrational) and charioteer (rational) in the *Phaedrus* (246a–248e, 253c–256c) leaves little doubt about his ethical focus. The three parts of *psychē* are as follows: the "intellectual" (*logistikon*), seat of mind and reasoning (*nous*); the "desiring" (*epithumētikon*), whose only concerns are primitive appetites and fiercest desires; and the "emotional" (*thymoeides*), an intermediate actor (*Republic* 550b) corresponding to the *positive energy* or the *will* (*Republic* 440e–441a).

This "topic," with some resemblance to Freud's second topic of psychic processes, emphasizes a tension between bodily longings and intellectual aspirations. Curiously, though, the *emotional* part does not arbitrate between these tensions but instead acts as a steady auxiliary of the reasonable parts (*Republic* 440a–b).

There is no place for negotiation within the *psychē*, but only a struggle between the good (i.e., tamed and directed by reason) and the bad. In order to keep pure and separate the most valuable and "divine" part of man, Plato introduces an ontological discontinuity and problematic split in the *psychē*:

> But the matter begins to be difficult when you ask whether we do all these things with the same thing, or whether there are three things and we do one thing with one and one with another—learn with one part, feel anger with another, and with yet a third desire the pleasures of nutrition and generation and their kind, or whether it is with the entire soul that we function in each case when we once begin. That is what is hard to determine properly. (*Republic* 436a–b)

Aristotle criticizes Plato's highly specialized *psychē*, as well as his disregard of all physiological processes. And if Aristotle occasionally refers to the Platonic model in its bipartite (*On the Soul* 432a24) or tripartite version (*Movement of Animals* 700b22), mostly in the ethical texts (*Nicomachean Ethics* 1102a26), he also develops a more comprehensive interpretation, giving their fullest articulation to all the meanings of *psychē*.

Aristotelian Holistic Theory

Aristotle, the most important ancient thinker for our topic, investigated the manifold aspects of *psychē* at considerable length in several texts. Undeniably, his concern with physiognomics relates both to an interest for its own sake and to the prominent role of the interconnection between *psychē* and *sōma* (material body) in his philosophy. Aristotle's theory of *psychē* is hard to grasp, because of the difficulty of his terminology and style, as well as conflicting assertions that give way to discrepant interpretations ranging from crude materialism to high intellectualism (Sorabji 1974). Underlining some crucial difficulties, Ackrill's seminal study (1972) provides a consistent interpretation of Aristotle's various definitions of the soul:

1) "primary/prime actuality (*entelecheia*) of a natural organic body" (412b5–6);
2) "of a natural body which has life in potentiality" (412a27–28); and
3) "substance (*ousia*) as form (*eidos*) of a natural body which has life in potentiality" (412a20–21).

The genetic paradigm (Jaeger 1934; also applied to Aristotle's psychology by Nuyens 1948) retraces a hypothetic evolution from a dualistic and Platonic view (in the lost *Eudemus*) to the definition of *psychē* as complete realization of an *entelecheia* of the living being. But this analysis seems to leave a number of issues unsolved. For instance, Aristotle criticizes all previous theories, rejecting Democritean materialism (*psychē* made of concrete atoms), Platonic dualism, and Pythagorean mathematicism (*psychē* as number). Moreover, Aristotle seems to conceive the body–*psychē* relation within the framework of the "hylomorphic" theory of the solidarity of form (*morphē*) and matter (*hylē*: Labarrière 2005b).

This polyvalent concept becomes a crucial philosophical tool when explaining major biological mysteries, such as determining the origin (*archē*) of all faculties and activities of living beings. Basically, it is a "key" to understanding various life processes. *Psychē* is responsible for the unity and organization of living substances as well as their capacity to interact with their environments (e.g., nutrition, motion, sensation, action, …). To Aristotle, then, *psychē* is more living "spirit" or formal energy than the immaterial counterpart of a material substance. Some (e.g., Kahn 1966) suggest that *psychē* might correspond to the notion of "person," in light of the essential Aristotelian inseparability

of material *sōma* and immaterial *psychē*. Nonetheless, this interpretation, only partially valid, fails to encompass all meanings of the word. The complexity derives from the fact that *psychē* features in all biological questions and is invoked as a global principle for various questions: the animation of a *sōma*; the cohesion and unity of a living individual; the rationality and organic consistency of physiological activities; and the existence of esthetic and mental activities. We could say that the *psychē*, which is in a way "all existing things" (*On the Soul* 431b21), is all but the material and static matter in a living body: simultaneously an immanent agent and transcendent cause (*aition*) that converts material substance (*hulē*) into an animated, functional *sōma*. Since *psychē* is synchronously the formal, efficient, and final cause of the living *sōma* as an organic and organized whole, it "belongs to a body" (*On the Soul* 414a21), "cannot be separated from the body" (*On the Soul* 413a4; see 407b2–23; *Metaphysics* 1026a5), and must be considered as an abstract entity. The connection and intricate relation between matter and form, material substance and organic and dynamic functions, and physical elements and mental activities are at the heart of Aristotle's investigations on the nature of *psychē* (Caston 2009).

Aristotle considers that the *psychē* present in plants, animals, and humans is basically the same. But he distinguishes different abilities (*dynameis*) and degrees in its activity: the vegetative function (*threptikon*), shared by all, the essential function (*On the Soul* 415a24–25); the sensitive function (*aisthētikon*), lacking in plants; and the rational function (*dianoētikon* or *logistikon*), exclusive to human beings. This short set is sometimes enriched with other faculties (414a31): "vegetative, sensitive, appetitive *(orektikon)*, locomotive *(kinētikon),* and intellective," occasionally completed by the "imaginative" ability (*phantastikon:* 432a31). Among these occasional functions, Aristotle does not adequately explain the "appetitive," since it potentially involves all the other activities of *psychē* and explicitly comprises the three Platonic aspects: *epithymia*, *thymos,* and *boulēsis.* But Aristotle seems to admit that "in a certain way the parts (functions) seem to be infinite" (432a24), and modern scholars disagree on the number. Attaching importance to the unity of *psychē* and non-aggregative form (414b20–28; 432a15–b6; see *Metaphysics* 1045b21),[1] Aristotle is somehow reluctant to call these faculties "parts" of *psychē* (413b25), as did Plato. Besides, this division, which outlines the correspondence and continuity between psychic faculties and physical organs, is more theoretical (to describe living processes analytically) than concrete (433a32). At any rate, all psychic activities and vegetative functions (respiration, generation, sleeping, dreaming, fantasy, …) must be considered within the same interpretive framework: they fully involve the body in the dynamic of the *psychē*, and physical and psychological determinations are equally essential to understanding its process and meaning.

3. Psychology in the "Modern Sense"

The Sensitive and Intellectual Faculties

Aristotle's views on *psychē* seem somehow close to the functionalism of cognitive psychology. Nevertheless, as Aristotle clearly points out, the study of *psychē* does not belong exclusively to natural science (*Metaphysics* 1026a4–6; *PA* 645a33–b10) but touches also on the philosophy of the mind, cognitive processes, metaphysical theories, politics, and ethics. Unlike Aristotle, whose conception of *psychē* is comprehensive, other ancient

philosophers are chiefly, if not exclusively, interested in the human *psychē* (*On the Soul* 402b4, 410b17), and their speculations focus on intellectual faculties that are shared to some extent with irrational (*aloga*) animals. Obviously, *aisthēsis* (sensation/perception/comprehension) comes first, since without sensory experience humans could neither learn nor think; and it is indeed difficult to say whether perception was identified with intelligence before Plato, as stressed by Aristotle (427a17; see Theophrastus, *On the Senses* 4 [Parmenides], 25 [Empedocles]; more generally Pigeaud 1981, 32–41), or if *aisthēsis* referred to a number of heterogeneous activities ranging from feeling to thinking. Even if Aristotle rejects the conflation of both faculties, he states that all cognitive processes are based on sensation, which is—historically but not fundamentally—the condition that makes reflection possible at all (*On the Soul* 429a1). Aristotle's account, however, raises many questions: what kind of intelligence was possessed by animals (Labarrière 2000); did he have concept of "consciousness" (Caston 2002); what was the status and function of what he calls the "common sense" (*On the Soul* 425a14–b2) which differed from the five senses and was thought to coordinate them into a kind of *synesthesia* (Gregoric 2007). More positively, Barnes concludes, "Philosophy of mind has for centuries been whirled between a Cartesian Charybdis and a scientific Scylla: Aristotle has the look of an Odysseus" (1971, 114).

Ancient philosophers were much concerned with theories of perception. Moreover, sensation figures prominently in doxographical collections, significant because sense perception is the doorway to the material world and, therefore, is inextricably linked with the question of whether sensitive (and hence intellectual) faculties have a true knowledge of reality.[2] Distrust of the senses should not be overemphasized, and—apart from Parmenides and some texts of Plato (and the Skeptics)—ancient philosophers are generally confident regarding sensory information. Yet, after Socrates, who placed ethics at the core of philosophy, mental faculties receive increasing attention from philosophers, whose concern is usually directed to physical conditions and the development of what constitutes reason (*nous*). As a result, in Platonic and Hellenistic philosophy, *psychē* becomes a metonym for the purely intellectual faculty. Even if Stoic doctrine allows for variations, the "split" between a material *psychē* that obeys the laws of physics and a highly intellectual *psychē* that does not exclude free will is exemplary. Materialists like the Epicureans (who were less interested in the system of mental activities and less fond of methodic organization and refined terminology), the Stoics argued that *psychē* or *pneuma psychikon* is a mixture of air and fire, and (in accord with Aristotle) that all psychic activities are physiological. The Stoics, nonetheless, distinguished two hierarchic levels corresponding to sensitive and intellectual functions, calling the latter the *hēgemonikon,* the "governing part" located in the heart, while the rest of the *psychē* is diffused throughout other parts of the body (Figure 30.1).

The Power of "(Re-)Presentation"

The connection between these two parts (sensitive/intellectual) is implemented by a basic faculty identified by Aristotle (*Motion of Animals* 700a15–24, 701a33–b1, etc.): that is, perceptual and cognitive "presentation" (*phantasia*). This ability, simply defined as "that in virtue of which an image occurs in us" (*On the Soul* 428a1–2), performs the transfer of sensory information (or mental reproductions stored in memory)

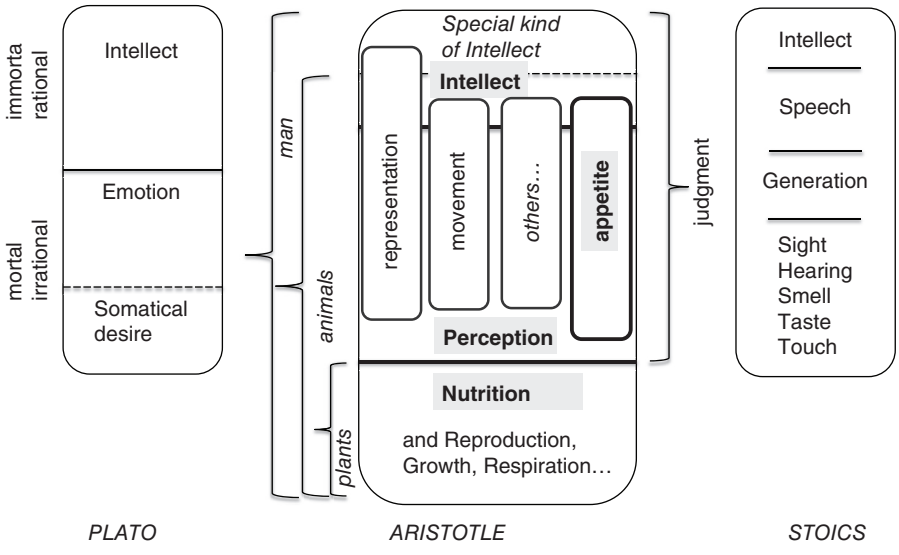


Figure 30.1 Psychic faculties according to Plato, Aristotle, and the Stoics.

and presupposed formalized interpretations (Frede 1995). Through this operation ("awareness," "understanding"), the *hēgemonikon* organizes and transforms sensations, impressions, and images as cognitive data, without which a person is unable to think. The Stoics developed Aristotelian assumptions into a more complex and detailed system. Peripatetics produced empirically oriented "Parva Naturalia" (*On Memory, On Sleep, On Dreams, On Youth, Old Age, Life and Death and Respiration*, etc.) that investigate "phenomena common to soul and body" (*On the Senses* 436a6–8). If all psychic faculties were not simultaneously somatic, one might say that *phantasia* is the junction of *psychē*. We might go too far in interpreting it as "self-consciousness" (Long 1999), yet such a faculty, embracing perception, abstract thought, imagination, memory, and latent concepts, is key in Stoic epistemology. With no mechanical impact on behavior (for the mind may accept some "presentations" as true and reject others), it belongs nonetheless to the four main powers of the *hēgemonikon* (impression, assent, impulse, and reason). By assenting to an impression, the intelligent *psychē* enables impulses that convert practical desires and drives to specific actions. Reason (*logos*), the characteristic faculty of humans, is thus the "leading" and coordinating part of the "governing part," ensuring the unity of all mental functioning.

Ethical Implications

The "representation" stage is the hinge where philosophies of self-control (*enkrateia*) and freedom from emotions (*apatheia*) place moral choice (*prohairesis*), which Aristotle considered "a principle that the human being is the source and origin (*archē*) of his actions" (*Nicomachean Ethics* 1139b4). The equivalent of the modern concept of "will" is lacking in antiquity (Kahn 1988). However, the "use of impressions" (*chresis ton phantasion*) depends on rationally oriented choices. In Epictetus' version of Stoic ethics,

where the traditional distinction between "what is up to us" (*to eph' hēmin*) and "what is not up to us" (*to ouk eph' hēmin*) is a major axiom, the person is concerned only with the former, and moral actions depend directly on the assent given (or not) to the impressions related to these actions. The Stoic concept of the *hēgemonikon* as "the thinking center," or "the center of individual agency and morality" (Long 1999)—yielding a rational "monism"—is thus the physical base of the Stoic ethical system, where deliberate actions result from rational choices. A major paradox raised by this doctrine lies in the gap between general determinism and human free will. On the moral level, Stoic doctrine somehow reproduces the psychological tension between the corporeality of *psychē* and its rational activity. Somatic mechanisms and cosmic determinism (fate) hardly belong together with intellectual and practical freedom, which has been much criticized (see Plutarch, *On Stoic Self-Contradictions* 1055c10–1056b3). Stoics argued, nonetheless, that responsibility and determinism are "compatible" (Bobzien 1998).

Double Reality of Pathos

Another problematic aspect of Stoic doctrine implied by the rational monist *psychē* is its supposed unitary condition. Unlike Plato and a few dualists and heterodox exceptions (e.g., Poseidonius, who influenced Cicero), the Stoics did not consider passions as resulting from a distinct irrational faculty. Accordingly, they ruled out the possibility of conflicts within *psychē*: all passions (good or bad) were mere judgment errors (Sorabji 2000). Clearly distinguishing "errors" from "passions," Galen, who was not a Stoic, referred to standard Stoic doctrine when he praised both self-control and the help of a truthful censor for therapeutic "fraternal correction":

> Error (*hamartēma*) arises from a false opinion (*doxa*), but passion (*pathos*) from an irrational power (*alogos dynamis*) within us which refuses to obey reason; both are commonly called errors. (*On the Passions and Errors of the Soul* 5.2.15 Kühn)

The intellectualized Stoic view of the nature of passion results partly from the complex meaning of *pathos* (or its doublet *pathēma*). The ambiguity of this pivotal Greek word, ubiquitous in ancient texts, is indeed puzzling as far as psychology is concerned. It refers to everything "that happens" to somebody or something, whether for better or worse: sensation, emotion, passion, and even more global experiences. *Pathos* also refers to accidental properties (current in ontological debates), symptoms, and disease (in medicine). The term in Latin is similarly vague:

> What the Greeks call *pathē* I might call diseases (*morbi*), and that would be a literal translation, but it is not agreeable to our way of speaking. For envy, delight, and pleasure are all called by the Greeks diseases, being affections of the mind not in subordination to reason; but we, I think, are right in calling the same motions of a disturbed soul disturbances. (Cicero, *Tusculan Disputations* 3.4; cf. 3.10, 4.5)

This "double-dealing" of *pathos* emphasizes the analogy between physical and psychical *affects*, and also encourages equating them in a unity whose twofold nature is illustrated by their concomitant association with *pathos* itself. It also accounts for the importance of medical discourse in ancient "psychology" (Galen, *On the Doctrines of Hippocrates and*

Plato 5.432 Kühn), and the presence of several medical expressions and metaphors in Stoic writings (Cicero, *Tusculan Disputations* 3.12, 4.10, etc.). Every function related to *phantasia* (e.g., memory: *Soul* 449d) may be regarded as a *pathos* of the *psychē*. However, since "passions" are literally "things which one undergoes," the Stoics would be reluctant to say that the *psychē* suffers or is angry, that is, that the *hēgemonikon* is subject to the two cardinal passions (appetite and fear), or to various emotions considered as "irrational movements of the soul" or "impulses which are excessive" (see Lloyd 1978, 234), and whose species they carefully list. It is hard to admit that "the soul itself is transformed into the passion" (Seneca, *On Anger* 1.8.2).

Medical Approach and Typical Psychology

To avoid this flaw, Aristotle asserted that the *psychē* is not strictly affected, but rather a human is affected *through* the *psychē* (*On the Soul* 408b1–15). Given that somatic *pathē* also affects the man, such an assumption, highlighting the unity of psychological phenomena, insists on the consistency of the "person" (Ierodiakonou 2011, 8). Aristotle explains emotions/passions through a double, complementary causality: wrath (a paradigmatic example: 403a30–b2) is formally an "appetite for returning pain for pain," and materially "boiling the blood or warm substance surrounding the heart." Since "passion" is conceptually a twofold reality, philosopher and doctor synergistically treat the *pathē* that are psychosomatic "troubles." "Medicine heals the diseases of the body, and wisdom removes the passions of the soul" (Democritus: *TEGP* 192). Plato goes further, asserting that "it is indeed impossible to cure the body without the *psychē* and vice versa" (*Charmides* 156b–157b). This statement is, in fact, accepted by all physicians and, at least for the first part of the axiom, by philosophers as well. Diverted from theological etiology, preponderant in poetical texts for explaining the *furor* of Medea, Ajax, Heracles, or Orestes, for example, mental disorders such as *phrenitis*, *mania*, or *epilepsis* (the "sacred disease") are considered physiological problems whose somatic and mental aspects are correlated (see Pigeaud 1981; Drabkin 1955). According to the four humor theory, in its standard post-Hippocratic form, psychological and pathologic tendencies result directly from physiological predisposition: bile (black or yellow) and blood, together with phlegm, match the four classical elements and correspond to the four typical temperaments.

This relation is part of a much wider "ecological" perspective which regards animated beings (including humans) as part and product of a chain connecting biotope, body, character, habits, customs, and laws. First, knowledge of the climate, winds, and quality of waters in a country are essential for discerning the particular psychosomatic conditions of inhabitants and for finding adequate cures. Studying habits (*diaitia*) helps the physician infer the general characteristics (moral, mental, and physical) of a given population (Hippocratic *Airs, Waters, Places* 1). The human *psychē* is, mechanically speaking, highly conditioned by physical factors through its natural environment and by somatic constitution vis-à-vis various complex combinations of the four basic qualities: warm, cold, wet, and dry, through *krasis* (mixture or "temperament"). "Humor" is, therefore, a perfect psychosomatic key, since it affords a clinical picture that connects mental, ethical, and somatic features. Humans are thus part of a global ecosystem, and one's *psychē* and *ethos*, shaped by that ecosystem, is the result and symptom of this chain. This continuity of environmental effect appears as well in the vocabulary used to describe the landscape, character, and the body (*Airs, Waters, Places* 13). We shall consider the overlap of

physical and psychical terminology as proof of global perception rather than metaphorical transfer. Medical literature, much more interested in typical characters and general constitutions, developed a pioneer "ethno-psychology." The Hippocratic author gives long descriptions of Asiatic, Egyptian, and Scythian characters and customs, making it evident that physical and moral dispositions are bound (Anthropology: Knowledge of Man; "Ecology" in the Ancient Mediterranean).

In a more systematic way, "universal astrology" aims to describe all ethnological types, regarding various distinctive "characters" as co-determined by geographical and astrological affinities (Ptolemy, *Tetrabiblos* 2 1–3; Astrology). Greek *ēthos* ("character") refers to a constant or basic disposition, produced naturally by *krasis*. Accordingly, the variety of characters reflects the diversity and balance of components of a particular *krasis*. Besides, while there is a formal analogy between naturally induced tendencies (courage, pity, etc.) and occasional emotions (wine, fatigue, disease, … [Aristotle, *Problems* 953b20]), the main factors determining human and animal *ēthos* are warm and cold (*Problems* 955a32–33). It is important to note that *ēthos*, like *pathos*, has a distinctive polysemy, since (in psychology, ethics, and rhetoric) it means both mental dispositions *and* practical behaviors (Woerther 2007). Again, the difficulty for the modern reader is the ancient symbiosis of behavior and mental disposition which modern psychology separates.

Behavioral Studies and Animal Ethology

The first ancient text dedicated to human behavioral study is the *Characters*, attributed to Theophrastus. Developing a typology based neither on humors nor ethnicity, the *Characters* includes thirty portraits (or rather caricatures) of men as "psychological types" (*tropoi*), clearly inspired by Aristotelian ethics (Lombardi 1999). Theophrastus only mentions sets of behavioral habits and practices, focusing mostly on relational "pathologies" (the insincere man, the flatterer, the complacent man, the talkative man, etc.). In the prologue, though apocryphal (and probably Byzantine), the ancient intellectual milieu is emphasized as illustrated by the initial question: "Why it is that, while all Greece lies under the same sky and all the Greeks are educated alike, it has befallen us to have characters so variously constituted?" Theophrastus' gallery has no interest in etiology, and it differs greatly from Peripatetic psychological texts. In this regard, it diverges especially from a remarkable case study whose subject matter is melancholy, a cardinal "temperament" whose paroxystic form is the *mania*. The text tries to answer the following question:

> Why is it that all those who have become eminent in philosophy or politics or poetry or the arts are clearly of an atrabilious temperament, and some of them to such an extent as to be affected by diseases caused by black bile? (*Problems* 30.1, 953a10–12)

According to a global "psychosomatic" approach, the author considers the affective and intellectual tendencies of the *melancholic* and his unique place in civilization as the result of complexion, analogous to transitory physiological factors:

> As, therefore, he drinks and takes wine in different quantities, an individual changes his character, so there are men who embody each character. For the temporary condition of one man when he is drunk is the permanent character of another, and one man is loquacious, another emotional, another easily moved to tears.

Yet this particular inquiry is unique, hardly according with ancient literature (especially comedy) or Hellenistic and Roman philosophy, which is more interested in general or introspective psychology (Seneca, Marcus Aurelius) than in descriptive characterology. This aspect becomes even more acute in Christian literature, where inner experience is a key to psychology (Long 1973; on characterology before Theophrastus, Joly 1962).

Psychological mental tendencies and behaviors are frequently investigated through animals, used paradigmatically as early as Homer. Animals are thought to mirror typical human categories and practices. And they are philosophically interesting models in elucidating more complex human behaviors (see also Zoology):

> In the great majority of animals there are traces of psychical qualities which are more markedly differentiated in the case of human beings. For just as we pointed out resemblances in the physical organs, so in a number of animals we observe gentleness or fierceness, mildness or cross temper, courage or timidity, fear or confidence, high spirit or low cunning, and, with regard to intelligence, something equivalent to sagacity. Some of these qualities in man, as compared with the corresponding qualities in animals, differ only quantitatively: that is to say, a man has more of this quality, and an animal has more of some other. Other qualities in man are represented by analogous qualities: for instance, just as in man we find knowledge (*technē*), wisdom (*sophia*), and sagacity (*synesis*), so in certain animals there exists some other natural capacity (*physikē dynamis*) akin to these. The truth of this statement will be more clearly apprehended if we regard the phenomena of childhood. For in children may be observed the traces and seeds of what will one day be settled habits, though psychologically a child hardly differs for the time being from an animal (see Plato, *Republic* 441b). So that one is quite justified in saying that, as regards man and animals, certain psychical qualities are identical with one another, while others resemble, and others are analogous to each other. (Aristotle, *HA* 588a17–588b3; trans. Thompson)

Animal psychology is discernible by induction (or projection) through observing behavior. However, since animals are deprived of *logos*, they should not have virtues or vices. Yet this implication, easily bypassed by distinguishing "moral" and "biological" psychology (Labarrière 2005a), is speculative. Animals are generally credited (excepting by the Stoics) with "natural virtue" (*physikai arētai*; see e.g., Aristotle, *Eudemian Ethics* 1234a27; *Nicomachean Ethics* 1144b3, 1151a18, etc.). And they are described with common psychological/moral terminology (courageous, savage, mischievous, etc.). Even the decisive issue of intelligence in animals is generally resolved in a positive way. The majority of the ninth book of the *History of Animals* is devoted to examples of typical intelligence of animals especially regarding social relationships:

> [Animals] appear to have a natural capacity (*physikē dynamis*) corresponding to each of the passions of the soul: to good sense or simplicity, courage or timidity, to good temper or to bad, and to other similar dispositions. Some also are capable of giving or receiving instruction—of receiving it from one another or from man: those that have the faculty of hearing—not merely of hearing sounds but of distinguishing the differences of signs (*sēmeia*). (608a13–21)

This innate "natural capacity"—so to speak—anticipates the modern concept of instinct (Dierauer 1977, 138–148; 1997). Zoological literature emphasizes the fact that animals have access to affective conducts as well as rational cognitive processes, deliberative

strategies, and purposeful behavior (e.g., Plutarch, *On the Cleverness of Animals, On the Love of Offspring, That Beasts Are Rational*). Aelian, conveying an enormous collection of animal stories, reports observations that directly refute the Stoic position (*On the Characteristics of Animals* 6.50) and prove that some animals have reasoning power (*logismos*), and that some even practice dialectical reasoning (6.59).

4. Physiognomics

Body and Soul: Psychological and Logical Postulates

The common and ancient conviction of psychosomatic unity leads logically to physiognomic belief, practice, and theory, as a corollary of psychological doctrine (Boys-Stones 2007). Since *phantasia* is involved even in high intellectual activities, it is possible to say that all psychic affections (gentleness, fear, pity, courage, joy, love, hate, etc.) are related to the body, and that all psychological states are also material states of the body. The Stoic doctrine of the soul's corporeality has a wide-ranging general corollary: "The soul suffers with the body when the body is sick and being cut, and the body suffers with the soul; the body turns red when the soul is ashamed and pale when the soul is afraid" (Cleanthes, *SVF* 1.518). Physiognomy ("interpretation of the nature"), whose modern developments rely closely on the ancient theoretical construction, is a partly intuitive, partly technical method of deducing the moral character of a person from the observation of physical appearance. The relevant primary literature is not easy to circumscribe, as physiognomic evidence is widespread (Evans 1969), noted in rhetors, historians, and playwrights. In four treatises, however, the principles are developed, and examples of psychosomatic equations are offered: most importantly, *Physiognomonica*, attributed to Aristotle and probably written in the third century BCE (Vogt 1999); the treatise of Polemon of Laodicea (circa 110–144 CE), preserved in Arabic; the epitome of Polemon by the physician Adamantius (300–350 CE); and an anonymous Latin text (350–400 CE) drawn extensively from Aristotle and Polemon. In addition, we might add *That the Qualities of the Mind Depend on the Temperament of the Body*, where Galen, commenting on philosophical theories of the *psychē* and the interdependency between psychical and somatic traits, argues for an univocal determinism of body on character. This corpus is theoretically homogenous:

> Physiognomy has for its province, as the name implies, all natural affections of mental content, and also such acquired affections as on their occurrence modify the external signs which physiognomists interpret. […] I will give a list—a complete list—of the sources from which physiognomic signs are drawn. They are these: movements, gestures of the body, color, characteristic facial expression, the growth of the hair, the smoothness of the skin, the voice, condition of the flesh, the parts of the body, and the build of the body as a whole. Such is the list that physiognomists always give of the sources in which they find their signs. (pseudo-Aristotle, *Physiognomonica* 806a22–33)

The basic postulate of this hermeneutic discipline is that "mental character is not independent of and unaffected by bodily processes, but is conditioned by the state of the body"; yet, unlike their medical counterparts (see Figure 30.2), physiognomists allege a reciprocal causation: "… and contrariwise the body is evidently influenced by the affections of the

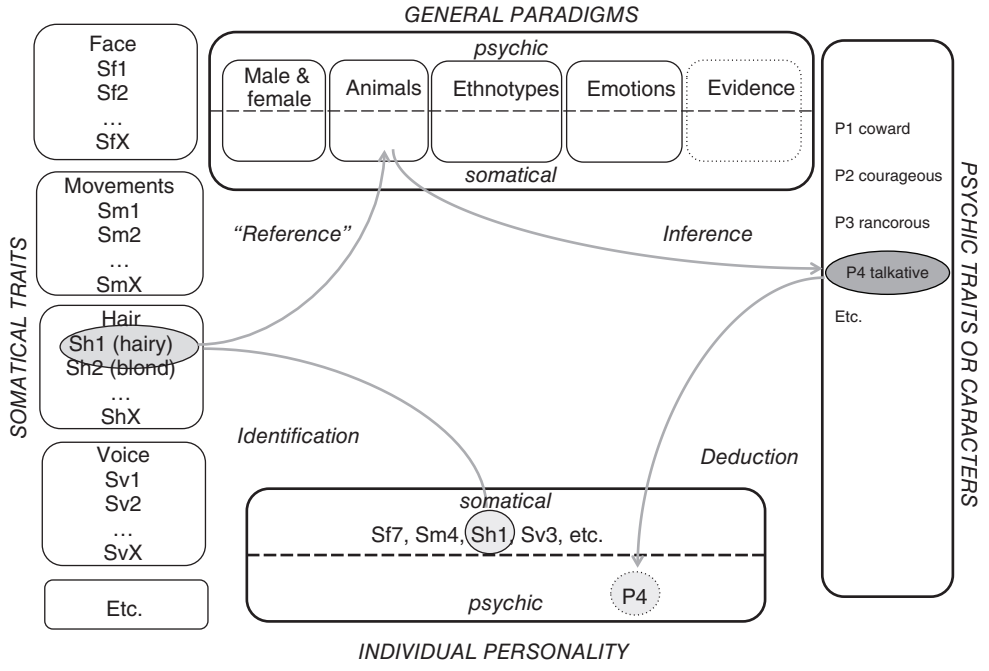


Figure 30.2 Diagram on the genres of faculties of *psychē* according to Plato, Aristotle, and the Stoics.

soul—by the emotions of love and fear (Galen, *Qualities of the Mind* 4.767.1 Kühn), and by states of pleasure and pain" (805a1–10; on the reciprocal influence of passions on the somatic state: Aristotle, *Motion of Animals* 701b33–702a21, cf. *On the Soul* 403a3–28). The third more implicit postulate is that a particular mental trait correlates with one or more particular physical traits. This is somehow the syllogistic conclusion of the two previous assumptions about "the fundamental connection of body and *psychē* and their extensive interaction" (*Physiognomonica* 805a9–11), validating all physiognomic equations.

The Method and Physiognomical "Patterns"

The list of physiognomic (somatic) features, among which the face plays a prominent role, is clear. But to what psychic categories, exactly, do they refer? Physiognomy aims to reveal not only the character (*tropoi, ēthē*), but all mental and internal arrangements, that is, the general psychic predisposition (*psychē* often supplanted by *dianoia*, "mental dispositions"). The focus is thus a global psychology in the most radical sense, and it is not surprising to discover that *ēthos* in this context refers entirely to the "body," superficially referring to "expressions of mood." In order to establish physiognomical equations and give assertions deductively, the physiognomist must rely on empirical evidence to match specific character traits on both levels. Three sorts of bodies seem to offer this opportunity and present an immediately perceivable articulation of relevant signs: emotional, ethnic, and animal. They determine the traditional tripartition of physiognomy depending on whether the discourse is based on pathognomic signs (the common expressions of emotions), ethnological (the physical features typical of a people), or

zoological (anatomical features of animals). In each domain, there is accord between somatic and psychical characteristics. And these characteristics provide general and paradigmatic patterns by which we can interpret the meaning of the first kind of traits and infer from their presence in someone's body the correlative mental quality. All individuals in these categories (every angry man, every Scythian, every lion) are supposed to exhibit the same generic symptoms which prove the constancy of the connection. As for the first kind, the symptoms of an emotional ephemeral state are considered somatic marks of the corresponding psychological trait of character: wide-open eyes are marks of a frightened man and consequently of a coward. It thus becomes easy to discern somatic signs, to refer to their universally psychic meanings, and then to apply the interpretive grid consistently for the purpose of decoding various physical characters. These three analogous methods exploit a wealth of traditional and familiar descriptions and collectively shared ideotypes that give credence to their statements and analogical processes. The physiognomical patterns are simultaneously illustrations, references, and proofs of a set of specific propositions. As for the "concordance tables" given by the physiognomists, they work both ways: from physical to moral, such as "those with thick extremities to the nostrils are lazy" (pseudo-Aristotle); and from moral to physical. *Physiognomista Latinus* provides a gallery of physical descriptions corresponding to different character types (courage, impudence, optimism, hypocrisy, loquacity, etc.: 90–115). However, the physiognomic game does not simply involve two dimensions (*sōma/psychē*). There is a third actor, *eidos*, representing psychosomatic coupling: the monkey, by nature endowed with hollow eyes and villainy (811b19), is living proof that these two seemingly disparate characteristics are twin manifestations of the same background, in other words, that the visible physical expression (small eyes) and the characterological expression (his petty behavior) exhibit a single *form* that speaks simultaneously two languages (Zucker 2006).

Cultural Issues

Physiognomics does not fulfill the specific conditions put forward by Aristotle (*Prior Analytics* 70b) to be recognized as a science. The theory is defective in many regards, especially concerning the precise coupling of traits (why is "big extremities" the natural expression of "courageous?"), and the status and logical validity of the criteria (ideotypes of animals, emotions, etc.). However, the technique of inferring character from physical appearances enjoyed great popularity in Greco-Roman literature and art (portraits traduce moral marks in physical characteristics), and it appears to have been a valuable instrument for assessing people in various social contexts:

> Physiognomy in particular, writes Adamantius, is a discovery of divine men which is able to confer the most and the greatest benefits on those who study it; for no one would give a deposit or entrust an heirloom, his wife, or his children, or even share any kind of friendship whatsoever with those who bear obvious signs of dishonesty, licentiousness, or any wrongdoing in their appearance. (*Physiognomics* A2)

Pythagoras himself is said to have resorted to similar practices for selecting his pupils (Aulus Gellius, *Attic Nights* 1.9.1). And, in spite of the failure of Zopyrus' diagnosis of Socrates (Cicero, *On Fate* 10, *Tusculan Disputations* 4.80), traces of this conception and its practical use in everyday life are numerous, particularly in Stoic and rhetorical

writings where it was widely applied. This tendency, yet to be explained by psychological theories, is also supported by a more general analogy between *psychē* and *sōma*, inscribed within language itself (and not only Greek and Latin). Indeed, one may regard the linguistic use of physical terms to describe psychological traits as a significant kind of metaphorical (or rather metonymical) process. When Adamantius (*Physiognomics* B28) says that "small faces indicate small characters," or pseudo-Aristotle (808a30) that "the small-minded have small limbs and small, delicate, lean bodies, small eyes, and small faces," the discourse seems merely to bring to light, almost tautologically and already integrated in common parlance, evidence of the duality of *physis* ("nature"). The general psychological terminology (affect, nature, disposition, shape, motion, … *pathos-affectus, physis-natura, ethos-mores, eidos-species, kinesis-motus,…*) is also common to *psychē* and body, and if this strengthens the physiognomical logic, it probably betrays more deeply the pre-existence of this connection, as a basic "intuition," a word that does not exist in Greek or Latin, but is roughly sketched in physiognomical writings under the Greek *epiprepeia* (Zucker 2012).

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NOTES

1 The unity is axiomatic and results from the action of the *psychē* or whatever initiates the development (*kinein*) from potentiality to actuality (*Metaphysics* 1045b21).

2 Note that all the ancient and diverse theories of perception (which is not distinguished from sensation) are quite strangely determined by the fundamental and common assumption that the perceiving organ and the perceived object must be somehow *similar* (or contrary), or become similar or isomorphic (as in Aristotle, *On the Soul* 416b35–417a21, 418a3–4).

CHAPTER 31

Anthropology: Knowledge of Man

Gordon Campbell

1. Introduction

Accounts of prehistory, common in many different works, tend to reflect the interests of the writer. That is, the writers' accounts of prehistory and how society developed often serves to justify their views of how society is, or should be. It is fair to say that no ancient writer can be seen as an objective scientific enquirer into prehistory, and stories about prehistory are told either to criticize or to legitimate modern society, and to privilege a writer's point of view. For example, the love poet Ovid gives a brief account of prehistory in which love is presented as the force that softened and civilized a brutish early humanity and rendered it fully human (*Art of Love* 2.473–480), while Vitruvius, the Roman writer on architecture, focuses on the acquisition of fire by early humans; naturally occurring fires led to the first social gatherings, the development of language, and the first societies and the development of houses (2.1).

Stories about prehistory tend to fall into two categories, primitivist and progressivist. In a progressivist account, bestial and savage early humans have been rescued from their miserable state by the invention of technology and the development of culture and civilization. For primitivists, on the other hand, early humans lived in a perfect Golden Age of leisure, purity, and freedom from which we have declined into a world of toil and injustice made only just bearable by technology. Of course, these two categories are far too crude, and many writers produce more nuanced stories, often including themes from each tradition, but it is preferable to keep the terms, crude as they are, rather than to disregard them completely.

Similarly, ethnographic accounts tend to be used to examine a writer's own society by contrasting it, favorably or unfavorably, with that of peoples beyond the Greek and Roman world. There are a variety of ways in which this is done, but, roughly,

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ethnographic accounts can be put in two categories: ethnocentric and anti-ethnocentric. An ethnocentric account sees the writer's own world as the most culturally advanced and other peoples at the "edges of the earth" as backward, savage, and barbaric, while anti-ethnocentric accounts tend to view "primitive" peoples as morally superior, living a pure, simple life that the corrupt center has lost.

What links ethnographic accounts closely to stories of prehistory is a strongly marked tendency of ancient writers to view peoples living far away as somehow living back in time: what Johannes Fabian (1983), speaking of modern anthropologists, has called the "denial of coevalness." As you travel out from the Mediterranean world, it seems that you are traveling back into prehistory, and so what you find out there depends on your views of prehistory: a primitivist finds a Golden Age world, or remnants of a Golden Age still existing, perhaps on a perfect island or even the Isles of the Blessed themselves, but a progressivist or anti-primitivist finds savage barbarity, and backward people barely evolved from wild beasts.

2. Origins

Given the link sketched above between prehistory and ethnography, it is worth looking at ancient ideas of the origins of things and where we came from. Homer, the earliest extant Greek source, is, sadly, not that interested in our origins, but he does preserve hints of a tradition of the origins of gods and humans from Ocean: "For I am going to see the limits of fertile earth, Okeanos, begetter of gods and mother Tethys …" (*Iliad* 14.200); "Another of the everlasting gods I would easily send to sleep, even the streams of the river Okeanos who is the begetter of all …" (*Iliad* 14.244; for Homer's view of the world, see Greek and Roman Cartography).

Aristotle seems to have this tradition in mind when he comments on Thales' theory that the world was originally watery and has since dried out, saying that Thales' theory is just like the earliest speculations about human origins (Aristotle, *Meteorology* 983b27; KRS 7-72; Matter). This theory of Ocean as the origin of life seems to echo Middle Eastern theories of water origins, especially the Babylonian *Epic of Creation* (*Enuma Elish*), Tablet I.1–9, in which the world was originally formed by the mingling of waters creating pastures and reed beds. In the Babylonian version, it is easy to see the environmental origins of the myth. Clearly the writer understood that the Mesopotamian landscape was formed by the silting of the Tigris and Euphrates flowing down into the sea. The Greek version does not fit the Greek landscape so well, but with Homer's mention of the constellations plunging into Ocean (and presumably rising from it again: *Iliad* 18.489), Ocean can reasonably be interpreted as the origin of gods and men.

Another valid interpretation of Ocean as the origin of all things is that it is a region of creative chaos. Ocean is stormy, misty, in constant flux, and ancient sources frequently report that sailing into Ocean takes the traveler into a region where the laws of nature break down and elements which should be separate become mingled; the air is full of water, and the sea becomes sludgy until sailing is no longer possible (e.g., Pytheas of Massilia; Romm 1992, 20–26; Geography; Hydrology). Also, Ocean is seen as the most ancient area of the world, and so it is not too surprising if there the world is still in a chaotic pre-cosmic state. This also accords well with ideas of the Aithiopians, for example, living on the edge of Ocean as the most ancient and primitive (see further below).

Birth from chaos is also found in the earliest Greek account of cosmogony, in Hesiod's *Theogony*:

> First the Chasm [*Chaos*] came into being, and then broad-breasted Earth, secure seat for ever of all the immortals who occupy thepeak of snowy Olympus; then misty Tartara in a remote recess of the broad-pathed Earth … (116–119)

What Hesiod means by *Chaos* has been questioned since ancient times. It seems to be a chasm (*chasma* is simply a different case ending of the nominative *chaos*) that comes into being, and out of which are born the gods, including Gaia and Ouranus, but a chasm in what is not explained. Perhaps the best explanation is that Hesiod is attempting to accommodate different theories of cosmogony. One of these would be the myth of the *Hieros Gamos*, the divine marriage and separation of earth and sky. Here is Euripides' version:

> The tale is not mine, but my mother's—how sky and earth were one form. But when they had been separated apart from each other, they brought forth all things, and gave them up into the light: trees, birds, beasts, the creatures nourished by the salt sea, and the race of mortals. (fragment 484 Nauck, trans. KRS, 43)

Thus the chasm in Hesiod's version should be the gap caused by the *separation* of Gaia and Ouranus, but there is confusion in Hesiod's account because Gaia comes *out of* the chasm. We can say that chaos is thought of as a creative force or area. Hesiod also calls Tartarus, the underworld, a *chaos*, seemingly meaning not simply a great cavern but also a dark, misty, and stormy region, more nearly the modern understanding of the word *chaos*.

In the *Theogony*, Hesiod pays little attention to human origins, only hinting at a possible connection between us and the Giants ("the race of both men and powerful Giants": 50). Ovid preserves a similar tradition (*Metamorphoses* 1.156–162) that humans were born from earth mingled with the blood of the Giants killed in the battle with the Olympians, "but that race was contemptuous of the gods, eager for savage slaughter, and violent: you would know they were born from blood." Similarly in the *Enuma Elish*, humans are created by Marduk, the chief god, as slaves to the gods by mingling the blood of Quingu, vizier to Tiamat, with earth.

In *Works and Days* (109–205), Hesiod also has the gods creating races of humans. They create five races: the golden, silver, bronze, the race of heroes, and iron. We are not told how or why they do this or why the races they create get worse and worse when we should expect the gods to get better at creating races with practice. Hesiod seems only interested in showing how we have declined from the pristine state of the Golden Race, who did no work, were rich in flocks, and lived in harmony with the gods. We have already been given in both *Works and Days* and the *Theogony*, however, a different explanation for the seeming enmity of the gods toward humans: at a feast at Mecone, "when men and gods were coming to a settlement" (*Theogony* 540), Prometheus had tricked Zeus by dividing up the feast unfairly, making Zeus choose the bones wrapped in fat while humans got the meat. In response Zeus punished humans by taking fire from them. Seeming to represent humanity, Prometheus in turn steals fire back. Zeus then punishes humans by the creation of Pandora, the first woman (*Works and Days* 70–83).

This is the first account of the purposive design of a human by the gods in extant Greek sources. Although only one person is created, the story shows that the idea of gods intelligently designing people was familiar, or at least acceptable, to Hesiod's audience.

As time passed, Prometheus himself took on the task of molding humans from earth and water (e.g., Apollodorus, *The Library* 1.7.1; Ovid, *Metamorphoses* 1.80–83; Lucian, *Prometheus* 11–17; Pausanias 10.4.4). A variant on the myth of gods molding us from earth and water, or perhaps an alternative to it, is the myth of our autochthonous origins: that we, or certain heroes, simply grew out of the earth. Examples of this are Erechthonius, born from the soil of Attica, and Pelasgus the hero of Arcadia, born from Arcadian soil (e.g., Pausanias 8.1.4), Variants include Cadmus at Thebes sowing dragon's teeth which grow up from the soil into Theban warriors, some forming the aristocratic population of Thebes, the "sown men" (Ovid, *Metamorphoses* 3.3–130).

Scientific theories of human and animal origins were similar:

> By the late fifth century, the theory was firmly established that the first humans were born from the ground, that earth and water were the substances of which they were composed, and that heat was an agent in their manufacture. The contiguity of water and earth was generally attributed to the unfinished state of the cosmos … No other basic hypothesis, so far as we know, was ever put forth in scientific philosophy. (Blundell 1986, 48)

The main difference from mythological accounts is that no divine input was needed; life simply arose spontaneously from the earth. This may seem bizarre to modern readers, but in the ancient world it was commonly believed that life regularly arose spontaneously. Various writers record the spontaneous contemporary birth of cicadas, mice, frogs and worms, etc., when water and earth became heated by the sun. Diodorus Siculus appeals to modern spontaneous generation in support of his account of the origins of life. He argues that the earth, originally "like potter's clay," when heated by the sun began to ferment and created pustules covered with internal membranes where creatures were formed, just as today swamps can create creatures when heated by the sun (1.7). Lest we feel superior, the spontaneous generation of life was commonly believed until proven impossible by Pasteur in the nineteenth century (Pasteur 1876; Schrijvers 1974, 251).

In view of this ancient belief in the spontaneous generation of life, it was not too difficult to account for the origins of life. The origin of species and the differentiation of humans from other animals, however, were more difficult because there was no theory available of the gradual evolution of animals from single-celled micro-organisms into more and more complex creatures. The nearest to an evolutionary theory is found in the fragments of the Presocratic philosopher Anaximander, who argues that humans were either originally similar to fishes (KRS, 136 [*TEGP* 38]), or were originally born inside fishlike creatures (KRS, 135 [*TEGP* 39]). This hypothesis seems designed to account for the survival of the original humans, born into a world covered in water, presumably as infants who could not feed themselves. Being born inside fishlike creatures protects them from the water, and they can presumably gain nourishment therein and grow until they are fully developed, leaving the creatures as they burst open and stepping out onto the now dry land as the waters recede. It seems, therefore, that Anaximander was not quite tracing a direct human-fish ancestry but attempting a pragmatic theory of our survival in a watery world without parents to protect and feed us.

Two detailed accounts of the origin of species are extant: those of Empedocles and Lucretius. For Empedocles' theory, incorporating inter-species hybrids, see Campbell 2000; Sedley 2007, 31–74; The Failure of Evolutionary Thinking in Antiquity. Lucretius' theory resembles Empedocles' but does not rely on inter-species hybrids (5.837–877). Lucretius too appeals to contemporary spontaneous generation of creatures, in particular cicadas, to support his argument. He argues that all sorts of creatures were born from the earth when the world was younger, warmer, and thus more vigorous. We see only small creatures created today, but the early earth could produce bigger and more varied creatures. Since no pattern was available for the earth to follow in creating animals, however, all sorts of malformed animals arose, including hermaphrodites, creatures with no mouths, no eyes, with limbs stuck to bodies, and so on. These creatures would clearly die out and were hence unable to form a successful species. Just occasionally the earth would produce, by chance, an animal equipped with the right sort of organs and limbs to be able to live, feed itself, and reproduce. But Lucretius also adds a second stage in which animals are naturally selected in what has been seen as a forerunner of Darwin's theory of the survival of the fittest. Lucretius argues that there must have been many extinctions of animals in the early world. Some, like lions, have been kept safe by their strength, others, like deer, by their speed in flight, and others, like foxes, by their cunning. We imagine that weaker creatures have died out in competition with lions, slower animals in competition with foxes, and so on. Lucretius is adamant, though, that species are fixed and cannot mutate into other species. There is absolutely no room for inter-species evolution: all animals were born from the earth in their present form.

This theory has attracted a great deal of attention owing to its similarity to Darwin's, and the stress on competition in both theories. Less noticed, however, is Lucretius' claim that some species have survived because of cooperation with humans, including sheep, dogs, oxen, and horses. All were saved from extinction because of their domestication by early humans. Lucretius' language to describe this cooperation resembles that describing the cooperation between people during the formation of the first village societies (5.1011–1027; Campbell 2008).

3. Prehistory and the Development of Society

The Golden Age and the Primitivist Tradition

As we have seen, ancient theories of prehistory can be crudely divided into two categories, primitivist and progressivist (or anti-primitivist). That these categories are not absolutely fixed is nicely illustrated by Lovejoy and Boas' inclusion of Hesiod in both categories (1935, 25–31, 196–199).

The dominant myth in Hesiod, however, is strongly primitivist. The first humans lived a perfect, blessed life until their decline through the silver and bronze to the present iron race (above). The idea of a Golden Age or Race became powerfully influential in Greek and Roman thinking and grew more moralized over time. Hesiod does not tell us why the Golden Race was beloved of the gods, but we can imagine that their piety ensured their blessed life. A tradition of the perceived decline of justice over time, one of Hesiod's main concerns, also developed. In Aratus' account of the decline of the human races, the Maiden Justice (*Dikē*) once lived among the

Golden Race giving justice and "urging judgments more advantageous to the people," but, when the Golden Race degenerated into the Silver, *Dikē* retreated to the mountains and only occasionally came down to harangue the people for their wickedness. When they were replaced by the Bronze Race, who began warfare and ate the oxen which pulled *Dikē*'s plow, she finally left earth, becoming a constellation (*Phaenomena* 96–136).

Long before Aratus, Empedocles in the fifth century BCE had already produced a similarly moralizing version of the Golden Age, with a more strongly marked vegetarian message (DK 128 = *TEGP* 189). Empedocles offered a radical theology in which people of the Golden Age did not worship the traditional Olympian gods, and not even Cronus, the usual king of the gods at that time, but only Cypris (Aphrodite). Their sacrifices were not of real animals but models and perfume, and honey instead of blood. Empedocles followed Pythagoras' theory of the transmigration of the soul in which human souls could transmigrate into animals. On this theory, killing animals is murder, and eating meat is cannibalism. This is an instance of a common use of stories about prehistory to moralize about the present; the implicit message is that the animal sacrifice and meat eating of his own day is not sanctioned by antiquity but, rather, is an aberration and perversion of the original, ideal sacrifices in the Golden Age. For other uses of primitivistic thinking about prehistory in ancient sources, see Lovejoy and Boas 1935, 23–102.

Anti-Primitivist Ideas

Hesiod tells different, incompatible stories about the reason for the gods' enmity toward humans. One of these is the story of Prometheus' theft of fire (above), the symbol of human intelligence and technology. Hesiod tells us that the gods keep the means of life hidden from men, and that life would be easy otherwise: we would only have to work one day a year. Prometheus' gift, then, rescues us from a harsh and difficult life (*Works and Days* 42–105). Fire does not return us to a Golden Age of leisure, but at least it helps us survive in a harsh and unfriendly world. Beyond that, we can perhaps develop arts and technologies, and the cities and civilization that make life bearable. Thus, progressivist and anti-primitivist prehistories see technology as rescuing humanity from an original miserable, brutish life, without arts, technology, clothes, or even fire. In general, such accounts tell us that humans developed their culture by degrees, over time, by trial and error, under the stimulus of necessity, and often with nature as their teacher. There are many variations on this basic narrative, and frequently we find culture-heroes or gods credited as the first discoverers of particular arts and technologies. We might expect the progressivist mode of thought to privilege humans as Promethean beings quite able to develop their own culture themselves and not in thrall to the gods, but this is frequently not the case. Pliny the Elder, for example, gives a long list of first discoverers in which no distinction is made between gods and humans (*NH* 7.56). Furthermore, the Homeric Hymn to Hephaestus credits the god with our technological salvation:

> Sing of Hephaestus famed for his skill, clear-voiced Muse—of him who with bright-eyed Athena taught glorious crafts to men on earth, who aforetime lived in caves in the mountains like wild beasts. But now having learned crafts from Hephaestus, the famous craftsman, they easily live out their life to its full span abiding free from care in their own houses.

The motif of living like wild beasts is common in such accounts, and caves and mountains feature regularly as the habitats of early humans. There is quite a bit of variation in these progressivist accounts of prehistory and the development of civilization. Some are dark, but others include some positive aspects of the lives of primitive people. Moschion paints the harshest picture:

> And law was humble and brute strength was enthroned with Zeus, and the weak was food for his betters. And when time the father and nurturer of all things, changed mortal life again, either by the forethought of Prometheus, or through necessity, or again through long practice making nature herself their teacher, then were discovered cultivated fruits, the food given by chaste Demeter, and there was discovered the sweet stream of Bacchus. And earth till then unsown, was now ploughed by yoked oxen; and cities were turreted and roofed houses built; and they changed their savage way of life for civilization. (*TrGF* 1.97, fragment 6)

For Moschion there was originally no law, only might was right, and humans were cannibals. Then he gives a range of ways in which we may have been rescued from this brutish state: either by Prometheus, necessity, long practice with nature as teacher, or the gifts of Demeter and Bacchus. All of these are part of the same story of progress.

4. Lucretius

Lucretius, on the other hand, giving us the longest and most detailed account of prehistory and the development of civilization (5.772–1457), presents a more nuanced picture of the lives of early humans. Just as in Moschion, humans are born without technology, not even fire or clothes, but some aspects of their lives are made to seem attractive:

> And for many rolling cycles of the sun through the heavens they led a life in the wide-wandering manner of wild beasts. Nor was anyone a tough guider of the curved plough, nor did anyone know how to work the fields with iron, nor to plant new shoots in the ground, nor to prune old branches from high trees with sickles. What the sun and showers had given, what the earth had created of her own accord, this was a pleasing enough gift for their hearts. Among the acorn-bearing oaks they cared for their bodies for the most part; and the arbute berries you now see ripening in winter time with crimson Punic colour, at that time the earth bore most abundantly and larger than now. And the flowery newness of the world then bore much tough fodder besides, ample for poor mortals. (5.925–944)

Lucretius' account privileges Epicurean ethics; the first people had little, they wandered like wild animals, but they were nourished by nature's bounty and were happy with what little they had. Lucretius proceeds to contrast modern luxury, unhappiness, and warfare. The first people may have had no technologies, they were attacked by wild beasts and died in agony from their wounds, and they often died of starvation, but there was no organized warfare wherein thousands might perish in a single day. People then might die from unwittingly eating poisonous plants, but at that time there was no deliberate murder, unlike today. Then people died from lack of food, now we drown in

excess. Lucretius' prehistory is a patchwork of topics borrowed from both primitivist and anti-primitivist traditions. Like all other ancient writers on prehistory, he is less interested in the realities of the lives of prehistoric humans and more in what moralizing value he can glean from them. The outline is roughly progressivist: humans have invented their own culture and owe nothing to the gift of the gods, progress has occurred, but not necessarily in the right direction. Cities, in particular, are considered a mistake by Lucretius. The ideal stage seems to be the first village societies (5.1011–1027), when people had just enough technology to survive and be safe—huts, fire, and animal skins to wear—but had not yet succumbed to luxury and excessive desires. Living in their huts with warm fires, they softened physically, but more importantly, when they settled down, married, and had children, they softened psychologically:

> And then eager neighbours began to form friendship pacts with one another neither to harm nor be harmed, and they entrusted children and the female race to each other's care, signing with cries and halting gestures that it is right for all to pity the weak. (5.1019–1023)

Before this point there had been no cooperation, marriage, or society, not even any food sharing. They had been to the University of Life and majored in the School of Hard Knocks:

> Nor were they able to look to the common good, nor to use any customs or laws. What booty fortune had obtained for each person, each carried off at will for themselves, taught (*doctus*) to live for himself and so to be strong. (5. 958–961)

These people are clearly similar to Homer's Cyclops (*Odyssey* 9.106–115). Similarly, they have no society, no assembly, and each Cyclops pays no attention to the others.

But now people have acquired the psychological ability to make the conceptual leap from "every man for himself" to "it is right for all to pity the weak," and thus society was able to come into existence. This state sadly did not last. Lucretius does not explain why the first societies ended; but the clear candidate for their demise is the rise of false beliefs about the gods. The gods do exist, Lucretius insists, and early humans could even see images of them, but gods do not interfere in the world. However, when early humans looked up and wondered at the regularity of the motions of the heavenly bodies, they were at a loss to explain them and so assumed that the gods must control the world (5.1169–1193). This simple cosmological mistake led to fear of the gods, fear of death, and fear of punishment in the afterlife, which in turn led to all the evils of modern life: sibling rivalry, family breakdown, sexual excess, societal competition, politics and warfare, etc. (3.59–93). So cities rose. Technocrats arose, outstanding in their abilities to use the new technologies. They became the first kings and built citadels *for their own protection* (5.1105–1109). Clearly the friendship pacts of the first societies had broken down. Thus humanity started on the slippery slope toward civilization, and land and flocks were divided up for the first time (n.b., the theme of lack of land boundaries and of common ownership of flocks in the Golden Age). There followed the discovery of gold and invention of property, and people began to compete for power to try to gain some stability in their lives. Unknown to them, they were driven by a psychological disturbance caused by the fear of death. Political competition caused even more instability, until there was a revolution, kings were overthrown and killed, and a

period of anarchy followed. Only then did people "worn out by living a life of violence" (5.1145) agree to appoint magistrates and accept restrictive laws to hold violence in check. This was not an ideal solution, however, since as Lucretius tells us "hence comes the fear of punishment that taints the prizes of life." Law for Lucretius was just a stop-gap measure, necessary to restrain the violence caused by the fear of death, but bringing its own problems. Another Epicurean writer, Diogenes of Oinoanda, looked forward to a future paradise when everyone has been converted to Epicureanism, and "there will come to be no need of city-walls or laws and all the things we contrive on account of one another" (fragment 56 Smith; Campbell 2003; Campbell 2006; Kenney 1972; Furley 1978).

5. Ethnography

The Ethnographic Tradition

Ethnography was a genre or sub-genre of ancient literature. The word is a modern coinage, but strong similarities between ancient ethnographic accounts indicate that, even though unnamed, authors were conscious of writing within some sort of generic parameters. As such, ethnography had "rules" and ancient readers expected the inclusion of certain *topoi*. From Herodotus onward, writers began with locating the boundaries of a country and discussing its geography, climate, and resources (see GREEK AND ROMAN CARTOGRAPHY). Then the people's origins, their physical description, their agriculture, religious, social, and military customs, and politics were described. It was also customary to include natural or man-made wonders (*thaumata*), weird creatures, or huge monuments such as the pyramids. Not all ethnographies have all of these topics, and often ethnographies were quite brief excurses in an author's work (Rives 1999, 11–21; Murphy 2004, 77–128; Skinner 2013). Because most readers were unfamiliar with the peoples and countries being described, a distinctive technique of writing arose in terms of contrasts and comparisons with the writer's own culture. Often, inversions are found, in which the other people completely invert Greek or Roman customs (Hartog 1988). The most extreme example of this is Herodotus' ethnography of the Egyptians (Book 2), who seem to live in a mirror world, doing everything back to front, including writing from right to left, hence Hartog's title *The Mirror of Herodotus*. A similar technique of description by negation is often found, frequently used in prehistories as well, for example, "they did not have this, nor did they have the other"—a sure sign that the author's own society is being implicitly contrasted (Davies 1987, 1988). These techniques tend to make ancient ethnographies a view of the author's own culture through a distorting mirror, and ethnographers frequently exploited their accounts of other peoples to moralize about the failings of their own. Ethnographies are often classed as ethnocentric or anti-ethnocentric. In an ethnocentric prehistory, the Greek world is viewed as more advanced and developed than the margins, and so marginal peoples are viewed as less civilized and even more bestial than the Greeks. An anti-ethnocentric ethnography inverts this attitude and views the supposed primitiveness of far away peoples as a cause of their moral and physical superiority. Of course, just as with the terms primitivist and anti-primitivist, these terms are far too crude, and motifs from both traditions are often found in the same account.

Wonders of the East

In general, with increasing distance from the center, increasing primitiveness is assumed. This can mean different things to different writers. Out there may be people still living in a surviving fragment of the Golden Age, or they may be barbaric savages who eat you as soon as look at you, or, more interestingly, people who embody characteristics from the different traditions. Again Hesiod provides some of our earliest evidence for ideas of far away peoples. Fragments of the *Catalogue of Women* give interesting ideas about eastern and southern peoples:

> [The Boreades pursued the Harpyiai] to the lands of the Massagetai and of the proud Hemicynes (Half-Dog men), of the Catoudaioi (Underground-folk) … Huge Gaia (Earth) bare these to Epaphus … Aithiopes and Libys [i.e., Gaia was the mother by Epaphus of all the African tribes]. (fragment 40A)
>
> No one would accuse Hesiod of ignorance though he speaks of the Hemicynes (Half-Dog people) and the Macrocephaloi (Great-Headed people) and the Pygmaioi (Pygmies). *(fragment 44)*

As can be seen, the lands to the east of the Black Sea, occupied by a real people, the Massegetai, are also home to hybrid peoples like the Dog-Heads and peoples with distorted bodies such as the Big-Heads, while to the south live the Pygmies. This is a fascinating glimpse into an early example of the "wonders of the East" tradition. The "East" tends to include both Asia and Africa (often Libya in ancient sources), and commonly there is little distinction made between them; they are far away, hot countries where the order of nature seems to break down and all sorts of strange creatures arise. This long-lasting tradition developed particularly after Alexander's expeditions with the *Alexander Romance*. But earlier, Ctesias had written in the fifth century BCE of the Dog-Heads and other extraordinary creatures of India:

> In the mountains dwell men who have the head of a dog; they wear skins of wild beasts as clothing, and they speak no language, but bark like dogs, and in this way understand one another's speech. They have teeth bigger than a dog's, and nails like those of a dog, but larger and more rounded … They understand the speech of the Indians, but cannot respond to them; instead they bark and signal with their hands and fingers as do mutes. (*Indica* 20)

It seems that for Greek writers the farther east the weirder things get. The norms of nature became distorted, and even the division between humans and animals was breached, resulting in creatures who may be either dogs or humans, or perhaps both. It is not clear whether the Dog-Heads are evolving into humans or into dogs, but clearly their doggy status is a source of moral excellence for them. They show many of the outstanding features of the Golden Race: long life, purity, and justice. They serve to challenge Greek ethnocentric ideas and even ideas of anthropocentric superiority (Romm 1992, 77–120). The tradition culminates in book 7 of Pliny's *Natural History*, a fascinating compendium of ideas about the people, flora, and fauna of the East. As Trevor Murphy (2004, 92) has said:

> In the monsters of *Natural History* book 7 we have examples of the human body being run by the imagination through a schematic series of variations. The subject of this gallery is the human body in every permutation and extreme, forms as bizarre among humans "as tigers and peacocks are among animals" (*NH* 7.7).

We hear about the Shadow Feet, the Winnowing Fan Ears, the Ear Sleepers, Big Legs, Backwards Feet, and so on. Other hybrids are recorded by quite sensible writers like Aristotle:

> The proverbial expression about Libya, that "Libya always brings forth some new thing," has been coined because of the tendency for even heterogeneous creatures to interbreed there. On account of the paucity of water, different species encounter one another at the few places which possess springs, and there they interbreed. (*GA* 746b7–13)

Diodorus Siculus (2.51.2–4) also agrees that Libya, Egypt, Arabia, and India are full of hybrids and huge and "fine beasts" but attributes this to the greater heat and thus greater fertility of the earth in those regions.

Arcadia

Distance from the center leads to an assumption of primitiveness, but there are exceptions, one of which is a region within Greece itself in the central Peloponnese: Arcadia. Perhaps because of its mountainous landscape and pastoral economy, Arcadia is often granted extraordinary antiquity in Greek sources and is regarded as the most ancient region in Greece, and indeed the Arcadian people as the earliest of all humans. Mountainous regions tend to be regarded as liminal, and, frequently, ancient paradises are thought to hide behind natural boundaries such as rivers, forests, and mountains. Arcadia is a pastoral paradise, a remnant of a sort of Golden Age, whose people still eat acorns (the food of the Golden Age), and practice justice and perfect hospitality to strangers. Arcadian egalitarianism is a strong theme in many sources:

> The Arcadians receive both masters and slaves at their feasts and they lay one table for all and place food in the middle and use the same mixing bowl for all. (Theopompus in Athenaeus, *Deipnosophists* 4.149d)

Statius reports a tradition in which the Arcadians were born before the stars and moon, from "the hard stock of trees, when the earth in wonder felt the first footsteps of man" (*Thebaid* 4.275–284).

Music is the characteristic art of the Arcadians, and we are told that without the practice of music the Arcadians tend to revert to a bestial state. Liminal creatures with an interesting bestial side, they are a hard people who inhabit a hard landscape, softened only by music which renders them properly human (Polybius 4.19–21). In particular, they have a tendency to lycanthropy, becoming wolves especially when they commit human sacrifice and cannibalism. They seem to be on the limits of humanity and bestiality (Hartog 2001, 133–150; Ferguson 1975, 29–39).

Aithiopians and Hyperboreans

If the East and other hot countries are imagined to produce monsters, the South, although frequently conflated with the East, also is a haven for the remnants of the Golden Age. Living beyond the climactic zones in a temperate region, the Aithiopians are regarded as the most perfect of people, tall, beautiful, and just; the most pious and virtuous, who still live on terms of friendship with the gods. Homer is again the earliest extant source:

> For Zeus is at Ocean among the blameless Aithiopians, gone to earth for banquets; all the gods are there with him. (*Iliad* 1.423–424)

The Aithiopians seem to have avoided the rift between gods and men caused by Prometheus' trickery at the feast at Mecone. They still feast with the gods, providing refuge from the mundane human world. They are also long lived, vegetarians or fish eaters. In Herodotus they serve as a useful foil to the extravagance and luxuriousness of the Persians. Jealous of the Aithiopians for possessing the Tables of the Sun, upon which cooked meats miraculously appear every morning, the Persian King Cambyses sets out to invade (4.17–25). Being an irrational eastern tyrant (common in Herodotus), he forgets to provision his army. They get part way across the desert before running out of food, first starting to eat grass, and then one another. Regressing through the stages of human cultural evolution, they do not arrive in any sort of Golden Age, but rather in a dark anti-primitivist version of prehistory. In seeking to attack a golden-age-style paradise, they regress in the opposite genre of prehistory (Romm 1992, 49–60).

The Hyperboreans also live at the edges of the world, beyond the North wind, *Boreas*, as their name suggests. They live beyond the Rhipaean mountains and beyond the climatic zones in a temperate land, spontaneously fertile and similar to the golden-age landscape. They too eat acorns, like the Arcadians, and practice justice. As Romm has argued (1992, 60–67), they are a northern counterpart to the Aithiopians, embodying ancient piety, in particular in their worship of Apollo who visits and feasts with them (Pindar, *Pythian* 10.29–43).

Herodotus tells us that the Hyperboreans had previously sent yearly gifts to Apollo at Delos, carried by two Hyperborean maidens (4.32–35). One year the maidens failed to return, and the Hyperboreans henceforth sent the gifts wrapped in straw in a relay through subsequent neighbors until the gifts reached Delos: a familiar story of the retreat of divinity from the mundane world due to increasing injustice. In a parallel development, as time went on and the true geography of the North was better understood, the Hyperboreans were reported to live on a narrower and narrower strip of land until they had to move on to an island to save their mythical existence (cf. Diodorus Siculus 2.47).

Scythians

The Hyperboreans may have been an entirely mythical people, but a semi-real people also dwelt in the north around the Black Sea, the Scythians. I say "semi-real" because they attracted a great deal of mythologizing treatment in Greek writers. Had the Scythians not existed they would have surely been invented (Campbell 2006, 86). Francois

Hartog (1988) shows well how they are constructed in Greek literature by opposites and inversions, and how particularly useful they are for Greek self-definition. The Greeks are a settled people, with cities, agriculture, and a complex religion. In contrast, the Scythians are nomadic horse herders, lacking agriculture and settled homes. They hold their wives in common, and have only a few gods. In addition, they practice human sacrifice, drink the blood of enemies, and even scalp them.

As with accounts of prehistory, there are two contrasting approaches to the Scythians. The first, found in Homer, is the "milk-drinking" tradition of the Scythians as the most hospitable and pious people. Zeus, bored with the Trojan War, looks north to the "noble mare-milkers, milk drinkers, and the Abioi, the most righteous of men" (*Iliad* 8.16). Aeschylus confirms this tradition:

> And afterwards you will come to the most righteous of all men and the kindest to strangers, the Gabioi, amongst whom neither the plough nor the earth-clearing mattock cuts the ground, but self-sown soils bear food unstinted for mortals. (fragment 196)
>
> The well-ordered Scythians, drinkers of mare's milk. (fragment 198)

The alternative tradition of the "blood-drinking Scythians" is reported at length in Herodotus, book 4. They drink the blood of the first man they kill, scalp their victims, and also make drinking cups out of their skulls. They worship Ares, whose symbol is a scimitar set upon top of a huge pile of sticks. This scimitar is fed with the blood of slaughtered captives, whose throats are cut and right arms chopped off, simply thrown into the air and left where they land (4.62). Clearly the Scythians have complete contempt for their defeated enemies, and this treatment of corpses would have horrified a Greek audience.

It is sometimes argued that the reception of the Scythians by Greeks became more negative as time went on and contact between Greeks and Scythians increased, but the two traditions carried on in parallel, becoming more literary topoi than reality. Strabo (7.3.9) argues that writers choose to report the blood-drinking Scythians in order to excite their readership, but they should choose to report the milk-drinking tradition because it is more morally improving (West 2002; Hartog 1988).

Gauls and Germans

The Gauls and Germans tended to serve similar purposes of self-definition for the Romans; they are the Romans' own "northern barbarians." As such, accounts tend to be romanticized, simplified, distorted, and mythologized. They are particularly useful as foils for Roman moralists who like to use them as a distorting mirror in which they view their own society. Often they are held up as examples of primitive purity and piety to highlight and criticize Roman decadence and immorality. There is a strong tendency for Roman writers to view them through a filter of early Roman simplicity and moral excellence. Because of the closer contact the Romans had with Gauls and Germans, however, accounts tended to be more nuanced than Greek accounts of the Scythians.

Greek writers tended to make less distinction between Gaul and Germany than did Roman writers. Diodorus Siculus (5.24–31) refers to *Galatai* living from Spain to the Black Sea, and he does not mention the Germans at all. Strabo (7.1–3) considers the Germans "true" Gauls living in the manner of the Gauls before their "enslavement."

Poseidonius, on the other hand, reports Germanic feasting habits (fragments 67, 68, 69 Kidd). For Julius Caesar it was particularly important that *Gallia* (Gaul) be seen as a geographical and (potentially) political unity, to gain political approval for his proposed conquest. He would be conquering a discrete area of land and people rather than leading his legions into an infinite wasteland of northern barbarism (cf. *Gallic War* 1.1; Riggsby 2006, 21–45). Caesar's propaganda needs were also served by what he saw as a Gallic tendency toward division and factions. The *Gallic War* famously opens with the seeming oxymoron: *Gallia est omnis divisa in partes tres* ("Gaul as a whole is divided into three parts"). The ethnographic theme continues in book 6: "In Gaul there are factions not only in all the states, and in all the cantons and their divisions, but almost in each family" (6.11). This is convenient since his readers would be well aware of the Roman tactic of divide and conquer: the Gauls are a self-dividing people, thus inviting conquest. Beyond the stereotypical representation of Gauls as tall, muscular, pale, long-haired, rash, trouser-wearing, and warlike, Caesar also tells us that they are highly superstitious, commit human sacrifice, count by nights rather than days, believe that they are descended from the underworld god, Dis, and believe in the transmigration of souls. Because of this they do not fear death and so are fearless in battle. There are clearly some inversions in Caesar's description, including a claim that they do not acknowledge their sons until they are at the age for warfare, a clear inversion of Roman practice. However, such details may nonetheless be true (Riggsby 2006, 47–71).

For Caesar the Germans live a more primitive and simpler life. They are contrasted to the Gauls, becoming, as Riggsby says, "the other other" to the "other" of the Gauls (2006, 47). They are completely warlike with no interest in peace, they practice no agriculture and are semi-nomadic, swapping their land each year since they do not want to settle down, and they exchange warfare for agriculture, which would lead to greed for more land, introduce inequality, and foster money, luxury, and politics. In fact, they seem to be good anthropologists and appear to have read Lucretius' account of the beginnings of civilization. As ever, they are viewed through a Roman prism.

Tacitus gives more detail in the *Germany* and a more nuanced account. The Germans have some agriculture but do not bother to grow anything except grain for making beer, of which they are over fond. In a manner reminiscent of Homer's Cyclopes (*Odyssey* 9. 106–115), they have no cities and even refuse to build their houses next to one another. They are endlessly warlike with no interest in peace, and even invert the Roman custom by always going armed to public meetings, which often become violent. A youth is given a shield and spear instead of the *toga virilis* when he comes of age, an inversion noted by Tacitus (*Germany* 13). Despite their negative qualities, Tacitus praises their purity and morality. In this he tends to see them as noble savages, still preserving the pristine purity that the Romans have lost. Adultery is rare, and "no one calls it 'up to date' to seduce and be seduced" (*Germany* 19). Clandestine love letters similarly are unknown, only virgins may marry; a widow cannot remarry. She must be, in Roman terms a *univira*, a "one-man woman." A woman loves her one husband not for himself but as the embodiment of the married state, and it is considered wicked to restrict the number of children or kill any born after an heir is produced. Clearly Tacitus assimilates the Germans to an idealized vision of early Roman pristine purity. He has a strongly nostalgic tendency to see the Germans—and the Britons in the *Agricola*—as noble savages retaining the qualities of morality and freedom that the Romans have lost under the Empire (Rives 1999, 42–56; O'Gorman 1993).

6. Conclusion

We have briefly and selectively tried to argue that accounts of prehistory and ethnographies tend to be less objective scientific works and more concerned with moral and political questions. Prehistories were written to criticize or legitimate the writer's own society. There are strong similarities between accounts of prehistoric peoples and peoples far away from the center, both viewed as living back in time in more primitive societies than Greece or Rome. This can be viewed either positively or negatively. Societies may retain their pristine purity in a continuation of the Golden Age, or they may live in a dark bestial anti-primitivist world. Ethnographies, in particular, are constructed by contrasts and assimilations with the writer's own society, so that we learn more about the Greeks and Romans than we do about other peoples.

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FURTHER READING

Lovejoy and Boas 1935 is still the best sourcebook, containing a huge range of sources on ancient prehistories and ethnographies. The analyses do tend to be rather outdated, however. Campbell 2006 is a useful survey, following a pattern similar to the one in this chapter. Hartog 1988 founded modern thought on ancient ethnography and is a good starting point if rather a difficult read. Similarly, Romm 1992, much more accessible than Hartog, is a ground-breaking work on the "edges of the earth."

On ancient ethnography two recent works, Almagor and Skinner, eds. 2013, and Skinner 2012, are valuable additions to the literature. Cole 1990, who traces the themes of Greek anthropology back to Democritus, is still valuable if we are not persuaded by his main argument. On the Persians, rather neglected here, Harrison 2010 is worth consulting. On the Gauls and Germans, Woolf 2011 and Riggsby 2006 are two of the best and most recent works.

PART VI

Food Sciences

CHAPTER 32

Greek and Roman Agriculture

Philip Thibodeau

1. Introduction

By some estimates, as many as four out of five persons in the ancient Mediterranean were "country people" (*agroikoi* or *rustici*) who made their living as peasant farmers, herdsmen, agricultural slaves, or in some other role raising animals and plants. The farmer's life was a touchstone experience, one that the epic poets frequently drew upon as a source of comparisons for the deeds of heroes in combat:

> And just as a man will raise a healthy olive cutting in an undisturbed location where enough water runs to keep it moist—it is fine-looking when in bloom, as gusts from every wind shake it and the white blossoms burst open, until suddenly one wind comes in a massive blast and uproots it from its hole, laying it out on the ground—in the same way Menelaus Atreus' son killed then stripped the armor from Panthos' son, Euphorbus of the fine ash-spear. (Homer, *Iliad* 17.53–60)

The religious calendars of most cities were built around the local farmer's calendar, and the ostensible aim of much ritual practice was to ensure that harvests were bountiful and animals fertile. Lingering anxieties over the success or failure of crops gave force to famous myths like the story of Demeter and Persephone. Agricultural products constituted the overwhelming bulk of goods bought, shipped, and sold in the Mediterranean, and the sophisticated urban populations of the Classical world ate their daily bread thanks to the labor of mostly illiterate peasants.

Despite its importance to society, agronomy was one of the least "pure" of the ancient sciences in that its store of knowledge was almost entirely empirical in origin and its implementation heavily constrained by cultural habit and the environment. The

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innovations (mechanization, chemical pesticides and fertilizers, genetic modification) which have made it possible for modern cultures to consign the work of agriculture to a small segment of the population were entirely absent. The ancients' sophistication lay instead in their ability to exploit the chief advantages of the Mediterranean climate—abundant sun, mild winters, and a long growing season—and to find ways of hedging against such ever-present risks as drought, flooding, erosion, and disease. Over time a vast body of hard-won knowledge was passed down, and a portion of it committed to writing. Nine ancient texts on agronomy survive complete: Hesiod's *Works and Days*, Xenophon's *Economics*, the elder Cato's *On Agriculture*, Varro's *On Agriculture*, Vergil's *Georgics*, Columella's *On the Subject of Farming*, the elder Pliny's *Natural History* (especially Books 14–15, 17–20), Palladius' *Treatise on Agriculture*, and the massive Byzantine *Geoponica*. Another two dozen authors are preserved in substantial fragments, and there is also much relevant information to be found in, for example, Aristotle's writings on animals and Theophrastus' on plants. A century's worth of diligent archaeological work has filled in many blanks in our knowledge of ancient farm practice; recent investigation of seeds, pollen, and animal bone remains has demonstrated that ancient agricultural achievements were even more impressive than once thought (see, e.g., Jashemski 1979; Kron 2004, 2008). All of this material enables us to track the progress of Mediterranean agriculture at a level of detail that, for the ancient world, has no parallel outside of China.

The portrait which emerges shows that forms of cultivation were diverse and constantly evolving; in the centuries between Homer and the fall of paganism, significant changes in method, technology, and preferred crops occurred. Imperialism, both Greek and Roman, spread established techniques, crops, and species to lands on the margins while simultaneously introducing new forms of cultivation to the Mediterranean core. All of these changes took place against the background of the perpetual challenges posed by the diverse environments of the Mediterranean.

2. Earth, Water, and Time

The first element of farming is soil, a compound of organic matter (plant and animal remains, fungi, bacteria, and protozoa) and crushed minerals derived from underlying bedrock. The exposed white cliffs on the Acropolis and many Aegean islands serve as a vivid reminder that much of Greece's bedrock is composed either of limestone or marble. Such stones, when weathered, produce soils that have a neutral to slightly alkaline pH; hence a well-limed soil is often desirable for growing plants with a Mediterranean origin, like fennel and fig trees. Some crops such as the olive can thrive in a soil low in organic matter, but the most sought-after agricultural land was always that which was, in ancient parlance, "fat" (*pakhus, pinguis*). Certain areas were gifted with rich soils thanks to the action of rivers, lakes, volcanic activity, or some combination of the three. The floodplains of the Peneios in Thessaly and the Po in Italy featured rich alluvial muds, as did upland lake basins like those surrounding Lake Copais in Boeotia and the Fucine Lake in the Apennines. The volcanic activity that created the Greek islands of Cos, Chios, Lesbos, and Thasos was also a key element in the *terroir* that made the wines from those islands so famous, and in eastern Sicily and Campania volcanic soils formed the basis for those regions' legendary productivity. But such areas of natural fertility were more the exception than the rule.

Greek and Roman farmers improved the quality of their soils through various forms of cultivation, the most significant of which were plowing—"What comes first in good farming? Good plowing" (Cato, *On Agriculture* 61)—and digging. The action of the plow contributes to soil fertility by raising up nutrients leeched downward by rain, and by uprooting weeds, which become a green manure as they decompose. (Of course, eliminating weeds also makes more water, nutrition, and light available for crops.) By breaking up the soil surface and shattering clods, plowing enables the ground to absorb and retain more moisture when it rains—crucial in a dry climate. Farmers also dug and plowed around the bases of their fruit trees and vines with the aim of trimming back surface roots. Such trimming forces plants to send their roots deeper into the soil, where they are less vulnerable to drought (cf. Columella 2.2.24). With such ends in mind, ancient farmers typically plowed or dug up their cropland three times a year.

The set of implements used to move earth remained relatively stable over time; evidence for new tools often occurs in the context of the expansion of Greco-Roman farming into new regions, northwestern Europe in particular. The typical plow was a simple ard or scratch-plow made entirely of wood, pulled by oxen or donkeys. Hesiod's famous description highlights the use of different woods for different components, and he warns the farmer to be prepared for the implement to break:

> Many logs are bent, so bring home, whenever you find one, a plow-tree; search in the hills or the fields for one. Make it from holm oak—this is the stiffest wood for plowing with oxen, once the servant of Athena has fitted it to the stock and fastened it tight to the pole with pegs. One should make two plows, working on them at home, a single-piece and a jointed one, since it's much better this way: if you happen to break one, you can throw the other over the oxen. Poles of bay-tree or elm are the least prone to worms; the stock is made of oak, the plow-tree of holm oak. (*Works and Days* 427–436)

Plows with iron shares were more durable and feature prominently in our literary sources (e.g., Vergil, *Georgics* 1.43–50), but they seem to have been used mainly in heavier clay soils, like those found in the northern Roman provinces. The most common tools for digging were mattocks (usually two-pronged) and hoes, well suited to light, rocky soils. Rather surprisingly, spades seem not to have been employed in Greece during Archaic and Classical times (Isager and Skydsgaard 1992, 49). The earliest evidence for shovels is Roman, with the greatest number of remains again found in the northern parts of the empire. Another tool whose absence is worth noting is the wheelbarrow, common in ancient China but essentially unknown in the Classical world (Lewis 1994). Most loads were carried in baskets, sacks, litters, or carts.

A second technique for improving soil quality was the addition of amendments, especially manure. Already in Homer there are several references to manure which suggest that it was collected for use (*Iliad* 18.575), the most famous involving Odysseus' dog Argos, who heard the voice of his owner while laying "on a mass of dung, both mule and cow dung, which was piled before the doors until such a time as the slaves of Odysseus should haul it off to manure a great field" (*Odyssey* 17.297–299). Manure was collected from a variety of species. Khartodras, an agricultural writer from the fourth century BCE, believed that the best kind of manure came from humans, followed by that from swine, goats, sheep, oxen, and mules (Theophrastus, *Inquiry into Plants* [*HP*] 2.7.4). By Roman times, the maintenance of aviaries led farmers to appreciate the qualities of bird droppings; Varro agreed with those of his contemporaries who considered it the

best material (1.38). A century after Varro, Pliny describes recent efforts to improve soils by adding marls (chalky clays) and mined earths (an interesting anticipation of modern mined fertilizers) whose origins he traces to Britain and Gaul (*NH* 17.42–49). Manure was piled on litters, spread in the fields, and plowed in just before sowing in the fall.

Besides the creation of productive soil, water poses another second set of elemental challenges. The most basic issue is lack of adequate rainfall, particularly in Greece. Not all of Greece is arid: the western half of the Balkan peninsula features some of the highest annual rainfalls in Europe, and lands on the north end of the Aegean receive adequate annual rain. But the south-central core of Greece, including places like Athens, Thebes, Corinth, and the Cyclades, lies under a rain shadow where rainfall amounts total 35–40 cm (13.7–15.7″) per year; given annual variations, drought conditions and consequent crop failures could have been expected about one year in three (Osborne 1987, 34). Another distinctive feature of Mediterranean rainfall is that it tends to be starkly seasonal; outside of the high elevations, most areas are characterized by hot, dry summers and mild, wet winters. To ensure that plants benefited from the winter rain, farmers planted most of their grains and legumes in the fall and harvested them the following summer (in Attica, for example, grain was sown in November and harvested in July). During the late summer, tree fruits ripened, and drought-tolerant crops like millet, sesame, and poppy could be grown; but the dog days were a slow time for farmers (cf. Hesiod, *Works and Days* 582–596) and a lean time for grazing animals, given the scarcity of vegetation.

In addition to plowing, which helped to conserve soil moisture, Greek and Roman farmers made use of irrigation. Since most smaller streams run dry during the Greek summer, irrigation was used there mainly in two places: in areas adjoining large lakes and rivers, and in the neighborhood of an ever-flowing spring (Horden and Purcell 2000, 237–257). Alcinous' garden precinct in the *Odyssey* had such a spring to water vegetables and young trees:

> Beyond the courtyard, near to the doors, lies a large four-acre orchard with a hedge running all around it. Tall, heavily laden trees grow there, pear, pomegranate, and apple, rich in glossy fruit, sweet figs, and flourishing olives … Beyond the furthest row again are neat beds with every kind of plant, flowering all year round, and there are two springs, one flowing through the whole garden, while the other runs the opposite way, under the courtyard sill near where the people of the city draw their water. (7.112–131)

In the absence of springs, wells were also sometimes used. It is said that the Stoic philosopher Cleanthes maintained himself as a young student in Athens by working nights in an urban vegetable garden operating a well to water the plants (Diogenes Laërtius, 7.168–170).

Frequently problems with water are caused by topography. Farms on level ground need drainage ditches to prevent water from settling in low-lying areas, where it would breed insects and drown crops. Farms on slopes are in turn vulnerable to flash floods, which could carry off topsoil and carve deep gullies across fields; hence the importance of drainage ditches designed to channel runoff (cf. Cato, *On Agriculture* 43). On sloping farmland, terraces could also be constructed to control erosion and increase infiltration of water into the subsoil. Although rarely mentioned in ancient sources, archaeological evidence suggests that the sort of terracing commonly seen on hillside farms today in Greece and Italy was also prevalent in antiquity, and that terraced plots were used to grow fruit trees, olives, and vines (Price and Nixon, 2005).

The rainfall situation in Italy was generally less dire than in Greece. Almost all of the major Etruscan and Roman settlements were located on the western side of the peninsula, where rainfall far exceeds that of south-central Greece: Rome (87.3cm [34″] per year) and Naples (100.6 cm [39.5″]), for example, receive more than twice as much rain as Athens (36.6 cm [14.5″]) and Corinth (40.9 cm [16″]). With more rivers that run through the summer and an impressive network of aqueducts, farmers in Italy were able to make more use of irrigation. Ovid casually alludes to the presence of large-scale irrigation works in the landscape of his hometown:

> Sulmo, which is one-third of the Paelignian countryside, holds me—a small area, but in good health because of the waters that irrigate it. Even if the Sun holds his astral body close enough to split the earth, and the Dog Star flickers aggressively, running water will wander through the croplands of the Paeligni so that the grass remains green and fertile in the tender soil. (*Amores* 2.16.1–6)

Italian farmers also devised what was, in effect, a way of turning surplus water into money: by channeling water into otherwise unused grassland, they created a water meadow (*pratum irriguum*) where hay would be grown for horses and draft animals. The labor required to maintain land as meadow was less than that for any other kind of crop—three annual mowings and the occasional reseeding, according to Pliny (*NH* 18.258–263). And the general shortage of high-quality feed ensured a steady return. In a letter to his brother, Cicero reports excitedly on a piece of land he had just purchased: "I've never seen a place so shady in the summer and with water in so many places … Caesius [the bailiff] thinks you could easily make 33 acres of water meadow here" (*To Quintus* 3.1.3).

A third critical "element" which farmers had to manage was time. Many agricultural activities can only be accomplished within narrow windows of time that rapidly open and close (Hanson 1999, 147–150). Once ripe grain has been cut down, for example, it must be gathered and brought under shelter before rain or wind get to it (cf. Columella 2.20.1; Vergil, *Georgics* 1.311–337). The breeding of animals also had to be precisely timed to ensure that the young are born in a season when there would be appropriate feed for their mothers. In Archaic Greece, the erratic civic calendars were of no use for tracking annual phenomena, so farmers looked to the stars and the natural world for temporal indicators. Hesiod in his *Works and Days* identified a set of such indicators which would become canonical: the autumn rising of Arcturus in the east at dawn signaled that the grapes were ripe and ready to be picked; the setting of the Pleiades in the west at dawn marked the time to plow and sow; and the grain harvest commenced once the Pleiades had risen in the east at dawn (West 1978, 253). Hesiod's poem concludes with a list of activities to be performed or avoided on various days of the lunar month (765–828). And it marks the beginning of a long-standing belief among farmers that operations begun during the waxing of the moon would be followed by "growth," while those undertaken when the moon was waning would be subject to decay.

From 450–350 BCE, a number of philosophers and scientists—including Euctemon, Eudoxus, and Callipus—expanded the list of astral signs and correlated them with specific weather events: for example, on the seventeenth day of the sun's passage through Leo, Lyra sets, Pegasus rises, there is rain, and the summer winds stop blowing (so Euctemon; Lehoux 2007, 233). An anecdote told about the famous atomist Democritus makes clear the relevance of these annual forecasts to the farmer's needs:

> Democritus was nicknamed "Genius" because of the numerous predictions he made based on his observation of the skies; one time when he met his brother Damasus he predicted a storm for him, foretelling its coming from certain stars. And those who believed him brought their crops in (for it was summer and they still lay on the threshing floor), while the rest lost everything to a large and unexpected squall. (DK A18)

Some authors drew up catalogs which predicted the weather on the basis of the behavior of birds and other animals. An early specimen of this genre has come down to us in the pseudo-Theophrastean treatise *On Weather Signs* (Sider 2007), and the subject proved to be surprisingly popular, with poets like Aratus of Soli and Vergil rendering it into verse.

Two further developments served to free anxious farmers from the necessity of actually observing the heavens. The annual records of celestial events were turned into *parapēgmata*: stone inscriptions that featured lists of stellar risings and settings (Astronomy; Greek Calendars; Time-Telling Devices). Each event had one or more holes drilled next to it; each day a single wooden peg would be moved from one hole to the next, indicating by its position which constellation was in the process of appearing or disappearing. Greek *parapēgmata* mainly recorded astronomical data, while Roman versions tended to indicate what tasks needed to be done, such as harvesting or breeding (Lehoux 2007).

Julius Caesar's reform of the Roman calendar in 45 BCE was another key moment in the history of the farmer's year-scheme (Roman Calendars). The fact that the Julian calendar was essentially fixed with respect to the astronomical year meant that the times for performing certain tasks could now be tied to specific calendar dates; thus, its introduction set in motion a process that led to lists of calendar dates replacing the compendium of celestial signs. The earliest attested calendar of rural activities was a beekeeper's almanac compiled by Caesar's own freedman, Julius Hyginus (Columella 9.14). The first calendar to relate all of the farmer's tasks to the Roman months was composed a generation later by Columella (11.1–2), who gave both dates and star risings for each entry. Around 150 CE, the brothers Quintilii composed the first such work in Greek (*Geoponica* 3). In the fifth century, the Roman agronomist Palladius took the further step of organizing his entire treatise according to tasks appropriate to each calendar month and dispensed entirely with references to the rising and setting of stars.

3. Cereals and Legumes

That a single grain of wheat could, under the right conditions, produce a plant with ten or twenty grains on its head was a simple miracle, the repetition of which made it possible for millions across the Mediterranean to eat bread. It was an elaborate process which required regular spells of intense labor, a sound understanding of technique, a small arsenal of tools, and different varieties of seed. On a year-to-year basis, farmers chose which grains to plant on the basis of a general desire for self-sufficiency, and this led them to prize yield and robustness in the face of weather extremes above other factors such as taste. Over the long term, however, demand for breadstuffs with better taste and texture triggered a gradual shift from the barley regime of early Greece to the bread-wheat culture of Imperial Rome.

The staple grains of the ancient Mediterranean were barley and wheat. Barley has two cultivars, a two-rowed form higher in carbohydrates but low in protein, and a six-rowed

form higher in protein but low in carbohydrates, both of which were widely grown. In semi-arid lands, barley offers the highest yield of any grain per plant (from 5:1 to 10:1, typically) and was the chief grain for farmers in Attica, where it was consumed in the form of barley cakes and porridge. An Athenian inscription from 329 BCE implies that the barley-to-wheat ratio for the local harvest that year was 9.2:1 (*IG* II 1672). The Romans by contrast regarded barley as a second-class grain. Pliny reports that barley was grown primarily as animal feed (*NH* 18.75), and Josephus states that in his day in Palestine the rich ate wheat while the poor ate barley (*Jewish Wars* 5.427).

Emmer wheat (*Triticum dicoccum*) was one of the first domesticated crops and the principle wheat of Mediterranean farmers in Classical times. Emmer thrives in Italy and the damper parts of Greece, but it is a hulled wheat: its individual grains, bound tightly to their husks, must be parched and pounded before processing. Though never going out of use entirely, over time it faced increasing competition from two species of naked wheat, so-called because their husks are more loosely attached to the grain. The first competitor, durum wheat (*T. durum*), was known to the Greeks as *semidalis*, a Semitic word which points to its origins in the Near East. Still used today for couscous and pasta, durum was consumed in many forms but could not be milled into good flour. For that the ancients turned to bread wheat (*T. aestivum*), whose softer, moister grain yields a fine flour for baking. Durum was grown throughout the Mediterranean, but bread wheat did best in regions further north, such as the area around Pontus, the chief source of bread wheat in Roman times (Sallares 1991, 313–389).

Other grains were planted in environments characterized by extremes of wetness or dryness. Native to west Africa, millet does well under dry, hot conditions, and it produces a large yield of small seeds. It was the stereotypical summer grain, often planted when the grain crop of the previous winter had failed. Rye, by contrast, thrives in cold, wet conditions, mainly grown in northern Greece where it was used as a fodder crop. Spelt is a hulled wheat with a pedigree nearly as ancient as emmer, having spread from Iran to Germany and finally to Britain, where it was preferred until the Roman conquest. (Owing to an old scholarly confusion, many standard dictionaries translate a common Latin word for grain, *far*, as "spelt:" spelt was in fact a minor component of the Classical grain repertoire, and the term *far* denotes emmer wheat.) Oats were regarded as a weed by the Greeks and Romans, who used the crop to feed their horses, but in Northern Europe they were popular for human consumption (Sallares 1991, 361–368).

The primary tool for harvesting grains in antiquity was the short hand-sickle, wielded by a harvester who grasped the stalks with his left hand and cut with his right. Two innovative forms of harvesting technology were deployed on large farms (*latifundia*) in Imperial Roman Gaul. According to Pliny (*NH* 18.261), reapers there made use of a long-handled sickle or scythe. On level, unobstructed ground, a scythe is superior to a sickle because it can cut more grain in the same amount of time. Pliny (*NH* 18.296) and Palladius (7.7.2–4) also report on the use in Gaul of a two-wheeled reaping device with a sharpened comb at the front which cut off grain heads as it advanced, driven forward by a team of oxen; several artistic representations of this device survive (Shaw 2013, 299–304; cf. Raepsaet 2002, 266–267; LAND TRANSPORT AND VEHICLES). It is likely that both innovations were inspired by labor undersupply, rather than by a landowner's desire to increase profits through efficiency. In a region characterized by large-scale plantation-style cereal monoculture, the population density would be too low to supply enough seasonal laborers to bring in the harvest, a job which, as noted above, needed to be accomplished in a narrow time frame.

Greek and Roman farmers grew legumes on a large scale, as numerous references to their threshing show (cf. Homer, *Iliad* 13.588–590). Chickpeas, lentils, peas, and broad beans were as important a part of the cuisine of the ancient Mediterranean as they are today: roasted chickpeas were a popular snack, while the others were made into soup. Legumes were considered drought tolerant and could be grown in summer, but broad beans require substantial moisture and cannot be raised in places like Attica without irrigation. The ancients also raised cow peas, vetch, and lupines as a food for animals and as a famine food for men. In a diet of limited meat consumption, legumes are a necessary supplement to cereals, since their proteins contain some of the critical amino acids which cereals lack; hence the Pythagorean taboo against beans, in combination with vegetarianism, may be regarded as one of the earliest medically unsound diet fads.

Growing the same crop on the same piece of land year after year generally results in declining soil fertility and diminishing yields. To avoid depleting the soil through repeated monoculture, the ancients devised three major expedients.

(1) The application of *manure* was described above; Greek and Roman farmers were diligent collectors of animal dung but usually did not have all that would be required to maintain annual monocultures.

(2) In *bare fallow*, land is planted with grains one year and left unplanted the next. The fallow soil did not stand completely undisturbed, but was plowed three times over the course of the year to prevent weeds from going to seed; decaying weeds provided the soil with organic matter, while the act of plowing helped restore moisture. Bare fallow seems to have been the default cultivation regime in the drier parts of Greece and Italy throughout antiquity.

(3) *Crop rotation* generally denotes an alternation between a cereal crop and a crop of legumes. Legume plants contain more nitrogen than other crops thanks to the nitrogen-fixing bacteria on their roots, and when plowed in they help boost the fertility of a soil. The use of pulse crops as green manure is alluded to several times by Theophrastus, but in a way suggesting that the practice was limited to certain regions like Thessaly and Macedonia (*Causes of Plants* [*CP*] 4.8.1–3; *HP* 9.7.2, 8.9.1). Roman authorities took crop rotation for granted and recommended the use of beans, vetch, and lupines. Vergil sums up the conventional wisdom on land restoration in his day thus:

> Every other year you should let your fields go fallow and mow them, let your land slowly harden through disuse; or, when the seasons shift, plant golden emmer wheat in the same place where you previously harvested an abundance of legumes with their rattling pods, or the seeds of frail vetch, or bitter lupines with their crackling stalks and noisy growth. A crop of flax drains your land, a crop of oats does too, and so do poppies drenched in Lethe-like sleep—but alternation is an easy job, so long as you're not ashamed to enrich your dry soil with rich manure, or to toss messy ashes on the worn-out fields. (*Georgics* 1.71–81)

4. Vines and Tree Crops

Of the three foods that constitute the famous "Mediterranean triad"—grain, wine, and olive oil—two come from trees (since the Greeks and Romans both regarded the grapevine as a kind of tree). Vines and fruit trees were ubiquitous in the ancient landscape at every scale: from the pair of productive grape vines running over the cottage

of a retired schoolteacher (Suetonius, *Grammarians* 11), to the orchard that Laërtes, ruler of Ithaca, intended to pass on to his son Odysseus:

> When I was a little boy I once followed you around the orchard and asked you for trees. We went through them and you made promises as you spoke about each one. You gave me thirteen pear-trees and ten apples and forty figs, and here are the fifty rows of vines you promised you would give me; each was ever-bearing, and hung with all sorts of clusters of grapes whenever the season designated by Zeus made them feel their weight. (Homer, *Odyssey* 24.337–344)

The vast plantings prompted Varro to write, "The whole of Italy is planted with so many fruit trees that it resembles a giant orchard" (*On Agriculture* 1.2.7).

The olive, fig, and grape were native to Greece, well adapted to its soil and climate, but it was human art that made them numerous and prolific. To create new plants, farmers avoided growing them from seed because the resulting trees take a long time to reach maturity, and they do not grow true to type (Theophrastus, *HP* 2.2.4; *CP* 1.9.1). The commonest alternative is and was to make cuttings from trees with desirable traits, plant the cuttings in a nursery, then transplant the cuttings to a permanent home once their roots were established. Ancient farmers propagated olives from cuttings by planting out knot-like trunk growths called *ovoli* and grafting cultivated stock onto wild trees (Isager and Skydsgaard 1992, 35–38). In Greece, new grape vines were made from cuttings, from the transplanting of suckers, and by layering (fixing branches into the soil until they take root); Roman farmers add grafting to this list. Theophrastus refers to three different methods of grafting. Roman agronomists describe at least five. Both Greek and Roman sources knew multiple methods of layering. Cato, for instance, recommends a procedure called air layering (*On Agriculture*, 52), in which a branch is inserted through a pot full of soil suspended in the air, then snipped and planted out once the branch takes root. Most of these techniques are still in use today, virtually unchanged.

Once mature enough to bear fruit, trees were carefully pruned to ensure maximum production. Pruning is an art that requires deep knowledge of how trees respond to different cuts made at different places and at different times, and mastering it made the vine-dresser (*ampelourgos, putator*) a highly respected agricultural professional. (Trygaeus, the hero of Aristophanes' *Peace*, was one such expert.) Some of the most technical pages in Cato (*On Agriculture* 32–33) and Columella (4.23–29) are devoted to the intricacies of pruning and training the vine. But the effort involved was worth it, since careful pruning can cause a tree to produce more than double what it would if left untended. Also the subject of elaborate advice, repeated digging of the soil and timely manuring likewise have the potential to double or triple yields.

Evidence for wine-making in Greece goes back to circa 4500 BCE (Oil and Wine Production). Introduced to southern Italy during Mycenaean times, viticulture was practiced by the Etruscans. Roman wines were considered undistinguished until the second century BCE, when famous brands such as Falernian and Caecuban were developed. In addition to a drink which was an important source of nutrition, the vine produced raisins and table grapes. Greek vine growers typically allowed their plants to spread on the ground or to grow as dwarf trees, either free-standing or supported by simple poles (Isager and Skydsgaard 1992, 32). Vine-training equipment among the Romans was much more elaborate, with continuous trellises and various styles of pergola in general

use (White 1970, 231–236). Theophrastus refers once to vines growing on interplanted trees (*CP* 3.10.8), but in Italy the practice was so common that the "wedding" of the grapevine and elm tree became a standard poetic cliché (cf. Catullus 62.49–58).

The oil extracted from the fruit of the olive tree was highly prized as a fuel for lamps, a preservative for food, insect repellant, skin moisturizer, soap, and base for drugs and perfumes. Despite its utility, the tree has certain shortcomings. The sheer size of a mature tree hampers harvesters; ancient representations show pickers beating the branches with sticks and collecting the fruits that fall to the ground—an effective technique, yet one that produces bruised fruits. Like many stone fruits, the olive only yields a full crop in alternate years; Columella recommends that farmers establish two groves to ensure some yield every year (5.99). The olive also takes a very long time to become established, not producing its first fruits earlier than its fifth year, and not reaching full production until around age 30. On the other hand, once established, an olive tree is virtually impossible to kill: even cut down to the ground, it will re-sprout vigorously (cf. Theophrastus, *HP* 2.7.2).

The fig tree is easy to propagate and highly productive. A planting of figs yields more calories per unit area than any other crop, and in dried form the fruits made up a major share of the winter diet for field slaves and peasants (Cato, *On Agriculture* 56; Columella 12.14). Its one shortcoming is a tendency to drop its fruit before ripe, a habit which can be cured by ensuring that the fig wasp is able to pollinate the flower within each fruit. To that end, farmers either planted their orchards near wild trees or picked wild figs and hung them in cultivated trees; the female fig wasp was thus encouraged to fly from the wild to cultivated fruit, which it would pollinate while mating with the male wasp. Theophrastus (*HP* 2.8, *CP* 2.9) and Aristotle (*HA* 557b) were both intrigued by this process, but their ignorance of pollination thwarted their attempts to explain it.

Other fruit trees cultivated by Greek farmers included apples, pears, quinces, and pomegranates; the almond was a favorite nut. The Romans grew all of these species and more, giving them names which hint at the history of their introduction from foreign lands: "Persian apples" (peaches), "Median apples" (citrons), "Punic apples" (pomegranates), "Persian nuts" (walnuts), and "Armenian trees" (apricots). The Roman general Lucullus is famous for having introduced the cherry to Italy from Pontus after a victory there in 74 BCE (Pliny, *NH* 15.102), but this particular species was probably *Prunus cerasus*, the sour cherry, since *Prunus avium*, the sweet cherry, was already known to the Romans under the name *cornus*. Multiplication of the number of cultivars over time occurs with almost every farmed species; in the case of trees, we find 32 named varieties in Cato, 23 in Varro, 119 in Cloatius Verus (circa 20 BCE), 125 in Columella, and 194 in Pliny (White 1970, 262). This increase represents the combined result of introductions from abroad, abetted by Roman imperialism, and efforts to breed new varieties from known stock.

Trees, vines, and other woody perennials contribute greatly to the resiliency of the land in which they are planted, particularly in an arid environment. In return for a modest allocation of light and water, each tree raises the average moisture level in its immediate vicinity, holds the soil in place with its roots, and contributes a steady stream of organic matter to the soil in the form of dead branches and leaves. Intercropping, or the growing of grains or legumes between fruit trees, is thus an ecologically sound way of increasing the total average yield from a single piece of land. And this method was practiced by ancient Mediterranean farmers (Theophrastus, *HP* 8.3.5, 8.6.1; *CP* 3.6.1, 3.10.6; Columella 5.9.12; Pliny, *NH* 17.202) as well as their modern descendants.

5. Vegetables, Herbs, and Other Plants

Kitchen gardens are not clearly attested until the Classical era in Greece but must have been known in some form millennia earlier. Vegetable gardening is both resource and labor intensive: even a small plot requires deep digging, artificial watering, annual manuring, and regular weeding. Nevertheless, if an urban market lay nearby, gardening could be lucrative, and Cato rated it as the second most profitable use of a given piece of land (*On Agriculture* 1.7). High profits help explain some of the technological developments attested in the Roman era, such as waterwheels and valve-pumps used to supply irrigation (Pliny, *NH* 19.60), or attempts to extend the growing season for plants by employing cold frames made from glass (Pliny, *NH* 19.64; Columella 11.3.53). In early Imperial Rome, the gardener's handbook also appears for the first time as a distinct literary genre (Thibodeau 2011, 220–222). Vegetables and herbs were commonly raised, but gardeners could also make a tidy profit growing flowers like roses and lilies for urban markets, or flax and hemp, the two most important fiber crops.

In Greece the most important vegetables besides legumes were root crops (turnips, carrots, radishes), alliums (onions, garlic, leeks), lettuces, beets (for their greens), celery, and the fruit of various ground vines (gourds, cucumbers, watermelons). Cato takes the growing of such vegetables for granted, but goes on at length about the importance of *brassica* (cabbage or kale: *On Agriculture* 156–157) and describes in detail how to raise asparagus in beds (161) in a manner suggesting that cultivation had only recently begun to replace the gathering of the wild plant (the *corruda*; cf. 6). A curious Latin poem from the era of Augustus entitled *Moretum* ("The herb-and-cheese mix") describes a poor market gardener who made a living from selling cabbage, beets, sorrel, mallow, elecampane, skirret, leeks, lettuce, and gourds (72–78) while growing red onions, chives, nasturtiums, endives, and arugula (84–86) for his own consumption; the distinction indicates that there was an upscale market for mild-flavored vegetables, while workmen preferred those that were more pungent.

Herbs are easier to establish and maintain than vegetables, and they provide seasonings which play a major role in defining the character of an ethnic cuisine. The primary culinary herbs of the ancient Greeks are still with us today: basil, coriander, cumin, mustard, mint, fennel, thyme, sage, parsley, oregano, marjoram, and saffron. Bay leaves and myrtle berries were also commonly added for flavor (Jashemski 1999). The Romans took most of their herbs from the Greeks, but they were the first to cultivate lovage, a celery-like plant native to sub-Alpine Liguria (Pliny, *NH* 19.165), and they utilized the bitter herb rue to a degree which may seem surprising today (Andrews 1948).

6. Animals

For ancient farmers, domesticated animals played varied and sometimes contradictory roles. From one point of view, they were co-workers, providing labor or other benefits (e.g., manure) for the homestead. But they could also be regarded as products, like crops, to be milked, shorn of their wool, butchered for meat, or sold off as necessity demanded. Finally, animals were fellow creatures whose needs for food, shelter, and water had to be met, even if it put them in competition with humans. A farmer's decision about whether to raise animals, and if so, how many and of what kind, was thus shaped by many different considerations. Animals were always highly valued for practical, religious, and sentimental

reasons, but as Varro and Columella point out, agriculture in the strict sense of the term dealt only with the planting and improvement of the soil, not with animals (Varro, *On Agriculture* 2 preface 1–5; Columella 6 preface 1–3). The degree to which animal husbandry and arable farming in the Mediterranean competed with or complemented each other has been the object of intense scholarly scrutiny for the past few decades (Whittaker 1988; Howe 2008).

Raising horses is expensive because of their elaborate training regime and because they require large quantities of high-quality fodder—barley, oats, melilotus, hay, and fresh grass. Cattle require about 12 kg (26.5 lb) per day of grass, hay, legumes, or clover; they prefer well-watered grazeland but can make do with dry meadow or woodland. Roman agronomists say that they should be fed on tree leaves during the lean summer months (Cato, *On Agriculture* 54), a diet which would have kept the animals alive but left them sluggish and unable to perform much work. Cattle were given salt supplements at the end of summer to make them put on water weight (Aristotle, *HA* 596a10–24). The characteristic forage area for pigs was woodland, where they could root for acorns, roots, grubs, and other pungent detritus; on the homestead they were fattened for slaughter on beans, barley, and damaged fruit.

Sheep and goats, the ovicaprids, are less demanding than equids and cattle and were invariably raised in greater numbers in the Mediterranean. Both animals produce skins, milk, and meat. Sheep also yield wool. Arcadia "the mother of flocks" (*Homeric Hymn to Pan* 30) was later significant as the spiritual birthplace of pastoral poetry. Cato (*On Agriculture* 10.1) says that an olive grove of about 160 acres should include a flock of 100 sheep to dung the soil and suppress weeds.

Ovicaprids are suited to rugged and relatively dry landscapes like those found in the Mediterranean. Goats prefer a mixed scrub which allows them to nip the greenest parts from a variety of grasses, shrubs, and trees. Sheep prefer forbs and grasses with which they have an ambiguous relationship. A sheep's first instinct is to bite only the top part of the blade, a cut which benefits the plant, forcing it to send out multiple stems (tillering). However, if sheep cannot access new areas of grass, they return to what they have already nipped and eat that down to the ground—a quick death for the plants in dry weather. There was thus a fine line between moderate grazing, which would create thicker turf, and overgrazing, which left the ground bare. Cereal crops benefited from light grazing: winter wheat has an unfortunate tendency to produce a long, thin stalk which eventually collapses under the weight of the ripening head. By letting sheep graze lightly on the young crop, farmers prevented excessive stem growth and encouraged tillering, leading to higher yields (Theophrastus, *HP* 8.7.41; Vergil, *Georgics* 1.111–113; Pliny, *NH* 18.161). But in many areas, overgrazing by sheep was a major contributor to deforestation, desertification, and erosion (Hughes 1994, 77–79).

7. Conclusion

It has been estimated that at any given moment during the Hellenistic period or in the Roman Empire there were no more than a hundred practicing experts in the science of geometry, and perhaps several thousand dedicated medical professionals (Netz 1999, 282–292). Persons with agricultural expertise, by contrast, would have constituted the vast majority of the 60 million persons who then lived around the Mediterranean. Few

would have possessed mastery of all skills and facts; but most, from daily experience in a landscape full of farms, would have known how things were done. Xenophon in his treatise on homesteading makes the banal-seeming but important point that agronomy was distinguished from other forms of science precisely by being so ubiquitous and readily available:

> Farming is not so troublesome to learn. By watching workers perform some tasks and hearing about others, you can immediately know what to do … And I think you know a great deal already without even being aware of it" (*Economics* 15.10).

It was access to this "cloud" of knowledge that gave farmers so many different options and so much flexibility in dealing with an ever-changing environment, and that ultimately allowed them to keep their families fed and, with some help from traders, markets, and governments, to feed the great ancient cities as well.

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FURTHER READING

There exists a vast and ever-expanding body of high-quality scholarship dealing with all aspects of ancient Greek and Roman agronomy. Much of it takes the form of monographs devoted to certain crops (Tchernia 1986), animals (Griffith 2006a, 2006b, McInerney 2010), growing regions (Jashemski 1979, Decker 2009), social classes (Frayn 1979), techniques (Shaw 2013), or agronomical texts (McCabe 2007, Thibodeau 2011). In many works, the study of agronomy is embedded in broader discussions of food supply (Garnsey 1988), trade (Horden and Purcell 2000), labor (Burford 2000), culinary tradition (Dalby 1997), ecology (Hughes 1994), or bio-ecology (Sallares 1991). The best English-language survey of Roman agriculture remains White 1970, while the best overviews of early Greek agriculture are Isager and Skydsgaard 1992 and Burford 2000.

CHAPTER 33

Animal Husbandry

Kenneth F. Kitchell Jr.

1. Introduction

The term *husbandry* is used today in multiple ways, but for our purpose animal husbandry refers to the organized keeping of animals by humans in ways designed to improve the animals' usefulness to their keepers. This often, but not always, includes the concept of selective breeding, where the traits of particular interest to human keepers are encouraged and enhanced. The term is most generally used in reference to farm animals, but in reality, and especially in antiquity, the range of animals was much broader.

Still, it is widely agreed that the husbandry of sheep and goats was predominant, followed by that of cattle and swine, the main animals to provide food, by-products, and sacrificial victims. Such utility ensured that once an animal was domesticated, some degree of selective breeding must have inevitably arisen to produce increasingly specialized specimens. The extent to which agriculture and animal husbandry/pastoralism were interconnected is often debated, but it is particularly important to remember that the two were closely related, especially in the earliest historical periods. In return for protection and a regular food supply, animals supplied their keepers with food (meat, milk, cheese), pelts, fiber, transportation, hauling, plowing, and more. Moreover, their manure and their efficiency in clearing stubble or dormant fields could assist in agricultural endeavors. Thus, some have argued that husbandry, especially of ovicaprids, was intimately tied to the work of the fields. Others argue that there was little necessary connection. Conflicting views are set forth neatly in Whittaker 1988.

After a time, and under certain conditions which undoubtedly varied chronologically and geographically, the number of animals in a given area would undoubtedly begin to strain local resources. When browsing land was converted to cultivated fields or when socio-economic pressures—such as a growing population—required elevated animal

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production for food or fiber, the increased number of animals necessary would outstrip a location's ability to support them. In such situations, if enough dry fodder could not be stored to last the winter, seasonal transhumance of flocks and herds would have been introduced. In its basic sense, transhumance involves moving livestock, most commonly sheep and goats, who are much more agile in rocky terrain, to higher elevations during the summer months where browse does not suffer from the dry Mediterranean summer. The shepherds of *Oedipus Rex* (1132–1140) are the best-known example of this from antiquity. Cherry (1988) thoroughly discusses the evidence for and against Bronze Age transhumance. Hodkinson (1988) and Skydsgaard (1974, 1988) hold differing views on the interaction of transhumance and agriculture. One should also consult Frizell (2004a). Great variety must have existed in the details, but we are probably on safe ground in assuming that transhumance was practiced as the economy demanded. If local grazing would suffice for a small farmer, for example, he would have no reason to move his meager flock. Larger flocks, such as those kept as part of a wool industry, may well have exhausted local food sources, requiring transhumance if ultimate economic goals were to be met.

The feeding of flocks of any sort would also vary by era and place. Small farmsteads probably had their livestock browsing nearby, where they were kept from arable fields and ate whatever nature provided. Once the fields had been harvested, livestock could eat stubble and chaff. Such small herds were also fed agricultural by-products such as grape skins or crushed olives. Prize animals or those being bred for specific traits could be fed special fodder, but this decreased the profit margin. If the owner could afford it, pens and enclosures also helped increase yield. Many modern-sounding techniques were employed to help better the breeds—branding, castration, special fodder for pregnant animals, selective breeding, importation of breed stock from abroad, and culling the herd. We even hear of birth control devices for sheep (Varro, *On Agriculture* 2.2.15).

One must keep in mind that different styles of animal husbandry arose over the ages in response to differing time periods, technology levels, the social status of those involved (e.g., Mycenaean rulers, and owners of *latifundiae* [large Roman plantations], versus subsistence farmers), geographic and climatological pressures (the relatively poor soil of Attica versus the fields of Thessaly), political upheaval, the sacrificial demands of religion (Jameson 1988), changing economic incentives (e.g., an increased export market for Hymettan honey), and much more (Howe 2008).

Evidence for husbandry also varies greatly by time period. Interestingly, we know more about husbandry patterns in the Mycenaean era than in Classical Greece, and the practices in the Roman provinces are often better documented through archaeology than those from Italy itself.

Husbandry has become an active area for recent scholarly study and is, at its best, both multi- and interdisciplinary in nature. Ancient authors from Homer and Hesiod to Aristotle and up through the tenth-century *Geoponica* offer valuable information on the day-to-day practices of animal breeders. Xenophon's *Economics* treats the effective running of a farm, and his *On the Art of Horsemanship* sheds light on Greek horse husbandry. But it is the Roman agricultural authors who leave us the most detailed information. Varro (*On Agriculture* 1.1.8–11) and Columella (1.1.1–14) offer historical overviews of authors on husbandry who came before them. Other extant Roman authors such as Cato or the veterinary writers mentioned below focus almost exclusively on practical exposition. All these were preceded by Mago the Carthaginian, who is cited

by Varro, but whose dates are uncertain. Mago's twenty-eight book treatise on agriculture was held is such high regard that it was translated from Punic into Greek and Latin at state expense. Columella calls him the "*rusticationis parens*," or "the father of husbandry." Other authors (e.g., Aelian, Pliny the Elder, or Athenaeus) dutifully collect and preserve the opinions and reports of earlier agricultural authors. White (1977) has gathered much of this together in a very useful source book. In the past, archaeologists have, understandably, been less prone to pay the same attention to the faunal remains of a site when there was a monumental building to investigate. This trend seems to be changing, and archaeology is increasingly turning to the systematic study of animal remains to shed light on ancient practices. Husbandry is increasingly studied in the work of ancient economists. In light of these myriad approaches, therefore, the following is organized according to the type of animal involved.

2. Ovicaprids: Sheep and Goats

Sheep and goats were among the first animals domesticated by humans (cf. Varro, *On Agriculture* 2.2.2). Recent scientific investigation claims that the domestic sheep (*Ovis aries*) was the result of several domestication events. These began up to 8,000 years ago and involved various types of wild caprines bred first for meat and then for secondary products such as wool and milk (Bruford and Townsend 2006; Chessa et al. 2009; Clutton-Brock 1981, 52–57; Pedrosa et al., 2005). The wild sheep involved in this process include the European mouflon (*Ovis musimon*), originally found in the wild only in Corsica and Sardinia, and the urial or Asiatic mouflon (*Ovis orientalis*). Wild sheep were not indigenous to Greece in the post Pleistocene and were therefore introduced by humans. Once domesticated, sheep provided a host of products for humans including foodstuffs (such as meat, milk and cheese: Dalby 2003, 300), and industrial products (such as wool, horn, pelts, knuckle bones for gaming, and manure). And they were a very common sacrificial offering. The domesticated goat (*Capra hircus*) descends from wild goats, which were initially hunted for their meat and then domesticated circa 8,000 BCE (Clutton-Brock 1981, 57–61; Hatziminaoglou and Boyazoglu 2004; Luikart et al. 2006; cf. Varro, *On Agriculture* 2.3.3). The most likely ancestor of *Capra hircus* is the bezoar goat (*Capra aegagrus*), but other breeds are not out of the question, and cross-breeding between domestic and wild goats must have occurred.

A goat produces more milk for its size than a sheep or a cow, and its cheese has an excellent flavor. Its finer hair (especially that of Cilician goats) was used to make fabric, while coarser hair, including that from the goats' beards, was used in ropes and even to fill in chinks in boats (Varro, *On Agriculture* 2.11.11; Vergil, *Georgics* 3.311; Laures and Pascual 1983). In general, goat-hair cloth was seen as a poorer and more rustic garb. Goat skin was used for bags, tents, rough coverings, and wineskins (Jameson 2012, 10; White 1970, 315–316). Its flesh was eaten, but opinion differed on its quality (Dalby 2003, 160). Goats need less water than sheep, and they can exist on rougher fodder, even fish (Aelian, *On the Nature of Animals* 16.35). For an overview of sheep and goats in antiquity, see most recently Kitchell (2014, 76–77, 168–170).

Cherry (1988) is of the opinion that ovicaprids were kept in small numbers and primarily for meat during Neolithic Greek times until the emergence of nucleated, more densely populated settlements. Most theories state that once the animals began to be

kept for purposes other than meat, they would be kept alive longer. Sheep and goats were obviously herded by the Minoans, but factual information is sketchy. It is possible that the Minoan state owned herds of domestic goats as well as herds of the impressively horned kri-kri (Bloedow 1990; 2003, 19). Linear B tablets, on the other hand, offer a trove of information about the Mycenaeans, who kept enormous herds of sheep and goats (one summary tablet alone lists 10,000 head of sheep) and evolved an intricate bureaucracy to manage them. In the Knossos tablets, sheep are tallied far more often than any other domestic animal involved in the Mycenaean palace economy (Cherry 1988; Enegren 2002; Rougemont 2002, 20–30; Ventris and Chadwick 1973, 131, 195–205). Goats were second in the numbers being kept, with careful notes taken on the gender of each animal (Ventris and Chadwick 1973, 199–200; Enegren 2002, 15–16). Odysseus' many herds included goats (*Odyssey* 14.101–102, 17.212–213), and Hesiod has advice on rearing them (e.g., *Works and Days* 582–585, 791–792).

Aristotle gives details on goats and sheep, such as longevity, number of young, pasturage, and training the leader of the flock (*HA* 573b17–574a16, 596a13–596b10; Ryder 1983, 42–43). Putting sheep into two basic groups, broad tailed and long tailed, Aristotle states that of all herd animals the latter are the stupidest (610b22–28). During Archaic, Classical, and Hellenistic times, smaller, individual herds appear to be the norm and were kept for subsistence, but *poleis* and wealthy individuals could support larger flocks as well to provide surplus and serve industrial purposes (Hodkinson 1988).

We have a great deal of information concerning ovicaprid husbandry in the Roman period, largely thanks to agricultural authors such as Varro (*On Agriculture* 2.2.1–20), Columella (7.2.1–5.22), and Pliny (*NH* 8.187–204). Of special interest is the fact that while goats may seem hardier, they are more susceptible to weather and disease (Varro, *On Agriculture* 2.3.5), requiring constant attention from their shepherds, the best of whom carry a book with them outlining care and cures. Those tending sheep were also encouraged to keep such a book at hand. This implies literacy in the trade, if only, perhaps, for the head shepherds. White (1970, 301–312) offers an admirable summary of the evidence, including various breeds and the qualities for which they were bred, such as quantity or fineness of wool, color, size, and quality of milk (cf. Columella 7.2.1–3; Thompson 1988). Most writers divide sheep into those that were raised for wool and thus wore protective "jackets" (*tectus*, or *pellitus*: to keep the wool free from burrs: Diogenes Laërtius 6.41; Varro 2.2.18) and those not so protected (*colonicus*). White also discusses various ways sheep were herded, from transhumance to integration into the running of an average farm.

We have reports of intentional crossbreeding. Pliny (*NH* 8.199) mentions Umbrian sheep, a cross between the Spanish/Corsican *musmo* and domesticated sheep. Columella relates in detail the attempts by his uncle Marcus to cross wild African rams with domestic ewes (7.2.4–5). Other evidence for selective breeding may be indirect but seems clear. Herodotus (3.113), for example, speaks of Arabian sheep, one with tails so long they must be supported in little carts and another with a tail one cubit (46 cm [18.5"]) wide. Strabo (10.1.14) recounts that sheep on Euboea have white or dark wool depending upon the river from which they drink. Ryder (1983, 146–170) studies the various types known to the Greeks and Romans, differentiating them mostly by horn shape, leg length, body type, the sort of wool they produced (long, shaggy, fine, etc.), and where they lived. In literature, sheep and goat herding is often associated with country life and pastoralism, beginning with the Cyclops' herds and culminating in bucolic works such as those of Theocritus and Vergil.

3. Cattle

Today's 800 breeds of modern cattle are generally divided into the western *Bos taurus* and the eastern *Bos indicus* (Bradley and Magee 2006, 317). All western modern cattle are descended from the now extinct aurochs. They were domesticated perhaps 10,500 years ago and first used for milking in the fourth millennium BCE (Bollongino et al. 2012; Clutton-Brock 1981, 62–68). Classical scholars occasionally use terms (cattle, cow, bull, ox) loosely. Here, "cattle" will be used as a collective noun referring to domesticated herds of members of the genus *Bos*. "Cow" refers to a mature, female member of the genus *Bos* and is also used as a generic term for *Bos taurus*. "Bull" refers to a male member of *Bos taurus*. An ox is an adult bull that has been castrated to render it more trainable (Aristotle, *HA* 632a14–21 describes the process) and is used here to refer to a *Bos taurus* in its role as draft animal.

Cattle provided many benefits to those who kept them: meat; milk; hides; leather; manure (for fertilizer or fuel); and muscle power, commonly called "traction" (Land Transport and Vehicles). Milk drinking was rare in Greco-Roman antiquity, and while cow's-milk cheese was known (Aristotle, *HA* 522a29–32), that of goats and sheep was preferred (Dalby 2003, 80–81, 217–218). Neolithic finds attest to domestic cattle, and the importance of the bull in Minoan culture is clear from their art. The exact extent to which Minoans raised cattle domestically or captured them in the wild (cf. the Vapheio Cups) must remain a matter of conjecture, however. We are more fortunate to have written records concerning herds tended by the Mycenaean Greeks, who clearly had a cattle herding industry, although they are much less frequently mentioned on Linear B tablets than are sheep and goats (Ventris and Chadwick 1973, 131–132, 198; Enegren 2002, 14–15; McInerney 2010, 48–73). Interestingly, tablets from Knossos (the Ch series) record the names of oxherds as well as the names of their cattle (Killen, 1992–1993). Notable examples include *Aiolos* ("Nimble"), *Kelainos* ("Blacky"), *Xouthos* ("Swifty" or "Tawny"), *Podargos* ("Swift-foot"), *Stomargos* ("Noisy"), and *Oinops* ("Wine-faced").

Cattle husbandry is implied by the pervasive need for their products. Beef was a dietary staple for Homer's heroes and warriors, whose armor and shields made extensive use of leather as well (Arms and Weapons). In later periods of Greek history, cattle were kept less for dietary needs than to provide adequate numbers of draft and sacrificial animals. Prevalent as draft animals (Pettegrew 2011, 561), oxen essentially fulfilled the roles served today by railroads and the trucks, hauling large blocks of stone for public buildings, produce from the fields, trade goods to and from harbors, and more. The ox was also an essential animal for plowing. There is evidence for Mycenaean ox plows (Pullen 1992), and Hesiod lists three essentials for anyone: house, wife, and ox (*Works and Days* 405). The ox was so vital to farming that Aristotle says that it was a poor man's slave (*Politics* 1252b). See Figure 33.1.

Cattle became important in ostentatious public sacrifices where hundreds of head of cattle could be sacrificed at once. The large, state-sponsored sacrifices of Athens in the late fifth and fourth centuries required 6,528 oxen each year (Howe 2008, 60). This high demand for cattle implies a thriving cattle breeding program, and Osborne (1987, 182) offers excellent data on the numbers of oxen needed at Athens and the herds kept by the city-state.



Figure 33.1 Oxen pulling a cart. Mosaic. Villa Romana Casale from Piazza Amerina, Sicily. (*Source:* Shutterstock/Luigi Nifosi.)

The Roman world was equally dependent on cattle, and their husbandry was treated in depth by writers such as Varro (*On Agriculture* 2.5.1–18), Columella (6 preface 26.4), and Pliny (*NH* 8.176–186). References are collected by White (1970, 275–288). Varro's list of terms indicates the complexity and precision of cattle husbandry. Each of the four stages of the life of a bovid has a name:

1) *vitulus* or *vitula*, calf;
2) *iuvencus* or *iuvenca*, yearling;
3) *bos novellus*, a "newling cow," indicating tenderness; and
4) *vetulus*, old.

The male of groups three and four is a *taurus*, and the female is a *vacca*. A sterile *vacca* is a *taura*, and a pregnant one is a *horda*. Bulls were kept for breeding and were exhibited in beast fights in the amphitheater (Toynbee 1973, 149–162; Jennison 1937, 26–27). There were established processes for training oxen to pull plows, for their feeding regimen, and for branding, castration, and herding.

Columella (6.1.1–2) lists seven breeds: the Apennine (strong but unattractive); the Campanian (small and white, cf. King 2002, 410); Etruscan; Latin; large whites (*vasti et albi*); red (smallish); and Ligurian (cf. Strabo 4.6.2). Varro (*On Agriculture* 2.5.9–11) compares types from around the Empire. Lepetz (1995) and Audoin-Rouzeau (1995) trace breeding programs in the provinces, noting selection for larger size.

4. Pigs

Sus scrofa was the ancestor of today's domesticated pig (*Sus sus domesticus*). It was domesticated perhaps 8,000–9,000 years ago (Clutton-Brock 1981, 72), probably independently in multiple areas. The ancestor of modern domestic pigs was the European, not Near Eastern, wild pig (Larson et al. 2005). It would have been rather easy to domesticate, with young taken from wild mothers killed in the hunt. Domestic pigs both foraged and were fed in sties. They ate a broad spectrum of food such as barley, field stubble, and acorns, and they put on weight faster than other herd animals. Their milk was of little use, but the meat was sought after and, as today, there was a use for virtually every body part (Dalby 2003, 168–169). In fact, Pliny (*NH* 8.209) lists 50 "flavors" of pigs. This popularity of pork and the use of pigs as sacrificial animals gave rise to a robust pig farming industry, and the high number of young in a litter certainly offered a good return on investment. Linear B tablets mention over 320 pigs, most of them sows and some designated as "fattened pigs" (Ventris and Chadwick 1973, 132, 198, 205–209; Enegren 2002, 13–14). Such an industry demands swineherds, and Odysseus' swineherd, Eumaeus, is full of information: his pigs have sties and an encircling enclosure; only sows are penned, 50 per sty, while the boars sleep outside. All were guarded by dogs (*Odyssey* 14.5–28). Other Greek sources offer little on the art of swine husbandry, but papyri indicate a thriving pig trade near Alexandria (Thompson 2002). Aristotle comments on the pig's diet and fattening regimen (*HA* 595a13–b5), and he discusses the spaying of females (632a22–27). Some sense of the pig's prevalence can be found in the number of Greek words from husbandry: *delphakion* and *choirodelphax (*piglet; but cf. Schaps 1991); *hapalias, thēlazōn choiros* and *orthagoriskos* (suckling pig); *kolabros* and *choirophorēma* (piglet); and *metachoiron* (runt). Add to this at least five terms for a pig sty: *karpōn*, *suobaubalos* (*stathmos*), *hyōn*, *choireōn*, and *choirotropheion*.

Roman agricultural authors such as Varro and Columella provide us with a wealth of detail concerning pig farming, well summarized by White (1970, 317–321). Varro offers meticulous directions for their purchase, care, and breeding, including castration and spaying (*On Agriculture* 2.4.1–22). He even reports that pigs could be trained to come to the sound of a horn (2.4.20). Columella notes that a form of branding with liquid pitch helped keep piglets with their sows, and he offers a list of diseases and cures (7.9.1–11.3). Citing earlier authors, states Pliny that wild pigs were kept in preserves as well as in the cities (*NH* 8.205–213; cf. Jashemski 2002, 105 for Pompeii). Romans especially liked to fatten their pigs, even to the stage where they could not walk, and there is some evidence of selective breeding in favor of this trait.

Italy was the primary provider of pigs, especially in the Po valley, but authors also praise those of Spain, the Sequani, and Belgae (White, 1970, 320–321). MacKinnon (2001) describes two basic breeds in Italy, a large, fat, short-legged one and a smaller, bristled, long-legged one. The smaller was kept in herds that foraged for food in forests and primarily provided meat for the Romans. The larger breed was stall-fed, which rendered it more expensive and a sign of the prosperity of its owner. Latin, too, has a wealth of husbandry related terms: *sus* and *porcus/porca* (generic and for adults); *porcellus/porcella* and *porculus* (piglet); *porcilia* (sow); *porcetra* (a sow that has given birth to one litter); *aper* (boar, especially wild, cf. *apra*); *scrofa* (breeding sow); *verres* (a boar-pig); and *maialis*, a castrated boar. See Figure 33.2.



Figure 33.2 Pigs attended perhaps by Odysseus and his faithful swineherd Eumaeus. Red figure pelike by the "Pig Painter," Athens, 470–460 BCE. Cambridge, Fitwilliam Museum GR.9.1917. (*Source:* Fitzwilliam Museum, University of Cambridge, UK/Bridgeman Images.)

5. Horses

The horse was the last of the major animals to be domesticated, probably kept first as a food source. By the Iron Age, the domestic horse existed in two essential groups: the small "Celtic" ponies of Britain, Western Europe, and Greece and the taller horses originating in Scythia and the Russian Steppes (Clutton-Brock 1981, 80–86). Both sorts eventually became well known in the Mediterranean. Hyland (1990, 11–29, 266) lists almost 50 breeds named by the ancients (cf. Anderson 1961, 15–39; Varro, *On Agriculture* 2.7.6). These

were bred for specific traits. Those that raced carrying single riders or drawing chariots were undoubtedly bred for speed, turning ability, and endurance. The same traits were sought in horses utilized to convey the Roman post (*cursus publicus*) or military messages. Those used in war or the hunt required even temperaments and a sturdier frame. The most famous ancient breeding grounds lay in Sparta, Argos, Thessaly, Macedonia, Sicily, and North Africa.

Unlike cows, sheep, and goats, the horse was not kept for multiple products or purposes. Oxen did most heavy hauling, since efficient harnesses had not yet been invented for draft horses (Land Transport and Vehicles). Moreover, from Mycenaean times onward, ancient horses were on the small side. The Scythians may have milked them (Herodotus 4.2), and Aristotle mentions their milk and cheese making in Phrygia (*HA* 521b33, 522a28–29), but the horse's importance for the Greeks and Romans lay almost exclusively as a conveyor of humans, either as single mounts or in chariots, most commonly in war or for racing. Since horses require more care and more expensive food than mules and donkeys, they were a symbol of wealth. Classes of society (*hippeis, equites*) were created to indicate people with enough money to own horses for cavalry use. Even the owner of a single mount needed stables, handlers and grooms, pasturage, and a steady supply of grain. Breeders who produced horses for sale must have incurred heavier costs, including the importation of breeding stock from abroad, but the profits could be correspondingly high (Anderson 1961, 128–137).

Minoan Crete shows little evidence of the horse, but the Mycenaeans knew it well. Linear B tablets are fairly quiet on actual horses (Ventris and Chadwick 1973, 132) but speak in detail about the chariot industry and horse tack (519–521). Mycenaean art also frequently depicts chariots. And the internment of horses with Mycenaean nobles shows the high esteem in which they were held. The horse is mentioned continuously throughout subsequent Greek and Roman literature. Xenophon's *On the Art of Horsemanship* dealt with all aspects of acquiring, keeping, training, and riding horses. Earlier than this, and probably one of its sources, was a work by Simon of Athens (circa 470–420 BCE; Zucker 2008). Aristotle speaks at length on many subjects concerning the horse: dentition, mating, birth, and life-span (*HA passim*, especially 575b20–77a18).

The Roman agrarian writers Varro (*On Agriculture* 2.7.1–16) and Columella (6.27.1–35.2) transmit practical information for horse husbandry, especially concerning the prevention of and cures for the horse's many diseases. Detailed treatments are to be found in what is called the Hippiatric corpus, that is, books devoted to the treatment and prevention of equine diseases, such as the *Mulomedicinae* of Vegetius, Pelagonius, and Chiron (McCabe 2007; Fischer 2008). Such was the investment in a horse that one was even brought to a healing spa (Frizell 2004b; Kitchell 2004).

6. Mules

Mules were ideally suited for carrying humans and objects over a wide variety of terrains (Land Transport and Vehicles). They are larger, stronger, and more tractable than donkeys, swifter than yoked oxen, and tougher than horses. In what Gregory (2007) has called the "equine hierarchy," it was second only to the horse and far above the donkey, providing services that made it an invaluable asset. Toynbee (1973, 185–192) and Romer (2000, 82–84) list its jobs: working on an individual farm pulling a plow, working in teams to draw carts and wagons; individual pack animal; and bearing burdens for the Roman army. They turned mills; helped pull boats along canals; dragged cut trees, firewood, and marble blocks; and carried game back from the hunt. Mules even carried

mail when they powered the carts of the Roman *cursus publicus*. They were invaluable for the army and followed it throughout the provinces (Armitage and Chapman 1979, 345–349). Trajan's column has seven scenes with mules, showing them pulling artillery, carts, or carrying panniers; and they appear six times on the Marcus Aurelius Column (Dixon and Southern 1992, 236). Lysias (24.11) implied that the mule is a mount for the wealthy and is to be preferred to riding a horse. With such a multiplicity of uses and its obvious economic value, it is no surprise that both Greece and Rome had thriving mule farms (Hyland 1990, 35–36, 71–72), or that many people made their living as mule breeders, muleteers, or as craftsmen of harnesses and bridles (Molin 1995).

Aristotle discusses the reasons for the mule's infertility and various factors affecting its generation (*HA* 577b5–578a5; *GA* 748b34–49a7). This sterility led to specific breeding techniques in order to provide the number and types of mules the ancients required (e.g., Columella 6.36.1–37.10). Before proceeding, however, terms must be clarified. In English, the term "mule" should technically be reserved for the offspring of a female horse (mare) and a male donkey (jack, he-ass), and "hinny" should be reserved for the offspring of a female donkey (jenny, she-ass) and a male horse (stallion). *Burdo* is a later Latin word that also indicates the offspring of a stallion and a she-ass (Isidore, *Etymologies* 12.1.60).

The mule was preferred by the ancients for working purposes, as it was a bit larger and sturdier than the hinny. Despite these distinctions, the words were often used loosely, even by the ancients.

An indication of the value of this animal to the ancients is the survival of three veterinary works devoted mostly to horses, mules, and donkeys. Two are entitled *Mulomedicina*, penned respectively by Chiron (Oder 1901; Fischer 2008) and Vegetius (Lommatzsch 1903); while, another, whose title is not known, is a series of commentaries on works by Pelagonius (Adams 1995; Fischer 1980). All were written rather late but are essentially compilations containing centuries of lore. Wright (1977), further, has shown that the presence of Roman troops in a given place brought with it the presence of "mule doctors."

7. Donkeys

The donkey or domestic ass (*Equus asinus*) was probably domesticated from the wild ass, or onager, circa 5,000–6,000 years ago and perhaps in two separate events (Beja-Pereira et al.; Clutton-Brock 1981, 91–101) and was widely used thereafter as a beast of burden. It had a lower status than a horse or mule (Land Transport and Vehicles). But it was able to carry heavy loads and is most commonly shown working alone, not in a pair. It is sure footed, making it an excellent choice for the rocky and mountainous agricultural settings of both Greece and Rome. Donkeys are far sturdier than horses, and they are as hard working as mules. They were especially valuable for several reasons: their ability to exist on coarse fodder; their need for less water than horses; their long life expectancy (30–40 years). The best, according to several authors, were found in Arcadia and Reate. There is some evidence that donkeys were intentionally bred with onagers, but the onager itself was never domesticated.

A Linear B tablet from Pylos lists donkeys along with other equids. Donkeys are commonly shown hard at work on Greek vases. In real life, they carried panniers, bore loads on their backs in special frames or woven baskets, were ridden with wooden saddles, pulled wagons, propelled millstones, were used for light plowing, and much more. They

could even be used as protectors of sheep flocks (Griffith 2006, 224). As did mules, donkeys often worked in trains to carry mass quantities of goods such as olive oil, wine, or grain. Even the poorest of farms needed a donkey. Cato states that an olive grove of 240 *iugera* (circa 150 acres) needed four donkeys to function properly, three to carry manure and one to turn the millstone (*On Agriculture* 10.2). Donkeys that were bred for labor were normally castrated in youth. Many donkeys must have accompanied Roman soldiers on the march, carrying everything from provisions to tents.

The donkey was equally important for its role in mule breeding. As a result, there was a thriving trade in breeding donkeys for stud purposes. Columella describes at length the procedure to be followed in mating donkeys with mares, and we even hear of special breeding stations designed to let the shorter jack-ass mate with the taller mare (6.37.10). Breeding donkeys fetched prices far in excess of their farmyard cousins. Varro (*On Agriculture* 2.8.3) records that one senator paid 400,000 sesterces for a he-ass, a price which Pliny, in his description of ass breeding, says was probably highest ever paid for an animal (*NH* 8.167). Pliny also tells us that Nero's wife Poppaea had a herd of 500 she-asses with foals so that she could take frequent baths in their milk (*NH* 11.96.41).

8. Dogs

The dog was the first animal domesticated by humans, descending from tamed wolves, perhaps 12,000 years BCE (Clutton-Brock 1981, 10). Greeks and Romans bred them for special tasks and also imported breeds from other countries. Hull (1964, 21) notes sixty-five breed names in Greek and Latin literature. Grattius (*Cynegeticus* 150–262) has an extensive list of breeds, including some that have been identified from as far away as China (or Tibet), Britain, Germany, and the modern Ukraine. Most breed names came from the place where they were developed. The Cretan hound, known for speed and agility, was a particularly important breed. The Locrian hound was recommended for boar hunting, and there are references to Elean, Arcadian, Tegean, and Argive hounds, to name a few. From outside the Mediterranean, Indian and Persian hounds were well known, and Libyan hounds are mentioned.

Greco-Roman dogs fall into three basic groups: guard dogs, hunting dogs, and pets. Guard dogs (Molossians and others) were bred for strength and aggression, to protect homes, villas, and flocks. Hunting dogs, such as the Laconians or Cretans, were bred to be long and sleek, with pointed muzzles and erect ears. The most common pet dog is the Maltese or, more properly, Melitaean dog. A small dog with curly hair and a tail curled at the end, it is often depicted on Greek funeral monuments, and a poem of Martial is a tribute to a Melitaean named Issa (1.109). Dog breeding could be lucrative. Plutarch reports a large dog owned by Alcibiades that cost 7,000 drachmas (*Alcibiades* 9.1).

9. Small Animal Husbandry

In addition to larger herd animals (*pecus*), many other types of animal were bred by the ancients. We have far more evidence from Roman times in authors such as Varro and Columella, but a rich Greek vocabulary used in these works indicates that earlier Greek small animal husbandry existed. Vase painting also offers indirect evidence. The prevalence of cock fighting in Athens and the frequent use of it as a love gift certainly speaks to breeding for aggressiveness. The presence of birds such as herons and geese in the

women's quarters of Greek houses surely speaks to their being bred in captivity (wild herons are aggressive). But it is the Romans who specialized in (and virtually industrialized) *pastio villatica*, a term variously interpreted, but referring in general to the rearing of otherwise wild animals in enclosed areas near a farmstead. Such an area was called a *vivarium* ("live animal area") or, in an expansion of its earlier and narrower use, a *leporarium* ("hare warren").

Humans have robbed bee colonies in the wild from Neolithic times (Morse and Hooper 1985, 167), but organized beekeeping is at least as old as the Egyptians and was common throughout the Aegean Bronze Age, attested both by Minoan hieroglyphics and the remains of clay bee hives (Davaras 1986; Kitchell 1981; Woudhuizen 1997). The list of usable products that resulted from this husbandry is extensive. Honey served as a sweetener, a preservative, and an ingredient in many medicines (Dalby 2003, 179–180; Pharmacy). Wax was used so commonly (writing tablets, lost wax method of bronze casting, lubricant, seal impressions, encaustic painting, etc.) that an extensive apiary industry can be assumed. Laws governing the industry are as early as Solon (Plutarch, *Solon* 23.6). Aristotle studied the bee and its lifecycle closely (*HA* 623b5–627b23). Authors such as Varro (*On Agriculture* 3.30), Columella (Book 9), and Vergil (*Georgics* 4) speak extensively about beekeeping, giving practical advice on establishing a colony; how to prevent loss in the hives from a very long list of pests, ranging from lizards to moths; full details of handling the bees; location and relocation of hives; tanging (attracting swarms by clanging brass together); harvesting the honey and wax; and more. Ancient clay beehives are frequent archaeological finds and were generally designed to lie horizontally (Crane, 1983a; Jones 1976; Jones et al. 1973). Literary sources tell us they could also be made of bark, wood, and wicker as well, but these have perished.

The edible dormouse (*Myoxus glis*) is an arboreal rodent known for its deep sleep in hibernation, during which time they lay on fat, making them a desired food source for the Romans, who raised them in darkened areas (called *gliraria*) and in *vivaria* in tubs called *dolia* (cf. Varro, *On Agriculture* 3.15.1–2; Pliny, *NH* 8.224; Dalby 2003, 122–123; Food Storage Technology). They were even the target of early sumptuary laws (Pliny, *NH* 8.223), and their prices were controlled by the Edict of Diocletian (4.38).

Pliny tells us that Fulvius Lippinus, before the Civil Wars of 49 BCE, began the practice of keeping snails and fattening them for consumption in *vivaria* (*NH* 9.173). Moreover, the enclosure was divided into areas for individual species, including foreign species brought in from as far away as Illyria and Africa. Such farms included artificial islands (to keep the snails in place) and drip irrigation to create a misty atmosphere (Varro, *On Agriculture* 3.14.1–5).

The Romans kept rabbits and hares, tending to them with the aim of fattening them and producing food for the table. Discussing this at length, Varro speaks of three species: Italian, the white hare of Gaul, and the Spanish rabbit (*On Agriculture* 3.12.1–7).

Many types of birds were kept: chicken, duck, teal, goose, guinea fowl, crane (*grus*), peacock, thrush, pigeon, and turtle dove. The business could be extremely lucrative. Various types of enclosures existed, generally called *ornithon*, *ornithoboscion*, or *aviarium*, but specialized names such as *chenoboscion* (goose-cote) are numerous. Some consisted largely of netting, and they displayed songbirds in flight for pleasure, rather resembling modern natural enclosures. These could be large operations and entailed landscaping, diverting sources of water, specialized food, and numerous slaves as keepers. Eggs and chicks were on sale for those beginning their collection. There are several

breeds of chicken, and wild and tame pigeons were interbred, perhaps evidence of selective breeding. Peacock eggs were often slipped beneath brood hens. On all the above, see especially Varro (*On Agriculture* 3.1.1–15.2) and Columella (8.1.1–15.7).

Continuing a tradition that was at least as old as Persia, the Romans also kept large tracts of land filled with game for hunting animals such as boar, wild sheep, and deer. Such animals would have required some care, but less than those mentioned above.

10. Aquatic Husbandry

Both Greeks and Romans engaged in what is today called aquaculture to meet their culinary demands. The Greeks built enclosures within rivers and basins for raising eels, but they also managed large man-made fishponds. Such endeavors require significant aquatic engineering and feeding regimens. Roman *piscinae*, or fish farms, were extremely common and produced both freshwater and saltwater fish on a large scale (Higginbotham 1997; Marzano 2013). Some were large and quite complicated, with a sophisticated system of tanks for fish in various stages of development. Freshwater complexes could be built near a river, using piped-in water, but saltwater ponds were often built with enclosures jutting out into the ocean in lagoons. Some installations mixed both saltwater and freshwater, imitating brackish conditions more suitable to certain fish. There were also large Roman installations given over to the breeding of oysters and other shellfish, the most notable of which lay in the vicinity of Baeae and Puteoli. Aristotle describes the creation of artificial oyster beds by transplanting oysters (*GA* 763b1–5). Marzano lists other mollusks, including scallops, farmed by the Romans (2013, 195–197).

11. Exotics

Appearing in ancient sources are many animals which may have been formally tended and controlled by humans, but for which evidence is slight. The ferret, for example, was muzzled and used to flush rabbits out of their warrens. Were they bred for the job or taken as young and then trained? Aristotle (*HA* 632a11–14) mentions castration of deer, and fawns appear as pets on *choes* (wine jars), leading one to posit husbandry. Elephants were fairly common in antiquity. Carthaginians, Indians, Hellenistic Greeks, and Romans all used them in warfare, as performing animals, for hauling, for drawing chariots in Roman triumphs, and as animals to be hunted down in the Roman games (Pliny, *NH* 8.4–35; Scullard 1974). We also hear of elephant handlers and trainers (*elephantistes*, *rector*, *magister*, *moderator*). Thus it is certain that tamed herds existed. These were the North African elephant (*Loxodonta africana pharaoensis*), a smaller species from North Africa that went extinct in Roman times. Aelian (*On the Nature of Animals* 2.11) writes at length about a herd of twelve performing elephants born in Italy. But there is no record of selective breeding to improve the stock or even of directed breeding to replenish the herd. The reasons for this are many. Elephants are expensive to keep and, when in heat, virtually unmanageable. It was generally more economical to capture, train, and export them. To this end there existed the Roman Imperial post of *procurator ad elephantos.*

Both Bactrian (two-humped) and dromedary (single-humped) camels have been domesticated and herded by humans, but uncertainty exists about the date (Clutton-Brock 1981, 126; Bulliet 1975, 35–37). They were widely used throughout the Near East, and

Romans used them as baggage animals, apparently bringing them into Europe (Clutton-Brock 1981, 129; Bartosiewicz and Dirjec 2001). There is some evidence of experimental breeding programs, and papyri evidence attests sales and even a camel tax (Callender 1970; Daniel 1986; Potts 2004). The existence of robust camel husbandry is therefore fairly certain in the eastern reaches of the Roman Empire.

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CHAPTER 34

Oil and Wine Production

Rafael Frankel

1. Introduction

The vine, olive, and wheat are the three staple plants of Mediterranean dry farming. Ideally suited to the mild climate of the region, where it rains only in winter, their products—wine and raisins, olive oil, pickled olives, and grain—can be stored indefinitely, thus comprising the basic components of the Mediterranean diet. As a result, these crops, playing a crucial role in economic and especially technical history, were an integral part of Mediterranean cultures, literature, art, customs, folklore, and religions.

The study of ancient agriculture and installations for processing agricultural products is based on four main sources: archaeology, texts, art, and pre-industrial evidence. The latter is of particular importance. In archaeological remains, usually only the stone elements survive, whereas pre-industrial apparatuses are not only complete, but their operations can be recorded. Even after new techniques are introduced, older methods usually continued to be practiced, and nearly all the ancient methods are noted even in recent times. Such pre-industrial equipment, furthermore, reflects marked regional diversity that often retains characteristics of ancient machines of the same region. Several Roman writers devoted chapters or entire books to agriculture and related subjects. These include Cato the Elder, Varro, Columella, Pliny the Elder, and Palladius. Commissioned by the Roman Senate, a Latin translation of Mago the Carthaginian's important agricultural manual has not survived, but it was quoted extensively by Varro, Pliny, and Columella. Various aspects of the subject are explored in Greek sources, particularly Theophrastus, whose *Wine and Olive Oil*, however, has been lost (Einarson and Link, Appendix 1). The only Greek agricultural manual to survive, the *Geoponica*, is much later (tenth century CE). An important earlier Greek source for the technical aspects is

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Hero of Alexandria, whose works, however, are extant only in Arabic. Talmudic sources are also of value (Frankel 1999, 186–206).

2. Origin and Domestication of the Vine (*Vitis vinefera L*)

The wild subspecies of the cultivated grape (*Vitis Vinefera* L. subsp. *sylvestris* [CC Gmelin] Berger) is found in the coastal areas of the Mediterranean area—excluding Tunis, Libya, Egypt, and the Levant, but including the Black Sea and the southern coast of the Caspian Sea (Zohary 1996, Map 2.1). Pips and skins of grapes have been found in a Chalcolithic (fourth millennium BCE) context at Tell esh-Shuna in the Jordan Valley and at several Early Bronze Age (third millennium BCE) sites in Israel and Jordan—all in areas where the wild variety was not found, providing clear evidence for domestication. The cultivated vine and wine production probably reached the southern Levant, from the area south of the Caspian and Black Seas, and from there it reached the western Mediterranean. The fact that the names of wine in Semitic and Indo-European languages derive from the same source corroborates that wine production originated in one area. In Biblical Hebrew, wine is *yayin*; in the dialect of northern Israel and in Ugaritic, wine is *yn*. Both are cognate with the Greek *oinos*, Latin *vinum*, and Cypro-Syllabic *wo-i-no*. All of these words almost certainly derive from the Hittite *wiyanas*, corroborating the origin of wine in Anatolia (Brown 1969). The same term has survived in modern languages: wine (English), *vin* (French), *wein* (German), and *vino* (Italian).

3. The Origin of the Olive (*Olea europaea* L.)

Unlike the vine, the olive was indigenous to the southern Levant, and the wild olive (*Olea europaea L subsp. oleaster*) was used by man before domestication, clearly evident in a submerged fifth millennium BCE site near Haifa (Galili and Sharvit –1995). Providing a clue to the date of domestication, wild olive stones are consistently smaller than those of cultivated olives, as examined at Chalcolithic sites (fourth millennium BCE: Liphschitz and Bonani 2000). We see a sharp increase in quantities of olive wood (Liphschitz et al. 1991) and the percentage of olive in the Early Bronze Age pollen count (third millennium BCE: Baruch 1986), suggesting that the olive was first domesticated in the southern Levant at that time. The wild olive is also indigenous to the coastal region of southern Anatolia, southern Greece, southern Italy, southern Spain, western North Africa, and most of the Mediterranean islands. In contrast with the vine, the olive was probably domesticated independently in the Levant, Crete, Spain, and North Africa. This is reflected in the difference in terminology: oil: *šemen* (Hebrew, Ugaritic), *elaion* (Greek), *oleum* (Latin); olive: *zayit* (Hebrew), *zt* (Ugaritic), *ze/irtu* [*se/irdu*] (Akkadian), *elaia* (Greek), *olea* (Latin).

4. Olive and Vine Cultivation

As in the past, olives are usually grafted. Wild saplings are the usual root stock, and scions are taken from particularly fruitful trees. Theophrastus (*CP* 1.6.10) recommends this practice, but Pliny describes it as peculiar to Africa (*NH* 16.129). It is hinted at in the New Testament (Romans 11.179), though there the wild olive is the scion. Quoting

Cato, Pliny recommends 25–30 feet between trees for Italy (*NH* 17.93); for Africa, quoting Mago, 75 feet; and for hard soil, 45 feet. Columella recommends that the vines be planted at intervals of five to eight feet, in rows at a maximum ten feet apart (4.3–4). Columella suggests that the planting hole be filled gradually over a period of three years, a procedure apparently learned from Mago (5.5.4) but already recommended by Theophrastus (*CP* 3.4.2). Columella also describes propagation by layering (4.15) and pruning (4.9–11).

Pliny (*NH* 17.164–166) describes five of the different ways to grow vines: allowing the vine to trail on the ground; as a small bush; tied to vertical posts; on horizontal "yokes" in rows on a fence; and growing overhead. A sixth method allows the vine to climb trees specially planted for this purpose (*arbustum* in Latin). Archaeological evidence also suggests that vines were planted in rock-hewn pits or channels. Stakes on which the vines climbed were often set in small round rock-cut holes around these channels and pits (Israel: Zartal 1995; Getzov 2004; France: Brun 2004a: 203, 204, 214). Regarding harvesting, Varro recommends picking olives by hand, preferably without gloves (*On Agriculture* 1.55.1–3). If the olives are to be picked by beating, Varro recommends reeds, not poles (cf. Theophrastus, *CP* 1.20.3). Greener and more bitter is the oil extracted early in the season (*omphacium* [as in Greek and Hebrew]: Pliny, *NH* 12.130; also called Green, Summer, or White Oil: Theophrastus, *CP* 6.8.4). This early oil was used mainly for cosmetics (Theophrastus, *On Odors* 4.15).

5. Pickled Olives and Raisins

Columella refers to the preparation of pickled olives (12.49–50). Palladius describes nine methods, including pressing, cutting, and the use of steam and boiling (12.22). Regarding raisins, Columella quotes Mago's instructions for making raisin wine (*passum*: 12.39); the grapes are dried on reeds laid on poles fixed to stakes or tied to poles. Special equipment, however, was probably designed for this purpose (see below).

6. The Production of Wine and Oil

Simple Equipment

There were three stages in the production of both olive oil and wine:

Oil	Wine
Crushing the olives to a mash	Treading the grapes to express most of the must
Pressing the mash to extract the expressed liquid	Pressing the grape skins and stalks (the rape) to extract the remaining must
Separating the lighter oil from the watery lees	Fermentation

The main difference is that most of the liquid is extracted in the first stage in the production of wine, but in the second in the production of oil. In the most primitive methods, however, wine and oil were often produced using similar equipment, and more sophisticated methods frequently employed identical presses for the second stage.

In the basalt region of the Golan heights at Chalcolithic sites, olive oil was produced in stone troughs (Epstein 1978, 1993), whereas in limestone areas, "cup marks" or rock-cut mortars were often used (e.g., Van den Brink et al. 2001). However, most common were ubiquitous treading installations, somewhat misleadingly called "wine presses," initially used both for wine and oil (Joel 2.24; Figure 34.1). To distinguish this installation, sometimes called a "winery," from true wine presses (see below), it will here be called a "wine press." The "wine press" consists of a slightly sloping treading floor that leads down to a collecting vat. The simple installations for oil can, however, usually be distinguished from those for wine. Those for wine generally have larger collecting vats and are usually cut into bedrock, in the middle of the vineyards in the countryside, while those for oil have smaller collecting vats and are almost always in the town or village (Frankel 2006).

"Wine Presses"/Treading Equipment

Treading grapes is widespread in artistic depictions, appearing on Egyptian wall paintings, Attic vases, Roman and Byzantine mosaic floors, and elsewhere. Still practiced particularly in the production of port wine in Portugal, the treading of grapes, a time of rejoicing, was and still is often accompanied by music as shown by ancient depictions (Isaiah 16.10; Jeremiah 48.33; Brun 2003, 57.216; Brun 2005, 267). *Geoponica* provides the most detailed description of treading grapes (6.11; White 1970 xv).

In Biblical Hebrew, the terms for a treading equipment/"wine press" are *gat* (also used in later literature), *pūrāh*, and *yeqeb (*also the collecting vat). In the Septuagint, these are usually translated as *lēnos* (see *Geoponica* 6.1.11), but where *yeqeb* means "vat" it is translated as *prolēnion*, "in front of the 'wine press'" or *hypolēnion*, "below the wine press." In the Vulgate, these terms are all translated as *torcular*, a word whose meanings further include a press room with all its equipment and true presses. Palladius calls a "wine press" *cella vinaria* and the treading floor *calcatorium* (1.18).

There are considerable differences between wine production in the southern Mediterranean and the Levant, where it almost never rains during the vintage season, and other parts of the Mediterranean, where it often does. In the former, the simple open-air "wine press" developed in size and complexity. Elsewhere, although we have some examples of complex "wine presses" within buildings, the grapes were usually trodden in the vineyards; but the must was collected in ceramic vessels rather than in vats, as attested by ancient illustrations and archaeology. Many Egyptian wall paintings show built wine presses with the must flowing into vats, whereas Attic vases show the grapes being trodden on small wooden stools as the must flows into jars (Sparkes 1976). Similarly, the rock-cut Greek presses known as "patitiri" consist of treading floors without collecting vats (Mee and Forbes 1997, 260, figure A16 MS123). The technical tradition of collecting the must in ceramic vessels and not in vats continued also in fixed presses, as shown by later illustrations (Brun 2003, 56, 57, 201, 210) and excavations. In some cases, there was only a ceramic vessel (e.g., Athens, the Acropolis: Dorpfeld 1895, 168–169 figures 5, 6), but the must often flowed into an intermediary vat and then into rows of large jars (*dolia*) where it was fermented (Brun 2005, 14, 15, 22). Palladius (1.18) provides the

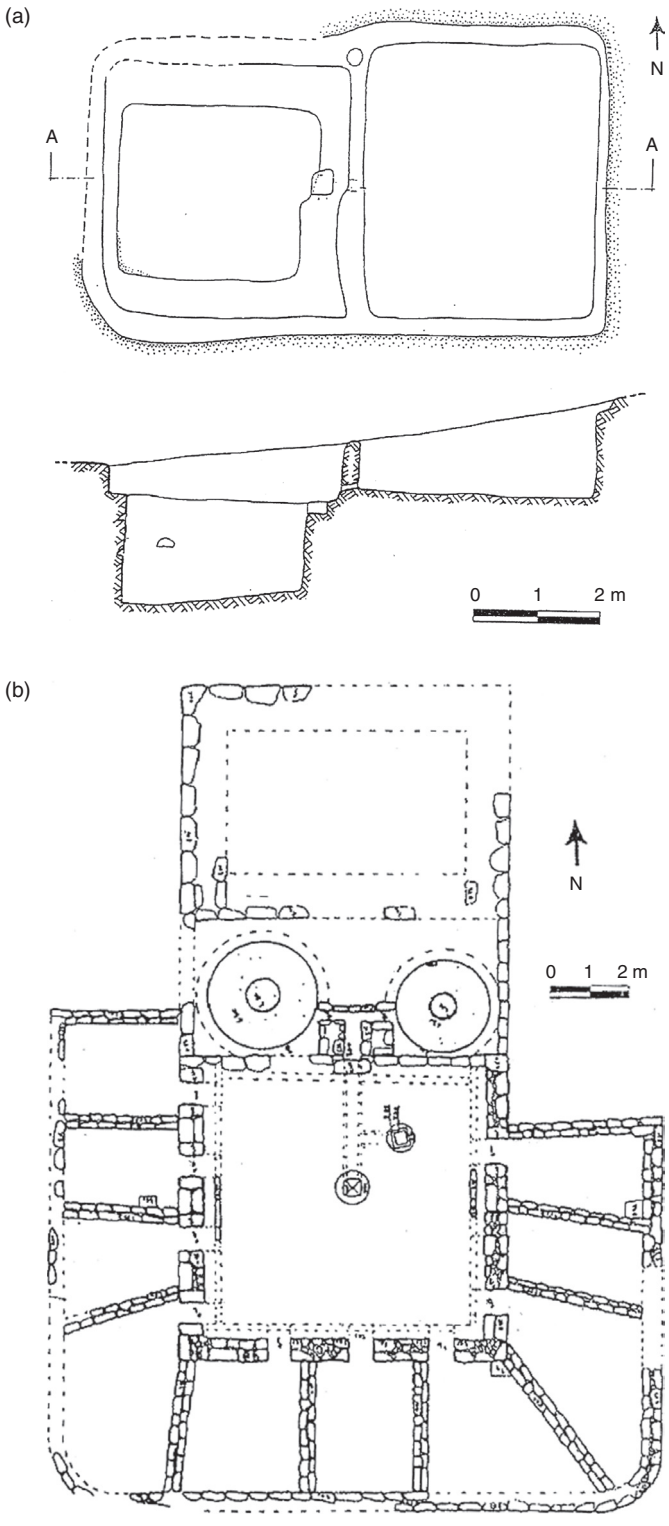


Figure 34.1 Wine presses **(a)** Simple wine press (Ayalon et al. 2009: 22, figure 1.3). **(b)** Complex wine press (Ayalon et al. 2009: 408, figure 70.7).

only detailed description of a "wine press." He describes the must as flowing through intermediary vats to ferment in ceramic vessels. He calls the press as a whole a *cella vinaria* and defines the building itself as a *basilica*, consisting of a treading floor (*calcatorium)* connected to two lower vats (*lacus)* by three or four steps. Channels or pipes led from the vats to the *dolia*, and wooden casks (*cupa*) were placed in between if necessary. Thus Palladius mentions both ceramic vessels and wooden barrels. The former were probably permanent, and the latter were mobile. Wine was generally stored in ceramic vessels, but Pliny mentions the use of wooden barrels in the Alps (*NH* 14.132), which later became a common practice in western Europe (Brun 2003, 104, 109; 2004a, 28; 2004b, 286; 2005, 66–67, 149, 151). As a result, from the Middle Ages onward, grapes were often trodden in barrels in the vineyards.

In the southern Levant, there were almost certainly thousands of rock-cut "wine presses." Similar numbers likely existed in other parts of the Levant, Anatolia, and North Africa. In most cases undatable, they were probably used for long periods. At the same time, they developed in size and complexity, reaching a peak in the southern Levant at the end of the Byzantine period before the Moslem conquest (640 CE). In the Byzantine period, the floors were usually mosaic pavements. In addition to the basic elements of treading floors and collecting vats, there were usually intermediate vats to filter the must or allow remaining particles to settle and true presses of various types (see below). Around the treading floor there were often auxiliary floors and/ or cells serving different purposes. The smaller cells probably held ingredients to add to the must. The larger floors were almost certainly intended to allow the grapes to stand in the sun for some days, as recommended both by Columella (12.27) and Pliny (*NH* 14.77). At the same time, the first must, flowing of its own accord before the grapes were trodden, the *protropum* or *mustum lixivium,* was particularly prized and collected separately. A group of sophisticated "wine presses" with all these elements had an additional collecting vat. This allowed for industrial production with three batches being processed simultaneously. Fermentation occurred in one of the collecting vats; the second batch was trodden on the treading floor, while the must flowed into the other collecting vat and the rape was pressed; and the third batch was spread on the auxiliary floors while the first must was collected separately. The area of the treading floor in some of these presses reached over 30 m^2 (320 ft^2). The volume of the collecting vats extended to over 10 m^3 (350 ft^3: Frankel 1999, 51–60, 146–158: Avshalom-Gorni et al 2008).

Although grapes were almost always trodden, there is also evidence for the use of stone rollers both in Israel (Amit and Baruch 2009) and in Northern Syria (Callot 1984, plates 8, 9, 11).

Some installations consist only of vats without treading floors. These probably served for the production of red wine in which the skins and stalks (the rape) are left in the must during fermentation.

Another unusual type of installation was found at Hippos-Suseita (Segal et al 2005, figures 5, 6, 50) Adjacent to two large "wine presses" were six small mosaic pavements, three on each side of a small corridor. The pavements on one side had small collecting basins; those on the other had small channels clearly leading to removable collecting vessels. Such equipment was almost certainly intended for drying raisins in the sun, and the collecting vessels were meant to collect the first must. To date these machines are unique, probably because raisins could be dried in the same way on the auxiliary floor or even on the treading floor of other "wine presses."

Olive-Crushing Devices

Micha 5.15 refers to treading olives, and there exists a Greek term for shoes worn to tread olives (*kroupexai*: Amouretti 1986, 286 15). Pre-industrial evidence also exists for this practice (Frankel 1999, 46). However, in contrast with grapes (almost always trodden), olives were crushed in other ways: the simplest method, still in use, by mortar and pestle, or by large cylindrical stone rollers (for photographs: Jerusalem: Frankel, Avitsur, and Ayalon 1994, 30; Greece: with metal bar inserted into the roller as handle: Oeconomou 1996, 367, figure 5, both examples operated by women).

The most important development in crushing olives was the introduction of the rotary olive crusher (Figure 34.2). A vertical round crushing stone (or stones—commonly one, but often two and sometimes three) revolves both on its own axis and around the crushing basin. One end of the horizontal shaft passes through a hole in the center of the crushing stone and usually revolves on a pivot in the center of the basin while the other end serves as a handle. The device was usually operated by a horse or donkey harnessed to the handle and walking around the basin. In some cases, the crushing basin is concave with the convex crushing stones. In other cases, the crushing surface is flat with wheel-shaped crushing stones. In still others, there is no central pivot, but the crushing stones are connected to the shaft in such a way that they keep each other in position.

A sixth-century BCE round pit with a round depression in the center from Clazomenae has been suggested as the earliest example of a rotary crusher. How this device functioned is far from certain (Foxhall 2007, 140–143). The earliest clear rotary crusher seems to be from Pindakas, identified as fourth century BCE by Foxhall (2007, 170). The rotary olive crusher almost certainly originated in the eastern Mediterranean, probably in Greece or Anatolia, but in due course it was used throughout the Mediterranean (although less frequently in the west: Brun 1986).

Another olive-crushing device, the horizontal oil mill, is found in the western Mediterranean at Volubilis, Morocco, and in Lower Guadalquivir, Spain. Also rotary, this device was horizontal, similar to the donkey mill used for grinding grain (Moritz 1958, 74–96), from which it probably derived. It consisted of a conical/bell-shaped lower stone on which a ring-shaped upper stone with a bell-shaped aperture rotated. There were spiral striations on the crushing surfaces of both stones (Frankel 1999, 72).

Cato explicates how to make and assemble a crushing device (*trapetum*, a term deriving from the Greek word for treading; *On Agriculture* 29–22). With the late eighteenth-century discovery of the Campanian *Villa Rustica,* destroyed in 79 CE, scholars identified Cato's *trapetum* with olive crushers found at these sites. These were particularly finely made examples of the rotary olive crusher that had concave crushing surfaces operating with two vertical convex crushing stones.

Columella discusses olive-crushing devices in great detail:

> *molae* (mills) are more practical than the *trapetum* which was, in turn, more practical than a *canalis* (channel) and *solea* (sole of shoe). *Molae* are more easily managed since they can be either lowered or raised according to the size of the berries so that the kernel, which spoils the flavor of the oil, is not broken. Moreover the *trapetum* does more work with greater ease than the *solea* and *canalis.* The *tudicula*, resembling an upright threshing sledge, performs its function without much trouble except that it frequently becomes clogged if you put too many berries into it. (12.52.7–8)

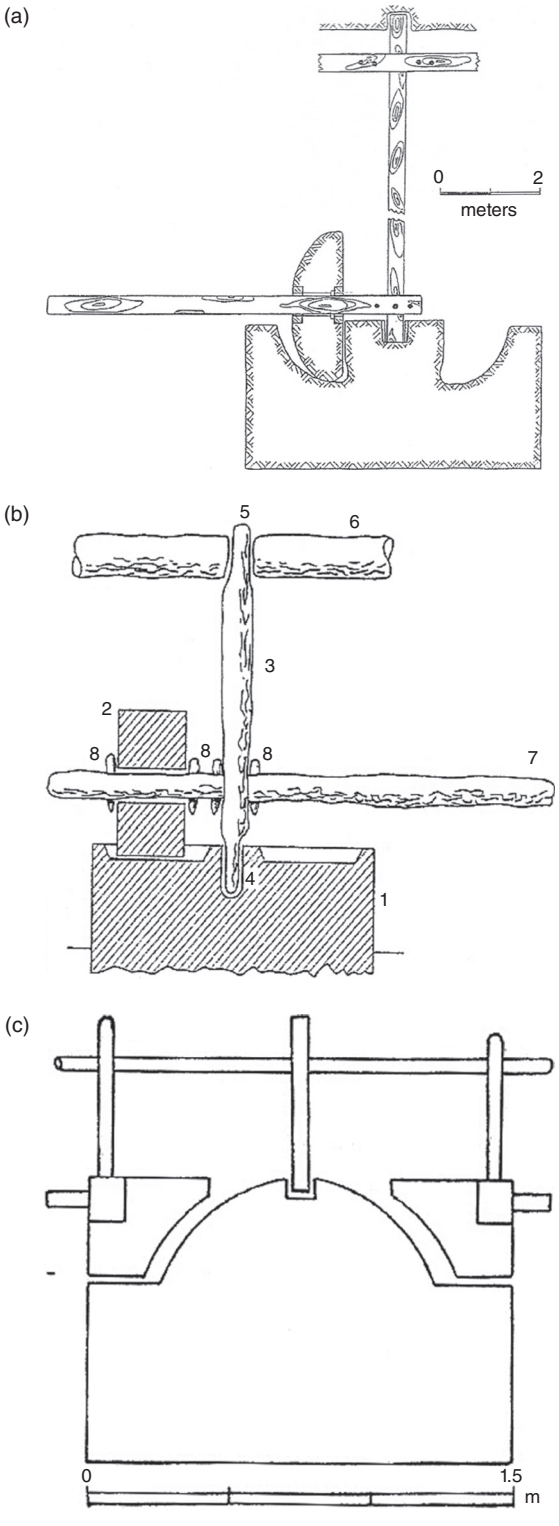


Figure 34.2 Olive crushing installations **(a)** Rotary olive crusher with concave crushing surface (Frankel et al. 1994: 33, figure 24b). **(b)** Rotary olive crusher with flat crushing surface (Frankel et al. 1994: 31, figure 21). **(c)** Horizontal oil mill (Frankel 1999: 72, figure 4).

The *tudicula* is a bronze rectangular object, elliptical in section, with rows of knobs on both sides (Brun 2003, 149). The *canalis* and *solea* may have been a reciprocal crusher in which a vertical stone wheel was rolled back and forth in a trough, though more probably it referred to treading olives in a trough. It has been suggested that while the *trapetum* was the vertical rotary crusher with a concave crushing surface, the *mola olearia* was one with a flat crushing surface: the argument is that the archaeological evidence suggests that the crusher with a flat crushing surface is later, and the written evidence suggests that the *mola* is later. It is, however, more probable that the *mola olearia* is the horizontal oil mill. The upper stone of the horizontal oil mill is easy to raise and lower, while the vertical crushing stone of the rotary olive crusher cannot be raised or lowered at all. The name, *mola olearia*, also hints at its similarity to the donkey mill for grain (Columella came from Spain where the horizontal mill was used: Frankel 1993, 1999, 68–75).

7. Oil Presses and True Wine Presses

The second stage in both processes, pressing, was less important in the production of wine, where it was sometimes omitted.

The simplest method was to place a weight, usually stone, on a board on top of the material to be pressed, usually in a sack. This method leaves no archaeological trace, but pre-industrial examples have been recorded.

Lever Presses

The introduction of the lever press was the first important turning point in the history of the press. The lever press differs from a simple lever. In a simple lever (e.g., a see-saw), the point of the applied force stands at one end of the lever, the load point at the other, and the fulcrum somewhere between them. In the lever press, the point of the applied force/free end of the beam is similarly at one end of the lever, but the fulcrum/anchoring point is at the other end, and the load point/pressing point stands between them. The character of these three points varies from press to press, determining their typology. The lever press is a "machine" in that it exploits the mechanical advantage of the lever. If the pressing point is below the middle of the beam, the effective force achieved is double the applied force, and the nearer the pressing point is to the anchoring point the greater the effective force (Motion and Energy).

The primary typology of lever presses is determined by the manner in which the force is applied, the three main types being: lever and weights presses; lever and drum presses; and lever and screw presses (sometimes with weights, sometimes without). Lever and weights presses already appear in Syria and Cyprus in the Late Bronze Age (circa 1400 BCE), and pre-industrial examples of all three types were functioning until recently.

Lever and Weights Press: Figure 34.3

A depiction of a lever and weights press on an Attic scyphos (sixth century BCE: Brun 2003, 199) suggests that sometimes the weights were sacks of stone, which would not have left any archaeological evidence. Simple weights with one perforation, however, have been recorded in Israel (Frankel 1999, 99–100), Cyprus (Hadjisavvas 1992, 71, 72 figures 140, 141), and Greece (Foxhall 2007, 158, figure 6.17). More sophisticated

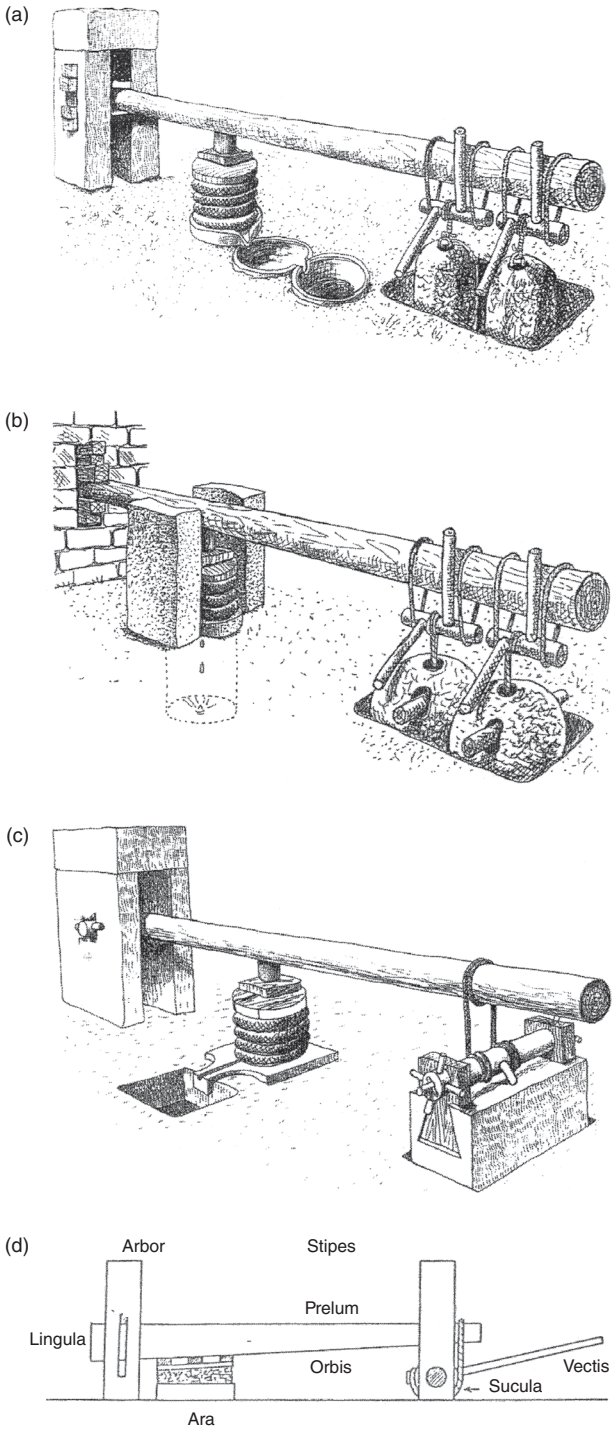


Figure 34.3 Lever and weights and lever and drum presses **(a)** Phoenician Zabadi press. Note the slotted piers, lateral oil collection, and weights with metal hooks (Frankel et al. 1994: 44, figure 38). **(b)** Judean Maresha press. Note the niche in the wall and central oil collection weights with reversed T bores (Frankel et al. 1994: 41, figure 35). **(c)** North African press. Note the perforated piers and Semana weight (Frankel et al. 1994: 47 figure 42). **(d)** Cato's lever and drum press (Frankel 1999: 86, figure 8).

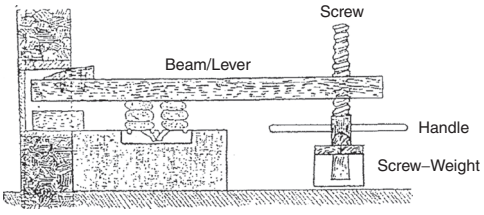
weights can be divided into two main groups. In the Levant, the drum (winch/capstan) that raised them was attached to the beam; in the western Mediterranean, it was attached to the weight. In the Levant, the main weight had a bore in the shape of a reversed T. The bottom end of the rope was tied to a horizontal rod in the arms of the T, and the top end was attached to the drum on the beam. In Galilee, some of the weights had metal hooks, but these almost certainly functioned in a similar manner. In the west, primarily in France and North Africa, the main weight was the Semana weight, rectangular in shape with dovetail mortises on the short sides connected by a groove on the upper surface. In Greece, the weights had two vertical rectangular bores, some of the weights simply being rectangular in shape and section (Foxhall 2007, 190, figure 6.29b), whereas others were T-shaped in section so that the bores were in the arms of the T (Foxhall 2007, 191, figure 6.32). The Semana weight and both Greek types almost certainly functioned in the same manner, the drum being attached to the weight. The Semana weight probably developed from the Greek weights. Significantly, in Cyprus there are both weights with T-shaped bores and Semana weights.

The most common way to anchor the beam is in a niche either in a monolith or in the wall. These are simple in Cyprus (monolith: Hadjisavvas 1992, 112–114, figures 311–313) and Judea (niche in the wall: Ayalon, Frankel, and Kloner 2009, 376–377, figures 65.2, 65.3) but complex in North Syria (niche in the wall and monolith: Callot 1984, plates 69–83). In Phoenicia, the beam is usually anchored between two slotted stone piers, and in eastern North Africa between two perforated piers. In the southern Levant, perforated piers appear only in lever and screw presses (Figure 34.4). In western North Africa, there are pier bases with four mortises while in Southern France and parts of Italy, the Tivoli pier base has two mortises. Both types probably supported similar wooden piers. In the Campanian *Villa Rustica*, the beams were anchored unusually using two shafts connected at the bottom. Presumably one served to fix a wooden anchoring post, and the other served as a manhole to enable installation and servicing.

The pressing point usually consisted of a round press bed connected to one or two lateral collecting vats. In western North Africa, the press bed was usually square, and in Greece it was usually pear shaped with a protruding spout. In Judea from the Iron Age until modern times, the oil collection was central, not lateral. Instead of press beds and collecting vats, there were central vats above which was placed the material to be pressed.

Lever and Drum Press

Lever and weights presses were found in most of the Mediterranean basin, but in Italy the typical lever press was the lever and drum press, in which there was no weight. Instead, the press worked by turning a drum attached to the ground beneath the free end of the beam—the drum lowered the beam to exert pressure. The olive grew wild only in the southern regions of Italy, and the cultivation of olives probably developed later there than in other areas. In lever and weights presses, turning the drum first lowered the beam. Only after the beam could descend no further, turning the drum raises the weight into the air. In presses with Semana or Greek weights, before the weight is raised into the air, the press effectually serves as a lever and drum press. There is, therefore, little doubt that the lever and drum press developed from earlier Greek models (Halies: Foxhall 2007, 144, figure 6.9). Lever and drum presses, also the dominant type in Dalmatia, are likewise found in France and Cyprus. Two unusual examples of lever and drum



Lever and screw press (Frankel 2010: 96, figure 2)

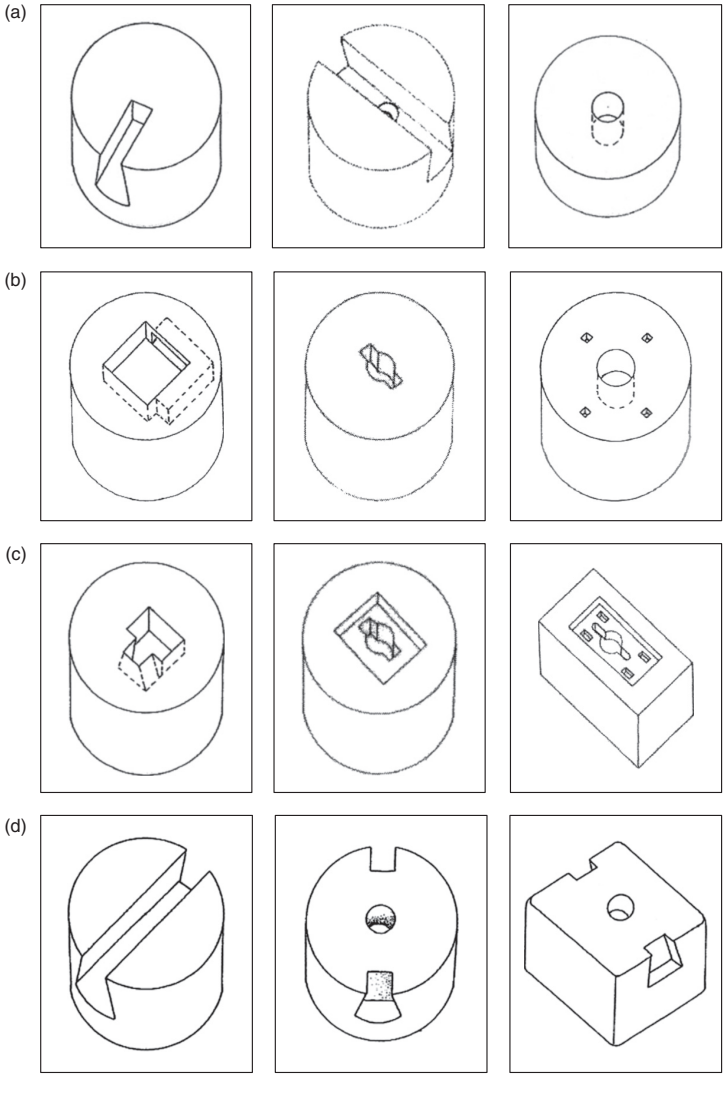


Figure 34.4 Screw weights (Frankel 1999, CD).
First column: WEIGHTS WITHOUT SOCKETS **(a)** Mi'ilya weight **(b)** Luvim weight **(c)** Bet-Ha-'Emeq weight **(d)** Midrasa weight.
Second Column: WEIGHTS WITH SOCKETS FOUND IN THE LEVANT **(a)** Din'ila weight **(b)** Kasfa weight **(c)** Sarepta weight **(d)** Samaria weight.
Third Column: OTHER WEIGHTS **(a)** Perforated screw weight **(b)** With socket and four holes **(c)** Rectangular internal dovetail mortises depression and four holes **(d)** Arginunta weight

presses were recovered in Israel (interesting examples of "conceptual transfer"—the idea arrived from Europe without details, and so a new type was invented: see Frankel 2012; 'Ad and Frankel 2012). Pre-industrial examples were found in France ("casse cou" or "casse coué": Humbel 1976, plates XIII–IV; Frankel 1999, 172, map 45).

Lever and Screw Press

The second turning point in the history of the press was the introduction of screw presses (last centuries of the first millennium BCE). The first of these was almost certainly the lever and screw press, in which the screw replaced the rope of the other lever presses. The top of the screw was usually twisted into a nut attached to the free end of the beam. Many types of pre-industrial lever and screw presses have survived. In some, the bottom of the screw is attached to the frame of the press; in others, it is attached to the ground; and in yet others, it raises a box of stones or stones placed on a board (Frankel 1999, 108–111). None of these, however, would leave clear archaeological evidence. Nonetheless, the most common lever and screw press, in which the screw raises a screw weight, did leave archaeological records. A great variety of screw weights have been recorded, divisible into three groups. The first had both a socket in the upper surface, in which the screw rotated, and mortises that held a frame attaching the weight to the screw. The most common subtype, the Samaria weight, found throughout the Mediterranean, had external dovetail mortises. In Spain, Italy, and the Levant, the screw weights are cylindrical, whereas in France, Greece, and Anatolia, where the rectangular Semana weight is attested, the screw weight is rectangular (the Arginunta weight). The second main group also had a socket in the upper surface but, instead of mortises, in some the socket penetrated through the weight, in others small holes bored the upper surface. In the third group, found only in the southern Levant, instead of a socket in the upper surface there is a mortise. Clearly the screw was fixed to the weight and did not rotate. Therefore, it is clear that the nut was turned, not the screw.

In Italy, the great variety of extant Samaria weights suggests that this type developed there (Liverani 1987). The southern Levant shows a remarkable degree of local regional diversity. In Samaria (between Galilee in the north and Judea in the south), nearly all the weights are Samaria weights that probably derived from Italy. In Phoenicia, however, the weights seemed to have developed locally. Two weights of the third group, without sockets (Mi'ilya and Bet Ha-'Emeq weights), developed there in that order; and later the Din'ila and Kasfa weights, both of the first group, with sockets developed from them. It is unlikely that the screw press was invented in Phoenicia; the concept of a lever and screw press was apparently imported (another example of "conceptual transfer:" Frankel 1999, 107–121; 2012). There is a similar variety of types in Anatolia (e.g., Frankel 1999, figure 23: seven types all from the Pontus region, all with sockets) and probably also in other regions, but their detailed geographical distribution has as yet not been investigated.

Single Fixed Screw Wine Press

In the Levant, considerable evidence attests the use of lever and weights presses in "wine presses." With the introduction of the screw, a specific screw wine press appeared. In the center of the treading floor of the more sophisticated "wine presses," there are mortises

of two types, closed dovetail and square, the same types used in the Phoenician screw weights. The mortises served to secure the screw of the single fixed screw wine press. The skins and stalks of the grapes remaining after treading were piled up around the screw and enclosed within a wound rope or a wooden frame. Then a pressing board with a hole in the center was placed on them with the screw protruding through the hole. The material was pressed by turning a nut that was twisted on the screw above the board. This press seems to have been in use only in the southern Levant, where it is depicted on several mosaic floors. The Talmud also hints at this type of press (Frankel 1999, 140–146, 192–193).

Direct Pressure Screw Presses

Pre-industrial evidence affirms many types of direct pressure screw presses (Figure 34.5): with one screw or two; with revolving screw(s) or fixed screw(s); and with screw handles at the bottom or at the top. However, in most regions, sparse archaeological evidence suggests that the presses were usually made completely of wood. At Herculaneum, a complete single screw press was found (Brun 2003, 62). At Pompeii, there survives a painting of a double screw press (Brun 2003, 218). Both examples are of fuller's presses. The few other examples are usually screw press bases: stone slabs with a press bed in the center with mortises on either side that could have held any one of the types mentioned above or even wedge presses. In the southern Levant, evidence for direct pressure screw presses is found mainly in regions where screw weights are not found. In Lower Galilee and the Golan between Phoenicia to the North and Samaria to the South, there survive many typical screw press bases. In Judea south of Samaria, there are two other types: grooved pier presses ("Judaean Piers"), consisting of two piers with mortises and grooves to secure the screw mechanism; and cross presses cut into vertical stone surfaces usually in caves. Both these types held single revolving screw presses (Frankel 1999, 122–136). Thus, direct pressure screw presses were found in the areas that were Jewish in the Roman period, in Galilee and the Golan Heights in the North, and in Judaea and Transjordan (Peraea) in the South. This, however, is a case of passive ethnicity. These types of presses were not used exclusively by Jews, nor were they particularly identified as Jewish, as shown by the fact that the press described in the *Mishna* was of the Phoenician type (Frankel 1999, 190).

8. Written Sources

Cato details two similar lever and drum presses: one for oil, another for wine (*On Agriculture* 18–19). The beam (*prelum*) was anchored between two slotted piers (*arbores*, the slots *foraminae*) similar to the Phoenician slotted piers but of wood, and the drum (*sucula*) was secured between two perforated piers (*stipites*).

The most important source, however, is Pliny the Elder, who summarizes the history of the press while discussing wine production (*NH* 18.317; both Cato and Pliny use the term *torcularium*). Earlier scholars have thought that Pliny described four types. However, he almost certainly described only three (Jüngst and Theilscher 1957, 108–109). The first, used by "our forefathers," was a lever and drum press; the second, introduced "within

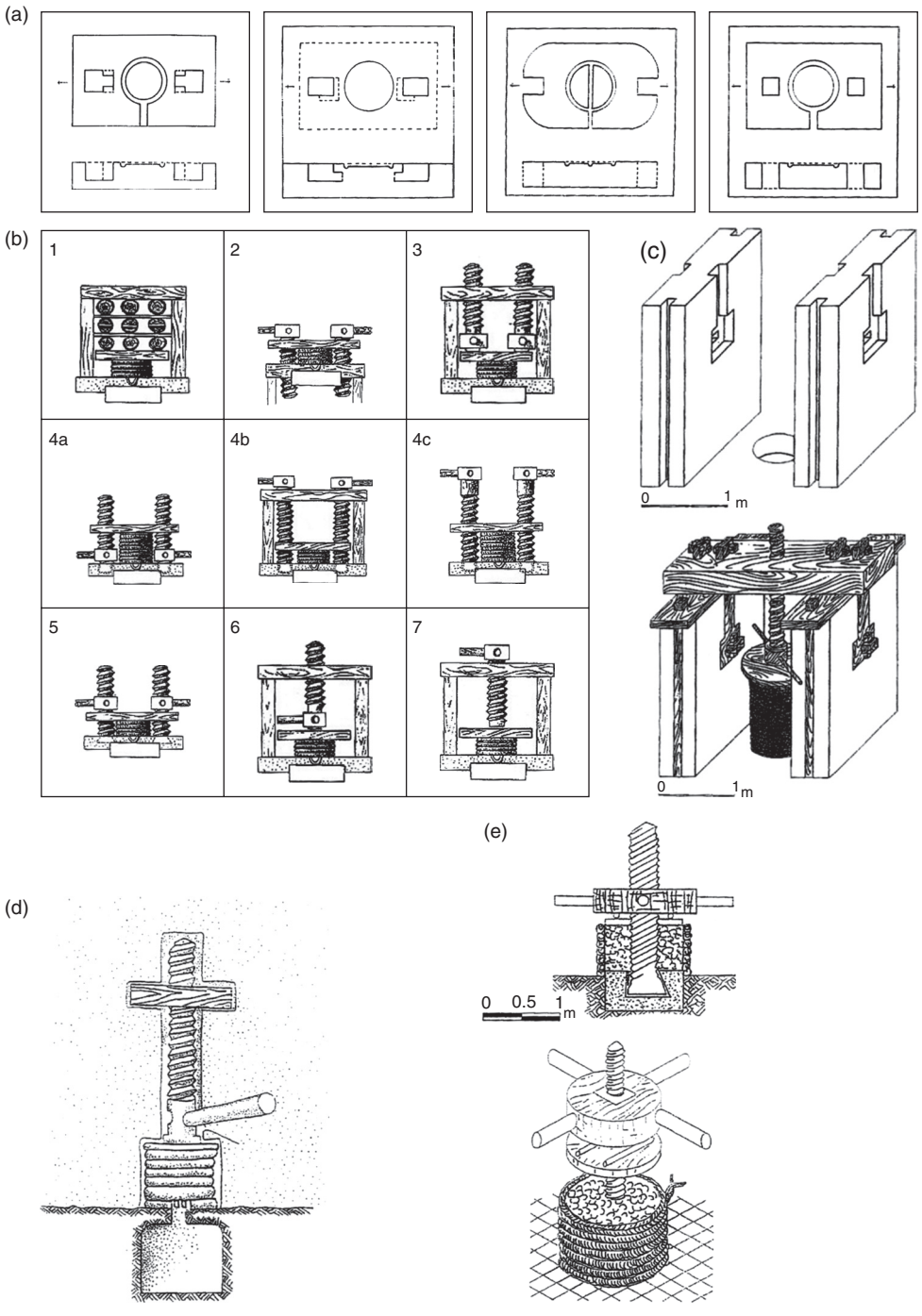


Figure 34.5 Direct pressure screw presses **(a)** Screw press bases (Frankel 1999; CD). **(b)** Possible reconstructions of screw press bases including wedge press (Frankel et al. 1994: 64, figure 63). **(c)** Grooved pier presses ("Judaean Piers") piers above; reconstruction below (Ayalon et al. 2009: 384, figures 66.1–2). **(d)** Cross press (Ayalon et al. 2009: 18, figure 4). **(e)** Single fixed screw wine press (Ayalon et al. 2009: 18, figure 5).

the last hundred years" and "invented in Greece," was a lever and screw press that raised a box of stones; the third, invented "within the last 22 years," was a direct pressure single screw press.

Hero of Alexandria, "the mechanic," a contemporary of Pliny (Neugebauer 1938), described four presses that were seemingly improved versions of those already in use. Hero states that they are used both for oil and wine, but his description refers only to grapes. Hero's first press is a lever drum and weights press, where the drum is attached to the ground. Instead of pulling the beam end down directly (as in the presses of Cato and Pliny) it pulls the beam end down by raising a weight hanging on a rope going through a pulley attached to the free end of the beam. Here we have a combination of the Roman lever and drum press with the Levantine lever and weights press. Hero's second press is a lever and screw press that raises a screw weight, with a socket (apparently a Din'ila weight, mentioned above). This press, however, functions in an unusual manner: the screw, hinged to the free end of the beam, is wound into a nut of the same length as the screw; the nut is attached to the screw weight in such a way that it can revolve in the socket in a manner similar to that in which the bottom of the screw is usually attached to the screw weight in other lever and screw presses. When the nut is turned, it swallows the screw, lowers the beam, and finally raises the weight into the air. Hero's third press is a double screw direct pressure press, in which the screws are attached to the screw base in a way that allowed them to rotate. The fourth press is a single rotating screw press. In another context, Hero hints at a wedge press, stating that it was used for perfumes (for Hero's presses, see Drachman 1932, 63–85; 1963, 110–122). Vitruvius mentions both a lever press and a direct pressure screw press (6.6.3), anticipating Pliny's dating of the direct pressure screw press by about fifty years.

Referring to an oil press, Justinian's *Digest* (19.2.19) mentions *praelum* (both the beam and the press as a whole), *trapetum*, *fiscus* (frail), *regula* (wooden frame used instead of a frail), *suculum* (drum), *tympanum* (pressing board), and *cocleas quibis relevatur praelum* ("the screws that raise the beam"). Interestingly, in the Greek translation of the *Digest, praelum* is translated as baddēn, clearly the Hebrew/Aramaic *bad* (plural: *baddim* [Hebrew], *baddin* [Aramaic]). The citation of both drum and screws has led Rossiter and Haldenby (1989) to reconstruct a lever drum and screw press, but the reference was probably to components of different types of press.

Many ancient sources refer to the three qualities of oil (e.g., Pliny, *NH* 15.18), and in Diocletian's list of official prices they are called *olei floris, olei sequenties*, and *olei cibari* (Lauffer 1971, 102–103. *Olei floris* is translated as Greek *omphakinon*: see above). A discussion of the subject in the Babylonian Talmud includes what is apparently the most detailed description of olive oil production in ancient literature:

> They bring [the olives] to the oil press, crush them in an [olive] mill and put them in frails. The oil that comes out is the first, they put them under the beam. The oil that comes out is the second. Then they [the beam the frails and the olive mash] are dismantled, crushed again, and put under the beam again. That is the third. (Menahot 86a)

The first oil is therefore that which seeps out after crushing but before pressing. Several ancient oil presses in Israel have additional collecting vats not connected to the actual press that clearly served to produce first oil.

9. Oil Separation

The third stage in oil production is separating the oil from the watery lees (*amurca*). All procedures are based on the fact that the lighter oil rises to float above the heavier lees, and the simplest method was to skim off the floating oil. Cato refers to a *capulator* ladler who works with a shell (*conca*: *On Agriculture* 66), while Columella (12.52.11–12) recommends standing rows of pans (three rows, one for each of the qualities of oil) and pouring the expressed fluid from one to the other, each time skimming off the oil. Archaeological evidence, however, attests other methods: primarily overflow and underflow decantation. In overflow decantation, there was an outlet at the top of the collecting vat or vessel and the floating oil was poured or allowed to flow to another vat or vessel. In underflow decantation, the outlet was at the bottom, and the lees were allowed to flow out first and then the oil. From the earliest times, overflow decantation was used in the Levant, whereas underflow decantation was used in the Aegean. In the western Mediterranean, there is both archaeological and preindustrial evidence for a sophisticated device that allows both oil and lees to flow to separate vessels after the oil has risen above the lees. Columella refers disapprovingly to a *structile gemallar* (double structure?: 12.52.10), presumably a separating device with two compartments, but we cannot know according to what principle it operated (Frankel 1999, 174–176). Primary sources enumerate the many uses of *amurca* (Cato, *On Agriculture* 91–101, 103).

10. Conclusion

The way wine and oil were produced in antiquity and the technological developments are clear, but many questions will only be answered by additional detailed archeological surveys and excavations.

The most significant aspect of oil and wine production is regional diversity and resultant local technical cultures, the existence and development of which can be traced over long periods.

The first stages of production, the treading of grapes, has not changed. In the southern and eastern Mediterranean, the must was collected in large collection vats, whereas in the north ceramic vessels were used. For olives, a rotary crushing basin with vertical wheel-shaped crushing stones, the *trapetum*, was invented in the east (probably Anatolia); and an olive mill with a horizontal crushing stone, the *mola olearia*, was developed in the west.

The first seminal advance in pressing was the introduction of the lever and weights press in Syria and Cyprus circa 1400 BCE. The main regional differences were in the type of weights—a drum was attached to the weight in the North and Western Mediterranean, whereas it was attached to the beam in the east. In Italy and surrounding areas, there was no weight; instead, the lever and drum press was employed. The main variants of the anchoring points are the twin slotted piers in Phoenicia (also in Cato's press), the twin perforated piers of Northern Africa (used in the southern Levant only in lever and screw presses), the complex niches of Northern Syria, the single slotted pier in Cyprus, and the subterranean shafts in central Italy. Regarding the pressing point, an unusual method is the central collection of the southern Levant that continued there from circa 800 BCE until the twentieth century CE.

The second advance was the introduction of the screw. According to Pappus of Alexandria, the screw was invented by Apollonius of Perga (*fl.* 220–170 BCE; Drachman 1963, 204–205; MOTION AND ENERGY).

According to Pliny the Elder, the screw press was introduced from Greece. Both Pliny and Hero describe the lever and screw press and the direct pressure screw press. Pliny states that the former was introduced in the first century BCE AND the latter in the first century CE, but Vitruvius already knew of the latter. Pliny's lever and screw press lacked the usual screw weight; instead, the screw was attached to a box of stones. This is possibly connected to the fact that in Italy the lever press was a lever and drum press without weights. Hero's lever and screw press had a screw weight that was almost certainly the Phoenician Din'ila weight. If so and if the Din'ila weight developed in Phoenicia from the weights without sockets, it is probable that the concept of the lever and screw press reached Phoenicia considerably earlier. Currently, the only hint of the idea's origin is Pliny's assertion that it reached Rome from Greece. However there is as of yet no hint of an early screw press in mainland Greece. Furthermore, the great variety of screw weights found in Anatolia suggests that perhaps it originated there. The Samaria weight, found throughout the Mediterranean but in the Levant in a limited area in the south, probably derived from Italy at a later stage.

The single fixed screw wine press is connected to the screw weights without sockets, and both types are found in the same region, the southern Levant. Both use the same types of mortises, and both work on the same principle of a fixed screw.

The Direct Pressure Screw Press is almost certainly found in Jewish areas because the screw press reached these regions later when this type already existed. It was also easy to adapt the Maresha lever and weights press typical of the region to the grooved pier press. There is, however, no hint as to where these devices originated.

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CHAPTER 35

Cooking and Baking Technology

John Paulas

1. Introduction

This chapter reconstructs a history in the ancient Mediterranean of the stage of food processing where heat is applied to food. Modern food science, looking to modern physics, considers cooking and baking in light of three processes: conduction, convection, and radiation (McGee 2004). In contrast, ancient Greek writers mostly spoke about cooking food using a binary of boiling/baking (*hepsein/optan*), basing their understanding on the perceived media of cooking in their elemental sense: water/liquid or air. Latin writers (such as Cato) were comfortable with using the verb *coquere* (to cook) generically for all cooking processes, whether boiling, frying, or baking. A specific and varied Latin vocabulary with Greek borrowings for cooking processes such as boiling or cooking directly in coals, however, was applied in both everyday and professional language as is evident throughout Apicius' cookbook (for specific vocabulary, see Grocock and Grainger 2006).

A history of cooking and baking requires marshaling several types of evidence: for example, the surviving structures for cooking; ceramic evidence for cooking; various pieces of equipment used at this stage of food preparation; organic residues; preserved remains of seeds, bones, and prepared food; and visual and textual evidence. Comparative evidence from observable or observed modern cultures, when used prudently, can provide important *comparanda* especially when ancient descriptive evidence is lacking. Scientific, gas chromatography–mass spectrometry analysis of organic residues on ancient pottery vessels can provide clues to cooking practices. The difficulties in interpreting this evidence, however, must be kept in mind, such as false data due to contamination by deposition and modern handling, and the fact that the chemical residue detected most often corresponds to a general range of organic materials rather than pinpointing, for example,

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a particular plant (see Beck et al. 2008 for methodology). Finally, experimental archaeological attempts to reproduce ancient cooking and baking technologies and techniques, even though incapable of replicating the exact conditions of ancient cooking, give a clearer sense of why certain technologies appear as they do and what issues are at stake in exploring ancient cooking.

Our evidence allows for different discussions of cooking practices based roughly on periods and places. For example, Neolithic cooking in Northern Greece might lack visual and written sources but might be attested by structural evidence and other archaeologically visible remains, such as faunal remains and organic residues. Various possibilities for the cooking practices deduced from this evidence can thus be laid out, but often we can go no further than eliminating certain possibilities and describing what is left (for using Neolithic and Bronze Age evidence, see Isaakidou 2007, 11–19). Roman baking, in contrast, is well attested in written and visual sources, in the well-preserved remains of ovens, and even in the remains of whole carbonized bread loaves. This plethora of evidence permits scholars to discuss Roman baking in much greater detail and with greater certainty. Nevertheless, many details of Roman baking are still mysteries that only allow for the same reasoning to be applied as when evidence is lacking for Neolithic cooking in Greece.

2. Paleolithic

The Upper Paleolithic (circa 34,000–23,000 before the present) in southern Greece provides evidence for the oldest extant clay hearths, and archaeologists suggest they were used for cooking (Karkanas et al. 2004). At Klisoura, in the Peloponnese, the "structured" clay hearths, formed in situ, most likely were used as satellite hearths where embers were imported from "unstructured" hearth fires (Karkanas et al. 2004, 522–523). One clay hearth was found to contain mineral traces interpreted as possible evidence for "roasting grains of wild grasses" (Karkanas et al. 2004, 522). It is unclear whether grains of seed grasses were roasted to be eaten directly or in preparation for other cooking processes. Moreover, fragments of deer, hare, bustard, and partridge bones found in the area of the hearths are taken as further evidence of cooking (Karkanas et al. 2004, 522).

3. Neolithic

Scholarly work on Northern Greece offers the clearest glimpses into what we consider the earliest examples of Neolithic cultures in Europe. The extensive and well-defined site of Makriyalos in Pieria is of particular interest for summarizing Neolithic cooking techniques (see also Gimbutas, Winn, and Shimabaku 1989 on Achilleion in Thessaly). Neolithic pottery from Makriyalos elucidates the most common cooking techniques from the Neolithic to the end of antiquity. The main finds include rounded vessels used for cooking in water/boiling and shallow, flat vessels consistent with dry cooking over/on a heat source (Urem-Kotsou and Kotsakis 2007, 237). On the basis of this evidence, the preparation of meat in liquid seems to have been the most common archaeologically attested activity at the site in the late Neolithic (Urem-Kotsou and Kotsakis 2007, 237). The "moderate" size of these vessels for cooking meat in liquid suggests that cooking was done on a smaller scale for the household (Urem-Kotsou and Kotsakis 2007, 239).

Ceramic pots of closed, rounded shape, suitable for preparing foods in liquid, contained residues consistent with ruminant and non-ruminant fat (Urem-Kotsou and Kotsakis 2007, 237). Fuller gas chromatography–mass spectrometry studies have yielded data that point to the possible presence of animal lipids, alkane residues consistent with waxy plant leaves, and the residues of pine burned to heat the cooking pots (Urem-Kotsou et al. 2008). Such studies highlight the utility but also the significant limitations of organic-residue analysis in determining what cooking pots contained. For example: "Alkanes with 12–18 carbons … are not particularly diagnostic, with multiple botanical sources … as well as possible modern sources (petroleum products)" (Beeston, Palatinus, and Beck 2008, 76).

The excellent evidence from Çatalhöyük in south-central Turkey allows us to see a possible shift in Neolithic cooking technology to ceramic cooking pots. Early on, ubiquitous enclosed clay structures, identified as "ovens," found both in interior domestic spaces and on rooftops, were used to cook meat and plants (Atalay and Hastorf 2006). Post-cooking cut marks, especially on sheep and cattle ribs, are typical of consumption and suggest that ribs, in particular, were baked in ovens (Russell and Martin 2012, 90). The absence of evidence of the pre-cooking butchering of bones suggests that meat still attached to the bone was often cooked in liquid. Clay balls are found with mineral inclusions, presumably to retain heat and prevent breakage (Atalay and Hastorf 2006, 309). Scholars hypothesize that the clay balls were heated on hearths or in ovens and, most commonly, were placed in skins or woven baskets filled with liquid to induce boiling (Atalay and Hastorf 2006, 306–309). These clay balls decrease in number when tempered ceramic vessels appear, suggesting that this method of boiling food in liquids was replaced by boiling in pots placed directly in/on a heat source (Atalay and Hastorf 2006, 309).

Robb (2007) has argued for the existence of an unusual "earth oven" or pit-cooking technique in the Neolithic Mediterranean. The basics of this technique may have involved heating a pit, then placing food in it, and covering the food with organic materials to steam the food. In Salento, Abruzzo, Tuscany, on the island of Lipari, and elsewhere, archaeologists have found, at a large distance from inhabited spaces, so-called "strutture di combustion." These pits are as long as several meters and up to 30 cm (11.8″) deep with fired rocks, burnt branches, and wood coals (Robb 2007, 149). Archaeologists tentatively related the structures to ceramic production for lack of traces of animal bones, but Robb (2007, 150–152), basing his argument on North American and Polynesian *comparanda*, has convincingly argued that these pits were used for roasting large animals. Whole animals covered by organic materials and slow cooked in the heated pits for hours, as in Polynesia, are easily removed and not likely to leave easily identifiable traces (Robb 2007, 151).

4. Bronze Age (circa 3000–1100 BCE)

From the earliest periods in the Bronze Age on Crete, in the Aegean, and in southern and mainland Greece, cooking vessels include one-piece ceramic cooking pots with deep bowls and three legs (tripod cooking pots; Figure 35.1), trays with legs, and flat dishes (Betancourt 1980). A small number of lids with fire marks have been found for some of the baking vessels (Betancourt 1980). The tripod cooking pot and



Figure 35.1 Tzedakis and Martlew 1999, 108, figure 77. Chania Museum 6975. A reconstructed Late Minoan tripod cooking pot (circa 1480–1425 BCE). The fragments of the original pot comprising the right-hand side of the body and rim were found to contain various organic residues. (*Source:* Instap Study Center of East Crete.)

legged tray vessels presumably raise the cooking surface above the heat source. Flat baking dishes seem to be placed directly on/in the heat source. The deep bowls of the tripod-type cooking pots likely mark them out as pots for boiling food in liquid. Globular-conical ceramic cooking pots and jugs for cooking in liquids have also been found on Crete, in Thebes, and elsewhere in the Bronze Age Mediterranean. These pots could fit into a cylindrical, open-front cooking stand that surrounded a heat source (Tzedakis and Martlew 1999, 102, figure 72-3; see below for cooking stand shapes from Bronze Age Italy).

Some have used gas chromatography–mass spectrometry analysis to claim the possible presence of animal products, grain, pulses, legumes, plants, olive oil, grapes, pine resin, oak-barreled wine, and even snails or crustaceans in various tripod cooking pots and cooking jugs of the Bronze Age (Tzedakis and Martlew 1999; Tzedakis, Martlew, and Jones 2008). But many of these results are to be taken "not only with a grain, but with a veritable stalactite of salt" (Beck and Stout 2008, 11). One example of a near certain find in a tripod cooking pot is evidence of the herb rue (genus: *Ruta*) in a pot from Mycenae (Beck and Stout 2008, 10). Although uncommon in cooking in the modern world, this herb is used frequently in ancient recipes, such as Cato's olive dip (*On Agriculture* 119). Pictorial depictions of tripod cooking pots in large-scale hunting scenes in Pylos perhaps indicate the use of tripod cooking pots to boil meat for large-scale meals (Sherratt 2004, 194; Hamilakis and Sherratt 2012, 190).

Thera, the volcanic island famous for its catastrophic destruction in the Bronze Age, offers unique evidence for cooking in the Aegean. On the site of Akrotiri, excavated shafts reveal what appear to be kitchen assemblages (Birtacha et al. 2004). In one of the shafts (65N), two fixed hearths have been identified along with ceramics and tools related to grinding, but the presence of only one tripod cooking pot suggests that the space was not used primarily for boiling (Birtacha et al. 2004, 397). From organic remains, it is clear that the hearth/ovens were fired by both olive wood and animal dung (Birtacha et al. 2004, 410–415). The presence of baking trays with burn marks, "horseshoe-shaped" raised sides, and open fronts leads to the conclusion that baked items could have been removed through the open front without removing the tray from the hearth/oven (Birtacha et al. 2004, 396–397). Strikingly, among the sherds of a "horseshoe-shaped" baking tray were found vertebrae of two tuna, perhaps blue-fin, extremely rare evidence of the harvesting and consumption of migratory fish in this period (Birtacha et al. 2004, 409–410). The bones of one fish were blackened as though one of the slices of tuna was burned, perhaps because cooking was suddenly abandoned (Birtacha et al. 2004, 410).

The study of evidence from Bronze Age Italy provides a thorough typology of another cooking technology common in the Mediterranean from that time forward: the cooking stand (Scheffer 1981). Ceramic cooking stands are meant to support a pot or other food-preparation vessel over a fire. They have a variety of cylindrical, semi-cylindrical, and cone-shaped walls and an opening in the bottom ranging from a round hole to an open side (for images, see Scheffer 1981, 30). Archaeologists distinguish cooking stands from braziers in that braziers, even ones with built-in cooking supports for vessels, are intended to hold fire in their own bowl or tray, whereas cooking stands themselves do not hold the fuel (Scheffer 1981, 25–26).

5. Bronze Age Bread Baking

Although several Linear B Greek words for different roles of grain processing appear on tablets (e.g., *a-to-po-qo* = a male baker), evidence for Bronze Age bread baking techniques on Crete and in mainland Greece is scant. Akrotiri once again provides evidence for grain processing, and if Sarpaki's interpretation of certain ceramic finds is correct, portable, legged, flattop "ovens" for making flatbread may have existed (2001). Other techniques, such as cooking dough directly on coals, cannot be ruled out, but such methods are archaeologically invisible. A Cypriot red polished ware vessel from the twentieth century BCE on display in the Getty Villa (2001.78) is decorated with multiple three-dimensional figures involved in what appear to be stages of bread baking, such as grinding grain on a quern and forming loaves. One figure stands in front of the opening of square chamber raised above the ground. If this is an oven, it is remarkably similar in appearance to ovens seen a millennium and a half later in Archaic and Classical Boeotian figurines (see below).

Meanwhile, in Egypt, evidence abounds in this period for both simple and complex bread-baking techniques. Well-preserved examples of simple, unleavened flatbread 12.7 cm (5″) in diameter have been found in New Kingdom Theban tombs (BM EA 5341). In the Old Kingdom, bread molds are attested, as are large-scale baking complexes (Curtis 2001, 121). Middle Kingdom and New Kingdom images and scale models show

complexes for bread baking and beer brewing, activities connected by the overlap of ingredients (Curtis 2001, 125–128). Archaeologists have discovered 110 baking rooms at Amarna with ovens (Curtis 2001, 129). Estimates of production reach as high as 20,000 loaves per day (Curtis 2001, 130). Experimental archaeology has attempted to reconstruct a New Kingdom technique of baking bread in long, conical bread molds (Samuel 1989, 254). The oven used was a thick-walled, barrel-shaped, mud-plaster oven modeled on one found at Amarna (Samuel 1989, 264).

6. Iron Age (circa 1100–700 BCE)

In the Iron Age Mediterranean, a new cooking technology appears, the iron spit (later Greek *obelos*). In Kommos on Crete, iron spits are found in the context of hearths, and, therefore, are likely to be spits for roasting above a heat source (Hoffman 1997, 143). On Cyprus, Crete, and in the Argolid, "warrior" graves are equipped with both spits and spit-rod supports (for lack of a more descriptive term called "firedogs" and/or "andirons" in the scholarship) to hold them above a heat source (Hoffman 1997, 144).

7. Archaic and Classical Periods (circa 700–323 BCE)

Homeric epic gives us glimpses into cooking practices, but owing to the nature of its composition, it is unclear to what period, if any, we might attribute its heroic cooking. Scholars have located the beginnings of Homeric feasting in the Iron Age because of the frequent mention of roasting spitted meat (Sherratt 2004). Whatever the case may be, we have in the epics an early description of cooking in the Greek world. In Homeric epic, heroes eat roasted meat and bread. The nature of this bread and how it is prepared is unclear, although wives send bread from home with the guests at the cursorily described wedding festivities in Sparta in the *Odyssey* (4.623).

As part of sacrificial ritual in epic, meat is butchered before being roasted on spits over wood fires. The internal organs are roasted separately from the butchered cuts of meat. Ancient scholia (D ad *Iliad* 1.463) explain the mysterious *pempōbola* held by youth attendants (*Iliad* 1.463; *Odyssey* 3.460) as large five-tined forks likened to tridents in general appearance, presumably for spitting meat or innards. These *pempōbola* are otherwise unknown, as the Greeks, the source of our later written evidence belongs, either did not use them or called them by other names. Fifth-century BCE sacrifice scenes show a youth holding over the flames innards, most likely, at the end of a bundle of several *obeloi* (e.g., Paris, Louvre G 402). Perhaps the Homeric epic imagines a use of several bundles in a related manner or vice versa, but the exact nature of the sacrificial utensils called *pempōbola* remains the mystery.

Heroic epic focuses on the ceremonial part of sacrificial feasting, but most of the meat butchered for large-scale sacrificial cooking in the Archaic and all later periods was cooked by boiling, not roasting over coals. There was a practical reason for boiling meat in the context of sacrifice. The ritual barbecuing on an altar could at best only provide part of the meat required for a community feast. An important study based on remains of butchered bone shows that, although cattle, sheep, goats, and pigs were appropriate as victims in the visible part of the ritual, the meat of other animals such as deer, donkeys, and dogs was boiled with cuts from the victims to increase the quantity of meat (Ekroth 2007).

At major Greek festival sanctuaries, such as Olympia, a type of dedication involves using a *lebēs*, a tripod cooking stand with a cauldron, to boil sacrificial meat. These bronze cauldrons are found in Greece from the Geometric period (circa 900–700 BCE), and the Orientalizing period (circa 700–600 BCE) sees innovations from the Near East, including changes in both the tin content of the bronze and the decorative designs, such as griffin-headed protomes (Mattusch 1988, 35). Evidence from the Archaic/Classical period includes iron, tined, claw-like utensils (Gr. *kreagra*) used for grabbing boiling meat from the cooking liquid (Baitinger and Völling 2007, 96–97).

8. The Archaic and Classical "Kitchen"

Since the seminal work of Brian Sparkes on the kitchen in Late Archaic and Classical Greece (1962; 1965), scholars have in general reaffirmed his findings that "mobility is a marked characteristic of Greek cooking equipment" (1962, 127). Stationary kitchen fixtures are extremely rare, and evidence for fixed cooking locations is often difficult to identify. Cooking stands of various shapes, such as the high-walled horseshoe, held pots above coals lit on the ground. As boiling and stewing were still the most common cooking techniques, the ceramic *chytra* (deep pot for boiling) was of prime importance to the Greek kitchen as was the ceramic *lopas* (shallower casserole with distinctive sagging bottom; Sparkes 1962, 130). These vessels had handles on their sides and could be lidded. A ceramic pan (*tēgana*) with a hole allowing a handle to be inserted was used for frying in shallow oil. Sparkes (1962, 129) identifies a common portable brazier—with a pedestal and a shallow, round, or rectangular top for coals—as the ancient Greek *eschara*. Braziers occasionally have lugs on their side, which could have been used to support spits, and could be topped by other cooking equipment, such as a portable oven.

Portable ceramic grill grates with legs, as well as portable "cooking bell" ovens, "barrel cookers," and other easily moved equipment attest to this characteristic mobility and small scale. Images and accounts leave us with the idea that large, relatively permanent versions of typical portable oven shapes existed, but these are clearly modeled on smaller, portable equipment. The Classical Greek finds for such items are ceramic including the grill grates, similar in appearance to modern metal ones. For some cooking vessels, the "paddle-and-anvil" method of shaping the unfired clay provided the thinness necessary to prevent breakage when placed on the fire (Sparkes 1991, 13).

Although mobility in location of cooking was the norm, Olynthus in Macedonia provides unique evidence for fixed cooking spaces in the house (Cahill 2002). A narrow, two-story, vented "flue" shaft for cooking adjoins a large room that occasionally contains a fixed hearth. A bathroom abuts these rooms. The fixed hearth in this large room shows little evidence of cooking, so it was likely primarily a heat source, although a bronze rod (spit?) and possible spit supports have been found in one room containing a hearth (Cahill 2002, 139). Identifying the "flue" with the *ipnos* of Attic comedy (2002, 161), Cahill cites Aristophanes *Wasps* 139–144, where Bdelycleon's father has gotten into an *ipnos* and tries to escape "like smoke" through the opening in the roof of the upper story, which may be closed by a tile. A room with a bath is implied to be nearby. This description fits well with evidence from Olynthus where these "flues" constitute "more than half the rooms" with evidence of cooking (Cahill 2002,162).

Kitchen/bath complexes at Halieis, because they lack the Olynthian "flue" and generally lack fixed hearths, reinforce the traditional view of Classical Greek cooking as a movable activity (Ault 2005, 68). Eretria on Euboea offers evidence of relatively fixed places for hearths in clearly defined kitchen/bath complexes. In contrast to other sites such as Olynthus, these hearths are not found in the middle of rooms but against walls separating kitchen and bath (Reber 1998, 138). If necessary, an assemblage of kitchen equipment could be set up in a particular spot and a large, professionally directed feast could be cooked by a hired *mageiros* (originally butcher/cook, but comically elevated to "chef de cuisine"). Speeches made by such cooks in ancient Greek comedy, preserved by and large in Athenaeus' *Deipnosophists*, describe in detail and with great pride the cooking techniques they use for each fish, meat, or vegetable (boiling, grilling, roasting, frying, etc.; Wilkins 2000, esp. 369–414).

For fuel used in cooking, besides small tinder and twigs of various sorts, our literary evidence shows the supreme importance of charcoal (Greek *anthrax*) produced in wooded areas, such as Acharnia in Attica. Charcoal hawkers feature prominently in the opening picture of Athens under siege, drawn in Aristophanes' *Acharnians*. This charcoal was produced by burning wood for days in a low-oxygen environment: for example, a pit covered with leaves and dirt to avoid complete combustion of the wood (Olson 1991, 413). This process of "carbonization" (English *carbon* derives from the Latin word for charcoal) creates a product that produces significantly higher temperatures than non-carbonized wood and burns more evenly and controllably, making it a useful and reliable fuel source (Olson 1991, 412).

9. Archaic and Classical Baking

The late Archaic/early Classical period in Greece shows evidence for simple but effective baking technologies that appear with variations well into the Middle Ages and even the modern period. The "cooking bell" oven resembles in shape modern ceramic cloches under which bread is baked (Sparkes 1962, 128). Here, textual evidence helps. A passage from Aristophanes (*Clouds* 96) appears to identify this item as the Greek *pnigeus* (Latin *testu* or *testum*). There Strepsiades describes the theories of Socrates' "Think-shop," which picture the sky as a *pnigeus* and humans as charcoal pieces (*anthrakes*) within it. Sparkes reconstructs a method of using the "cooking bell":

> A space on the floor was cleared, and a small heap of lighted coals set down. The baking cover was placed over them or hung above them, and when the inside of the cover was hot enough, it was raised and the coals swept to one side. On to the warm floor was set the dough and the cover fitted over it, with leaves sometimes placed underneath the dough. The coals were then heaped over the sides of the cover … and the bread was then left to bake. (1962, 128)

Another portable oven can be seen in Sparkes' "barrel cooker" (1981, plate 3b = Athens, Agora Museum P 17822), a 37.5 cm (15″) high, open-barrel-shaped ceramic cooking stand. Attic vase painting shows a cooking stand of this type in use as an oven (1981, plate 3a [Paris, Louvre G 476]). A woman leans over a barrel cooker in which flames are seen through the opening in the bottom. In her hands she holds a lump of dough, which she seems about to affix to the upper parts, presumably, of the inside

walls (Sparkes 1981, 175–176). Exact parallels of this kind of baking can be found in terracotta figures from an Athenian colony of the Thracian Chersonese, Cyprus, and Sicily, where four cakes of dough are seen attached to the upper inside walls of the oven (Sparkes 1981, 176). Etruscan variants of a cooking stand of this shape from the seventh to sixth centuries BCE have narrower openings on the top and seem more likely to have been only supports for cooking pots, but the exact advantage and use of this shape of cooking stand are as yet unknown (Scheffer 1981, 52–54, 106–107).

Finally, there is an open-front, sometimes band-shell-shaped oven. This oven ranged in size from small and easily portable to large and fixed. Archaic and Classical terracotta figures, primarily Boeotian, along with an Archaic Boeotian vase show the use of a four-legged oven somewhat resembling television sets on stands from the 1950s (Sparkes 1962, 133–134; Higgins 1986). An Archaic Boeotian black-figure *lekythos* shows scenes of bread making in which this portable oven is used (Sparkes 1962, plate VII 2). A person on the right attends a fire built under the oven; a baker sitting to the left in front of the oven's opening, from which flames or smoke appear, uses a long stick to tend items within (Sparkes 1962, 127). Evidence of possible large-scale commercial baking activity employing such an oven shape (but without legs) is seen in an Archaic period terracotta model (see Curtis 2001, 292 for image). These ovens were perhaps seated on a large box or tray, which allowed hot coals to heat the oven (Curtis 2001, 293). Commercial bakeries, taxes on bakeries, and names of famous bakers are known in Athens from Classical sources (Curtis 2001, 293 with references).

10. Hellenistic Period (323–31 BCE)

The Hellenistic period offers glimpses of trade that moved cooking technologies throughout the Mediterranean. Even Athens, with its excellent clays for both coarse and fine wares, imported about one-third of its cooking materials during this period (Rotroff 2006, 63). Around the beginning of the second century BCE, portable braziers on stands appear. These braziers had ingot-shaped air vents, were topped by bowls with three molded lugs for the coals, and were commonly decorated with bearded male "satyr/silenos" heads projecting up from the edge. Imported not only to Athens and Corinth (another place rich in excellent clays), these braziers were found also in the Aegean, Asia Minor, Cyprus, the Levant, Egypt, North Africa, Sicily, and Italy (Şahin 2001, 2003; for Athens and *comparanda*, Rotroff 2006, 204–219; for Corinth, Edwards 1975, 119–120). Local imitations abound in many locations, and the original place or places of production of the standard version is uncertain. High concentrations were found in Greek sanctuaries, suggesting they played an important role in ritual cooking (Şahin 2003). The three lugs would have supported a round pot (Rotroff 2006, 200). Consequently, these braziers would have been used primarily for boiling and stewing. As we have seen, despite the ritual centrality of small portions roasted over an altar fire, boiling and stewing meat was the most important cooking technique in ritual contexts to process meat for consumption.

The most striking example of the movement of cooking technology can be found at Tel Anafa in modern-day Israel. The majority of typical cooking pots in the Levant from the sixth century BCE to the Hellenistic period are "globular" in shape with narrow mouths, ideal for boiling legumes and grains without excessive loss of water (Berlin 1993, 41). In the Hellenistic period, Greek *lopades* and typical Hellenistic braziers begin

to appear at Tel Anafa in great quantities (Berlin 1993, 42). Most surprising, in the Hellenistic period, there appears a small number of flat-bottomed, straight-walled new Italian cooking vessels (Berlin 1993, 43), which archaeologists call *orlo bifido* for their grooved rims (Rotroff 2006, 192–193). These pans are ideal for cooking casseroles set with eggs and were known to have been used for the Roman *patina*, a type of savory casserole named after the dish in which it was cooked, either directly on coals or in boiling water (somewhat similar to the modern bain-marie technique: Grocock and Grainger 2006). Pompeian red ware lids for these pans appear in equal number, perhaps connecting the area to the cooking techniques of the Italian peninsula (Berlin 1993, 44).

11. Republican and Imperial Rome (circa 200 BCE to 480 CE)

The Roman Republic and Empire are the most richly attested periods for cooking and baking practices in Classical antiquity, yet there are still many unknowns. General mobility of cooking places and portability of cooking equipment remain central to cooking practice and technology. Nevertheless, large immovable cooking and baking installations in domestic and commercial spaces appear frequently. Evidence from Pompeii, discussed below, is especially helpful in reconstructing cooking practices.

In *On Agriculture*, Cato the Elder provides invaluable evidence for the types of cooking on large Roman estates during the Republic. His recipes for the farm shed light on common processes: cooking in liquids, such as water and melted lard, and baking. For all of these processes Cato uses the generic term *coquere*. His recipes call for cooking wheat in water in *aulae* (pots; *granea triticea*: *On Agriculture* 86); frying "funnel cakes" and cheese-and-spelt dough in lard in copper pots (*encytum*: 79; *globi*: 80); setting wheaten cakes in a ceramic vessel (*irnea*) placed in a copper caldron of boiling water (*erneum*: 81); and baking breads under the *testu* or *testum*, "baking cover" (e.g., *panis depsticius*: 74; *libum*: 75; *placenta*: 76).

Portable braziers (*focus*, *foculus*), made of bronze or clay, were the commonest cooking equipment for poorer Romans, but they even featured prominently in homes and shops with fixed cooking equipment (Hermansen 1982, 194; Foss 1994, 66). The possibility existed of moving cooking equipment into various places in wealthy homes to expand the space for cooking (Foss 1994, 69–73). In the Imperial period (first century CE), literary evidence suggests that braziers were used for culinary purposes even in dining rooms (Foss 1994, 73). In one of his moralizing letters, Seneca addresses this practice with Stoic bluster on the ills of *luxuria*: "Lest any food starts to get lukewarm, lest anything is not boiling-hot enough for the already thick-skinned roof of the mouth, the kitchen accompanies the dinner" (*Letter* 78.23–24). The poor, when cooking for themselves (see below for commercial eateries), would likely have set up their braziers, fueled by charcoal, in a doorway or near the entrance, the only adequate sources of ventilation within the cramped walls of miniscule urban dwellings (Foss 1994, 77).

In larger Roman homes, such as at Pompeii, kitchen rooms (*culinae*) are common. Drains to the sewers, latrines with cesspits, and baths are found near these areas (see ROMAN DOMESTIC ARCHITECTURE). The most common fixed installation of these homes is a "stove" (Foss 1994, 78–82 for typology of Pompeiian fixed hearths and "stoves," which may have fallen under the Roman category of *focus* or *furnus*). The stove consists

of a long, flat surface, sometimes with imbricated edges in front to prevent coals from falling onto the cook (Foss 1994, 81). The stoves often have completely open or arched spaces below, perhaps for fuel storage (Foss 1994, 80–81). Some are vented with windows or roof openings. Occasionally, stoves have "burners," small fixed masonry cooking stands, perhaps to support individual pots (Foss 1994, 81). Small iron grill grates and iron tripods could have been used on top of the coals on these stove tops. Placing *patinae* directly on hot coals would have been common on such structures, a technique commonly referred by the Greek *thermospodium* "on hot coals" (for this interpretation, Grocock and Grainger 2006, 362). In the Villa of the Mysteries, which has a very large stove in a sizable kitchen area with two oven structures, the stove and oven attached to it abut a private *balneum* (bath). This large heat source would have helped warm the bath area. A small shrine or niche is frequently found in Roman kitchen spaces for offerings to the gods associated with the household (Clarke 1991, 9).

For the less wealthy "apartment dwellers," such as those at the Roman port of Ostia, cooked food would have been available in *popinae/cauponae* (taverns; Hermansen 1982, 194). The now-deprecated Hellenizing term *thermopolium/thermipolium*, still commonly heard and read by tourists visiting Pompeii, Herculaneum, and Ostia, appears only in Plautus (*Curculio* 292; *Rudens* 529; *Trinummus* 103), and, accordingly, was not a likely term for these establishments for either Latin or Greek speakers who frequented them (Holleran 2012, 142 with note 196). In Pompeii, such establishments could have serving counters with embedded *dolia* (see Food Storage Technology). These multi-gallon storage jars (only one of which in Pompeii was found with contents: walnuts) were perhaps for holding dried foods (Holleran 2012, 142–143). A sizable fixed hearth can be seen today at the end of one tavern (Caupona I.4.27; Foss 1994, 346, figure 2.18, 78–79 for a typology of hearths). This type of hearth has an extended bottom ledge for coals and a horseshoe-shaped top that could have supported a large cooking vessel. Other types with different shapes appear in Ostia and Pompeii. Although ventilation via "hoods" issuing through the top of a wall was possible for certain hearth types (Foss 1994, 82), literary sources hint that they did little good as smoke and grease were the most common visible features of these establishments (Hermansen 1982, 194).

12. Roman Baking

Until the Late Republic, Roman bread-baking technology seems to have been limited to the baking cover or crock (*testum* or *testu*, or Greek *clibanus*) using a technique somewhat analogous to the Greek "cooking bell" (above) but with different equipment. In his recipes for breads (*On Agriculture* 74–76), Cato mentions only the *sub testu* ("under a baking cover") method, either baking the bread under the cover on a hot/warm *focus* (75) or heaping hot coals (*prunae*) around the dome's sides and on its top (76). Roman *sub testu* baking lasted throughout antiquity. Ceramics ranging in date from the Late Republican (second to first centuries BCE) to the Late Imperial periods (fourth to fifth centuries CE) have been identified as baking covers (Cubberley, Lloyd, and Roberts 1988). These deep, roughly pie-plate-shaped lids have a projecting foot running around the bottom of their walls as if they could have been fitted atop something (Cubberley, Lloyd, and Roberts 1988, 103). Earlier examples are missing the tops of the dome, so it is unclear whether they are fully domed or flat topped, but near-complete examples from

the later Empire (circa third to fifth centuries CE) have a nearly flat top gently sloping from the flange to a knob-like apex with a hole (Cubberley, Lloyd, and Roberts 1988, 104–105, figures 1–2). Unlike the earlier Greek baking dome and later Medieval baking domes, none of the Roman examples have a handle or strap on top, but many have pie-crust or pie-plate flanges running around the tops of the sides, perhaps used to lift the cover and, most importantly, to keep the coals on top in place (Cubberley, Lloyd, and Roberts 1988, 103; for additional comparative and Medieval evidence Cubberley 1995). Critical to their identification as *testa*, all domes have evidence of burning on the foot, lower wall, and top flange (Cubberley, Lloyd, and Roberts 1988, 106). The burn marks, therefore, completely accord with Cato's techniques of *sub testu* cooking. The coals on top (*insuper*) and around (*circum*) the sides would have left traces of burning in those areas. Placing the crock on a hot *focus* would have left traces of burning on the bottom. The flat top with flange is certainly the only shape that would reasonably allow for Cato's technique of heaping coals above (*insuper*) the crock, a technique impossible with the Greek "cooking bell."

By the end of the Republic, a large built oven (*furnus*), fixed in place, appeared with the advent of large-scale professional miller-bakers (*pistores*), whose operations provided a vast amount of bread to the public. Although Pliny the Elder (*NH* 18.28), writing two hundred years later, places this event around the Third Macedonian War (170 BCE), his date cannot be verified. We do, however, have visual evidence datable on architectural and aesthetic analyses to around the end of the Republic/very early Principate (Parker 1877, 33–34). The simplest igloo- or beehive-shaped versions of the built oven and several processes of a milling-baking operation are depicted on the frieze of the tomb, still beside the Porta Maggiore in Rome, of the freedman miller-baker Marcus Vergilius Eurysaces. Given the small "oven" built into the "stove" in the first-century CE Casa dei Due Atri in Herculaneum, scholars have been inclined to see this technology as a development on country estates arising as a large-scale version of the *testu* (Frayn 1978, 30; 1979, 108–110). However much the general principle of creating an enclosed space to contain heat holds true for *furnus* and *testu*, the method of use, the look, and general heat-retention features of these built ovens do not fully resemble *sub testu* baking.

The numerous mill-bakery ovens still visible in Pompeii (Figure 35.2) are the largest and most complex examples of the *furnus*-type oven (Mayeske 1988, 153; for a full treatment of bakeries, Mayeske 1972; 1988). Typical examples have a beehive or domed mound for the baking chamber, which is encased in a large cubic brick structure with an insulating chamber above (Mayeske 1988, 153). An opening in the roof or a chimney vents the ovens. The baking chamber has a square opening in the front that allowed bread to be put in and removed. Below the openings of the baking chambers are ledges with square openings underneath them. It is now thought that these bottom openings provided a place to put ashes swept out of the hot baking chamber before the bread was baked, although the old interpretation of charcoal storage areas still remains a possibility in some cases (Mayeske 1988, 153).

The mill-bakeries in Pompeii have unmovable appliances and built structures for all stages of bread baking. After the grain was milled on the famous built-in mills with hourglass-shaped hoppers and the dough kneaded in stone-based kneading machines (Curtis 2001; Thurmond 2006), loaves were baked in large brick-enclosed ovens, often in molds or forms. In a few cases, sideways extensions of the oven ledge possibly allowed loaves to be passed seamlessly to the *furnarius* in front of an arched opening in the wall



Figure 35.2 Remains of a mill-bakery at Pompeii with its oven (rear) and mills (center). Photo by Vanessa Davies.

leading to the oven (Mayeske 1988, 153). A space extending on the other side of the opening allowed the *furnarius* to pass it along to a storage room when baked (Mayeske 1988, 153).

Due to the nature of the destruction of Pompeii, bread loaves were carbonized and preserved. In August 1862, Giuseppe Fiorelli's archaeological team discovered eighty-one perfectly carbonized round loaves in an oven of a mill-bakery. Although the common narrative dramatizes bakers suddenly fleeing the eruption of Vesuvius in the middle of their work, this account is by no means certain. The bakers could have as easily stowed already baked loaves in a cold oven for safe keeping as they attempted to leave town. Seventy-six of these circular loaves were of a standard size, averaging a little over 6 cm (2.5″) high and 20 cm (8″) in average minimum and maximum diameter, with eight defined wedge-shaped slices leading to a central circular depression. Four loaves averaged around 24 cm (9.4″) in diameter. One large loaf measured about 32 cm (12.5″) in diameter and was divided into fourteen slices (for these measurements and early chemical analysis, De Luca 1863).

In the first century CE, loaves like these seem to have been commonly baked in molds or pans, and a pronounced division between the top and bottom in the standard loaves may indicate that loaves expanded out of their pans while baking. Twenty-four large and small bronze baking pans were found in a bakery at Herculaneum (Mayeske 1988, 154).

The forms of metal baking dishes for breads and "pastries" (more or less also modern breads) range from plain pans to intricate molds in the shape of seashells, animals, or mythical creatures (Mayeske 1988, 154). A stamp on one of the carbonized loaves even mentions a maker, "Celer, a slave of Quintus Granius Verus" (Mayeske 1988, 154). The standard circular loaves with wedge-shaped slices are reproduced in a fresco from the *tablinum* (home office) of a house in Pompeii (VII.iii.30) of a togate figure distributing bread (Naples Archaeological Museum 9071). Some of the loaves in the foreground are similar in appearance to the large carbonized loaves with fourteen slices.

13. Late Antiquity

With the disruptions that led to the end of the western Roman Empire, cooking vessels adapted for use on flat surfaces decrease and built ovens disappear (Arthur 2007). By late antiquity, a marked increase in the old, portable, *testu*-type ovens occurs in Italy, the Balkans, and elsewhere (Arthur 2007, 178). The mill-bakery was no longer a fixture in the baking landscape and, thus, the old *sub testu* baking technology regained its earlier place as the predominant archaeologically visible method of bread making (Arthur 2007, 178). Simple flatbread preparation without equipment also predominated. In Byzantium, ovens are not found, even in the dwellings of the wealthy (Arthur 2007, 179).

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FURTHER READING

Several excellent treatments of food in the ancient world are available as resources for the reader interested in a broad spectrum of cooking and baking practices. Curtis' (2001) volume on ancient food technology is now the *locus classicus* treatment of Greek, Roman, Near Eastern, and Egyptian cooking and baking. For detailed scientifically informed discussions of ancient cooking, baking, and related practices, see Thurmond's (2006) readable account of Roman food technology. For a general overview of the place of cooking and baking in the ancient Greek and Roman worlds, see Wilkins and Hill (2006). Andrew Dalby's (2003) dictionary is the first reference for any specific topic related to cooking and baking in Greek and Rome.

CHAPTER 36

Food Storage Technology

Robert I. Curtis

1. Introduction

Storage, in its broadest sense, is a human behavior that has as its goal the safekeeping of a wide range of merchandise for later use. Each category, both natural products and man-made goods, has its own particular technological requirements to ensure preservation for short-, medium-, or long-term periods. Among the most perishable commodities requiring the application of storage technology is food, whether in its natural state or processed in some fashion. Prerequisites to food storage include a settled lifestyle, an intensity of agriculture that provides a surplus over immediate household needs, and the development of social and political structures to protect and organize storage at various levels.

Storage occupies a middle step between production or processing of foodstuffs and their distribution, sale, and consumption, and provides an important hedge against the vagaries of weather and climate that often result in fluctuations in food availability. The farmer, for example, might keep grain in excess of domestic consumption, needing to have seed for the following year's planting, to guard against bad or delayed harvests, or to await a better price on the market (Forbes and Foxhall 1995). Xenophon implies that Greek farmers should lay up a year's worth of food (*Economics* 7.36); Tacitus indicates that Roman military forts maintained a similar level (*Agricola* 3.2).[1] Urban dwellers stored food at home in storerooms and pantries, and food-shop proprietors maintained an inventory of provisions for sale (Mahon 2005, 81–82). Food storage strategies must take into consideration the quantity of food needing storage, length of time necessary for storage before it is moved, environmental conditions under which food is stored, and available technology to meet the requirements of particular foods.

Although all foods selected for later consumption or exchange require storage, the basic items include the "Mediterranean Triad" of wine, olive oil, and cereals.[2] Grapes

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can be consumed in their natural state, dried into raisins, or processed into various forms of grape juice consumed as a non-alcoholic drink or in cooking. Most grapes, however, were made into wine (Oil and Wine Production). The vintner treaded and pressed grapes to express the juice that he then transferred to containers for a short fermentation period and longer aging process. Wine needs to be kept cool, optimally around 50°–65° F, and away from oxygen to minimize microbial activity that can lead to spoilage (Prickett 1980, 53–67). Olives, cured in brine, likewise, can be eaten, but most were pressed to remove the oil, useful for many purposes including food (Culinary and Medicinal Uses of Oil and Wine). Olive oil, once separated from the sticky, black, watery *amurca*, unlike wine, needs to be kept relatively warm to prevent it from becoming turbid. Grain has several requirements to ensure that it remains usable even for short periods. Today, grain is best stored at temperatures below 60° F. An excessively hot or damp atmosphere causes grain to respire, giving off heat, oxygen, and water that initiate germination. Germinated grain becomes susceptible to the growth of fungi and molds, leading to spoilage. In addition, stored grain needs a place that is secure from rats and other vermin, such as weevils, which eat it or contaminate it with their droppings (Pals and Hakbijl 1992, 292–295). Consequently, all cereals require secure, dry, cool, dark, and confined storage. Storage of food, both liquid and dry, then, presented major technological challenges to ancient Greeks and Romans. The solutions entailed both containers to hold food items and built structures to house large quantities of food for varying periods of time.

2. Storage Containers

Any container of any size made from almost any material could serve to store food (White 1975, 51–104). So, for example, sacks, baskets, and wooden boxes might hold any number of foodstuffs, such as fruit, vegetables, beans, cereals, bread, cheese, and dried, smoked, and salted fish, while animal skins were ideal for liquids, particularly wine. Wooden barrels were suitable for both dry and liquid foods. All of these receptacles could hold food for a short time for domestic consumption or be transported by pack animal, cart, wagon, and ship to markets both near and far (Land Transport and Vehicles; Ships and Boats). Made of highly perishable materials, these relatively small containers rarely survive today, but they often appear represented in paintings or sculpted relief. Sturdier and larger vessels were also at hand.

Urban dwellers might choose from among many kinds of utilitarian containers made of various materials, including bronze vessels or terracotta *amphorae*, to store wine, oil, and other food items in kitchens, storerooms, and shops (Annecchino 1977; Monteix 2008, 127–128). These containers, however, were mainly for temporary, short-term usage, not storage per se, and their contents needed replenishing on a more or less regular basis. When it came to longer-term storage in bulk on farms or in public and private warehouses in cities and towns, the storage vessel par excellence was the *dolium*, or *pithos* in Greek.[3] The *dolium* was a large, terracotta container designed primarily to store liquid or solid foods, with secondary uses for water storage and other purposes.[4] While *dolia* took many forms, during the Greco-Roman period, most were generally ovoid or globular, with an open, but not particularly wide, mouth, flat everted rim, short or no neck, no handles, wide shoulder or belly, and a disk-shaped or pointed base (Figure 36.1).[5]



Figure 36.1 Dolia. Pompeii, Reg. I.22, first century CE. Note lead mend on third dolium from left. Photo by author.

In comparison to *amphorae* and fine wares, such as *terra sigillata*, *dolia* have received little scholarly attention. What studies exist tend to focus on Bronze Age *pithoi*, in part because scholars have seen these vessels as a gauge of storage capacity that reflected the wealth, status, and political power of individuals or centralized authority (Cullen and Keller 1990, 191; Christakis 2005; Christakis 2008; Giannopoulou 2010). Little has been done on Classical Greek or Roman storage containers.[6] Indeed, many *dolia* remain where found, unemptied, unstudied, and unappreciated, the attention given to them by excavators often limited to noting their number, placement, and whether buried or not (Stefani 2006, 157).

The manufacture of large storage vessels was a difficult and expensive task that required both technological expertise and a large investment of time, money, and labor (Brenni 1985, 11–14; Giannopoulou 2010, 49–77; Peña 2007, 32–35, 210–227). Large-vessel potters were most likely specialists who traveled from place to place to make *dolia* in situ on farmsteads or operated out of workshops (*figlinae*) that specialized in architectural terracotta decoration.[7] Socrates, in Plato's *Gorgias* (514e), for example, referring to a proverb cautioning against attempting a more complicated task before mastering a simpler one, describes someone who begins his training to become a potter by first attempting to make a *pithos*, or, as we might say, by putting the cart before the horse. Although difficult to distinguish after production, two processes probably account for producing most ancient *dolia*.[8] Slab building involves forming thin pieces of clay by hand and joining them by pressing their edges together. This method was particularly appropriate for

very large *dolia* or cylindrical storage vessels with a wide mouth and uniform diameter from top to bottom (Columella 12.4.5). The second method, coil building, was probably the most common technique used in antiquity for making *dolia* of all shapes.

Coil building, though encompassing several variations, basically involved the successive stacking of one coil of moist clay on top of another followed by pinching, drawing, and smoothing to fuse them. Anatolias (*Geoponica* 6.3) states that, while small *pithoi* were made on the potter's wheel, large ones were built up from the ground in a warm room. Starting from a narrow, flat base or point, the potter stacked thick coils to create a vessel whose diameter became first wider as the stacks of coils increased, then narrower to the point where the mouth was formed. As a result, the vessel, wider in the center or shoulder area than at the top or bottom, had a precarious stability that often required a support frame or partial to full burial in the ground (*dolia defossa*; Figures 36.1, 36.3). Greek Bronze Age and Geometric period *pithoi* often received painted, applied, molded, impressed, or incised decoration, but by the Classical and Hellenistic periods, reflecting their essentially utilitarian purpose, with the exception of stamped or incised notations, *dolia* remained plain (Devos, De Paepe, and Vermeulen 1999, 102–105; Ebbinghaus, 2005; Giannopoulou 2010, 72–73). While the clay was still wet, the potter impressed a stamp into the clay on the lip or shoulder to identify both the owner of the *figlina* and the master potter or slave who worked the clay. Additional information might include stamped or incised numbers to indicate the capacity or price of the vessel (Robinson and Graham 1938, 314–316; Brenni 1985, 34–37, 193–246).

Maintaining a certain degree of moistness and pliability to the coils was essential to ensure that the clay did not dry out too quickly, resulting in an insecure bond where coils joined. This created a weakness in the vessel wall that could lead to cracks in later stages of production or during use. Columella, for example, warns that heating *dolia* to apply pitch sometimes results in cracks (12.18.7), and Varro notes that the fermentation process in wine making sometimes created enough pressure inside the sealed *dolium* to rupture the walls (*On Agriculture* 1.13.6). Cracking was an ever-present hazard as seen in numerous *dolia* that have been mended with hammered or molten lead as a filler, sometimes using a mortise-and-tenon technique forming a "double swallow-tail" (Figure 36.1).[9] Proper drying required from ten days to two months, usually in the open air (Giannopoulou 2010, 73).

Following drying, firing further strengthened the clay. Small *pithoi* could be placed in a kiln; larger ones were usually heat-treated in a large bonfire and allowed to cool for up to a week. Cooler, but still warm, the interior of many vessels received a surface treatment to make the clay impervious to liquids (*Geoponica* 6.3). The potter coated the inside with beeswax or gum, especially if the *dolia* were destined to hold olive oil, or resin or pitch for wine.[10] Indeed, the scheduled reapplication of pitch, sometimes annually before each harvest, to ensure cleanliness and continued impermeability was an obligatory duty of the farmer (Columella 12.18.5–7; *Geoponica* 6.4–8; Brenni 1985, 12–14; Peña 2007, 211–213; Figure 36.2). The final step in making the *dolium* was to create a flat terracotta disk (*operculum*) to serve as a lid to cover the vessel's mouth. *Dolia* located without a roofed structure overhead, such as those found at the Villa Regina in Boscoreale, often had an additional terracotta top placed over the lid (Figure 36.3).[11] If correctly made, the *dolium* was a strong, durable, long-lasting, and, because of its large size, an essentially immobile storage vessel.



Figure 36.2 Tarring the Casks (first half of third century CE) from a series showing agricultural work throughout the year. Saint Romain-en-Gal, France. Musee d'Archeologie Nationale, Saint-Germain-Laye, France. (*Source:* akg-images/Erich Lessing.)



Figure 36.3 *Cella Vinaria*. Villa Regina. Boscoreale, first century CE. *Dolia defossa* with lids (*opercula*). Tops (*tectaria priva*) shown leaning against wall. Photo by author.

Dolia were large storage vessels, but defining large is not easy, and literary sources provide no help (Giannopoulou 2010, 27–28). Kostandinos Christakis (2005, 2) distinguishes *pithoi* from smaller vessels if they exceed 50 cm (20″) in height. This definition allows for vessels possessing a variety of heights and, depending upon their diameters, widely differing capacities. Bronze Age and Geometric period *pithoi* sometimes reached 2 m (6.5′) tall. Over time vessels tended to become smaller, so that by the Archaic and Classical periods *pithoi* of 1 m (3.3′) were normal, though larger ones continued to be made (Cullen and Keller 1990, 189–197). At Hellenistic Olynthus, where measurable, the height of *pithoi* ranged between 0.9 to 1.1 m (2.9–3.6′) with capacities varying between 150 and 340 liters (40–90 gallons; Robinson and Graham 1938, 313). Latin literary sources rarely report capacities of Roman *dolia*, though Pliny (mentions one of 387 liters (102 gallons; *NH* 9.93) and Cato records another at 1,290 liters (340 gallons; *On Agriculture* 112.3). Actual Roman examples are often much larger, some, reminiscent of Bronze Age *pithoi*, reaching 2 m (6.5′) tall with considerably greater capacity.[12] Although the range of *dolia* shapes was rather restricted, primarily from ovoid to globular, apparently, at no time in antiquity was there a standard *dolium* size or capacity. This probably resulted from the difficulty inherent in manufacturing large storage vessels to precise measurements and according to the wealth, preferences, and specific requirements of those ordering their production. Their size and the investment of skill and labor necessary to produce them did not lend *dolia* to mass production. Consequently, they were relatively expensive.

Information on the price of Greek *pithoi* comes only from excavations at fourth-century BCE Olynthus where excavators discovered in the "Villa of Good Fortune" a storeroom containing five *pithoi*, each having numbers incised into their rims. Robinson and Graham have interpreted these numbers to indicate the price of the vessels (1938, 314–316). Prices range from 31 drachmas, 1 obol to 53 drachmas, 4 obols, totaling up to 215 drachmas, or more than a laborer's wage for six months (Cahill 2000, 507 note 25). Writing in the second century CE, Apuleius gives the unit price for a Roman *dolium* (size unspecified) at 5 to 7 denarii (*Metamorphoses* 9.6.3). A century and a half later, reflecting rampant inflation, Diocletian set the maximum price for a 1,000 sextarii (540 liters/140 gallons)-capacity *dolium* at 1,000 denarii, a sum exceeding five weeks' wages for a farm laborer listed in the same document (*Edict* 15.97).[13] The relative value of these large storage jars can also be appreciated from three facts. First, *dolia* are often listed by name among items of property considered integral to an estate (Cato, *On Agriculture* 1.4–5; *Digest* 19.1.26, 54; Amyx 1958, 168–170). Second, when broken, unlike in the case of smaller vessels, such as *amphorae*, *dolia* are carefully mended rather than discarded. And, third, some farmers apparently chose to retain old *dolia*, rather than making or purchasing new ones, even though use of the former might be detrimental to the quality of wine produced (*Geoponica* 6.3).

Dolia provided food storage in various ways. First, they served as receptacles during food processing. So, for example, Manilius describes how fishermen placed their catch into wine *dolia* to be processed into fish sauce (5.679). Six *dolia* placed in the peristyle of a private house, converted into a fish-sauce processing center in first-century CE Pompeii, also functioned for that purpose (Curtis 1979). Here the *dolia* operated for short-term storage until the finished product could be transferred into smaller containers for transport or use. Cato suggests the employment of *dolia* to salt ham, but he adds that the meat remains in the *dolium* only a short time before it is removed and hung in

the meat locker (*carnarium*; *On Agriculture* 162). Second, *dolia* occasionally served, like *amphorae*, as transport containers. Underwater archaeologists, for example, have discovered ten Roman ships of early Imperial date that utilized *dolia* to transport wine between the western coast of Italy and southern Gaul. These specialized ships were specifically constructed to carry *dolia* of various sizes permanently fixed in their hold near midship (Brenni 1985, 53–56; Hesnard 1997). The primary use of *dolia*, however, was to store an assortment of foods for medium- to long-term periods.[14]

Roman agricultural writers often identify foods stored in *dolia*. Among those listed are vegetables such as turnips, and fruits, either fresh or dried, such as grapes, raisins, apples, figs, pomegranates, pears, raisins, and quinces. Some *dolia* seemed especially devoted to certain items, such as *dolia frumentaria* (wheat), *dolia olearia* (olive oil), and *dolia vinaria* (wine).[15] Archaeologists can sometimes identify food items in *dolia* by direct observation, such as carbonized material, or by scientific analysis of residue. Identified foods found in *dolia* dating from the Bronze Age to the Roman period include olives, olive oil, almonds, walnuts, grapes, wine, including both honeyed and resinated kinds, pears, figs, chickpeas, lentils, faba beans, peppercorns, various species of wheat, barley, and bitter vetch.[16]

Romans also employed a variety of other vessels to store foodstuffs, most of which were subjected to some level of processing, such as drying, pickling, or salting (Thurmond 2006, 166–187). Columella, for example, suggests storing lentils in reused wine or salt-fish *amphorae* sealed with gypsum (2.10.15–16). Pliny states that legumes could be stored in oil jars (*cadi olearii*) covered in ashes (*NH* 18.307). A two-handled terracotta pot sealed with cork, found in Herculaneum, held a mixture of lentils and vetch (Monteix 2008, 128). Columella recommends storing dried onions, together with thyme and a preservative mixture of vinegar and brine, in a *fidelia* (12.10). Wooden barrels, primarily transport containers, were reused in the legionary *horreum* at Vindonissa (Switzerland) to store pomegranates, cereals, and nuts (Columella 12.17.1; Jacomet et al. 2002). Cato advises that grapes, along with grape pulp, be placed in *urcei* and buried in the ground (*On Agriculture* 143.3), while Varro reports that grapes were stored in small vessels (*ollulae*) that were, in turn, placed inside *dolia* packed with dregs from the wine press (*On Agriculture* 1.54.2). Columella states that quinces were stored in *lagoenae* filled with honey (12.17.2), and he advocates storing apples in a wooden chest (*orcula*) placed in a cool, dry loft (12.17.5–6). Columella's mention of a loft brings us to the second Greco-Roman strategy for food storage, built structures that provide a physical setting for storage containers and additional methods to store food.

3. Built Structures

Bronze Age society was organized around palace centers that maintained large storage capacities, which some scholars have characterized as centralized storage for communal redistribution providing the elite with social, economic, and political power (Renfrew 1972, 296–297; but see now Christakis 2011). Palace records, such as Linear A and B tablets, basically receipts for inventories and the movement of goods in and out of storerooms, list wheat, oil, barley, olives, and figs (Renfrew 1972, 296), but tell us nothing of how they were stored. For that we have to rely on archaeological excavation.

Pithoi constitute the primary storage vessels placed in ground floor storerooms, on upper floors, and in corridors of Minoan palaces (Christakis 2008, 52–54). The West Magazine of the palace at Knossos, for example, containing 18 storerooms opening along a long corridor could hold up to 420 large *pithoi* (Christakis 2004). Three *pithoi* may have contained pulses, and ideograms for fig and wine stamped on some vessels may indicate other stored foods. Gypsum floors and thick walls without windows rendered the storerooms dark and cool. In addition to *pithoi*, the corridor and storerooms had rectangular, subfloor pits lined with either gypsum or plaster for additional storage. The storeroom of the Late Minoan (1600–1100 BCE) "Unexplored Mansion," near the Little Palace at Knossos, contained individual vessels of emmer wheat, bread or macaroni wheat, hulled barley, peas, beans, and figs (Jones 1987, 116).

The granary complex in the Middle Minoan I (1900–1700 BCE) palace at Malia, composed of eight above-ground, circular, structures, called koulouras, arranged in two rows of four granaries each, the whole surrounded on three sides by a wall, provided long-term storage of grain in bulk.[17] Averaging about 3.8 m (12.5′) in diameter and with an estimated average capacity of about 38.66 m^3 (1,365 ft^3) each, most structures had plastered interior walls and a central quadrangular pillar that probably supported a flat roof of indeterminate height (Strasser 1997, 77–79).[18] Domed roofs, however, may have been more common elsewhere.

Several ninth-to-eighth-century BCE clay granary models have been found in Corinth, Eleusis, and Athens (Young 1939, 186–187). The latter example comes from the Early-Geometric II (circa 850 BCE) burial on the Aeropagus (Smithson 1968). The whole is a terracotta chest with lid bearing five model granaries placed in a single row, all of which have a round base and dome-shaped roof. Just below the peak, the potter has cut into each vessel a small trapezoidal window with a flap. At the base of each granary is a pair of holes that do not penetrate to the interior of the vessel, suggesting that they run under the floor. Working near a Late Geometric house (760–700 BCE) at Lefkandi, archaeologists uncovered stone foundations of what may have been three above-ground circular granaries (Popham, Sackett, and Themelis 1979, 24–25). Though extant to only three courses, two parallel channels at ground level and bound by large stones penetrate the structures completely from front to back. The two holes at the base of the model granaries from Athens and the ground-level channels of the Lefkandi structures may represent the earliest evidence for subfloor ventilation for grain storage typical of later Roman granaries. These granaries provided dark, cool storage space for large quantities of grain stored in bulk. As shown in Egyptian models and paintings representing similarly shaped granaries, the grain was probably carried up to the window by means of a ladder propped against the outside wall and then dumped into the granary interior. When needed, grain was retrieved through a window or door near ground level (Curtis 2001, 100–104; cf. Pliny, *NH* 18.301).

Greek cities during the Classical and early Hellenistic periods appear not to have developed large-scale food storage facilities in spite of a growing population; at least none thus far have come to light. Unlike Bronze Age centralized political economies, the Classical economy, certainly as represented in Attica, was based on the small farmer who cultivated, processed, and stored grain and other products on his farm and transported the surplus to local markets or to Athens itself (Foxhall 1993; Bintliff 2008, 24–26). Xenophon says that a well-ordered estate had specialty storerooms, such as

a cool room for wine and a dry, covered one for grain (*Economics* 9.3); he does not, however, describe them or explain where they were located. Epigraphic evidence of leases and other documents provide names for storage buildings, such as *sitobolon* and *mukhos* (granary), *pithon* or *pitheon* (cellar), *oikia* (general building for agricultural work), and *pyrgus* (tower; Osborne 1985). The latter may refer to the stone-built circular or rectangular structures of various sizes found in southern Attica at Sounion and elsewhere in the Greek world.

John Young (1956) compared the Sounion towers with others found at Megara and on the Cycladic islands of Siphnos, Keos, Naxos, and Andros, all dating between the sixth and third centuries BCE, and he concludes that they were storage buildings.[19] Measuring between 9 and 24 m (79′) in height with a diameter of between 5 and 11 m (16-36′), the towers usually faced south or east and had one door, which was capable of being locked. Wooden joists on the interior walls held beams to support wooden floors for multiple upper levels, reaching five floors at Naxos. Many towers had a large opening on the second story reached by a ladder from the outside, and a few had windows at higher levels. Young argues that the lowest level, often subdivided by cross-walls into separate areas or rooms, was reserved for farm work, such as equipment storage, threshing or milling, and a *pithon* for oil vessels and partially sunken *pithoi* for wine. The ground floor would concurrently serve as subfloor ventilation for grain and other dry foods stored on upper floors.

Some urban houses also maintained a *pithon*. The best evidence comes from fourth-century BCE Olynthus, where several houses possessed rooms containing *pithoi* buried in the floor up to their lips (Robinson and Graham 1938, 61, 207–209, 259; Cahill 2000, 505–507). The five *dolia* in the *pithon* of the "Villa of Good Fortune," for example, had a combined capacity of 7,500 liters (1,980 gallons), and, to judge from physical remains, held olives and grain. The capacity of these vessels indicates the desire of the owner to store food long term, perhaps up to a year, as suggested by Xenophon (*Economics* 7.36). Houses in Halieis in the southern Argolid held from two to fourteen *pithoi*, probably for oil since most were not buried but often placed in stairwells or in other sheltered places around the courtyard (Ault 2000, 491)

Roman storage facilities were termed *horrea* or *granaria*.[20] Although the terms were often used interchangeably by ancient authors, Pliny (*NH* 18.301–302) asserts that the former was made of brick, the latter of wood. As the names imply, these structures most often held grain, though they could, and often did, store many other food items.[21] In addition, Roman warehouses frequently served the double function of storehouse and commercial exchange where food could be sold.[22] Some warehouses stored specific items, such as the *horrea piperataria* (Rickman 1971, 104–106) that housed and probably sold expensive spices, and *cellae* that specialized in wine (Richardson 1992, 191–195). Warehouses could be both public or private, and some, such as at Puteoli, rented space to individuals for short terms.[23] Although *horrea* held various categories of foods, their architectural design especially accommodated grain, the item for which storage facilities and mechanisms are best known archaeologically.

Although some indigenous populations in the provinces stored grain in underground pits, caves, and silos, Romans generally preferred above-ground storage, particularly in areas, such as Italy, that had wet climates (Varro, *On Agriculture* 1.57;

Columella 1.6.16; Salido Domínguez 2011a; 2011b, 61–66). Granary architecture showed remarkable variety. The more elaborate storehouses might have brick or stone walls three feet thick with windows on the north and east sides for ventilation, concrete floors, and vaulted ceilings (Vitruvius 6.6.4; Pliny, *NH* 18.301; Suetonius, *Nero* 38.1). The interiors of large granaries were often subdivided into rooms (*cellae*) that were sometimes subdivided further into individual bins (*laci*) according to the items stored (Columella 1.6.13; Palladius 1.19; Kaufman 1929, 49). The characteristic rural granary, such as found in Italy at Vicovaro in Latium, was most often made of wood and raised on supports (*horreum pensile*), as Columella recommends (1.6.16; Rossiter 1978, 57–59; cf. Pliny, *NH* 18.302). In terms recalling Greek farm structures, Columella (1.6.9–10) describes multi-storied farm buildings that stored liquid products, such as oil and wine, on the ground floor and grain and other dry products on an upper floor ventilated by small windows.[24] To keep out weevils and other vermin, agricultural writers recommended treating floors and walls, and sometimes the grain itself, with *amurca*, the lees of olive oil production. Glume wheats were often stored in spikelet form to guard against insects and fungus (Cato, *On Agriculture* 92; Columella 1.6.9–16; Pliny, *NH* 18.299, 305).

Some domestic spaces in urban areas also possessed storehouses. The private granary associated with the "Casa del Marinaio" (Reg. VII.15.15) in Pompeii provides one example. Although lying beneath the house, the granary had a single doorway on the north side opening onto a street. Constructed about 125–120 BCE, it had an earthen floor, thick walls, and numerous individual vaulted rooms off both sides of a central corridor (Franklin 1990; cf. Columella 1.6.12). In Herculaneum, storage was integrated into domestic space. So, for example, the Villa of the Papyri, a suburban villa located just outside the city, had a single room dedicated to storing loose grain. Several houses within the city possessed grain lofts in the form of an upstairs room. With walls covered with hydraulic mortar or having a series of masonry vats likewise lined, the room, supported by columns, extended out over the sidewalk. The loft, therefore, provided a dry environment with subfloor ventilation (Monteix 2008, 129–132). The most revealing archaeological evidence for grain storage, however, are the remains of large warehouses found in military camps and port cities.

Military stone-built *horrea* began replacing earlier wooden structures in Britain by the mid-second century CE.[25] Rectangular in shape and averaging about 20 m (65.5′) long and 8 m (26′) wide, they usually stood in pairs on high ground within the fort near the commander's residence. Walls, constructed of thick square stones up to 1.3 m (4′) thick, received exterior buttresses at intervals. Stone pillars or dwarf walls, either transverse or longitudinal, supported a raised wooden or flagstone floor. To increase subfloor ventilation, longitudinal floor supports, as at Corbridge (Figure 36.4), were broken at intervals in line with narrow vents inserted near ground level in the outer wall between buttresses. The roof, made of wood and covered with tiles, overhung the walls to provide cool shade and to allow water to run off at a distance from the building. Access to the interior was restricted to a door placed on one or both ends, sometimes preceded by a loading platform.

Aelius Aristides called Rome the "earth's warehouse" (*To Rome* 11), and with good reason. The capital city received vast quantities of merchandise from all over the Empire, much of which included food to support an ever-increasing population.



Figure 36.4 Military stone-built granary. Corbridge, Britain, third century CE. Note exterior buttresses and wall vents and interior flagstone floor supported on longitudinal sleeper walls. (*Source:* DeAgostini Picture Library/S. Vannini/Getty Images.)

By one estimate, the annual importation of cereal alone exceeded 400,000 metric tons and required 500,000 m^3 (653,975 yd^3) of storage space (Rickman 2002, 359). To accommodate this material, Rome possessed nearly 300 warehouses, large and small, known today primarily from literary and epigraphic sources. Many warehouses lay along the Tiber River or roads leading from the river toward the Forum, especially in the Aventine District in the area called the *Emporium*, where today stands Monte Testaccio, a hill formed by the broken remains primarily of oil *amphorae* from Spain (Rickman 1971, 87–122; Sebastiani and Serlorenzi 2011). Unfortunately, little remains of the city's warehouses beyond names and plans. *Horrea* in Rome's ports at Ostia and Portus, however, exhibit the same pattern as those built in the capital, located near the Tiber or along major roads. The buildings, some multi-storied, contained rows of deep narrow rooms that faced onto a central corridor or a square or rectangular courtyard, or, as at Portus, faced out from each side of a central wall. Thick walls, raised floors, and few windows and doors restricted access and kept the interior secure, cool, and dark (Rickman 1971, 15–86; Rickman 2002).

Horrea at other places in the Empire show similar characteristics, though expressing some local differences. Granaries at Karanis, a port city on the Nile River in the Fayum district of Egypt, for example, possessed features similar to those in Ostia, with the addition of underground facilities and some open bins suitable for the dry Egyptian climate (Husselman 1952). *Horrea* at Nauportus, lying on the Ljubljanica

River northeast of Aquileia, differed significantly from those in Ostia by having a row of long, narrow rooms opening their entire width onto a central market square (Horvat 2008).

How grain was stored inside granaries remains uncertain, but it was most likely contained in sacks, possibly placed within interior rooms or bins, since that would permit separate storage for different kinds of grain and allow old stocks to be distinguished from new ones (Palladius 1.19.2). Sacks stored in warehouses with cement or flagstone floors probably rested on wooden pallets to reduce moisture formation on the warmer grain. Thick stone walls, no windows, a solid roof, an elevated floor, particularly those made of flagstone, and limited access created a secure, dark, dry, cool room that provided the optimal environment not only for grain but for other food items which had similar storage requirements.

4. Storing Wine and Oil

The second and third legs of the Mediterranean Triad, wine and oil, had storage requirements different from those for grain. The farmhouse (Villa Regina) in Boscoreale had near the *torcularium*, or press room, a modest *cella vinaria* open to the sky which contained 18 partially buried *dolia* (*dolia defossa*) that kept the fermenting and aging wine cool and well ventilated (Figure 36.2). The Villa della Pisanella, also in Boscoreale, had a large *cella* of 72 completely or partially buried wine *dolia*, but its oil *dolia* sat on the ground near the oil press in a warm hallway (Figures 36.5R, Q, respectively).[26] Many port cities, such as Ostia and Massilia (modern Marseilles), also maintained *dolia* warehouses to store wine in bulk either awaiting export or sale to local retailers (Rickman 1971, 78–76; Hesnard 1995). Embedded *dolia* within warehouses, as with farms, were considered by law to be integral to the property (*Digest* 18.1.76; 19.1.26, 54). Varro describes rural fruit houses (*oporothecae*) built with windows facing north and walls, floors, and ceilings coated with marble cement to maintain a cool, dry environment (*On Agriculture* 1.59). After being cured in *dolia*, meat, such as pork, was hung in a special meat house (*carnarium*) until needed (Cato, *On Agriculture* 162.3; Columella 12.55. 3).

5. Conclusion

The frequent suggestions by Greek and Roman writers on ways to store food, particularly wine, olive oil, and cereals, the so-called "Mediterranean Triad," highlight the importance they attached to ensuring future access to these commodities. The ancients developed strategies to maximize quantity and to meet the technological challenges associated with storing a variety of foods with specific and differing storage requirements. From the Bronze Age on, for example, the primary storage vessel most often used by the ancients was the large terracotta *dolium* that was often buried to create a cool environment for wine. In addition, they devoted parts of farm buildings and houses or constructed special warehouses, *horrea*, to provide a dry, cool, dark environment ideal for storing grain and other foods with similar needs.

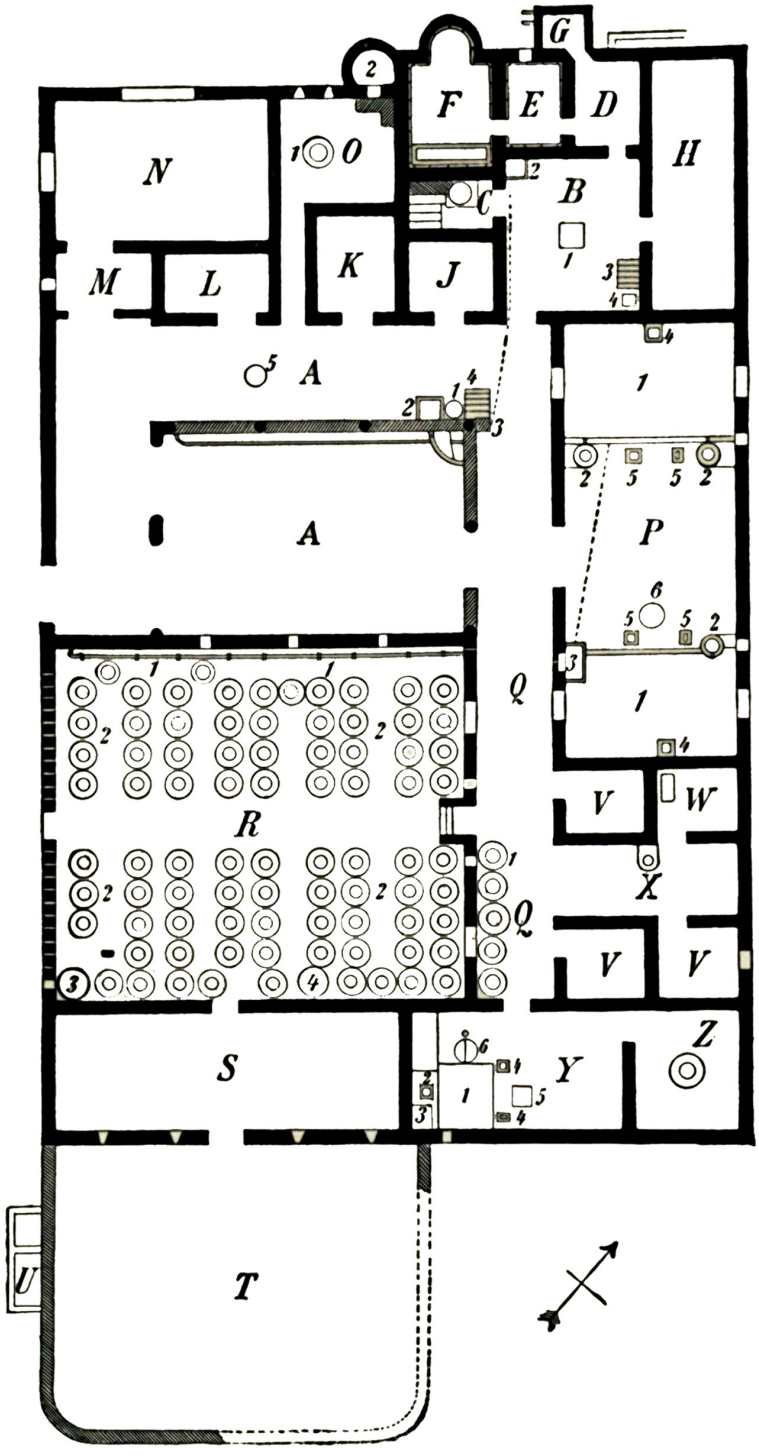


Figure 36.5 Plan of Villa della Pisanella, Boscoreale, first century CE. (Adapted from Mau, A. 1907. *Pompeii. Its Life and Art.* New York: The Macmillan Company. Plan IV, 361.)

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FURTHER READING

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Christakis 2005. Similar to Peña's study of Roman ceramic, but focused on the utilitarian Bronze Age *pithos*.

Cullen and Keller 1990. Brief chronological survey of the uses and artistic and literary imagery of Greek *pithoi*.

Curtis 2001. Wide-ranging discussion of food processing and storage from prehistoric times to the Roman period.

Giannopoulou 2010. Detailed ethnographic study of how *pithoi* were manufactured from the Greek Neolithic to the Byzantine period.

Peña 2007. Excellent overview of the life cycle of Roman pottery, generally, i.e., manufacture, distribution, use, reuse, maintenance, recycling, discard, and reclamation.

Rickman 1971. Still the standard work on Roman grain storage.

Thurmond 2006. Good explanations of the technical aspects of Roman food processing.

NOTES

1 Translations of most ancient sources cited can be found in the Loeb and Budé series; otherwise, the edition used can be found in the list of references.

2 Pulses, such as lupins, chickpeas, lentils, and faba beans, should probably also be included (Sarpaki 1992). For technical details of producing wine and olive oil and processing cereals, see Curtis 2001, Thurmond 2006, and OIL AND WINE PRODUCTION.

3 Brenni 1985, 10. I employ the term *pithos* when referring specifically to Greek storage vessels; otherwise I use the Latin term *dolium*.

4 Peña 2007, 194–196. Romans raised dormice in specially designed *dolia* (Varro, *On Agriculture* 3.15; Beerden 2012).

5 Brenni 1985, 9–10, 31–32; Tournavitou 1992; Giannopoulou 2010, 34, 41–42. Pliny (*NH* 14.134) states that excessively pot-bellied and wide-mouthed *dolia* were not suitable for wine storage. While many, but not all, earlier *pithoi* were made of coarse-grained fabric, by the Classical period Greek and Roman storage vessels had a finer fabric (Cullen and Keller 1990, 199).

6 While Peña (2007) discusses *dolia* as part of a general survey of Roman pottery, the only study to focus on Roman *dolia* is the 1985 MA thesis of Gianmarco Brenni. Brenni's work is a good start, but much remains to be done.

7 *Digest* 8.3.6; Brenni 1985, 7–8; Devos, De Paepe, and Vermeulen 1999, 96; Peña 2007: 33. Owners of large farms with clay pits may have provided material for the specialist potter. Columella (1.2.23), however, does not consider pottery manufacture as part of agriculture. Cato recommends the purchase of *dolia* in towns, especially Alba and Rome (*On Agriculture* 135).

8 Giannopoulou 2010, 66–70; Peña 2007, 35. Literary sources have little to say about how the skilled potter made a *dolium*. Pollux in the second century CE refers to a wooden frame (*kannabos*) in the shape of a *pithos* onto which the potter would pack clay to mold the vessel into the desired shape (*Onomasticon* 7.164). Archaeological evidence for this method, however, is lacking.

9 Cato, *On Agriculture* 39.1; Juvenal 14.308–310; Brenni 1985, 11–12, 33; Peña 2007, 213–227. Some *dolia* were mended by being bound with rush branches (Varro, *On the Latin Language* 5.5: *dolia sirpata*); Cato (*On Agriculture* 39.1) recommends a binding with oak wood in combination with a cement, for which he gives the recipe, followed by pitching.

10 Olive oil: Cato, *On Agriculture* 69.1-2; Columella 12.52.14–17; Christakis 2005, 52; wine: *Geoponica* 6.4–8; Columella 12.18.5–7; Brenni 1985, 34; Peña 2007, 211–213. The absence of an interior coating may suggest storage for cereals (Kimpe et al 2004).

11 Brenni 1985, 11, 32–33; De Caro 1994, 67. Cf. Cato, *On Agriculture* 11.2 (*opercula doliorum et tectaria priva*).

12 Brenni 1985, 188–191. Some *dolia* had scratched into their lip a number that Brenni interprets as indicating the vessel's capacity. The largest he records is 2,560 liters (675 gallons).
13 *Edictum Diocletiani* 7.1. Roman *dolia* apparently lacked any price indications, or, at least, Brenni (1985) does not mention them.
14 Romans also used other storage jars similar to or almost indistinguishable from *dolia*, such as the *metreta* (Cato, *On Agriculture* 100), *orca* (Varro, *On Agriculture* 1.13.6; Columella 12.15.2), and *seria* (Columella 12.55.4; Cato, *On Agriculture* 162). See White 1975, 166–167, 180–183, 185–188, respectively.
15 Cato, *On Agriculture* 4, 10.4, 11.2, 69, 162.1; Columella 12.44.2–3, 46.4, 47.1, 56.3; Pliny, *NH* 15.60–62; Palladius 4.10.33.
16 Jones 1987; Tournavitou 1992; Tzedakis and Martlew 1999, 144–147, 159–160; Wendrich et al. 2003; Mahon 2005; Christakis 2005; Stefani 2006, 157–160; Monteix 2008, 129; Lis and Rückl 2011.
17 Whether the four large, subterranean, circular *koulouras* in the Middle Minoan palace at Knossos were granaries remains debatable (Strasser 1997; Halstead 1997).
18 The Early Cycladic Melos Vase (2300–2100 BCE), found in Phylakopi, is a model of an above-ground granary complex composed of seven circular bins, but they lack their roofs (Oelmann 1925).
19 Isager and Skydsgaard (1992, 68) remain unconvinced that any particular building type always had an exclusively agricultural function.
20 Varro, *On the Latin Language* 5.105; Kaufman 1929; Salido Domínguez 2011b, 40–50. For other synonyms, see Dubouloz 2008; Geraci 2008.
21 Porfyrion, scholiast on Horace, *Ode* 3.12.18 (Holder and Keller 1894, 156), states "Moreover, today the warehouse (*horrea*) of Galba is filled with wine and oil and other similar things." Cf. Columella 2.10.16 (lentils); 12.15.2 (dried figs). See also Rickman 1971, 171; Rickman 2002, 361–362.
22 *CIL* 6.9801 (fish vendor in the *Horrea Galbae* at Rome); Dubouloz 2008; Capponi 2011; Virlouvet 2011.
23 Kaufman 1929; Dubouloz 2008, 286–289; Virlouvet 2011, 16.
24 Late-Roman villa owners, showing an increased concern for greater storage capacity, often utilized upper floors for food storage (Métraux 1998).
25 Gentry 1976; Johnson 1983, 142–157. For a discussion of military granaries in other provinces of the western Empire, see Salido Domínguez 2011b.
26 Columella 1.6.18; Brenni 1985, 46; DeCaro 1994, 63–69; Stefani 2006. Two buried *dolia* at Villa della Pisanella held cereal. On the necessity of a warm environment for oil, see Columella 1.6.18; Palladius 1.20.

CHAPTER 37

Culinary and Medicinal Uses of Wine and Olive Oil

John F. Donahue

1. Introduction

In his *Epitome* (a summary of a work written by the first-century historian Pompeius Trogus), the Roman author known to us only as Justin provides this assessment of what the early Greek colonists were able to teach the Gauls, predecessors of the inhabitants of modern-day France:

> The Gauls learned from these peoples, therefore, a more civilized way of life, their barbarian ways being laid aside and also softened; and they learned to cultivate their lands and to enclose their towns with walls. At that time, they also grew accustomed to live by laws, not by weapons; *then they learned to prune the vine and to plant the olive*; and such distinction was laid upon both men and their affairs, that it was not the Greeks who seemed to have immigrated into Gaul, but Gaul into Greece. (*Epitome* 43.4.1)

This passage is typical of an important theme in ancient history—the civilizing power of the Greeks and Romans. While we now know that this process was far more complex than Justin's top-down model suggests, there is no disputing the fact that the attributes of the civilized life that he speaks of—settled agriculture, peace, and the rule of law—were important features in the dissemination of Greco-Roman culture throughout the Mediterranean basin and beyond. But so too were diet and health, which were closely linked to agricultural production. This was especially the case with grapes and olives, which required specialized knowledge of planting, harvesting, and processing and, taken together with grain, formed a dietary triad that was every bit as important to ancient identity as politics, law, literature, and art.

This is not to suggest, of course, that grapes and olives were the only foodstuffs consumed by the Greeks and Romans. In reality, there was no single monolithic diet;

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instead, trade, as well as variations in region, custom, climate, and belief ultimately provided access to a wide assortment of fruits, vegetables and, when possible, meat and fish, while sauces, relishes, and spices served to provide additional balance, texture, and flavor enhancement to ancient dishes (Wilkins, Harvey and Dobson 1995; Brothwell and Brothwell 1997; Horden and Purcell 2000; Wilkins and Hill 2006).

Even so, within this framework of food availability and choice, grapes and olives endured as especially favored commodities. One reason had to do with the fact that the products produced from these foodstuffs—wine and olive oil, respectively—were widely traded and thus became essential components of the ancient economy (Purcell 1985; Tchernia 1986; Foxhall 2007). Equally significant, however, was the reality that wine and olive oil required careful cultivation and processing, and so they came to be regarded as symbols of a civilized people (Nadeau 2012). It is not entirely surprising then that Justin considered the Gauls fully civilized only when they had mastered the art of the vine and the olive tree. Indeed, success in these endeavors meant assimilating some of the most cherished of Greco-Roman ideals, namely, those having to do with the fertility of the land and the cultural primacy of the farmer and his farm.

Given the cultural importance of wine and olive oil in Mediterranean life, we will focus on the culinary and medicinal uses associated with them. As we shall see, it is here that the ancient evidence is most complete, thereby allowing us to appreciate more fully the versatility of these two commodities as well as the ability of the Greeks and Romans to process and utilize them in ways that would have significant impact, especially for ancient diet and health.

2. Processing and Production of Wine and Olive Oil

Wine and olive oil were essential to ancient Mediterranean culture as both substance and symbol. As the most favored and prestigious of beverages in the Greco-Roman world, wine could boast of a long history (McGovern, Fleming and Katz 1996; Unwin 1996; McGovern 2003, 2010); associations with the divine in the form of Dionysus, god of the vine (Hyams 1987; Carpenter and Faraone 1993; Seaford 2006); a central place in established drinking parties such as the Greek *symposion* (Murray 1990; Lissarrague 1990; Dalby 1996; Braund and Wilkins 2000; Davis in Harrison 2007) and Roman *convivium* (Slater 1991; Dunbabin 1993); and the advantage of making its consumers quite happy (Dalby 2003; Dietler 2006). The olive and olive oil enjoyed a similar status. Roman olive traders considered *Hercules Olivarius*, "Hercules the olive-farmer," as their patron, while Herodotus records that the Greeks attributed the first olive tree to Athena on the Acropolis in Athens (8.55). The cultural and culinary appeal of the olive was further enhanced by the unique properties of the olive tree itself, which the ancients considered the "queen of all trees" (Columella 5.8). Indeed, while it did not grow everywhere (Garnsey 1999, 14), given the proper conditions, the olive tree could produce fruit for many hundreds of years in the most favorable regions of Greece and Italy. It is no wonder, then, that Lawrence Durrell wrote in *Prospero's Cell* that the entire Mediterranean "seems to rise in the sour, pungent taste of these black olives between the teeth. A taste older than meat, older than wine" (Davidson 2006, s.v. "olives and olive oil"). A useful approach to understanding the culinary importance of these time-honored foodstuffs is to approach them first through the technological processes by which they were created, especially since products of varying quality could be produced at different stages of the

production process (Amouretti and Brun 1993; Thurmond 2006; Oleson 2008; Oil and Wine Production).

For both grapes and olives, the fruit had to be crushed and then pressed. In the case of grapes, a final process—fermentation—produced wine. The crushing of grapes was achieved by treading with human feet, a simple method that changed little over the course of antiquity. In regard to the development of additional technology, portable crushing apparatuses have not survived, and permanent treading floors have not always been easy to connect with wine. Even so, we know of installations that doubled as a site both to crush and to press grapes, such as the first-century Roman pressroom in the Villa of the Mysteries at Pompeii (Curtis 2008).

Like the grape, crushing the fruit of the olive into pulp to obtain olive oil was made possible by treading, but also by the early use of the pestle and mortar and the stone roller. As olive oil production increased in the Hellenistic and Roman periods, more sophisticated technology, such as the Roman *trapetum*, a rotary olive crusher, emerged. Archaeological remains of this device and its description as provided by the likes of the Roman historian and agricultural writer Cato (*On Agriculture* 20–22) leave us well informed about its operation, although its relationship to similar devices mentioned in the sources and the means by which it was able to avoid crushing the pit with its bitter taste is uncertain. In a final step, the mixed oil, water, and olive juice (*amurca*) settled in vats until the oil rose to the top and could be skimmed and stored in *amphorae*. The Greeks and Romans believed that the best oil came from "white," that is, "green" olives, picked early, although it was the ripe "black" olives that contained more oil.

Pressing was the most critical aspect of the processing operation, for this phase truly marked the dividing line between agriculture and food technology. Here, the technology advanced from the lever and weight press of the sixth century BCE to the direct screw press of the first century CE, with the most important advantage being an increase in efficiency and output and a reduction in the labor required. Curtis offers a useful summary of these devices (Curtis 2008). For our purposes, it was the result of this process that is most important.

Must (*mustum*), the juice produced from pressing the grape, was typically gathered in a tank (*lacus*) and then transferred to a deep fermenting vat (*dolium*), where its culinary usage depended upon whether it was fermented for wine or used immediately as a non-alcoholic beverage. The must destined to become wine was sealed and left in the *dolium* for as many as four months, after which time the mature wine was drawn off. According to the ancient sources, the resulting wine might display a range of colors, although it is difficult to say on the basis of the evidence how this range relates to the modern distinction between red and white wine (Dalby 2003, s.v. "wine-making"). Setting aside this question, the ancients, especially the Romans, zealously ranked vintages according to quality. Pliny the Elder devoted the entire fourteenth book of his *Natural History* to wine. In all, this work cites fifty kinds of quality wines, nearly twice as many varieties of vines, and some forty varieties of foreign wines (French and Greenaway 1986; Tchernia and Brun 1999; Robinson 2006). Equally prominent was the ancient custom of flavoring wine. The sources mention six kinds: salted wine, whose flavor was added before fermentation; pitched, resinated, and smoked wines, which acquired their flavors from the *dolia* used in fermentation; and two wines flavored after fermentation: *mulsum*, which contained honey (Dalby 2003, s.v. "mulsum"), and *conditum*, a spiced wine (Dalby 2003, s.v. "conditum").

3. Culinary Uses of Wine

It is clear from the sources that the ancients were thoroughly familiar with how to cook with wine, whether as a marinade ingredient, as a cooking liquid, or as a flavoring in a finished dish. As an example of wine used as both a marinade and cooking liquid, the fourth-century collection of recipes (*The Art of Cooking*) bearing the name of Apicius, the proverbial name of several Roman connoisseurs of food, has preserved a recipe for vegetable stew that utilizes two different wines, including *passum*, made from semi-dried grapes:

> Vegetable stew. Cook bulbs in *liquamen* [an alternate Latin name for *garum*, a very popular fermented fish sauce], oil, and wine. When they are cooked, add pig's liver and legs and wings of chicken, cut up. Let all of this cook with the bulbs. When it is done, pound pepper, lovage, moisten with *liquamen*, wine and *passum* to sweeten. Add some of the cooking liquor. Pour this back on the bulbs. As soon as they boil, thicken with cornflower. (Apicius 4.5.2)

Elsewhere in Apicius, we find wine as an ingredient in more than two dozen recipes, including purees, fricassees, and stews, as well as sauces for meat and seafood. Typically, it is only the generic term for wine, *vinum*, which is recorded in these recipes. As a result, it is difficult to know what kinds of wine might have been utilized in various dishes. Even so, it would seem likely, as is the case with modern cooking, that the Greeks and Romans would have cooked with wine that they normally consumed, since to do otherwise would have risked ruining a dish with an unfamiliar or inferior vintage. By the same token, the fact that there is scant evidence for including superior vintages as ingredients in cooking suggests that the ancients reserved these strictly for drinking, especially within the social context of the drinking parties mentioned earlier.

For the juice that was not fermented, we know of several usages. Especially popular was *defrutum* (in Greek, *hepsema*), must juice that had been boiled down to grape syrup. Apicius reveals that *defrutum* was essential for providing sweetness, flavor, and color in cooking, especially as a sauce with boiled and roasted meats and with seafood of various kinds. Grape juice boiled down to two thirds of its volume (*caroenum*) or to one third (*sapa*) were similarly used as a sweetener and coloring agent. Typical is the use of *caroenum* in this recipe for squid (note the lack of precise measurements, a standard feature in ancient cookery):

> Squid in the pan. Pound pepper, rue, a little honey, *liquamen*, and *caroenum*, add a few drops of oil, <and cook the squid in this in a shallow pan in which you also serve it>. (Apicius 9.1.1)

Finally, given the reality that the Greeks and Roman inhabited a pre-industrial world where famine may have been infrequent but food shortages were common (Garnsey 1988, 1998, 1999; Alston and van Nijf 2008), nothing could go to waste, including wine. A common practice was to utilize the detritus of the wine-making process to produce inferior wines, typically designated for slaves. Accordingly, we know of *lora*, an after-wine made from water mixed with the grape skins left over after pressing, and a *vinum familiae* (wine for the slave family), fermented and flavored with brine

and vinegar (Cato, *On Agriculture* 104). The product of a secondary fermentation of wine, vinegar was widely utilized as a culinary ingredient and as a preservative. Closely related to this beverage was *posca*, a drink based on vinegar heavily diluted with water and infused with herbs. Used as an everyday drink by the army and the urban poor, it was especially popular among the Romans, who found it to be economically convenient, since faulty storage of wine tended to produce vinegar. We also know of a *vinum faecatum*, made from the lees or sediment from the fermentation process (Cato, *On Agriculture* 153), and a *vinum praeliganeum*, a wine that would have been undesirable because it was made quickly from early-ripe grapes; Cato distributed this to his vintagers (Cato, *On Agriculture* 23).

Similarly, there were uses for wine that was old or had become bad. Old wine could be used in any number of dishes, as in recipes for cabbage (Apicius 3.9.1). When wine went bad, the ancients were anxious to extend its culinary life, sometimes through unorthodox but creative techniques. Cato, the exemplar of the frugal Roman farmer, would remove a bad odor from wine by thoroughly heating a thick, clean piece of roofing tile in a fire and, when hot, coating it with pitch, attaching a cord to it, and gently lowering it to the bottom of a jar, which he then sealed for two days. If the odor remained, he repeated the process (*On Agriculture* 110). Clearly, the goal here was to restore a smoky flavor to the wine, an essence with which consumers would have been familiar, while at the same time masking the undesirable odor. Masking or eliminating undesirable tastes or odors was common in ancient cookery, a reality that helps to explain in part the widespread appeal of sauces of all kinds in ancient cuisine.

4. Culinary Uses of Olive Oil

The olive and its oil were similar to the vine in that they were an important focus of ancient agricultural writers, who have provided much information on varieties (Columella 5.8; Pliny, *NH* 15.4), as well as on soil preparation, planting (Cato, *On Agriculture* 6–7, 45, 64–68), and processing and preserving (Cato, *On Agriculture* 64–68; Columella 12.49). Indeed, Cato's manual on farming, the first Roman prose text (circa 175 BCE), devotes more space to olive growing and oil making than to any other agricultural activity. Here, Columella confirms several of the advantages that the olive tree offered to the ancient farmer, qualities that have endured in modern times:

> For although it does not bear fruit every year but generally in alternate years, nevertheless it is thought of most highly because it is maintained by very light tending and, when it is not covered with fruit, it requires hardly any expenditure; also, if anything is spent upon it, it promptly multiplies its fruit. If it is neglected for many years, it does not deteriorate like the vine, but even during this period it nevertheless offers something to the head of the household and, when it is cultivated again, it recovers in a single year. (5.8)

As a fruit, olives are rich in calories, essential fats (lipids), and vitamins, and they contain significant traces of important minerals. They also contain higher levels of calcium than other vegetables, meat, and fish, and they are 100% digestible as a fat. One hundred grams (3.5 ounces) of olives provides 900 to 1,000 calories. In contrast, the calorific value of wine is slight: a full 70 centiliter (23.5 ounces) bottle of wine was equivalent to a mere four centiliters of oil (1.3 ounces; Mattingly in Shipley and Salmon 1996).

The ancients were certainly not aware of all of these properties, but they no doubt recognized the nutritional value of the olive and its oil. In ancient cuisine, the olive was common as an ingredient in salads and as an appetizer. Concerning the latter usage, we are reminded of Trimalchio's notoriously garish dinner, in which a donkey in Corinthian bronze stood on a sideboard, with panniers holding olives, white in one side, black in the other (Petronius, *Satyricon* 31). Although popular, the olive is naturally bitter and thus has to be cured with salt before eating. In fact, the olive remains unique among cultivated fruits in that no variety has ever been developed that can be eaten in its natural state.

To be sure, the olive was more widely embraced for what it yielded from the pressing process—olive oil. In a culinary context, olive oil (*elaion* in Greek, *oleum* in Latin) was quite versatile. Apicius records its use in more than thirty recipes, where it served as a marinade for meat and fish; as a cooking medium; and as a conserving agent. Olive oil was equally popular as a dressing for cooked food and green vegetables, as in this simple recipe for boiled turnips:

> Another method. Boil the turnips, serve sprinkled with oil; adding vinegar if liked. (Apicius 3.13.2)

Two additional features enhanced its appeal. First, olive oil enjoyed a higher "smoking point" (the boiling point at which a liquid begins to smoke, typically resulting in flavor and nutritional degradation) than water, thereby increasing its utility as a cooking medium. Second, it was important for providing nutritional balance and for making a grain-based diet more palatable. We now know that olive oil is high in monounsaturated fats ("MUFs," commonly identified as "healthy" dietary fat) as well as antioxidants, vitamins, and nutrients (Donahue, 2015). The ancients were not aware of these many advantages, of course, yet they benefited from them nonetheless by relying on olive oil for the fat requirements in their diet.

Finally, like wine, the quality of olive oil ultimately depends on a host of factors, including fruit variety, growing conditions, harvesting practices, and storage. Because quality is so closely tied to these factors, and because, once extracted, the oil has to be kept in a dark place with limited contact with air, monitoring was critical. Cato has left us well informed on this topic in his description of the olive oil watchman, responsible for maintaining the pressing equipment, supervising the pressing room personnel, and preventing theft (*On Agriculture* 67; for more on storage, Food Storage Technology).

5. Greco-Roman Medicine and Health

While wine and olive oil were staples of the Greco-Roman kitchen, they were also critical components of ancient medicine. This was because, by the fifth century BCE, the Greeks had embraced the notion that bodily processes, health, and disease did not depend on divine intervention but could be explained in the same way as other natural phenomena and that, as part of this thinking, food and drink played a critical role in maintaining health. In fact, in its broadest sense, the ancient Greek word for "diet" (*diaita*) meant not only choices of what to eat but also a way of life that included proper attention to exercise, sexual activity, hygiene, and sleep (Grmek 1989, 1998; Conrad et al. 1995; Nutton 2013; Holmes 2009).

Within this context of a more rationalist approach to medicine was the belief that health and illness were related to the notions of balance and imbalance in the body, a belief that was prominent from the time of the Hippocratic Corpus of the fifth century BCE through the Roman period and beyond. This belief was tied to a more complex theory that recognized four essential fluids, or bodily "humors"—bile, phlegm, blood, and black bile—as essential to health. Each humor was linked to a certain season (bile/summer, phlegm/winter, blood/spring, black bile/autumn), making it mandatory to adjust diet in order to counteract the effects of the environment on the body. So, for example, hot, dry foods were better in the winter, which was cold and wet, whereas, cold, moist, and easily digestible foods were preferred in summer, when it was hot and dry. Age and gender also played a role in this scheme. Children were thought to be warm and moist; young men warm and dry; mature men cold and dry; and old men cold and moist. Men were generally considered warmer and drier than women (Hipocratic *On Regimen* 1.23–24; Flemming 2000; Holmes 2009).

The key to this system was maintaining the proper balance among the humors by removing whatever was in excess and building up whatever was deficient in the body through certain foodstuffs thought to contain powers (*dynameis*) for maintaining health and for nourishment (*trophē*). Critical too in this system was the concept of cookery, or concoction. This was the result of a belief common among most ancient physicians that foods were absorbed through the blood vessels after they had been ingested and then transformed into liquid in the stomach (Wilkins and Hill 2006, 227–230). Digestion, therefore, was a form of cooking, and through a process of trial and error man was able to determine which foods were easier to digest and concoct (Hippocratic *Ancient Medicine* 3.36–54).

6. Medicinal Uses of Wine

Turning to wine and oil within this medical scheme, the Roman encyclopediast Pliny the Elder offers a useful starting point. Intensely interested in all aspects of viticulture, Pliny is recorded as saying that two liquids were especially agreeable to the human body, wine for the inside and oil for the outside (*NH* 14.29). As we shall see, while Pliny's assessment may be a bit too restrictive, it nonetheless confirms the power of these two foodstuffs in the ancient mind and helps us to understand how they were most commonly utilized in a medical context.

To consider wine first, evidence indicates that the Hippocratic physicians were the first to prescribe undiluted wine and that it was one of their main medicines. Especially striking in the Hippocratic writings and in much of the subsequent medical literature is the absence of any extravagant claims for wine; even so, its popularity is reflected in the wide variety of afflictions for which it was believed to be an effective remedy throughout the Greco-Roman period. Here, we shall briefly examine three of the most popular therapeutic uses of wine: as a disinfectant and astringent, most commonly for wounds; as a medicine for all kinds of afflictions, especially internal maladies; and as a substance mixed with or used in conjunction with other materials in order to effect a cure.

As a disinfectant, wine may have fallen outside of Pliny's assessment of its internal efficacy, yet its role here was essential. In the second century CE, Galen typically soaked exposed abdominal organs in wine before returning them to the abdominal cavity when

treating the severe stomach wounds suffered by those gladiators whom he attended early in his career (Singer 1997; Grant 2000; Powell 2003; Nutton 2013, 222–235). Further, given that gladiators were most often wounded in the summer when many of the contests were staged, there was a need to keep the wounds moist. Galen accomplished this by soaking linen cloths in wine and placing the folds on the wounds, and by covering these cloths in soft sponges, which he kept moist day and night (Mattern 2013, 93). Celsus, who wrote eight books on ancient medicine at Rome in the century before Galen (Hanson in Potter 2006), displayed a similar understanding, as he prescribed squeezing cold water or wine out of a sponge to agglutinate a wound (5.2). Finally, we know that wine was commonly utilized as an astringent to stop blood flow, a necessity in the case of wounds. Wool soaked in either red or white wine is attested (Hippocratic *Use of Liquids* 5), as was the use of various by-products of the wine-making process, including *oinanthe*, an oil or extract made from the vine itself or white wine (Pliny, *NH* 23.5). Although ancient physicians and medical writers knew nothing about pathogenic microbes, all of these practices connected with the treatment of wounds were medically advantageous, especially in light of modern studies which have shown that the ethanol and acidity in wine have the power to destroy microbes that cause food-borne illnesses (Mattern 2013, 93).

As a medicine, wine served most commonly as a remedy for fevers, as a purgative, and as a diuretic. For fevers, the emphasis was on wines with weaker alcohol content, often cut with cold water in an attempt to keep the patient cool. Thus do we find reliance on a range of options—white raisin wine, diluted wine made from pressed grapes, boiled-down barley water and sweet wine, and a recipe for an "old Thasian wine," consisting of 25 parts water and 1 part wine (Hippocratic *Diseases* 3.17). Celsus too called for wines for a range of fevers (3.14.1–2; 3.15; 3.16), as well as the use of dry wine added to an anointing mixture to keep the body cool (3.6.16). Not all Greco-Roman writers on medicine agreed with vino-therapy for fevers, however. Pliny (*NH* 23.24) argued that wine was never to be administered for a fever, unless the person was older or the symptoms had begun to lessen.

Gastro-intestinal and urinary ailments were some of the most common maladies recorded in the ancient medical literature. As a result, the use of wine as a purgative, or laxative, and as a diuretic to increase urine flow was clearly recognized by the Hippocratic physicians of the fifth century BCE, who were keen to classify the effects within the body produced by different varieties of wines:

> Water is cooling and moist. Wine is hot and dry, and it has something purgative from its original substance. Dark and harsh wines are more dry, and they pass well neither by stool nor by urine, nor by spittle. They dry by reason of their heat, consuming the moisture out of the body. Soft dark wines are moister; they are flatulent and pass better by stool. The sweet, dark wines are moister and weaker; they cause flatulence because they produce moisture. Harsh white wines heat without drying, and they pass better by urine than by stool. New wines pass by stool better than other wines because they are nearer the must, and more nourishing; of wines of the same age, those with bouquet pass better by stool than those without, because they are riper, and the thicker wines better than the thin. Thin wines pass better by urine. White wines and thin, sweet wines pass better by urine than by stool; they cool, attenuate and moisten the body, but make the blood weak, increasing in the body that which is opposed to the blood. Must causes wind, disturbs the bowels and empties them. It causes wind because it heats; it empties the body because it purges; it disturbs by

> fermenting in the bowels and passing by stool. Acid wines, cool, moisten and attenuate by emptying the body of its moisture; they moisten from the water that enters with the wine. (Hippocratic *On Regimen* 2.52)

What is remarkable to note here is the detailed nature of this system, surely the result of much trial and error over a long period of time. Even more impressive is this: that Hippocratic medicine had established mechanisms for accelerating and retarding bowel movements, urinary flow, hydration, and dehydration of the human body in relation to the ingestion of grape extractives, acids, tannins, and alcohol, and that these precepts were to endure throughout the Greco-Roman period.

Wine found its most extensive medical application when it served as a delivery vehicle for other drugs or when it was mixed with or was taken in conjunction with other substances (see PHARMACY). Since the evidence is more plentiful than can be reasonably treated here, a few testimonia will have to suffice in order to help us understand the versatility of wine in these contexts. Wine was very important as a nutriment, especially as *kykeon*, a mixture of barley, wine, and milk (Norrie 2003; compare *Homeric Hymn to Demeter* 210). For tapeworms, Cato prescribed that thirty pomegranates be crushed, placed in a jar with one and a half pints of strong black wine, sealed for thirty days, and then drunk before eating (*On Agriculture* 126). Wine also was a key ingredient in plasters to relieve affected body parts. Among many possibilities, we find a plaster of darnel meal boiled in diluted wine and mixed with sour wine lees (Celsus 4.29.2). Common too were salves and ointments for disorders of the eyes, a widespread affliction in antiquity due to the smoke produced from the oil lamps used for lighting. One such treatment called for pounding up saffron and myrrh in raisin wine and applying it on a probe to the eyeball (Celsus 6.6.1I). Skin disorders, especially burns and lesions of all kinds, called for wine as an element of relief (Hippocratic *Ulcers* 12; 22; Celsus 5.27.13), as did tooth pain and swollen gums (Celsus 6.9.2; 6.13.2).

As several of these testimonia reveal, there was a strong interest in ancient medicine in the therapeutic properties of all kinds of substances used for healing, a field commonly referred to as *materia medica* in antiquity, more generally as pharmacology today (PHARMACY). In *Aphorisms* and *Prognostics,* Hippocrates discussed more than 250 drugs, along with diet and diseases, while in the fourth century BCE, Theophrastus, the "father of botany," detailed medicinal herbs and herbal concoctions for physicians in his *Enquiry into Plants* (Jashemski 1999, 2002; GREEK AND ROMAN BOTANY). Galen, too, displayed great interest in the topic. Most important, however, was Dioscorides, who described some 600 pharmaceuticals in his *Books on Medical Material*, the most complete account of drugs and drug lore of Greek, Hellenistic, and early Roman Imperial times (Riddle 1985; PHARMACY). His work was typical in showing the overlap in ancient thinking between food and drugs in ancient thought, an inevitable consequence in a world where foodstuffs played a major role as substances for healing, given the absence of synthetic remedies. As we have seen already, wine was often indispensable in these concoctions. A final passage from Dioscorides provides a useful summary of the way in which wine could interact with other materials to provide relief for multiple ailments:

> The expressed juice from dried roses that were boiled in wine is effective for headaches, hurting eyes, earaches, hurting gums, anal pains, and for pains of the uterus when smeared on with a feather brush and when used as a wash. (Dioscorides 5.35)

The extent to which these remedies provided actual relief, of course is an important question to be addressed more fully at the end of this chapter.

7. Medicinal Uses of Oil

Although, like wine, olive oil was popular as a medicament for all kinds of afflictions, olives were not widely used in a therapeutic context in antiquity. About the olive, we learn from Celsus that it was considered a "weak" food nutritionally, to be classified with the likes of vegetable stalks, orchard fruits, snails, and shellfish, in contrast to "stronger" foods such as all breadstuffs made from grain (2.18.3). Even so, it possessed important attributes. The olive was agreeable to the stomach, especially white olives preserved in brine or vinegar, as well as black olives well ripened on the tree or preserved in raisin wine or boiled-down must. They were also among the least flatulent of foods and, when ripened, were thought to be good for the bowels (Celsus 2.24, 2.26, 2.29).

We are much better informed about olive oil. It is clear from the sources that, along with wine, olive oil was considered a staple of ancient medicine. Surely, part of its appeal lay in the fact that it was the only oil from plants that could be eaten raw and untreated. Like honey, then, it was a completely natural substance that did not have to be manipulated in ways that would have adulterated it. In addition, olive oil contains vital antioxidants and various vitamins with the ability to enhance and repair components of human skin.

The ancients, while unaware of these properties, nevertheless recognized the efficacy of olive oil and incorporated it into a number of therapies. Essentially, olive oil was important to the ancient mind because it was able to warm, moisten, and soften (Hippocratic *On Regimen* 2.58). As a result, its most common use was for the care of the skin, where there is much evidence for its use in plasters and on bandages to treat all kinds of afflictions, including surgical cuts (it was placed on the neck after a tonsillectomy), treatment of lesions and burns (Hippocratic *Diseases* 2.30, 2.13; Hippocratic *Ulcers* 11, 22), and also to soothe hemorrhoids (Hippocratic *Hemorrhoids* 3) and headaches (Celsus 3.9). Equally popular, it seems, was the use of olive oil in baths and in anointing the skin for various purposes. Oribasius, a Greek medical writer and personal physician of the Roman emperor Julian in the fourth century CE, preserved the works of many earlier physicians and medical authors, including that of Mnesitheus of Athens, an advocate of anointing as part of the regimen of young children:

> Regimen for young children. Excerpts from the works of Mnesitheus of Athens. The nurse must utilize a bath, bathing the child at length and using lukewarm water. During the first year, she must do this three times a day: in the morning after exercise; then at mid-day; and thirdly in the evening. After this time, she must remove the warm mid-day bath and replace it with an anointing of oil. Do not feed the child immediately after the bath, but wait. Do not give him anything to chew, but very fine wheaten flour that has been boiled or wheaten meal or crushed millet. (Oribasius, *Uncertain Books*, 37 = *CMG* 6.2.2, 135)

Other attestations for olive oil include its use an ingredient in ointments for the eyes, (Hippocratic *Regimen in Acute Diseases* 65), enemas for bowel disturbances (Celsus 2.12) and as a major component of soap (Hippocratic *Regimen in Acute Diseases* 65). Athletes regularly anointed themselves with olive oil as well, although it is difficult to

know if they did so in the belief that it provided various health benefits—making them stronger, protecting them from the sun and the elements, and preventing the loss of body fluids during exercise—or if the oil on their glistening bodies simply served to draw attention to their aesthetically pleasing physique (Miller 2006, 15; Regimen and Athletic Training).

8. The Question of Efficacy

To conclude, it is worthwhile to consider briefly if therapies such as those presented here concerning wine and olive oil actually worked. The question is linked to two larger issues. First, in trying to assess the effectiveness of foodstuffs like wine and olive oil as medicines, we must realize that the ancients often did not define illnesses in the way that we do. Not only were maladies often presented in a vague way, but also the treatments prescribed often depended on factors specific to the individual patient, such as age, gender, temperament, and environment. Furthermore, all of these factors had to be taken into account within the broader therapeutic framework of a humoral system whose aim was always to preserve or restore balance within the body. On the other hand, in modern medicine the same disease is often given the same treatment for all patients, a system that has been described as prescribing "a pill for every ill" (King 2001, 52).

Second, to what extent can we suppose that the placebo effect existed in ancient medicine, whereby a substance with no biochemical advantage was administered with the result that the patient sometimes felt better? After all, it is not difficult to see that wine with its ability to produce euphoria and olive oil with its soothing effects on the skin certainly had the power to ease suffering, even if the medical basis for such relief was not always clear. Even so, the question is not so easily answered, especially when we consider the wider social and culture settings within which ancient medicine operated. Religious belief, for example, most certainly played a role in ancient perceptions of medicine and healing. The person who paid a fee to sleep or "incubate" in the Temple of Asclepius in the hope of finding a cure for a particular ailment would have been most receptive to an ointment or medicine created with olive oil, largely because the patient went to the temple precisely with the goal of obtaining a curative dream (Healing Shrines). Similarly, in a non-religious setting, we can suppose that patients would also have been accepting of foodstuffs of this sort, especially when prescribed by a physician who was looking after their needs by means of a highly personalized regimen of care. This perhaps would have offered reassurance, however much the prescribed regimen may or may not have helped (King 2001, 52).

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FURTHER READING

Davidson 2006 and Robinson 2006 provide accessible entry points to a wide variety of topics relating to food and drink, both ancient and modern. Important too are the various works by Wilkins and his co-authors (1995, 2000, 2006, 2009). Nutton 2013 is indispensable on ancient medicine, while Mattern's latest book (2013) offers a lively and up-to-date account of Galen, the most famous physician of ancient Rome and one of antiquity's most prolific authors. Donahue's 2015 sourcebook gathers for the first time a wide array of primary source material on all aspects of food and drink.

CHAPTER 38

Nutrition

John F. Donahue

1. Introduction

When it comes to general health and well-being, perhaps no topic is more popular in America than nutrition. Nutrition, the process by which humans obtain the nutrients essential to support life and health, has blossomed into a multi-billion dollar industry. Consider the explosion of nutrition plans and diet books, most of which aggressively pitch various schemes for achieving weight loss as a means to a better, happier, healthier life. Or the tremendous interest in food itself, evident in a blossoming menu of television programs devoted to all kinds of cookery and culinary competitions. Or the ever-expanding popular literature on food, perhaps best exemplified by the critically acclaimed works of Michael Pollan, America's "liberal foodie intellectual" (see review by D. Kamp of *The Omnivore's Dilemma*, *New York Times*, 04/23/2006), whose award-winning books have critically examined many of our long-held assumptions about the foods we eat, while advocating a nutritional strategy best summarized by his now famous, seven-word aphorism: "Eat food. Not too much. Mostly plants" (Pollan 2008). Indeed, it is no wonder then that the present age has often been acclaimed as a golden era for the modern food citizen.

While it is easy to believe that we live in an age unparalleled for its focus on health and nutrition, the topic also provoked considerable interest in the ancient Greco-Roman world. Indeed, the literary evidence is both vast and diverse. Catalogs of foodstuffs and their properties in medical literature (especially the Hippocratic Corpus and the works of Galen and Celsus), cookbooks (most notably that of pseudo-Apicius), encyclopedias of natural history (Pliny's *Natural History)* and pharmacy (Dioscorides), and the Hellenistic treatises of Diocles of Carystus, Mnesitheus of Athens, and Diphilus of Siphnus, all preserve information essential to our understanding of ancient nutrition (Touwaide 2012). Furthermore, advances in technology have greatly enhanced our ability to study

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human and food remains through complex scientific methods, a development that has provided a most welcome addition to the written sources, which, as didactic texts written by upper-class male citizens, inevitably contain biases and shortcomings.

This chapter focuses first on our most substantial sources for ancient nutrition, namely, the medical works of the Hippocratic Corpus and the physician Galen. These are not the only sources on nutrition, of course, but they are the most influential and thus merit careful consideration. We shall then consider the modern scientific advances that continue to reshape our understanding of both nutrition and malnutrition through a brief overview of bioarchaeology, a burgeoning field that seeks to analyze and contextualize the human diet on the basis of archaeological remains. But first, a proviso: The literature of ancient nutrition and modern technological research on food and diet is far more extensive than can be treated in these pages. The hope is that this discussion will provide a basic understanding of the topic, and that the references and suggested readings will provide additional resources for the interested reader.

2. Hippocrates, Galen, and the "Powers" of Foods

The medical treatises from the corpus attributed to Hippocrates in Greece, fifth century BCE, and the works written by the Roman physician Galen during the Roman Empire in the second century CE provide the most sensible point of departure for our topic. These two collections, separated by some six centuries, remain the most significant sources on Greco-Roman nutrition, and they remind us of the vitality of ancient medical thought, a vitality that resonated long after the periods in which these works were written. To begin, both of these sources confirm that ancient nutrition was closely tied to the belief that foods brought certain "properties" or "powers" (*dynameis*) capable of nourishing or harming the body. This theory held that the four humors of the body—bile, phlegm, blood, and black bile—needed to be kept in balance through the powers of certain foods to remove whatever was in excess or to build up whatever was deficient in the body. Furthermore, each humor was linked to a certain season (bile/summer, phlegm/winter, blood/spring, and black bile/autumn), making it mandatory to adjust diet in order to counteract the effects of the environment on the body (cf. Culinary and Medicinal Uses of Wine and Olive). As noted by John Wilkins, whose excellent book on food in ancient literature informs much of the discussion to follow, ancient medicine relied much more heavily on the powers of food as the explanation for particular conditions than does contemporary medicine, largely because the range of causes for illness and disease in antiquity was quite narrow, owing to the ancients' lack of familiarity with modern concepts of virology, microbiology, and the like (Wilkins and Hill 2006, 215–216). As a consequence, ancient medicine was much less interventionist than its modern counterpart, a reality that helped solidify diet and nutrition as the most useful tools of medical practice (Wilkins and Hill 2006, 217).

3. The Hippocratic Corpus

Given these beliefs, ancient medicine meticulously categorized food and drink by their powers and effects on the body, and hence on health. Turning first to the Hippocratic Corpus, interest in nutrition is evident in a number of works, especially *Epidemics* and

On Regimen, and more specialized works, including *Regimen in Health*, *Regimen in Acute Diseases, Humours*, and *Aphorisms.* Of particular interest is *On Regimen*, which, in four books, offers a prescriptive course for living that is remarkable in its sweep, as it treats topics ranging from cosmology and bathing to exercise and dreams. Of special interest is *On Regimen* 2, where the reader is told that he must know the powers of various food and drink as well as "what these foodstuffs are by nature and what they are not" (*On Regimen* 2.39). This is followed by an extensive catalog of foods, where special emphasis is placed on the properties of individual items within a clear hierarchical structure. At the top of the list is barley, favored for a long time in the Greek world over wheat, which was much preferred by the Romans:

> Barley in its own nature is cold, moist, and drying but it has something purgative from the juice of the husks. This is proved by boiling unwinnowed barley, the decoction of which is very purgative; but if it be winnowed, it is more cooling and astringent. When it is parched, the moist and purgative quality is removed by the fire, and that which is left is cool and dry. When, therefore, it is necessary to cool and dry, barley meal thus used will do it, no matter how the cake is prepared … (Hippocratic *On Regimen* 2.40)

The passage is important to the study of nutrition for several reasons. First, the emphasis on the purgative qualities of barley underscores the importance of maintaining balance in the human body and implies, of course, the key role of digestion. The digestive process in ancient medical thought centered on the concept of heating, which helped to break down food in the stomach and intestines before the finest and moistest parts found their way to the proper parts of the body (Hippocratic *Fleshes* 13). In this way, the ancients appear to have understood the concepts of absorption and assimilation in the digestive process (Galen, *On the Natural Faculties* 1.8–9), even though they could never completely comprehend the functions of organs and systems in the absence of human dissection. Second, the excerpt reminds us that the Greeks and Romans routinely consumed foods that had been transformed at an earlier stage; in this instance, barley has become barley cake. This process of transformation, whereby simple grain could be elevated to the status of a culturally significant foodstuff like cake or bread, was the mark of a civilized society. Indeed, the transformation of grapes into wine and olives into oil were equally significant, with the result that these three products became foundational elements of the ancient diet (Garnsey 1999). Finally, as references to boiling and roasting in the excerpt above confirm, this process of transformation occurred through cooking. Cooking was critical to nutrition in that foodstuffs were often baked, boiled, roasted, or fried in order to deliver nutrients in the most palatable and useful way (Cooking and Baking Technology). To be sure, cooks and cooking had an important role to play in ancient nutrition, although the cook remained a contested figure in antiquity owing to his lack of knowledge about the medical outcomes of the food he prepared and the common perception that his aim was to produce pleasure or to provide a presence in Greek comedy (Galen, *Hygieina* or *Maintenance of Health* 2.11; Wilkins 2001).

On Regimen 2 continues by treating other kinds of grains (wheat, spelts, oats), followed by beans (including peas, chickpeas, lentils, and lupins), meat (from beef to hedgehogs), and birds and fish (Hippocratic *On Regimen* 2.45–48). The catalog concludes with a survey of the properties of wine, honey, vegetables, fruits, and nuts (Hippocratic *On*

Regimen 2.52–55). Again, what is most striking is the comprehensive nature of catalogs of this sort and the wide assortment of foods that comprised the Mediterranean diet, although the complicated issues of availability and access meant that not all of these foods were enjoyed by all peoples at all times. Finally, these comprehensive catalogs were accompanied by writings that sought to prescribe certain foods for specific maladies as found especially in the *Epidemics*. Thus is a patient advised to consume milk for ear pain (Hippocratic *Epidemics* 2.5.14), warm bread and neat wine for heartburn (2.5.18), and wine with equal parts of water and milk for anxiety, shivering, and yawning (2.6.23). Since no pharmacological treatise survives in the Hippocratic Corpus, these exempla are as close as we come to drug therapy in a system where the administering of foodstuffs such as these remained the most common way to maintain good health or to correct illnesses (Pharmacy).

4. Galen

In the centuries following the emergence of Hippocratic medicine, ancient diet and nutrition continued to attract interest, especially among Hellenistic physicians. Diphilus of Siphnus is known to have written a work on diet in the third century BCE; the celebrated Greek physician Diocles of Carystus also wrote on diet and nutrition as well as animal anatomy; and Mnesitheus of Athens wrote a work on diet in addition to his contributions on the classification of diseases. Regrettably, these works survive only in fragments or in later citations, a shortcoming that stands in sharp contrast to the remarkable and ever-growing corpus belonging to Galen. A towering figure in ancient medicine, Galen produced works that remain unparalleled not only for their sheer volume but also for their ability to synthesize with remarkable insight Greek scientific principles within the context of Greco-Roman social life (Wilkins and Hill 2006; Gill, Whitmarsh, and Wilkins 2009; Mattern 2013).

When it came to nutrition, Galen, like his Hippocratic predecessors, believed that a proper diet was the best way to ensure good health because foods had the power to affect well-being through their effects on the balance of humors. In his most important treatise on this topic, *On the Powers of Foods*, Galen provides an encyclopedic view of how the inhabitants of the Roman Empire ate in the second century CE. *On the Powers of Foods* generally follows earlier treatises on the subject and is characterized by a careful classification of over 150 foodstuffs according to their powers. Here among food and drink we find distinctions between salty and sweet, sharp and bitter, sour and watery, and of course, what was easy or difficult to digest (Grant 2000, 11).

Galen held strong, and sometimes surprising, views. Note here his assessment of beef, a foodstuff not easily surpassed in its capacity to provide protein:

> Beef furnishes nourishment that is substantial and not easily digested, although it generates thicker blood than is suitable. If anyone more inclined by temperament to melancholy should eat his fill of this food, he will be overtaken by a melancholy disease. These diseases are cancer, elephantiasis, scabies, leprosy, quartan fever, and whatever is detailed under the heading of melancholia … In the thickness of its substance, beef exceeds pork to the same degree as pork exceeds beef in viscosity. (Galen, *On the Powers of Food* 3.1, trans. Grant, at Wilkins and Hill 2006, 233)

As Wilkins has noted, Galen's commentary is quite severe (Wilkins and Hill 2006, 233). We are left to wonder if this might have something to do with the fact that beef was not widely consumed in antiquity beyond special occasions like religious sacrifices and that, as a result, it may have been easier to attach negative attributes to it. It also seems that thicker humors, such as those from beef, were more problematic for Galen than thinner ones, although the nutritive potential of the former was great (Wilkins and Hill 2006, 233).

Elsewhere, Galen was not afraid to go beyond the limits set by his predecessors, as he indicates in his views on wine:

> If they (sc. other doctors) believe that certain other substances are nourishing, but refuse to call them foods, I could summarize all their learning in just one book. But as it is only wine that they are unhappy about calling a food, although it is nutritious, they allow me to add to this work on foods a brief note about wines because those powers that Hippocrates mentioned in his book, *Diet in Acute Diseases*, belong to medicine rather than food. I am going to talk about the differences in their nutrition … (Galen, *On the Powers of Food*, trans. Grant, 188)

Indeed, Galen goes on to elaborate the nutritive properties of wine, maintaining that those that were red and thick were more nutritious than varieties that were white and thin in consistency, although the former were less easy to digest and assimilate owing to their thickness. Even so, for the stomach able to digest the stronger wines, plenty of nourishment would be provided (Galen, *On the Powers of Food*, trans. Grant, 188–189).

Two more items are notable when considering Galen's views on nutrition. First, as in the Hippocratic Corpus, the importance of cooking is easily detectable:

> Indeed, I do not consider it right for a doctor to be completely ignorant of the art of cooking, because whatever tastes good is easier to digest than other dishes that may be equally as healthy. (Galen, *On the Powers of Food*, trans. Grant, 131)

Galen himself wrote works on cooking and symposia, so his opinion here should not come as completely surprising. What he seems to have in mind is not the cook who was much abused in ancient comedy or the cook whose aim was simply to provide pleasure to the diner but he who, by his skill, might facilitate the digestive processes that were so important to maintaining health. Finally, we see in Galen an overlap between foods that were meant to sustain the health of the body and those that more closely resembled drugs, in that they were meant to produce a change in the body. Witness the description of garlic:

> But garlic is not eaten just as an accompaniment to bread, but also as a medicine for the health, because it contains aperient (to relieve constipation) and discutient (that which causes the dispersal or disappearance of a condition) powers. If it is boiled briefly to remove its bitterness, it is less efficacious, but it does not still retain its bad juices, in the same way as when leeks and onions are boiled twice. (Galen, *On the Powers of Food*, trans. Grant, 152)

As Wilkins has noted, additional foodstuffs, such as juniper, cedar berries, and various aromatics, receive similar treatment (Wilkins and Hill 2006, 235–236). Galen claims

that these items have little nutritive value, but it is interesting nonetheless that he sees fit to include them in a treatise on foods and their powers. This would seem to indicate that an intense interest in drugs, apparent since the Hellenistic period, still prevailed in Galen's time, although the line between nutritious foods and efficacious drugs was not always so clear.

5. Bioarchaeology and Nutrition

As this brief survey indicates, the Greek and Roman literary sources are valuable in providing insight on the range of foods available in the ancient Mediterranean world and on the importance of these foodstuffs in medicine and nutrition. Even so, the emphasis on catalogs of foodstuffs, combined with a limited knowledge of human physiology, has inevitably produced an incomplete account of ancient nutrition. This situation has improved dramatically, however, in recent years thanks to scientific advances in the emerging discipline of bioarchaeology (Larsen 1999, 2000; Buikstra and Lagia 2009; Schepaetz, Fox, and Bourbou 2009; Stodder and Palkovich 2012). As the study of human remains from archaeological sites or, more broadly conceived in Europe, as the analysis of all types of biological remains—plants, animals, and human—bioarchaeology has come to include the sub-disciplines of archaeobotany and archaeozoology as well as physical anthropology, paleopathology, and paleoepidemiology (cf. "Ecology" in the Ancient Mediterranean; Epidemiology and Pathology). Indeed, the success with which bioarchaeology has utilized highly technological and refined methods of scientific investigation—in order to transform our understanding of both nutrition and malnutrition—has proved to be among the most significant developments in archaeological research in the past twenty years (MacKinnon 2007).

In establishing a deeper understanding of nutrition and malnutrition in the ancient Mediterranean world, bioarchaeology has benefited enormously from advances in all of the disciplines mentioned previously, but particularly from the study of human (osteoarchaeology) and animal (archaeozoology) bone remains. The evidence concerning human remains typically comes from skeletons found in cemeteries, with the result that we possess reports from both individual sites (Hillson 2009) and larger integrative samples (Pitts and Griffin 2012). As Touwaide has noted (2012), important findings have emerged from the Greek colony of Metaponto in southern Italy (Henneberg and Henneberg 2003), Pompeii (Henneberg and Henneberg 2006), and Vallerano in the vicinity of Rome (Cucina et al. 2006). At Metaponto, systematic analysis of human remains from the seventh to the second century BCE has revealed that terrestrial animals and plants provided upward of 85% of the proteins ingested by Metapontines and that fish and seafood were also a regular feature of the diet. Interestingly, consumption of the latter was higher in the urban than rural population, suggesting that differences in social status and food variety were likely in play. At Pompeii, bone analysis has proved especially revealing because it provides a cross section of the diet of residents at a specific moment in time (79 CE). The results are similar to those at Metaponto, confirming a diet based mainly on carbohydrates with frequent consumption of fish and occasionally of meat. Such evidence is consistent with literary interpretations, which typically emphasize grain, pulses, and olives as the chief components upon which the ancient diet was largely dependent (Garnsey 1999; Brown 2011). On the other hand, the necropolis at

Vallerano (second to third centuries CE) has revealed a diet that does not seem to have been particularly carbohydrate based. This diet instead featured the consumption of meat and low-calorie agricultural products. Advances such as these have prompted calls for new research that would extend the time frame of analysis on bone remains to an annual or decadal scale, an approach that would lead to the creation of individual life histories. This new line of inquiry would have the advantages of reconstructing long segments of individual life histories, assessing variations in human behavior, and placing such behavior in the context of dynamic interactions within the natural environment (Zvelebil and Weber 2013).

Archaeozoology looms large as an essential specialty, most notably because the bulk of the remains from Classical archaeological sites are from animals that were consumed (see, e.g., Carter 2003b). Individual studies have tended to focus on the four main domestic food species—cattle, sheep, goats and pigs—while non-domestic species, including birds, hunted animals, and marine life, have also received attention (MacKinnon 2014). Larger studies have integrated findings from multiple sites, such as King's empire-wide survey of diet and nutrition based on a regional comparison of animal bones from Roman archaeological sites (1999). Formerly known as a field accustomed to listing faunal remains in appendices of archaeological site reports with little critical analysis beyond establishing a record of consumption at a given place and time, archaeozoology has begun to ask important questions about a host of issues relating to human–animal relationships in the past (Roberts et al. 2005; Sykes 2014), a development that should have important consequences for the study of ancient nutrition.

6. Advances through Technology

The question naturally arises as to how nutritional data of this sort can be extrapolated on the basis of bone remains alone. The answer lies in a host of technologies that have proved essential to expanding our understanding of ancient nutrition. Chief among these has been stable isotope analysis (SAI), which has emerged as a popular and highly effective research tool (Katzenberg 2000; Prowse et al. 2004, 2005; Schoeninger 2010; Killgrove and Tykot 2013). Unlike previous research, which has tended to reconstruct ancient diet on the basis of groups of people and over relatively broad time spans, SAI has allowed for the first time the direct estimation of the proportions of different dietary inputs, while granting for the study of individual diets and intra-community variations (Bogaard and Outram 2013). As Katzenberg has noted, by helping us follow the flow of nutrients from the base of the food web up through the trophic levels, SAI can help us obtain information about ancient diet and nutrition directly from human remains instead of the remains of tools and other objects (Katzenberg 2012, 97–99). In brief, the procedure relies on measuring the difference in the ratios of stable carbon (^{12}C, ^{13}C) and nitrogen (^{14}N, ^{15}N) isotopes, with variations in these levels relating to the environments in which humans live and the foods they ingest. For example, increased ^{15}N levels are generally found in humans who consume more fish in their diet, while herbivores have lower ^{15}N levels than those animals (including humans) who eat them (MacKinnon 2007). Beyond the locations mentioned above, several additional sites have produced important results on the basis of this technology, including the cemetery (first to third centuries CE) at Isola Sacra in Italy (Prowse et al. 2004, 2005),

the Roman military cemetery at Poundbury, England (Richards et al. 1998), and the Greek colonial site at Apollonia (fifth to second centuries BCE) on the Black Sea coast of Bulgaria. In general, the data from these cemeteries have confirmed the traditional portrait in the literary sources in which terrestrial foodstuffs predominate over other varieties, including marine resources, despite the proximity of many sites to the sea (Papathanasiou 2003, 320; Petrousa and Manolis 2010, 619–620; on the exploitation of marine resources, see Marzano 2013). Even so, there have been exceptions. At Apollonia, a mixed terrestrial and marine diet appears to have existed, with little or no variation by age, sex, or burial type (Keenleyside 2007), while at Isola Sacra, many skeletons, especially those of older males, have shown greater levels of ^{15}N, perhaps suggesting the importance of marine foods based on age and gender. At the same time, some older individuals have also displayed lower levels of ^{13}C, suggesting increased consumption of olive oils and possibly wine. On the other hand, sub-adults (older than five) appear to have subsisted on an almost entirely terrestrial diet (Prowse et al. 2004, 2005). Finally, efforts to reconstruct diet at a particular site over an extensive period of time have yielded interesting results, most notably at Thebes. Here, research utilizing SAI on gravesites dating from 3,000 to 300 BCE have revealed dietary variation on the basis of changes in levels of nitrogen. These results correlate with other evidence showing that, while natural resources were providing sufficient food during the Bronze Age, increases in population during the Classical period stretched natural resources to the limit ("Ecology" in the Ancient Mediterranean). Equally interesting, there are no recognizable differences between male and female diets. Whether these results are unique to Thebes or can be found in other sites affected by similar historical circumstances is a question for future research (Vika 2011).

SIA has been compared in its impact to the advent of radiocarbon dating and of calibration curves in archaeology (Bogaard and Outram 2013, 333), and its potential for integration with other disciplines is highly desirable (Papathanasiou, Theodoropoulou, and Valamoti 2013). Even so, it is not without its limitations. Researchers have struggled to overcome the problems of diagenesis, the postmortem altering of the chemical composition of bone (Liston 2012, 133). Furthermore, SAI provides only a "broad brush" picture of the ancient diet, and it raises significant issues of equifinality, that is, the principle that in an open system a given end state can be reached by many potential means. In the context of ancient nutrition, this means that we must be vigilant about inferring too much from the data, especially when multiple inputs might be contributing to the composition of any given remains. Similarly, SIA does not provide information about specific diseases or particular nutritional deficiencies, with the possible exception of insufficient dietary protein (Katzenberg 2012, 109). We shall have more to say on deficiencies in §7 below.

Additional technologies have also been important to the study of ancient nutrition. Thermal gravimetric analysis (TGA), a method of thermal analysis that measures changes in physical and chemical properties of materials, and X-ray powder diffraction, which uses X-rays on powder for structural characterization of materials, have been utilized at Porta Romana (a Roman necropolis at Milan: first and second centuries CE) to determine levels of strontium, barium, and zinc (Busetto et al. 2008). These trace elements are absorbed by bones only from food and are not compromised or altered postmortem; hence, they provide important information on diet. The presence of strontium, for example, is an indicator of a mostly vegetarian diet, as found in green leafy vegetables, while traces of

zinc indicate a principally protein diet, as found in red meat, dairy products, mollusks, and crustaceans. At the Etruscan burial site at Volterra (third to second centuries BCE), atomic absorption spectroscopy (AAS), a procedure that determines chemical elements by using the absorption of optical radiation (light) by free atoms in the gaseous state, has likewise measured strontium and zinc with interesting results. Here, elevated levels of these trace elements suggest a very rich diet, perhaps reflecting a wealthy Etruscan banquet (Bacci 2012).

7. Bioarchaeology and Nutritional Deficiencies

As a general rule, dietary deficiencies are not typically addressed as fully as dietary inputs in the ancient sources, nor do we always possess the kind of quantitative data that would be helpful in properly assessing insufficiencies and their impact upon ancient health and diet. As a result, scholars have been traditionally forced to make certain assumptions about daily or average food consumption, for example, when attempting to assess nutritional deficiencies (Touwaide 2012). Much like the advances noted earlier, the study of malnutrition and dietary deficiencies has benefited greatly from technological innovation, a development seen most clearly in the emergence of paleopathology, the study of diseases in ancient people, as a critical field of research (Aufderheide and Rodríguez-Martín 1998; Armelagos and Van Gerven 2003; Buikstra 2010; Grauer 2012; Buikstra and Roberts 2012). As MacKinnon has noted, this discipline is part of a huge and ever-growing body of research examining the broader topics of health, disease, medicine, and the social and biological factors surrounding these issues, and it now stands as perhaps the most productive area in the field of Classical osteoarchaeology (MacKinnon 2007, 480).

Much like the evidence cited earlier, skeletal materials recovered from ancient sites have formed the basis for many of the recent advances in paleopathology. Much attention has focused on examining stressors, that is, certain skeletal lesions and similar afflictions, for what they can reveal about nutritional deficiencies. One fruitful area has been dental examination, owing largely to the fact that teeth survive well in the archaeological record and that they are the one part of the skeletal system that has direct contact with the environment as evident in their use in chewing and as tools (Hoppa and Fitzgerald 1999). Analysis of 67 adult skeletons from the necropolis of Quadrella at Molise, Italy (first to fourth centuries CE) has revealed a high frequency of caries (tooth decay), abundant calculus, and low frequencies of tooth wear, pathologies that suggest a diet limited in hard, fibrous foods, and high in the consumption of carbohydrates (Bonfiglioli 2003). Analysis of teeth from the Late Roman period at Pigi Athinas in the foothills of Mount Olympus in central Macedonia yields similar evidence of caries and calculus (Tritsaroli 2014). On the other hand, cemeteries at Lucus Feroniae and Isola Sacra have shown lower frequency rates for these dental conditions, suggesting an improved diet (Manzi et al. 1999). These stressors have proved to be reliable indicators of nutritional and health status, although researchers have learned that there is much variation in the appearance and prevalence of these skeletal markers of stress among ancient populations by time, space, and culture, and that many of these features are nonspecific to a particular disease or stressor, making diagnosis difficult at times on the basis of bones alone (MacKinnon 2007, 482). Even so, progress has been steady.

Important too has been the new sub-discipline of historical anthropometry or auxology, which studies human stature and growth in past populations by measuring the effect of insufficient nutrition or unusually high levels of infection and other environmental stresses upon the mean height of a population. Stature is most accurately estimated from the lengths of complete long bones, especially the major bones of the leg. Examination of male skeletons from forty-eight Iron Age and Roman era sites in Italy has revealed that the overall standard of nutrition in the Greco-Roman Mediterranean often exceeded (sometimes by a significant margin) that of eighteenth- and early-nineteenth-century Europe, research that has called into question the traditionally pessimistic assessment of ancient living standards formed on the basis of comparison with evidence from the European ancient régime or the contemporary developing countries (Kron 2005; more generally, Bogin 1999, 2001). Although much remains to be done in reconstructing ancient populations with greater precision, the field holds much promise for nutrition studies.

Equally noteworthy has been the value of paleopatholgy in assessing the diet and nutritional deficiencies of specific populations such as women (Liston 2012) and children (Lewis 2007; Redfern and Gowland 2012). Isotopic analysis of skeletal remains of children at Isola Sacra has indicated that transitional feeding was well under way between one and two years of age, and that weaning was completed by two-and-a-half years of age. In addition, data on long bone growth have revealed that, while these infants may have been going through periods of "stress" likely associated with the cessation of breast milk and the introduction of complementary foods, their growth was not significantly affected, an indication that individual stress events were not chronic (Prowse et al. 2010, 188). For women, diseases caught from animals (zoonoses) through the handling and preparation of foods connected with meal preparation was always a threat. One such affliction, brucellosis, known today as Mediterranean Fever or Malta Fever, was characterized by an undulating fever, a symptom already recognized in the Hippocratic Corpus (*Epidemics* 1.24). Most commonly acquired in antiquity by contact with living animals, or by eating or handling uncooked meat and milk (Capasso 1999, 277, 286), brucellosis seems to be present in Greek women's skeletons at Corinth, judging from lesions on the vertebrae and sacro-iliac joints, the typical signs of this affliction (Barnes 2003, 441). Skeletal tuberculosis, which had a natural disease reservoir in cattle, was also associated with spinal lesions, although this affliction has not been widely identified in the skeletal remains to date (Roberts and Buikstra 2003). Beyond these zoonoses, other deficiencies especially problematic for women would have most likely included scurvy, which was caused by a deficiency in vitamin C, owing to a lack of fresh fruits and vegetables in the diet. It is present on bones in the form of porous lesions and layers of sponge-like new bone on the cranium, mandible, and on long bone shafts, as Ortner and Ericksen (1997) have shown. Not to be overlooked as well is anemia, a disease characterized by an insufficiency of iron, either from diet or from intestinal bleeding caused by parasite loads. Evidence from Herculaneum, for example, has suggested that anemia was fairly common among the city's population, a deficiency consistent with a diet rich in cereals and legumes (which do not promote iron absorption) but low in red meat consumption (which is rich in iron) (Bisel and Bisel 2002). Women would have been especially susceptible to anemia as a result of periodic blood loss through menstruation. This affliction is typically manifest in pathological bone formation, such as cribra orbitalia (CO), a spongy, porous area of bone on the superior surface of the eye orbit, and porotic hyperostosis caused by an expansion of the marrow-producing spongy bone of the skull into the exterior surface

of the cranial vault (Liston 2012, 137). Increasing use of bone histology is improving the diagnoses of lesions such as these, but the process is problematic because bone must be destroyed to produce specimens for microscopic analysis (Liston 2012, 137–138).

Finally, discussion of deficiency diseases of this sort raises the question of whether or not the ancients ever selected foodstuffs for therapeutic uses on the basis of their nutritional value. Indeed, there is at least some indication that this may have been so. In the case of women, liver (where iron was stored) was utilized in treating gynecological conditions, as were fats from various animals. This evidence, all of which can be found in the Hippocratic Corpus, suggests that the ancients recognized that these substances were necessary for this particular condition. As Touwaide (2012) has noted, the extrapolation of data such as this to other foodstuffs would be of great value to nutrition studies; this would provide us with a greater understanding of ancient nutrition, the reasons behind the selection of certain foodstuffs, the awareness of possible insufficiencies, and the knowledge of the ways to compensate for such deficiencies.

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FURTHER READING

The scholarship on ancient nutrition is voluminous and ever expanding. For reliable English translations of Galen's works on diet, see Powell 2003 and Grant 2000. For the Hippocratic Corpus, see the translations of various works cited in the chapter as found in the Loeb Classical Library series. Closely related to nutrition is ancient health and medicine, itself a large topic. For a useful entry point, see the essays edited by King 2005 and "Further Reading" at Culinary and Medicinal Uses of Wine and Oil. On general studies addressing a variety of issues in the interpretation of human remains, see Ubelaker 1989, Larsen 2000, Saunders and Katzenberg 1992, and MacKinnon 2007, who provide a comprehensive overview from the Greek world. From the vast literature on paleopatholgy, see Buikstra 2010, and the edited collections of Buikstra and Roberts 2012 and Grauer 2012 (and Epidemiology and Pathology). Touwaide 2012 provides a useful summary of nutrition and malnutrition.

PART VII

Technology of Human Life

CHAPTER 39

Greek Public and Religious Architecture

John R. Senseney

1. Materials and Forms

In its fully developed expressions, Greek public and religious architecture is inextricable from the orders which gave Classical buildings their characteristic forms and "ordering" sense of monumentality and unity. The Doric and Ionic orders arose first in monumental stone temples. Later they came to articulate the stoas (Latin *porticus*), multi-purpose public halls in the form of narrow porticoes, walled on the long backside and colonnaded on the front, and which framed the outdoor spaces of the sanctuary and the agora—traditionally the political, commercial, and social heart of the *polis* and filled with important cultic and civic buildings such as the council chamber or *bouleuterion*. Although earlier scholarship adhered to Vitruvius' claim that the orders came into being in wooden prototypes (4.2.1–5), it is now clear that they evolved in stone. The initial influence for developed forms may have come from non-Greek sources, such as the details of earlier Egyptian stone masonry recognized as "proto-Doric" (Coulton 1977, 32–33) or Levantine and Mesopotamian ivory furniture, reaching the Greek world by way of Neo-Assyrian exchange in the eighth and seventh centuries BCE (Gunter 2009, 132–133, 171–177).

The Doric order developed on the Greek mainland and nearby islands, as well as in Magna Graecia (southern Italy), from circa 725–675 BCE. This development was piecemeal, wherein individual elements (capitals, triglyphs, metopes, geisons, etc.) evolved in isolation rather than as part of a unified system of elements, and it was not until the all-limestone Artemision at Corkyra, circa 580–570 BCE, that these elements coalesced into what one may properly recognize as an "order" (Barletta 2001, 54–83). Yet even here, the ground plan itself was an anomaly, featuring a pseudodipteral arrangement otherwise not found again until the Hellenistic architect Hermogenes independently

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innovated it in the third century BCE (figure 39.1; Vitruvius 3.3.8). As opposed to a standard peripteral arrangement in which colonnaded wings (or *ptera*) surround the sekos (or central core of pronaos, naos, and opisthdomos), builders provided enough space on the stylobate for a dipteral arrangement of two colonnades (Figure 39.2), but only one colonnade was built. Pseudodipterality was not to be followed in subsequent Doric temples, and it is rather the earlier Temple of Hera at Olympia (circa 600–590 BCE) that heralds the standard hexastyle (six columns across the front), peripteral arrangement associated with the mature Doric order. Otherwise, the Olympian temple's extensive use of mud brick and wood, and presumably most of its forms, appear to have remained largely uncanonical from the perspective of later, fully developed Doric temples.

In the Cyclades and Ionia, the elements of the Ionic order developed in similarly piecemeal fashion in the contexts of both buildings and sculptural votives, with Cycladic

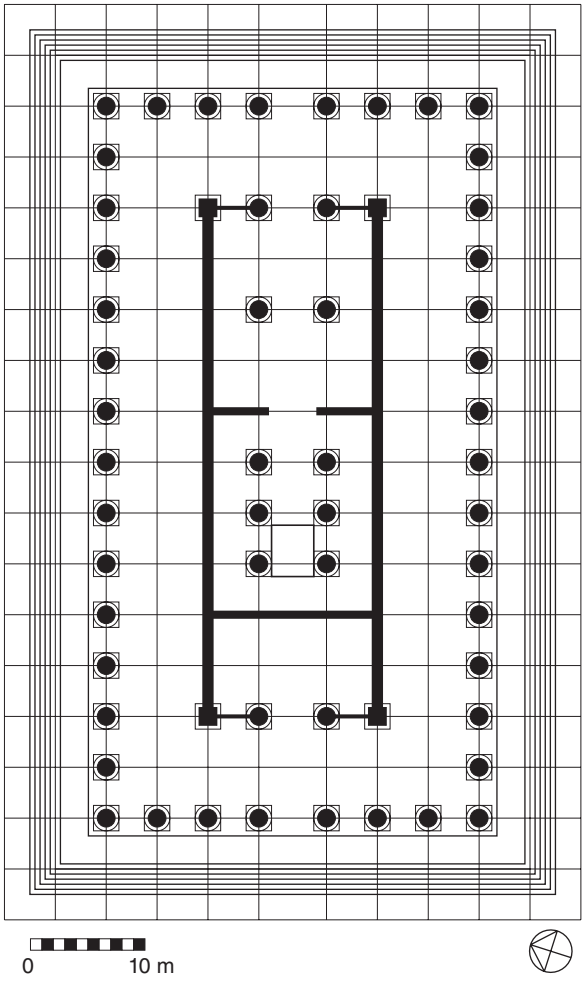


Figure 39.1 Hermogenes, Temple of Artemis Leukophryne at Magnesia-on-the-Maeander, begun circa 220 BCE. Restored ground plan showing modular, gridded underpinning. Adapted from Coulton 1977, figure 23.

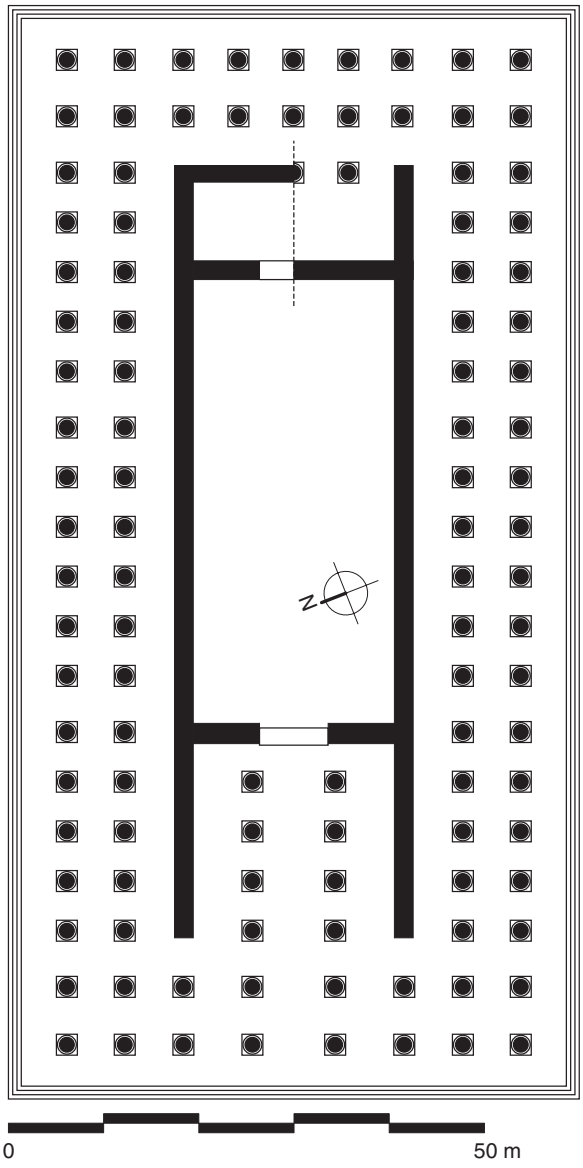


Figure 39.2 Chersiphron and Metagenes, Archaic Temple of Artemis ("Croesus Temple"), Sardis, restored ground plan showing alternative reconstructions of adyton and opisthodomos in the east, begun circa 560 BCE. Adapted from Ohnesorg 2007, plate 36.

masons innovating the use of marble in the features that would come to be recognizable as Ionic (Gruben 1997, 261–416; Barletta 2001, 85–90, 97–121). The earliest crystallization of the Ionic order proper is the first all-marble temple: the Archaic Artemision at Ephesus or "Croesus Temple" after the wealthy Lydian king who helped fund it. Its construction was led by the Cretan father-son duo of architects Chersiphron and Metagenes (Vitruvius 7 preface 16). Included among the seven wonders of the ancient world, the Ephesian Artemision fully integrated the individual elements of earlier

Cycladic buildings along with the octostyle dipteros (eight columns across the front with a dipteral arrangement: Figure 39.2) and colossal scale (approximately 60 × 115 m [197 × 377'] overall) of the recently completed "Rhoikos Temple" in Hera's sanctuary at Samos. As found in the contemporary, mid-sixth-century "Basilica" at Paestum in southern Italy on the opposite side of the Mediterranean, the columns of the Croesus Temple featured an early application of entasis or "tension:" the refinement of convex curvature in the vertical profiles of the shafts so that the columns appear to respond organically to the weight of the entablature they bear. The Croesus Temple was mostly completed in 560–550 BCE, and its Hellenistic replacement followed its basic form after the Archaic structure was destroyed by arson (Ohnesorg 2007). In addition to this specific Hellenistic manifestation, the Croesus Temple set the model for the material, form, refinement (entasis), finishing, and ornament of the Ionic order from the Archaic through Roman periods. What we call the "orders," then, were formal frameworks into which, during the sixth century, the elements—that had developed individually—were integrated in two different parts of the Greek world. This is not to suggest, however, that Greeks regarded the Doric and Ionic orders as mutually exclusive. Indeed, the rigid distinction between Doric and Ionic, along with Corinthian and Tuscan, was an Italian Renaissance notion (Rowland 1994).

From the Classical period, the most famous example wherein traditions merged is the Parthenon (Figure 39.3), built on the Athenian Acropolis by the architects Ictinus and Kallikrates between 447/6 and 438/7 BCE, with the sculptural program completed in 433/2 BCE under the direction of Pheidias (Barletta 2005, 88–95). The Classical Parthenon replaced a late Archaic precursor, the "Older Parthenon," whose construction began following the victory of Marathon in 490 and remained incomplete when destroyed in the Persian sack of 480. While the Temple of Athena Polias (later replaced by the Erechtheion) had been the traditional cult building of the city's patron goddess, the Parthenon was an important civic building, a thank-offering to Athena for Persian War victories. It was a centerpiece of the Athenian building program led by Pericles, whose other notable monuments include Mnesikles' Propylaia (the new monumental gateway to the Acropolis) and the Hephaesteum (Figure 39.4) built below on the Kolonos Agoraios, the hill overlooking the agora. Though outwardly Doric, the Parthenon's ubiquitous use of marble quarried on Mount Pentelikon may betray influence from the Cyclades, an innovator and stronghold of the Ionic order in which buildings feature marble throughout. As opposed to local precedents including the Older Parthenon in which the bottom step was of limestone, both steps of the Parthenon's stereobate, in addition to the stylobate, were completely in marble. On both ends of the sekos, the prostyle arrangement of six columns in front of the thickened end walls known as *antae* (Figure 39.3), rather than the two columns between them (called *in antis*), also Cycladic in origin, had been adopted for Athenian temples in the prior century. Forms that are specifically Ionic include certain moldings, the famous Panathenaic frieze running continuously around the upper walls of the sekos uninterrupted by the usual alternating triglyphs and metopes of Doric tradition, and—most explicitly—the four Ionic columns inside the rear chamber (Korres 1996, 22). Especially obvious when viewed in plan (Figure 39.3), the strong spatial contractions in the corner intercolumniations result from the typical Doric "corner triglyph problem." Contrasting with the standard hexastyle arrangement of Doric temples as found in the Older Parthenon and Hephaesteum (Figure 39.4), however, the Parthenon adopted the octostyle arrangement from Ionic

tradition (Figures 39.2, 39.3). This adoption resulted not from a simple interest in combining Doric and Ionic. Rather, it arose from an ingenious solution to the problem of how to re-use columnar drums from the smaller Older Parthenon while amplifying the overall size in the new construction, and creating an innovatively wide, spacious naos able to accommodate Pheidias' monumental chryselephantine cult statue of Athena Parthenos and surrounded by a two-story, columnar walkway.

In considering the formal aspects of Greek sacred architecture, the Parthenon may serve to illustrate an important distinction between schematic and visual features. The

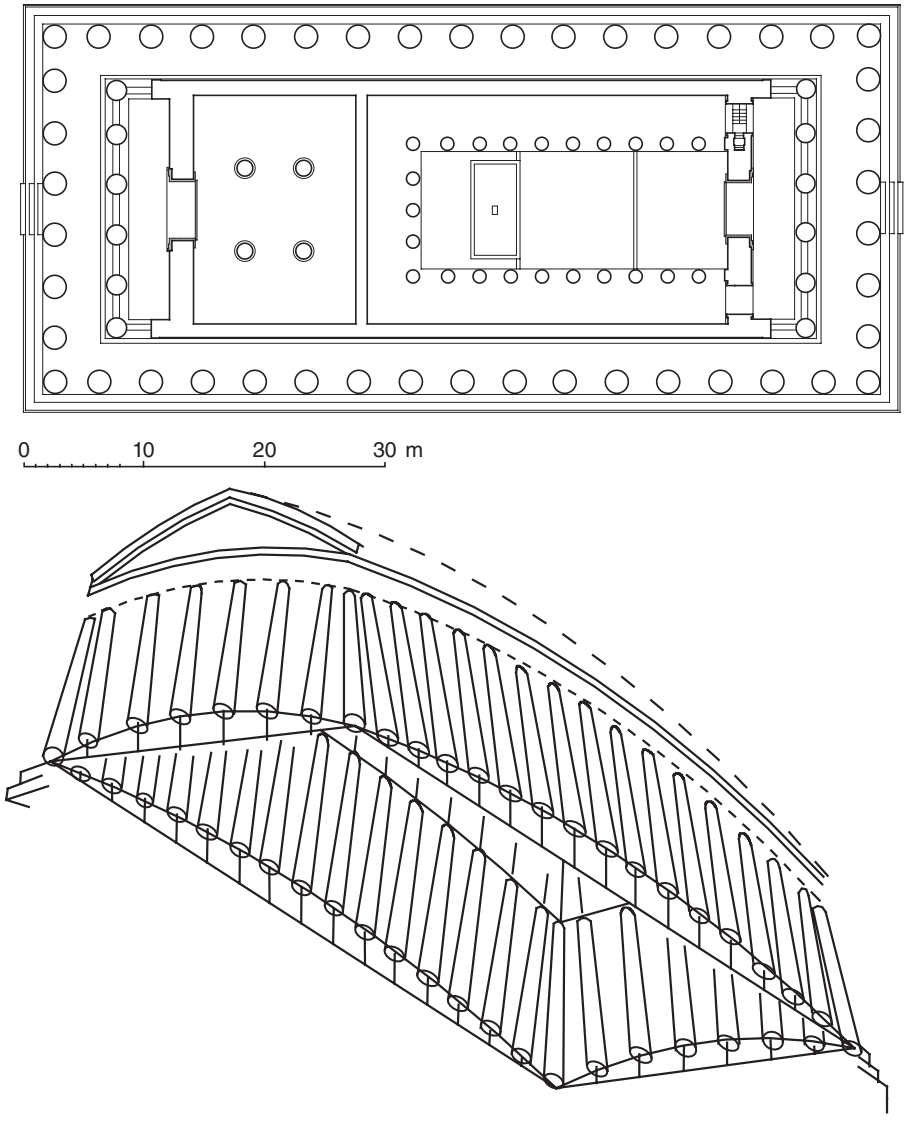


Figure 39.3 Ictinus and Kallikrates, Classical Parthenon, Athens, 447/6 – 438/7 BCE. *Top:* ground plan. Author's drawing, modified from Korres 1994: Figure 2. *Bottom:* Exaggerated refinements, showing curvature and columnar inclination. Adapted from Korres 1999, figure 3.29.

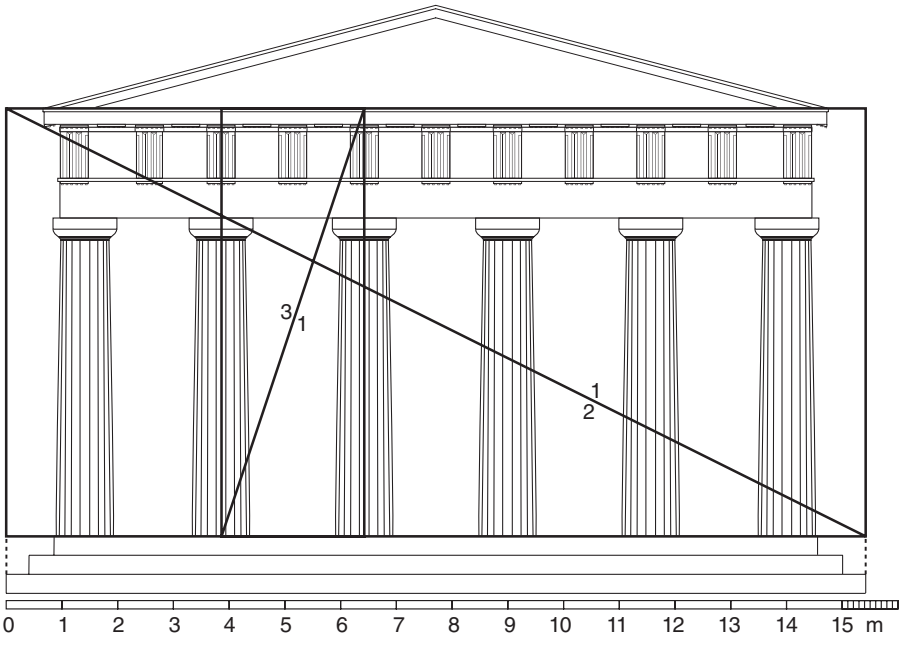


Figure 39.4 Hephaesteum, Athens, circa 450 – 445 BCE. Elevation showing integral proportions.

well-known application of the 4:9 integral ratio is schematic. This guiding scale determines the ratio of width to length of the stylobate, the diameter to standard inter-axial distance of the columns on the flanks, and the principal rectangle of the façade, including the cornice. Integral ratios drive the interrelationships of features in the Hephaesteum as well (Figure 39.4), and indeed are commonly found throughout the Greek world in the fifth century (Mertens 1984, 137, 144–145; 1993, 80–87; 2006, 143). Analysis taking into account the vantage points of viewers undermines the possibility that architects intended such ratios for visually ascertained harmonies (Senseney 2011a, 27–32). Rather, the sculptural expression of the forms themselves was central to monumental architecture. The proportions of individual elements, like columns, could be adjusted depending on the vantage point—as in the slight elongation of the columns of the Propylaia's west façade—in order to correct optically the effect of vertical compression when seen by viewers approaching from the steep incline below (Büsing 1984).

The reasons behind other refinements—such as the thickened end columns, inward-leaning columns, and curvature found in Parthenon and other monuments—were likely a mixture of concerns for optical correction and subtle adjustments to form that were intended to be noticed and appreciated. Curvature properly includes not only entasis, but also the similarly convex curvature applied horizontally in every course of masonry from the lowest step to the apex of the roof (Figure 39.3). According to both Vitruvius (3.4.5, 6.2.2) and Cicero (*To Atticus* 2.4), architects intended such curves as optical corrections, so that entasis adjusts for the illusion that a column with a straight profile appears to hollow in the middle, just as a straight beam appears to sag if not for an adjustment of slight upward curvature (Haselberger 1999, 56–60). Possible support for the corrective value of refinements may be provided by the controversial theory of the

Parthenon's "hyper-refinements" that enhance the refinements themselves: the slight raising of the northwestern and southwestern corners of the foundations in order to avoid optical convergences of curved lines when the Parthenon is viewed from a principal vantage point along the Sacred Way (Korres 1999, 85–94). As quantitative analysis demonstrates, however, the Parthenon's curvature with respect to earlier and contemporary buildings is exceptional precisely for the intensity of its curvature rather than its greater subtlety (Haselberger 2005, 127–130). Indeed, the Parthenon's curvature is an aesthetic feature enjoyed on site by the trained eyes of modern viewers, and there is no reason that the same positive, experiential value should not have applied to ancient viewers. Whatever the rationale, curvature is an extraordinary quality that epitomizes Classical Greek architecture's propensity for refining stone masonry to a degree never seen before or since in the history of architecture. As discussed below (§4), its execution required a mastery of tools and techniques in the construction process that came to crystallize notions of visual order that could not help but carry over into Classical perceptions of nature and the means of representing and understanding nature's order in the sciences.

2. Patrons and Architects

Traditionally, the economic force behind the creation of Greek public and religious architecture was the public funding of the *polis* where a monument was built, though exceptions exist. Private donors often funded a city's public buildings or significantly supplemented public funds (Coulton 1977, 18–21). In the case of Panhellenic sanctuaries, sometimes several city-states contributed to a temple's construction. Starting in the sixth century in Panhellenic sanctuaries like Delphi and Olympia, city-states individually built elaborate treasury buildings to showcase their votives to the gods. Constructed in the traditional orders, these were substantial monuments displaying the usual forms of sacred architecture, and they included celebrated examples like the Doric treasury of the Athenians and the Ionic treasury of the Siphnians at Delphi. The latter featured Archaic antecedents for the Erechtheion's famous Caryatids. Again in the sanctuary at Delphi, the well-known Stoa of the Athenians commemorates the victory over the Persians at Mykale in 479 BCE (Amandry 1953, 108–115). In the Archaic and Classical periods, this practice of city-states erecting stoas to commemorate important military victories was a tradition in its own right, beautifying sanctuaries as well as agoras with monumental expressions of the Classical orders (Senseney 2011b, 431).

In the civic realm, defensive architecture was also important. In addition to fortification walls, major engineering projects like the Megaran architect Eupalinus' mid-sixth-century kilometer-long tunnel through Mt. Kastro for a hidden aqueduct secured a water supply for Archaic Samos even during times of siege (Figure 39.5; see URBAN INFRASTRUCTURE IN THE ROMAN WORLD). The arrival of the tyrant Polycrates furthered the security and grandeur of Samos. During his reign (538–522 BCE), Samos added a new breakwater—stretching approximately 400 m (1,312′) into the sea—which served the city-state's defenses and provided safe harbor for ships. In the nearby sanctuary of Hera, construction began on a new, colossal dipteros to replace the recently dismantled Rhoikos Temple which appears to have faltered owing to the insecure foundations in the marshy terrain.

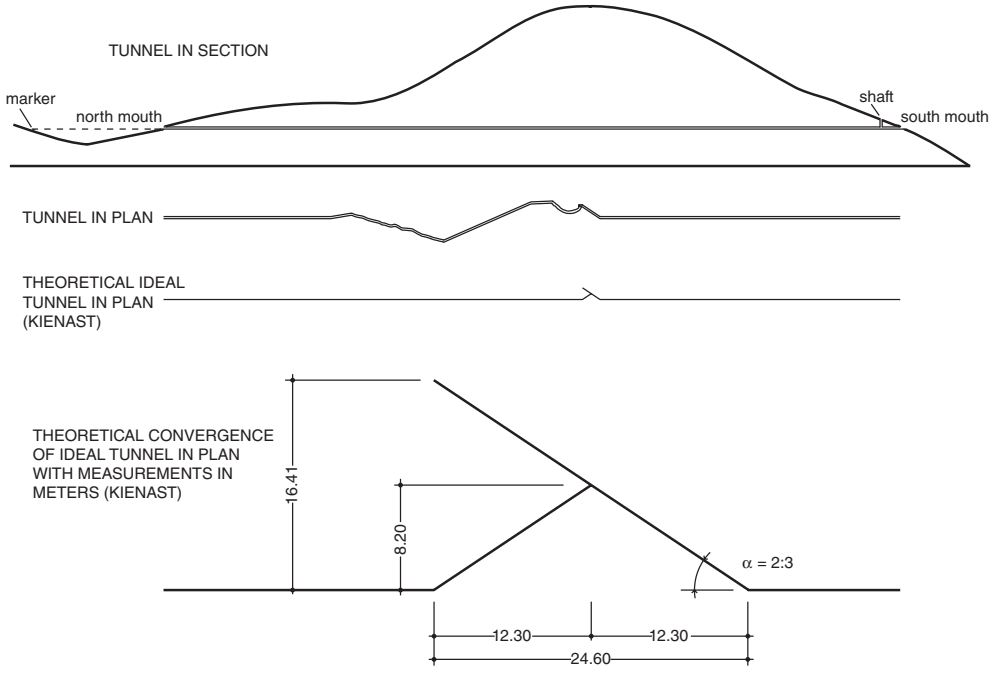


Figure 39.5 Eupalinus, Tunnel through Mount Kastro, Samos, circa mid-sixth century BCE. Tunnel in section, plan, and theoretical ideal plan with a detail of this ideal plan's convergence, according to Hermann Kienast. Adapted from Kienast 1995, figure 46a (section), foldout plans 3a and 3b, and figure 46a.

As demonstrated at Athens, changing political circumstances did not substantially alter how projects were supervised, but they could concretely transform a city's religious and public built environment. Under the Peisistratid tyranny, enduring through most of the second half of the sixth century, four architects began construction on the Temple of Zeus Olympios, whose colossal scale appropriately rivaled Polycrates' Heraion (Coulton 1977, 28). As with its Samian counterpart, the Olympieion came nowhere near completion during the tyrant's reign, and it remained unfinished until Hadrian's decisive intervention (circa 125 CE; Ward-Perkins 1981, 268). The degree to which tyrants like the Peisistratids personally supervised a project was fluid. At Athens and elsewhere, under tyranny or otherwise, the state usually appointed committees with revolving membership, which oversaw project development, the hiring of architects, and various associated costs of construction and continued maintenance, whether by contract or piecework (Coulton 1977, 21). The major change arising with democracy was not how architectural projects were supervised, but rather the nature of the public buildings themselves. Democracy brought about the unprecedented need to assemble some 5,000 citizens on the Pnyx hill, which at the end of the fifth century was provided with a retaining wall to frame a semicircular auditorium around the speaker's platform (Calligas 1996, 3). Shortly thereafter, that great cultural contribution of the Greek *theatron* as the place for *thea* ("seeing") received its first monumental construction in stone as the radial, circular form of the Theater of Dionysus, in which Athenians and foreigners assembled for important rituals of drama, as well as political events. Earlier in Athenian democracy, the

aggressively imperialist tendency of Athens' leadership of the Delian League had made possible the most far-reaching Athenian contribution in the history of architecture. In 454 BCE, Athens moved the league's treasury from Delos to Athens, at which time the city-state began to appropriate one sixteenth of the member states' annual tribute. With a combination of public funds and tribute from the Delian League, Pericles and the *ekklesia* oversaw a building program that included the best architects, finest materials, highest quality execution of form, and an impressively rapid period of construction (Kallet 2005, 40–57).

Beyond something like a statesman's glorification of his own city through building, architectural patrons, in particular, could leave a mark on distant places. Greek and Lydian inscriptions on the bases of the columns of the Ephesian Artemision confirm Herodotus' account that Croesus paid for the columns of that great Archaic temple (1.9.2; Hanfmann 1975, 10–11). In the Hellenistic period, the dedicatory inscription on the architrave of the Bouleuterion in Miletus (175–164 BCE) names the Seleucid king Antiochus IV (Wiegand and Schrader 1904, 1.2). At the same time, according to another inscription, the Attalid king Eumenes II (ruled 197–159 BCE) provided a donation for the monumental additions of the Asklepieion at Cos (Hansen 1971, 291, 466). Highlighting this program was the so-called "Temple A" (Figure 39.6), built on the upper terrace along the central axis of the sanctuary's contemporary pi-shaped stoa frame, about 170 BCE, and which has been shown to have been laid out according to a 3:4:5 Pythagorean triangle *ABC* and a module defined by the column-supporting paving slabs (Senseney 2007; Senseney 2011a, 163–164; see MATHEMATICS). Eumenes' follower Attalus II (ruled 159–138 BCE) donated the monumental stoa flanking the east side of the Athenian agora, and there are many such other examples by the Attalids and other monarchs.

Some of the most impressive examples of monarchical patronage were found in the great centers of the Hellenistic kingdoms, as in the Attalid capital of Pergamon. Following their successful battles against the Gallic Tolistoagii, the Attalid kings presented Pergamon as the successor to Athens' earlier position as the champion of Hellenism. The long-durational building program that gave rise to this idea began with the Temple of Athena, built on the Acropolis in the 330s and 320s BCE. On the authority of his victory over the Tolistoagii and Seleucids, Attalus I (ruled 241–197 BCE) became the first Attalid to take the monarchical title *basileus*, placing a lost sculptural monument on a cylindrical base near Philetaerus' temple upon which he inscribed the title (Pollitt 1986, 85). To underscore the martial basis of his monarchy, he re-designated this part of the Acropolis the Sanctuary of Athena Nikephoros, "bringer of victory." His successor Eumenes II amplified the sanctuary and its martial connotations with surrounding stoas: one L-shaped in plan, the other a simple linear extension, and both connected by a monumental propylaion. The L-shaped stoa and propylaion displayed sculptural reliefs representing spoils taken from the defeated Gauls and Macedonians, thereby continuing the tradition of stoas commemorating wars. Opening off the northern wing of Eumenes' L-shaped stoa was one of the most important contributions to public architecture: the library, which rivaled the famous library of the Ptolemies in Alexandria and established Pergamon as the center of monarchically sponsored scholarship. After the Third Macedonian War, won by the Roman and Attalid alliance in 168 BCE, Eumenes built the Great Altar, an iconic Hellenistic monument, in which the sculptural gigantomachy explicitly symbolizes the Attalid victory over the Macedonians (Stewart 2000, 40–41). Yet, just

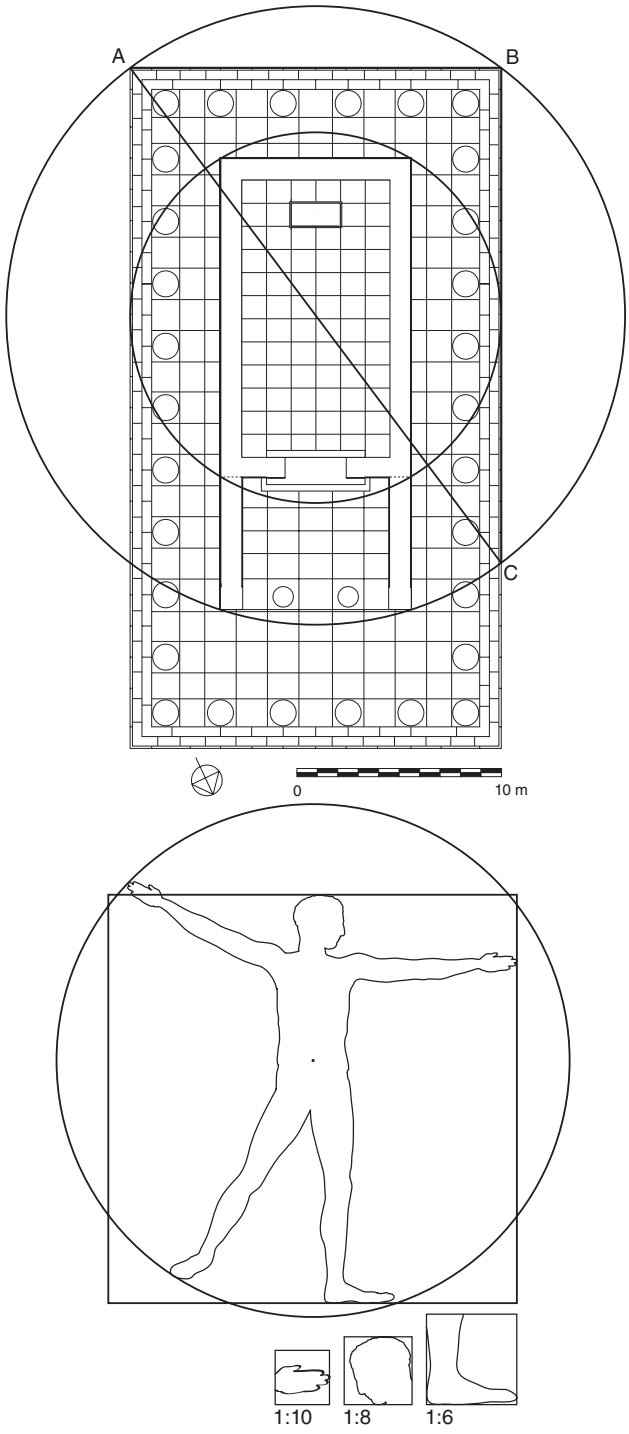


Figure 39.6 Geometric and modular underpinnings of temples. *Top:* Temple A at the Asklepieion at Cos, circa 170 BCE. Restored ground plan showing geometric underpinning of circumscribed Pythagorean triangle *ABC* determining the placements of features, with module established by column-supporting paving slabs. *Bottom:* "Vitruvian Man" as described by Vitruvius (3.2.1-4), in which the human body provides the model for temple buildings.

as Rome aided Eumenes, so did it hinder him. Following the Third Macedonian War, Rome strengthened Pergamon's Greek rival states, vastly limiting Attalid aspirations. Eventually, Eumenes' successor Attalus II bequeathed the Pergamene kingdom to Rome upon his death in 133 BCE, giving birth to the Roman province of Asia (Hopp 1977, 107–120).

The path toward the Attalid demise carried a significant consequence: the Roman patronage of Greek architects, who brought their masons, materials, and practices to Rome. The thoroughly Hellenic all-marble round temple of about 100 BCE next to the Tiber was made possible through an historical circumstance that began with the conclusion of the Third Macedonian War. Cn. Octavius, commander of the Roman naval forces in the Battle of Pydna that decisively ended the war, imitated his ally Eumenes' traditional Greek patronage of victory stoas with the Porticus Octavia built in the Circus Flaminius, funded with spoils of war and incorporating bronze Corinthian capitals taken from the Greek world (Senseney 2011b, 432–435). Following Q. Caecilius Metellus' triumph in the Fourth Macedonian War in 148 BCE, proceeds from the victory also funded Metellus' Pergamene-inspired Porticus Metelli (Kyrieleis 1976). Here, a *quadriporticus* surrounded the earlier-built Temple of Juno Regina along with a new construction: the Temple of Jupiter Stator, Rome's first marble temple, built by Hermodorus of Salamis, the earliest Greek architect known to have worked in Rome (Gros 1973). Roman conquests, combined with the decline of Attalid power, helped to shift opportunities for Greek architects to central Italy. Since Roman builders were unfamiliar with marble, Greek architects must have brought masons with them.

Arguably, however, the arrival of Greek builders in Rome was not so much revolutionary as it was part of a larger pattern of Hellenistic architects traveling to where commissions took them. In the third and second centuries BCE, Hermogenes, architect of the Artemision at Magnesia-on-the-Meander (Figure 39.1), also built the Temple of Dionysus at Teos. Mentioned by an inscription as active in Priene, he may have worked for the Attalids in Pergamon (Hoepfner 1997). Earlier in the fourth century, Pytheus, the architect of the Temple of Athena Polias in Priene, went to Halikarnassus to build the Mausoleion.

The projects that attracted Greek architects did not always come with the funding necessary to complete them. In the case of Archaic Ephesian Artemision, Croesus' donation enabled rapid construction. The Hellenistic Didymaion represents a different scenario, however. The architect Paionios, who had worked on the Hellenistic rebuilding of the Artemision in Ephesus, joined the Milesian architect Daphnis at Didyma in the early fourth century, but neither would ever see anything resembling a completed temple (Vitruvius 7 preface 16). By the middle of the third century, columns had yet to be erected, and the remaining construction proceeded only in spurts over the following centuries until the uncompleted project was finally abandoned well into Roman times.

Evidence concerning the related issues of funding, remuneration, and completion carries important implications for the social background and responsibilities of architects. Compared to the Hellenistic Didymaion, even a comparatively much smaller project like the Erechtheion, built in 421–405 BCE, involved a sequence of architects over time. According to inscribed records, two separate Athenian citizens with the title *architekton* worked on the Erechtheion for a single year each in 409/8 and 408/7, and the city-state paid both of them one drachma a day, exactly the same compensation as for the skilled workers they oversaw. A one to two drachma daily recompense was, in

fact, common for both architects and masons throughout the Classical period (Coulton 1977, 27–29). So, who were these architects? What was the nature of their work on larger projects for which they served only a limited term? And what do their responsibilities imply for the age-old question of why there is often more than a single architect at a given time, as in Paionios and Daphnis or Ictinus and Kallikrates, for example? To begin with, there is no reason to assume that the architects of the Erechtheion and similar projects were professional tradespeople who depended on a salary. As Coulton argues (1977, 23–29), rather, they were much more likely citizens of independent means who, in exchange for prestige, exercised their civic duty by contributing to the welfare of the *polis*. This higher status of architects is also supported by their level of education as implied by their achievements as writers. Along with cosmology, architectural writing was among the earliest manifestations of Greek prose, and throughout Greek history architects apparently learned their art through reading. As suggested by the evidence for later Greek architects' careers spanning multiple projects in various locations, including Rome, a turn toward the phenomenon of the professional architect may date from the fourth century.

Through their forebears, Hellenistic architects belonged to a tradition of educated individuals sharing theoretical knowledge via written works. In this sense, Greek architects were collaborators in a notably cohesive production across time, in which religious and public buildings shared a remarkable similarity through architects' adhesion to the traditions of the Classical orders. Likewise, individual projects required collaborations between sequences—and sometimes generations—of architects over time. This situation stands in marked contrast with modern architecture, which champions the personalized styles of individual architects created through design. In a world where architects commonly participated in projects begun by their predecessors, the very possibility for design in the modern sense was limited. Instead, the point of focus was construction. It is in this sphere that builders contributed so consequentially to Greek conceptions of order, which in turn help condition how order was perceived in other contexts.

3. Construction

Clear distinctions between architecture and engineering, as well as the division between design and construction, are modern. For Greek and Roman antiquity, distinguishing between architects and engineers is not always easy, and for the Archaic and Classical periods in particular it is perhaps impossible. In the sixth century BCE, Eupalinus created the 1036-m-long tunnel (3,400′) that carries the aqueduct via ceramic pipes through the mountain at Samos (Figure 39.5). He is called *architekton* by Herodotus, who groups the tunnel with the island's Temple of Hera and breakwater as three of the greatest of all Greek achievements (3.60.1–3).

In modern parlance, one might say that Eupalinus was responsible for the tunnel's design as well as its construction, which included simultaneous excavation from both mouths, as well as the stretch of pointed-vaulted masonry lining the north end. The project would have begun with the use of a simple sighting tube for surveying around the base of the mountain to find the correct levels and alignment of both mouths (Lewis 2001, 214–216). It has been hypothesized that Eupalinus next calculated the tunnel's anticipated length as the hypotenuse of a right triangle (Van der Waerden

1954, 102–105; Burns 1971, 178–182). This method, for which there is no evidence prior to Hero of Alexandria, is untenable (Kienast 1995, 196–201; Lewis 2001, 202, 227; see MATHEMATICS). More likely, Eupalinus obtained an accurate estimate of the total mouth-to-mouth distance by measuring the level distances between a pair of poles sequentially staked over the slope of the mountain (Kienast 1995, 129–139). Kienast proposes that Eupalinus established an ideal plan for the tunnel's trajectory (Figure 39.5), which was to run in a straight line from both mouths before angling eastward at a prescribed angle and distance from the point of convergence to ensure the meeting of both heads (1995, 164–172).

Again, however, this supposed plan must remain entirely hypothetical, and it is perhaps best to keep in mind the reality that success depended on issues that could not be predicted. In particular, the unexpected encounter with softer soils and subterranean water necessitated the observable zigzag on the tunnel's north end (Figure 39.5). The project demanded flexible thinking and spontaneity throughout the process: two teams with no more than two men each at any given time drove tunnel heads with nothing more than mallets and chisels over the course of at least eight years (Kienast 1995, 189). As opposed to the modern distinction between design and construction, the fluidity of these responsibilities is further underscored by the vaulted, masonry-lined dromos on the north end. Here, the inscription *paradeigma* (model) appears on the wall, signifying that the completed section establishes the direction to be followed by the remaining construction (Wesenberg 2007). In a way foreign to modern expectations of architecture and engineering, design and construction were part of a single, versatile process for Eupalinus.

Tools and machines were obviously central to building, and the question of machines further blurs the distinction between architecture and engineering. The chisels and mallets used to excavate Eupalinus' tunnel were part of the same set of tools, including rasps and abrasives, that shaped and finished the individual parts of monuments built according to the orders, such as paving slabs, base moldings, ashlar blocks, column drums, capitals, triglyphs, etc. Transporting and lifting these parts required machines. Architects were responsible for overseeing the construction and maintenance of the sledges, wheeled vehicles, and cranes employed at the quarry and construction site, without which the building process itself could neither begin nor progress. Again, an education was essential, so that architects could abstract into recipes of proportional relationships the relative magnitudes of parts of load-bearing machines that successfully achieved stability. In turn, these plans must be able to be recorded in writing and recreated by subsequent literate architects.

The compass and rule were the primary tools for creating both machines and the building parts they transported and lifted. Pivotal motion in machines derived from both the wheel and compass, and the rule imparted the measurements necessary for maintaining proportional relationships as provided by written formulas. The parts of buildings created with carving and finishing tools depended first on the application of the compass and rule directly to the stone surfaces, graphically constructing their forms prior to shaping them in three dimensions.

These graphic constructions included both the mason's shaping of forms to be carved directly from the block on which they were drawn, and the architect's projection of such forms as models on other surfaces. To the former category belong the circular, radial outlines drawn on the flat sides of column drums to organize the equal divisions of

the fluting on the profile (Schwandner 1985, 26–29, 67–72; Hellmann 2002, 38–42). Belonging to the latter category is the radial, semicircular drawing from the mid-third century BCE preserved on the socle wall of the adyton in the Hellenistic Didymaion (Figure 39.7), which establishes angular measurements readily applied to column drums of various diameters according to a simple procedure (Senseney 2011a, 121–122). In both kinds of drawings, a dark pigment was applied to the surface prior to incising, so that lines stood out clearly against their background (Haselberger 1991, 99–102).

In a third category of graphic constructions, the architect projected features at a reduced rather than 1:1 scale. To this category belongs the drawing of the vertically compressed column found at the Didymaion, which preserves a Greek architect's method for constructing entasis (Figure 39.7). This drawing shows half a column lengthwise from its central axis to its curved outer profile, sketched as a large circular arc with a compass-like instrument. While the base moldings are rendered at 1:1 scale with the features they project, the shaft maintains a 1:1 scale in the horizontal direction only, compressing the height of the column at a 1:16 scale that results in its rather squat appearance. In the case of standard Greek metric units like Ionian, Attic, or Doric feet, the 1:16 scale corresponds to the 1:16 ratio of one foot (0.3 m) to the sixteen dactyls into which it subdivides. In the drawing at Didyma, each of the horizontal lines drawn across the shaft is divided by a distance of one dactyl. On the basis of this drawing, a subsequent drawing was made, which transferred the 1:1 horizontal distances from the central axis to the curved outer profile to vertical distances protracted from one dactyl to one foot. In this way, the second drawing protracted along a single axis, stretching the circular arc of the first drawing's curved outer profile into an elliptical arc. By way of this second drawing, masons could ascertain the distances from the central axis to the outer profile corresponding to any point along the height of the shaft, transferring these measurements

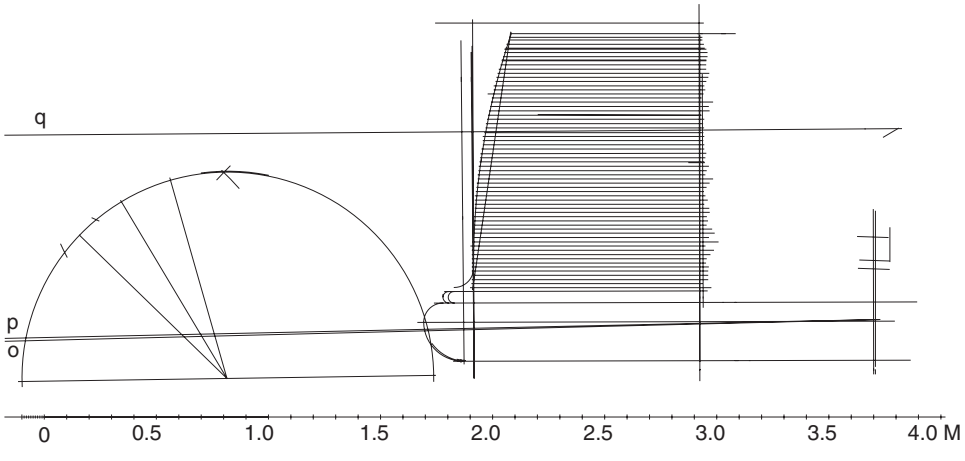


Figure 39.7 Sanctuary of Apollo, Didyma, begun circa 300 BCE. Restored working drawings for generating column fluting (left) and entasis (right), dating to mid-third century BCE. Drawn through both of these, *q*, *o*, and *p* are from a third drawing based on the working drawing for entasis, in which a full-length recumbent column shaft includes *q* as the central axis, *p* as the line of diminution connecting the lower and upper column diameters, and *o* as the curved outer profile. Adapted from Haselberger 1980, figure 1.

with their compasses as a diameter drawn on the top and bottom of marble blocks in order to apply the shaft's elliptical curve of entasis. Interestingly, the drawing itself has a geometric underpinning consisting of a 3:4:5 Pythagorean triangle *ABC* (Figure 39.8B), as well as a modular underpinning established by the maximum bulge of the curvature and its 3:4 ratio with a secondary unit that organizes the height of the drawing (Figure 39.8B, C). This rare surviving working drawing for the vertical curvature of entasis likely reflects the same tools, techniques, and principles of commensuration employed in the graphic projection for horizontal curvature, as found, for example, in the Parthenon (Figure 39.3; Haselberger and Seybold 1991; Senseney 2011a, 104–109).

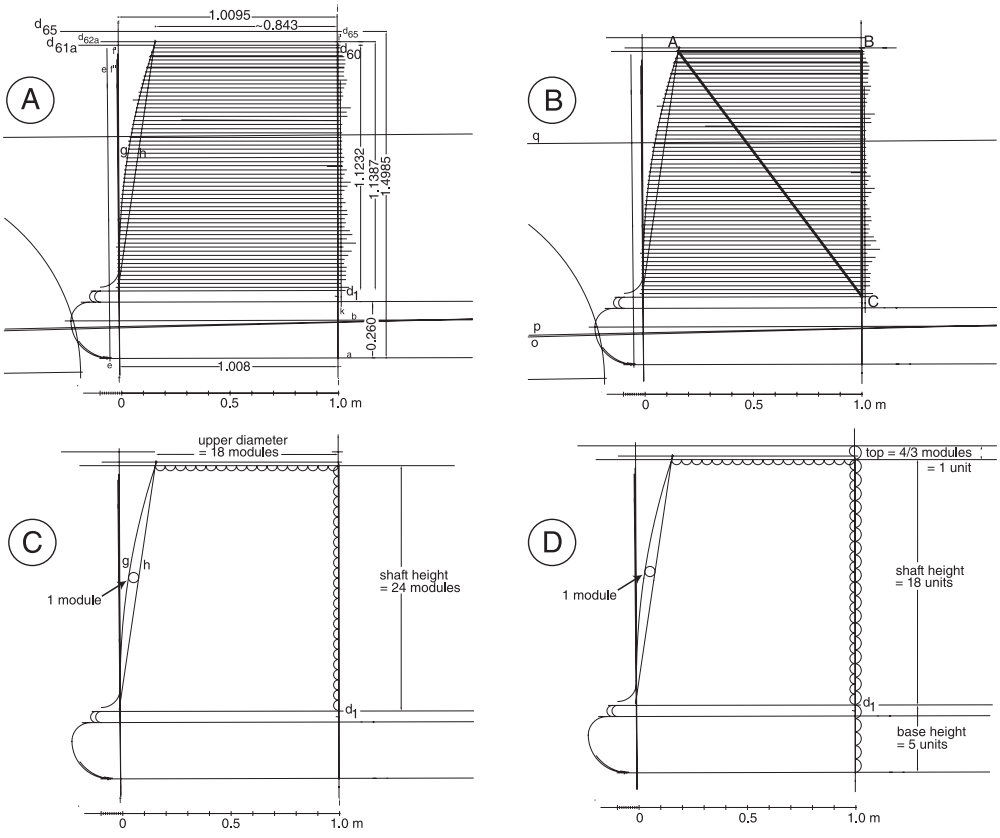


Figure 39.8 Sanctuary of Apollo, Didyma, begun circa 300 BCE. Restored working drawing for generating entasis, dating to mid-third century BCE.
A: Restored according to Lothar Haselberger.
B: Shown with underpinning of 3:4:5 Pythagorean triangle *ABC*.
C: Shown with modular underpinning, wherein the maximum height of the curve (*g*) above the line of diminution (*h*) expresses the module by which the upper column radius and height of the column are measurements of 18 and 24 modules.
D: Shown with modular underpinning established by *d65-d62a* as the dimension of the maximum curvature of entasis, and *d65-d61a* as 4/3 of that measurement, establishing the unit by which the divisions of the elevation are established: base = 5, shaft = 18, *d61a-d65* = 1. Adapted from Haselberger 1980, figure 1.

Dating to around half a century after the start of construction at the Didymaion, the entasis drawing at Didyma raises questions concerning the degree to which monuments were planned prior to building. Planning an overall building by way of scale drawing appears not to have been a part of traditional Greek architecture. The traditional Greek plans of the pre-building phase that ancient sources mention are not ground plans, elevations, and perspectives, but rather verbal descriptions specifying relevant materials and dimensions, known as *syngraphai* (Coulton 1977, 54–55). Despite their rather detailed character, these accounts provide little more than the general outlines of a project. Decisions about the details of form were made gradually at the point of construction where they were encountered—a principle that Trachtenberg has termed "myopic progression" in medieval architecture (2010, 134–139). Such is the case in the graphic projection of the Didymaion's columns, their entasis after construction reaching the level of the stylobate. In addition to such drawings, sources refer to the *anagrapheus*, full-scale template, and *paradeigma*, full-scale three-dimensional model of individual elements, as in capitals, for example (Coulton 1977, 55–59). We therefore have significant evidence for the shaping of buildings during the construction process, as well as the use of full-scale graphic and plastic models.

For traditional Greek architects, the question of design as a discipline largely limited to reduced scale projections of buildings prior to construction is irrelevant. Greek architects built, and they oversaw this actively creative process of formation while building. In this regard, the work of a building's originating architect as opposed to his successors need not have carried any privileged status.

This realization sheds important light on the nature of the Doric and Ionic orders. The orders did not simply limit creativity in the sense of eclectic form. Conversely, they facilitated creativity by providing a unifying framework within which architects and masons could work together. This observation holds for both active collaboration in which several architects worked synchronically, and for architects and masons who succeeded one another, even in projects that spanned several generations, like at Didyma. Variations in features like moldings within a single building do nothing to impair its overall coherence, and innovations and modifications introduced later play off and enhance earlier forms, drawing them into evolving expressions retro-synthetically. In this way, the orders were conduits for creativity in time, allowing for collaboration with the past and the future even across long durations.

Despite the traditional emphasis on the evolution of form in the construction process, there can be little doubt that Greek architects did eventually come to use scale drawings. In Aristophanes' *Birds* (performed in Athens in 414 BCE), the character named after the astronomer Meton describes his design for a city with a compass, straight edge, and, apparently, a protractor (Dunbar 1995, 556–557; Senseney 2011a, 90–91). Starting with the Theater of Dionysus in Athens, theaters commonly came to take their shape through the same circular, radial form that traditionally served the organization of column fluting at full scale. As for temples during the Hellenistic period, examples like Hermogenes' Artemision at Magnesia-on-the-Maeander and its modular arrangement appear to follow the graphic underpinning of a grid (Figure 39.1). For the Doric order, in which the "corner triglyph problem" and its resulting corner contractions prevent a gridded arrangement of columns, the modular Temple A at Cos reflects an underpinning of a circumscribed 3:4:5 Pythagorean triangle *ABC* (Senseney 2007), thereby prefiguring the approach to archetypal geometry and commensuration described by Vitruvius with

his so-called "Vitruvian Man" (Figure 39.6). The similarity to the underpinning of the entasis drawing at Didyma appears to suggest how traditional graphic constructions for individual elements using the compass and straight edge may have informed similar modular and geometric approaches to organizing buildings by way of scale ground plans. Unlike the case of modern architecture, such projections were starting points for verbal specifications (the *syngraphai*), open to eventual modification, and never the property of design as an art separated from the art of building.

4. Building and Knowledge

Today's engineering rests on theoretical principles acquired through science. In the Greek world, however, the empirical challenges of monumental construction in stone enabled the development of a theoretical basis for future building. In the sixth century, for example, Theodorus' construction of such monumental foundations for the Rhoikos Temple on the unstable terrain of the sanctuary of Hera near the Imbrassus River on Samos was unprecedented, and therefore a true experiment (Vitruvius 7 preface 12). Despite the experiment's apparent failure that shortly resulted in the temple's dismantling, the experience of working through the project's challenges rendered Theodorus an expert, able to consult about laying of foundations for the Croesus Temple on similarly marshy grounds of the sanctuary of Artemis at Ephesus. In addition, according to Pliny (*NH* 7.56, 198; 36.19, 90), Theodorus invented the square, level, and lathe. Just as Theodorus certainly included such inventions in his writings, so, too, did Chersiphron and Metagenes write of their innovative vehicles for transporting heavy marble columns and architraves from quarry to building site at Ephesus (Vitruvius 7 preface 12; 10.2.11–12). Perhaps it is this traditional character of architects as pioneers of tools, techniques, machines, structure, and widely applicable principles that underlies Pytheus' curious assertion that an architect knows more than even specialists know about their own fields (Vitruvius 1.1.12, 15). Against this background, it is understandable that, for Vitruvius, *architectura* comprises not only the art of building, but also time-pieces and machines (1.3.1), all three of which underpin and reflect the order of the *cosmos* (3.1.4; 9.1.1–2; 10.1.4).

The connections between Greek building, philosophy, and science are notable. Plato's dialogues are replete with references to craftsmanship, which provides his metaphors for the sense of order built into the phenomenal world and the transcendent, intelligible truths that underlie it (Senseney 2011a, 44–59, 175–188). Plato's contemporary, the mathematician and astronomer Eudoxus of Cnidus, used the compass and straight edge to envision cosmic order by way of the zodiac (Dicks 1970, 156–157; Evans 1998, 75–76), the circular, radial construction reflecting the same tools and techniques traditionally employed by builders in the graphic construction that organized column fluting. The form of the stone-built Greek theater, likewise taking its inspiration from circular, radial graphic construction, provided the model reflected in Vitruvius' description of the motions of planets along circular courses like those of an ascending stairway (9.1.5). As the place of seeing, the theater provided an appropriate model for envisioning the *cosmos*. The architect's graphic projection of the theater also preceded the theorization of vision itself by way of Euclid's *Optics*, written around 300 BCE. In this account, Euclid's circular, radial construction with the compass and straight edge

illustrates his theorization according to a cone of vision, in which the rays serve as visual conductors between objects and the eye.

Indeed, the connections between architecture and knowledge about the world led Plato to identify the *technē* of building as greater than the arts of medicine, agriculture, music, and other arts. According to Plato, the reason for building's privileged status is the "scientific" precision it allows for by way of its tools: compass, straight edge, square, plumb line, and peg-and-cord (*Philebus* 56b–c). To Plato's list one might add the dioptra, the surveying instrument used both in the art of building and in astronomy, which derived from the simple sighting tube used by Eupalinus, and whose form and principles were themselves the product of the compass and straight edge.

Shared tools and techniques are important intermediaries in the kindred sense of geometric order found in public and religious buildings on the one hand, and nature on the other. At least in the case of Euclid, a single individual wielded the builder's tools to impart a patently similar visual order to three separate written works comprising mathematics (*Elements*), the science of vision (*Optics*), and astronomy (*Phenomena*). A particularly instructive example of this shared pattern comes from the first theorem of Euclid's *Phenomena*, which provides his proof of the geocentric structure of the universe by way of a circular, radial graphic construction that abstracted the visual rays of an earthbound viewer observing the rising and setting of constellations through the dioptra.

The inevitable modern temptation to conclude that the art of building influenced mathematics and the sciences may not be helpful, since the very notion of influence implies a separation that is not entirely applicable to ancient Greek experience. Like building, mathematics and the sciences were arts (*technai*), and even Plato counted himself among such artists in identifying his own work as a kind of painting (*Timaeus* 19b–c). For Plato, the geometric drawings of the mythical architect Daedalus and astronomers may provide only a limited hint of beauty and truth, but one that may lead viewers toward apprehensions in a higher realm (*Republic* 509d–511e; 529e–530a). Against the background of Plato's unification of such seemingly different fields, we may consider how the pursuits of builders, geometers, and scientists were themselves shared by a standard set of tools and techniques employed in the construction of order in the world. From a modern perspective, this *cosmos* provided a framework subject to modification through later scientific discoveries, as in Copernicus' heliocentricism or Kepler's elliptical, rather than circular, model. As similarly seen in the monumental architecture of ancient Greece, the potential for adaptability and collaboration may be among the highest virtues of such order.

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status of Greek architects counters the views of Alison Burford, 1969, *The Greek Temple Builders of Epidauros: A Social and Economic Study of Building in the Asklepian Sanctuary during the Fourth and Early Third Centuries B.C.*, Toronto: University of Toronto Press, wherein Greek architects are portrayed as having risen through the ranks of skilled workmen. On the question of working methods and construction, Coulton's study predates Lothar Haselberger's discovery of the working drawings at Didyma, which led to the many insights into curvature and related questions of the "refinements" of Classical architecture as explored in Lothar Haselberger, ed. 1999, *Appearance and Essence. Refinements of Classical Architecture: Curvature*, Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology. In particular, Haselberger provides an authoritative overview of curvature in his introduction. An excellent reference for the methods of ancient Greek architects and related bibliography is M.-C. Hellmann 2002. A well-illustrated and accessible treatment in English for methods and materials in Greek and Roman architecture is Malacrino 2010. A detailed and interpretive study of primary sources and archaeological evidence concerning design and construction is Senseney 2011a. The authoritative study of Eupalinus' tunnel at Samos is Kienast 1995. Also important for Eupalinus' tunnel is Lewis 2001, an important study of ancient surveying and its instruments.

CHAPTER 40

Greek Domestic Architecture

Bradley A. Ault

Building Technology: Domesticating Raw Materials

> It is well to understand tactics too; for there is a wide difference between right and wrong disposition of the troops, just as stones, bricks, timber and tiles flung together anyhow are useless, whereas when the materials that neither rot nor decay, that is, the stones and tiles, are placed at the bottom and the top, and the bricks and timber are put together in the middle, as in building, the result is something of great value, a house, in fact. (Xenophon, *Memorabilia* 3.1.7; trans. Marchant 1938)

This metaphorical observation by Xenophon's Socrates enumerates the primary ingredients for Greek house building, and also the rudimentary sequence of Greek domestic architecture, and construction in general. Stone, tile, brick, and timber comprise the principal materials. Not "flung together," but properly ordered, like the troops which are the actual matter of his concern, so that "… the materials that neither rot nor decay, that is, the stones and tiles, are placed at the bottom and the top, and the bricks and timber are put together in the middle." But this was not always so, in Greece or elsewhere. There are other options for building materials and house construction: the use of wattle and daub, wood or rammed earth (*pisé*), pit or thatch houses, to name just a few. But the Greeks opted for, and indeed developed, a form of construction which remained superior and standard for vernacular building into the pre-modern era and is still a viable option for traditional house forms today, particularly in the Mediterranean region. Greek construction preferences were shaped not only by the availability and suitability of building materials, but also by the form they would ultimately assume, namely, that of the courtyard house. Whether located as isolated structures in the countryside or crowded together side by side in an urban setting, the courtyard house came to dominate.

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Beginning with stone foundations, these could be of mixed rubble (naturally collected, quarried, or broken up specifically for the purpose) or, if the stone sources were suitable for planar fracturing, as often found in the schist of the Cyclades, extracted as slabs (Higgins and Higgins 1996; Martin 1965, 112–155). Foundation stones could also be cut into blocks (square or polygonal, and if rectangular, the longer the better) or used in combination with a rubble bedding. In any case, unless utilizing exposed bedrock, which could be incorporated into buildings as both foundations and floors, walls were footed by laying them into a trench dug to varying depths and just wide enough for the purpose, in order to add stability and increase their load-bearing capacity. Local resources were always preferred, as distance increased the difficulties associated with transport (see Land Transport and Vehicles and Ships and Boats). Foundations may transition from bedding to orthostate courses, especially notable when cut stone or ashlar work is present. It is the orthostates or uppermost rubble courses, generally extending no more than 0.50 m (1.64′, and often considerably less) above ground level, which serve as a footing for subsequent mud brick courses, the primary building material for the walls themselves. Stone walls were employed in ancient Greek houses, but they are the exception (notable examples exist at Ammotopos in Epirus and on Delos, where both the stone itself and the construction techniques employed are quite different from one another).

Mud brick walls in combination with stone footings have a long history in the architecture of the ancient Near East and Aegean world, dating back to the Neolithic period and used widely during the Bronze Age (Aurenche 1981, esp. 60–70, 116–121; Guest-Papamanoli 1978). The utility of their pairing is obvious: the enemy of mud brick is moisture. Although unfired, sunbaked brick is exceptionally strong and resilient. It has great load-bearing capacity and will survive for centuries when kept dry, but will crumble or return to its natural state when exposed to damp. Therefore, the mud brick superstructure must be raised off the ground, especially where splashing or puddling from rain occurs, but also to prevent it from absorbing any humidity from the surrounding earth, all of which degrades and undermines the walls themselves. For the same reason, its exposed surfaces should ideally be protected from rain by a mud or plaster coating and, just as importantly, shielded from above by overhanging eaves or other measures.

Superseded in time by Roman developments in fired brick and concrete, the Greek use of mud brick extended from private to public constructions (Hellmann 2002, 106–109; Martin 1965, 46–64; where the introduction of baked brick in Greek contexts from the fourth century is also discussed). While their dimensions are variable from site to site, mud brick used in domestic structures tends to be rectangular, within the range of 0.4 m long × 0.2 m wide × 0.1 m thick (1.3 × 0.65 × 0.33′). The square dimensions of Vitruvius' *pentadoron* or "five palm" (2.3.3), about 0.4 × 0.4 × 0.08 m (1.3 × 1.3 × 0.26′), are for bricks best suited to public buildings. And while he also states there that the smaller *tetradoron* is used for private constructions, it is his "half bricks" (*semilateria*: 2.3.4), rectangular in form, that predominate in the Greek house (Hellmann 2002, 107; Schwandner 1999, 529). Both rectangular and square varieties were formed in wooden molds. Compositionally, ancient Greek mud brick has received little attention, but it can generally by described as consisting of coarse clayey soil, tempered naturally or deliberately with sand and gravel, with possible additives of straw or chaff, to inhibit cracking. Vitruvius' recommendations extend from the choice of clay for bricks to the best seasons for making them (2.3.1–2). Laid in parallel courses two wide, and bonded

with mud mortar, they provide for an average wall thickness of about 0.4 m (1.3′), and may alternate with perpendicularly laid header courses as well, building additional strength into the fabric of the wall. On account of its earthen composition, mud brick has ideal thermal and insulating properties. To a certain extent, it retains the cool of shade in the summer and preserves warmth generated in interior spaces in winter. It is a remarkably strong, stable, and economical medium.

Most ephemeral are the wooden elements of house construction. Building timber in the Mediterranean is a scare commodity, hence its tendency toward reuse. Doors, roofs, and other wooden constituents were routinely removed from structures once no longer inhabited, or when ownership changed, to be repurposed anew elsewhere (for examples, see Osborne 1985). Not routinely employed for framing beyond doorways, roofs, and as an additional strengthening element within mud brick walls (Hellmann 2010, 159; Schwandner 1999, 529–530), timber was also required for vertical supports, for shuttering the few windows Greek houses may have had, and for second-story constructions which required stairways, supporting joist beams, and floor planking (Schwandner 1999, 531–535). We know something of the range and appearance of wooden constructions from iconographic depictions and from the Macedonian tombs, where many such elements, especially the doors themselves, in addition to couches and other furniture, were translated into stone sepulchral monuments. Rarely, as in the stone-built houses of Ammotopos, beam holes preserved in wall elevations provide clues about the existence of wooden armatures (Schwandner 1999, 534). Offering a basic understanding for smaller-scale, more rudimentary designs is research into ancient timber sources (Meiggs 1982) and wooden roof construction of monumental architecture generally (Coulton 1977; Hellmann 2002, esp. 278–291; Hodge 1960; Martin 1965).

While stone house foundations have the greatest likelihood for in situ preservation in the archaeological record, and mud brick and wooden elements of the superstructure have disintegrated or vanished altogether, fired terracotta roof tiles may quantitatively be the most abundant class of artifacts recovered from domestic (and other habitation) sites. Indeed, for the purposes of archaeological survey, surface scatters of roof tiles are highly diagnostic. And although it is the cut stone monumental buildings of ancient Greece which may make the most profound impression upon us, the development of tiled roofs is arguably the greatest contribution of the Greeks to Western architecture. First appearing in association with monumental sacred architecture in the early-seventh-century Corinthia, where they replaced thatched and perhaps wooden shingled roof constructions, tiled roofs were designed as inflammable and impermeable coverings (Wikander 1990). They also protected the new pitched timber roofs designed to support their weight and, like the thatched roofs which preceded them, shielded mud brick walls from the elements. In spite of Greek experiments with tiled roofing systems dating back to the early Helladic period (at the House of the Tiles at Lerna and other so-called "corridor buildings" of the early Helladic period), and again in the Late Helladic (at Mycenae, Midea, Thebes, and Gla—the degree to which any of these had a lasting impact remains a matter of debate), the development of tiled roofs was essentially unprecedented (Coulton 1977, 35; cf. Hellmann 2010, 167–169).

The basic scheme is well known (Hellmann 2002, esp. 298–320; Martin 1965, 65–112; Schwandner 1999, 535–536): flat or gently curved "pan" tiles (Latin *tegula*, Greek *solenes*) cover the roof, their short ends overlapped in descending fashion perpendicular to its downward slope. Their long sides, as well as where they meet at the

roof ridge, are concealed by half-round "cover" tiles (Latin *imbrex*, Greek *kalypter*). Two primary styles of pan and cover tile pairings are identified: the Corinthian system is characterized by flat pan tiles and angular half-round cover tiles, while the Laconian system consists of curving pan and smooth half-round cover tiles. Hybrid pairings were frequent, as were the variant solutions adopted for finishing the eaves of roofs.

Within two hundred years, by the fifth century, the use of terracotta roof tiles had migrated from monumental architecture to regular use on domestic structures, both of which had previously borne flat or pitched thatch roofs. As a consequence of the significantly added weight of roof tiles, increasingly sophisticated and substantial pitched timber roof constructions were required to support them. The desired effects of a fire- and insect-resistant, water-retardant, permanent roof, and the added prestige it conveyed, led to the symbiotic development of terracotta and wooden elements of roofing systems, though flat or thatched roofs had not been abandoned altogether for houses or other buildings. These continued in certain areas, especially where regional building traditions remained strong, or where tiles or timber were unavailable or too expensive, as in the islands. Sections of flat roofs were also likely to have been interspersed with pitched and tiled roofs within the same structures. Not only were tiled roofs largely impervious to the elements, protecting the fabric of the building by shielding it from wind and rain, where rainwater is directed off the structure, but in so doing, they also facilitated the collection of runoff, especially into cisterns, where desired.

Numerous difficulties remain with regards to our understanding of raw materials, their procurement, and the construction of houses (and to a certain extent for other types of buildings), especially when considering their replication by the hundreds of thousands across the Mediterranean *polis* landscape. While we cannot provide answers to these questions here, it may be enough to pose them and, in so doing, suggest some possible outcomes that may pave the way for further exploration.

Where did the building materials come from and how were they obtained? Local sources were surely sought whenever possible, as already noted, and were likely sufficient for most needs other than timber. Indeed, suitable timber would have been the most precious commodity required for house construction (see below).

As with cut stone and carpentry, some sort of manufacturing expertise is required for the mass production of roof tiles. Even more so than with stone, mud brick, and timberwork, terracotta tiles required standardization and equipment, from molds to kilns, in addition to quantities of suitable raw materials from clay to fuel.

Who planned and built the houses? Given the consistent size of house plot allotments in orthogonally planned urban landscapes (ranging from 207 m^2 [2,228 ft^2] at Priene to 294 m^2 [3,165 ft^2] at Olynthus), as well as recurrent elements in the layout of the houses themselves (see below), it seems safe to assume that there were established guidelines and general oversight. The continuously bonded walls of neighboring houses along the frontage of insular housing blocks and the use of shared party walls between them support this. Noting slight changes in the fabric of the rubble foundations at Olynthus, Cahill (2002, 202–204) observes that it was most likely the householders themselves, along with friends and family, who carried out the actual construction. A similar situation is observed at Priene and Kassope (Hoepfner and Schwandner 1994, 314). Therefore, the erection of houses, like the building of city walls, was a communal enterprise, but one most likely organized along kinship and social lines (Sewell 2010, 95–97).

How much did houses cost and who paid for them? The figures we have for the cost of building materials in ancient Greece are only an index, for they will have fluctuated across time and place (Martin 1965, passim). Nevertheless, they do provide a basis for estimating the cost of building a house. A 294-square-meter house at Olynthus required perhaps1200–1500 roof tiles for its covered spaces. At a cost of 1 obol per tile, the price of roofing such a structure would amount to 200–250 drachmas. One meter cubed (35.3 cubic feet) of building timber cost 350 drachmas. 1,000 mud bricks cost 40 drachmas. Extrapolating to the appropriate quantities, the cost of a house of typical dimensions is estimated to have been between 1,000 and 2,000 drachmas (Hoepfner and Schwandner 1994, 316–317). However, the prices of houses in sales inscriptions from Olynthus ranged from 170 to 5,300 drachmas, reminding us of the many factors influencing value, especially those of the market and location (Cahill 2002, 276–281; Nevett 2000; where the 5,300 drachma price of a house on the edge of the agora sold for nearly 30 times that of the 170 drachma suburban property!). Given the absence of the sort of monetary economy which would support a financial outlay of 1,000–2,000 drachmas by most individual citizens, particularly at the time of a city's foundation, it was *polis* resources (especially in terms of liturgies levied on the wealthy) which saw to providing building materials for the construction of mass housing. As noted above, in exchange for these materials, the citizen body itself provided the labor for domestic building, as for the construction of city walls (Sewell 2010, 98–103).

The ancient Greek house then, was a masterpiece of organic vernacular architecture. State sponsored and citizen built, "something of great value" in Xenophon's words, the full measure of its utility was expressed in its layout. Along with the literal domestication of raw materials, the ordering, articulation, and elaboration of space encapsulates household organization and its relationship to the *polis* as a whole.

Architectural Syntax: Domesticating Space

The construction and design of any culturally specific style of housing ultimately comprises a series of variants on a theme. In the early Iron Age, tenth and ninth centuries, this "theme" was one indebted to types already established in the preceding Bronze Age. But by the eighth and seventh centuries, important changes can be noted in the layout of houses which come to full fruition only in the fifth and fourth centuries.

The Early Iron Age

The place to begin investigating post–Bronze Age domestic architecture is at Lefkandi on Euboea. Around 1,000 BCE, an enormous structure at the site known appropriately as Toumba, was erected there (Figure 40.1; Popham, Calligas, and Sackett 1993). Measuring some 50 m (164′) long and 10 m (32.8′) wide, it surpassed in size any construction in Greece for the past two and a half centuries, since the final phase of the Mycenaean palaces. With a shallow front porch and a spacious fore-hall, a large main living room terminates in two small chambers flanking a narrow passageway that in turn gives way to an apsidal back room marked by holes sunken into the floor, which may once have contained storage vessels. This so-called "Heroön" is a landmark in the history of Greek architecture, and not only owing to its unprecedented size. Built on a roughly polygonal cut stone foundation with a mud brick superstructure, the building bore a pitched and

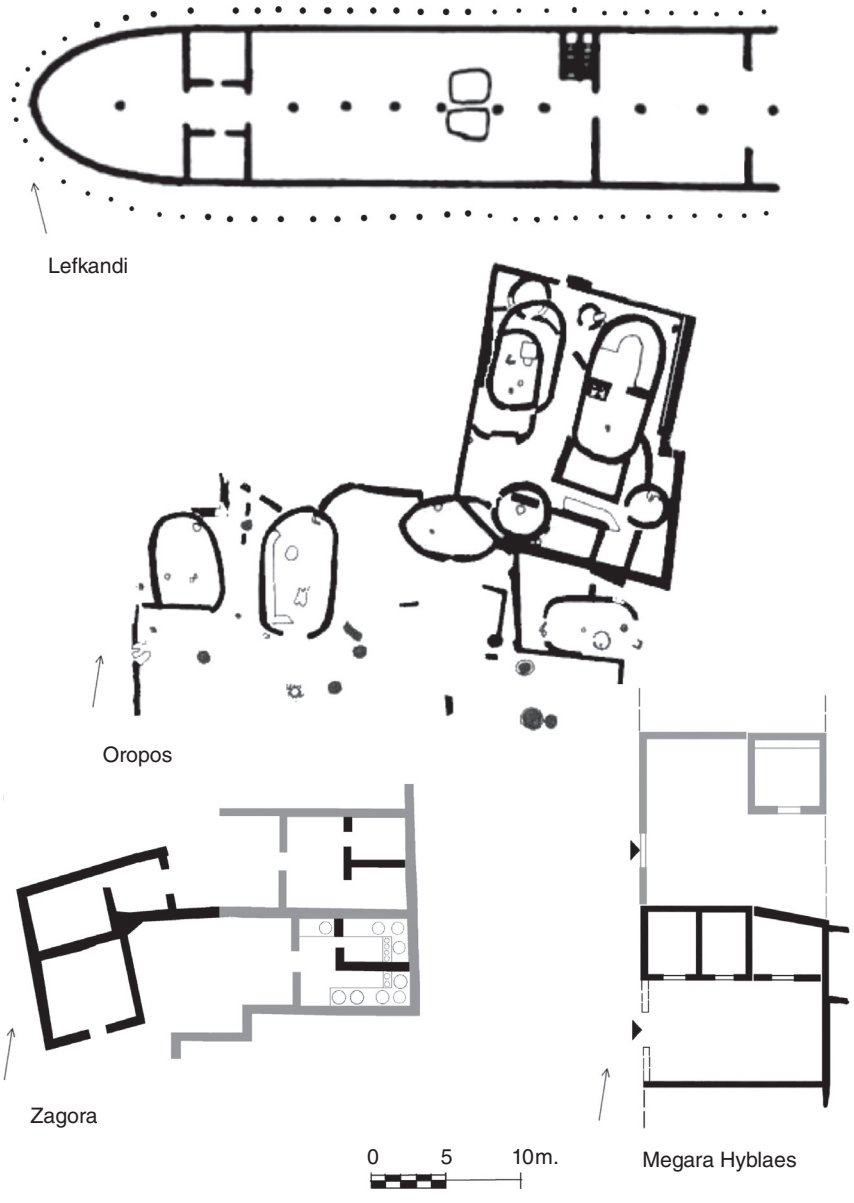


Figure 40.1 Early Iron Age house plans.

thatched roof characteristic of apsidal constructions (although in the Greek islands, apsidal structures characteristically also bore flat wooden and mud roofs). In order to support the internal span and weight of the massive roof, a regularly spaced series of vertical supports were necessary along the longitudinal axis of the building's interior. In addition, to protect its vulnerable mud brick exterior, the thatch roof was constructed with a 2 m (6.5′) wide overhang, in turn necessitating support on a series of regularly spaced vertical posts running around the exterior of the building. In essence, this is the first

peristyle in Greek architecture. Yet the plan of the building itself harks back to simple domestic structures dating back to the Middle Bronze Age, namely, the apsidal *megaron* house. The *megaron* form underwent a monumentalization as it was transformed into the throne room of the Mycenaean palace, but the basic design, a longitudinal, paratactic structure consisting of a porch, fore-hall, an expansive main room (the "great hall" or "*megaron*"), with storage areas concentrated toward the rear, the remotest and securest area of the structure, persisted as the most common form of house construction as well.

The edifice at Lefkandi looks back to the *megaron* as well as forward to peristylar architecture, itself without precedent in the Bronze Age. But in function and plan, the structure is also striking, for it stands as an amalgam of basically all building types: house, palace, tomb, and temple. Not only was it a monumental expression of the humble domestic form, but it also served as the sepulcher of the otherwise anonymous "Hero of Lefkandi" (thus its designation as an *heroön*), whose cremated remains were interred precisely in the center of the main hall, alongside a young female and four horses, all inhumed and presumably sacrificial victims to accompany him. Following what must have been elaborate funerary ceremonies, the building itself was partially demolished and interred within a tumulus (about 50 m [164′] in diameter) erected over it, and subsequent generations of Lefkandi began to be buried around its perimeter, marking the site's transformation from secular and regal to funerary and sacred.

The persistence of the *megaron* and even more basic forms for domestic structures is well documented throughout early Iron Age Greece, although their ultimate transformation is less well understood. In what follows, we will look to three examples in particular which serve to further demonstrate the period as one of foment. Across the Euboean Straits from Lefkandi, in northeastern Attica, lies Oropos. Perhaps to be identified with Homeric Graia, portions of the early Iron Age settlement have been recovered (Figure 40.1; Mazarakis Ainian 2002). These date to the eighth and seventh centuries and were discovered by chance beneath 3 m (9.8′) of alluvial soil deposited across the site by flooding which eventually necessitated its relocation. Utilizing the construction techniques of stone foundations, mud brick walls, and thatch roofs already observed at Lefkandi, the overall plan consisted of a complicated sequence of oval, apsidal, and circular structures individually devoted to metalworking, habitation, and agricultural storage. At least three of these "compounds" were eventually demarcated by peribolos walls (the largest enclosing an area of over 200 m^2 (2,153 ft^2). While these were certainly in part a measure to combat the ongoing problem of flooding, they also surely represent a step in the direction of household enclosure which would elsewhere and in time manifest itself as the courtyard.

The settlement of Zagora, on the isle of Andros, represents a move toward planned urbanism (Cambitoglou et al. 1981). Dated between 850 and 700 BCE, the houses there are all strictly rectilinear in plan. This allows them to utilize shared party walls, suggestive of intra-settlement cooperation, if not oversight (as does the massive fortification wall to the northeast of the settlement area). Construction is typical for the Cyclades, "stacked" stone superstructures and flat roofs of timber, stone slabs, and mud. In the initial phase, between circa 850 and 750 BCE, the houses exhibit sizable one-room *megaron*-derived plans (averaging between 50 and 70 m^2 [538 and 750 ft^2]), frequently with built stone benches along the interior walls, with circular recesses allowing for the emplacement of storage jars (Figure 40.1, in gray; see FOOD STORAGE TECHNOLOGY). Between 750 and 700, two of these houses in particular

undergo impressive remodeling and expansion. Not only were the single-room "*megara*" subdivided into smaller chambers, but the houses were extended westward from the open front porch, enclosing the facing "yard," itself closed off at the west by a series of additional sizable rooms (Figure 40.1, in black). These renovated houses exhibit an increasing segmentation and specialization of space and the activities performed there, as well as fully realizing the courtyard as integral to the articulation of domestic structure and organization.

At nearly the same time as these developments were taking place at Zagora, but at a great remove, in southeastern Sicily, the colony of Megara Hyblaea was established (in the second half of the eighth century; Vallet, Villard, and Auberson 1983). This early *apoikia*, "home away from home," is generally recognized as constituting the earliest regularly planned Greek city. With standardized house allotments laid out in long rows two houses deep and containing up to 24 plots (each averaging 11 m × 11 m [36′ × 36′]), these proto-*insulae* were embedded within a network of streets, itself not entirely regular, and so likely indicative of its early, experimental nature. Initially, in the eighth century, the houses themselves consisted of only a single room, averaging 5 m × 5 m (16.4′ × 16.4′), typically located along the northern limits of the plot (Figure 40.1, in gray). And while the extent to which the boundaries of the plots were originally demarcated by walls is unknown, by the seventh century, additional rooms were added, and the plot itself became increasingly identifiable as constituting a courtyard enclosure (Figure 40.1, in black). The parallel with house growth at Zagora, albeit independently and in quite different settings, is striking, as both convey the evidence for concurrent social transformations, including an increasing desire for privacy and security in the domestic sphere amid the growing density of urban space.

Classical and Hellenistic

The *koinē* of Greek civilization which had developed by the fifth century, predicated upon shared ethnicity, language, religion, and social customs, extended to building types as well. Domestic architecture was no exception. Greek houses offered a sheltered, yet open arrangement that was ideally suited to Mediterranean settings, in which the outdoors was essentially brought inside, harmoniously integrating exterior and interior spaces. This was accomplished primarily by means of the courtyard, typically the dominant element of the plan and occupying an average of 25% of the overall area of the house (Ault 2005, 60). Courtyard houses developed as an alternative to the one-room or linear, paratactic plans of early Iron Age houses (Lang 2005). As demonstrated above, already as early as the eighth and seventh centuries, the open area which lay in front of the house was increasingly privatized and drawn into a more integrated, radial, and syntactic arrangement of space. Only becoming common by the sixth and fifth centuries (insofar as the archaeological evidence attests), the courtyard served as the primary axis around which the house revolved (Ault 1999a; 2005, 60–62). It offered both living and working space, and provided light and air for the otherwise dark and stuffy house interior. Here were located any number of household implements and installations relating to the domestic economy. These included wells or cisterns (the latter fed by water collected from tiled roofs; cf. Hellmann 2010, 169–175), *koprones* for collecting household waste which was converted into fertilizer (Ault 1999b; 2005, 63–65), household altars

(Nilsson 1960), and stairways to second story rooms (which developed hand in hand with courtyard houses themselves), in addition to all other points of primary access to the rest of the house.

Given the intimate relationship between surveying, dividing up, and allotting agricultural lands as parcels to individual citizens, and the laying out of city plans and ultimately house plots (as documented in the foundation decree from Korkyra Melaina [*SIG*^{3} 141], cf. Cahill 2002, 219–221; Boyd and Jameson 1981; Hellmann 2010, 203–204; Martin 1973), there may also be a degree of correlation between the development of rural and urban courtyard houses, where the farmhouse courtyard served even more pronounced utilitarian functions for subsistence (Hellmann 2010, 139–155). In addition to this possible evolutionary scenario, with rural residences influencing the design of urban ones, two especially significant elements of courtyard placement are its southerly orientation and its role in controlling access and movement generally. In Aeschylus' *Prometheus Bound*, the hero refers to a time when "knowledge had they neither of houses built of bricks and turned to face the sun …" (450–451, trans. Smyth 1938). This is interesting for its mention of mud brick as a commonplace medium, but especially in the acknowledgment of just how commonsensical south-facing houses were. Xenophon's Iskhomakhos explains further: "I pointed out to her that the entire house has its façade facing south, so that it was obviously sunny in winter and shady in summer" (*Economics* 9.4; trans. Pomeroy 1994); as does pseudo-Aristotle: "With a view to well-being and health, the house ought to be airy in summer and sunny in winter. This would be best secured if it faced south and is not equal in breadth to its depth" (*Economica* 1.6.31–33, 1345a; emended trans. of Barnes 1984). The courtyard is nowhere mentioned in these passages because it is assumed to lie in the front (i.e., to the south) of the house. That is, indeed, the whole point of pseudo-Aristotle's second sentence. The advantage of the south-facing house fronted by the courtyard has been demonstrated graphically by Hoepfner and Schwandner (1994, 318–319, figure 303). It has most recently been taken up in a more nuanced analysis by a practicing architect (Sinou 2011), who shows how such houses were able to take the utmost advantage of light and air in proper measure during the appropriate season (cf. Hellmann 2010, 49–50).

The courtyard also provided the main access node for the Greek house both internally, and externally. Passage from the outside, public world to the private, domestic realm was normally possible by means of only one doorway. If at all possible, access between the two was gained directly via the courtyard. This, too, is implicit in the typological identification of the Greek house as being of "single entry courtyard house" design (Nevett 1999, 158–161), which allowed for restricted and surveilled access, controlled and monitored by household authorities. But whose access and egress were being controlled? Non-kin males and kin females were subject to particular concern, for reasons ultimately related to maintaining the integrity of the family and legitimate patrimony within the household. Pericles' law of 451 BCE, whereby citizenship was conferred only upon those males whose parents could both prove Athenian descent, provides an extreme example of this (Plutarch, *Pericles* 37.2–5; Aristotle, *Politics* 26.4).

Socially, a desire for privacy and control over movement amid crowded urban conditions is also communicated by screening off the courtyard and its entry doorway with high mud brick walls. Such entries may show several interesting varieties of design and finish (Hellmann 2010, 46–47, 163–167). They are often slightly recessed into the house façade, providing a tile-roofed alcove protecting the doorway. Framed with stone

or wooden jambs, there is evidence for the use of limestone pier or *anta* capitals crowning those at Halieis (Ault 2005, 42, note 109) and elsewhere. It is not uncommon for entryways to be furnished with two sets of double-winged wooden doors, one double-wide for wheeled traffic such as a cart, and one narrower, for pedestrians alone. Smaller traction animals such as donkeys or mules could have been stabled in the courtyard as well, but the presence of handcarts alone seems equally likely.

With their southern aspect radiating around the central court, the northern side of the courtyard invariably includes some sort of shaded portico which served both as a transition to the principal living rooms, and as a living and working space in its own right. This portico has variously been referred to as the *prostas* or *pastas* (following Vitruvius 6.7.1; cf. Ault 2005, 65–67), depending on its dimensions and its relationship with the rooms to which it gives way. In its most distinctive manifestations, this porch has been used to classify houses as *prostas* or *pastas* in type and seems to have a geographical basis. *Prostas*-style houses tend to be found in Ionia (as at Colophon and Priene, Figure 40.2, where the houses are more rectangular in plan), but also in Attica at Piraeus (Figure 40.2), reflecting the ideals of its master planner, Hippodamus of Miletus. *Pastas*-type houses were a distinctive feature of the Greek mainland (e.g., at Olynthus, Figure 40.2, which tend toward a squarish plan). Also existing are intermediate examples of such porches, which fit neither design unequivocally (as at Halieis, Figure 40.2). These examples I have termed simply "transverse halls." Such porches, in all of their varieties, may well be antecedent to the three-room suites so characteristic of Hellenistic houses and also stand as precursors to the development of full peristyle courtyards, hallmarks of aristocratic houses from the Hellenistic through Roman periods (e.g., at Eretria, where double courtyards also make an appearance, and Delos, Figure 40.2; Hellmann 2010, 58–62).

In any case, the presence of a portico on the north side of the courtyard, serving as an intermediate buffering space or anteroom to living rooms beyond, is as requisite a feature of the "single entrance courtyard house" as these defining elements themselves. It provided a covered room, enclosed on three sides and open to the courtyard on the south, suitable for any number of tasks, but also served as an extension in either direction of both the court and the interior rooms beyond, capable of providing light, shade, and air to the household interior (hence the windows to interior rooms frequently preserved in the back walls of such northerly located porticos at Delos).

The principal living rooms of the house comprised kitchens as well as dayrooms distinct from areas devoted to food preparation, in addition to sleeping quarters (*thalamoi*) and those devoted to storage (the *pitheon* or *tameion*). Olynthus provides our most distinctive suite of this type, the so-called "*oecus* complex" (after Vitruvius 6.7.2). Combining a kitchen (occasionally with a central hearth), bathroom (often with a terracotta tub or traces of one), and a walk-in fireplace (complete with its flue extending up through the second story), the Olynthian *oecus* or kitchen complex is the most developed of its type (Cahill 2002, 153–161). And while the fireplace/flue arrangement at Olynthus is a likely concession to its northerly climes, variants on this theme can be found at a number of other sites in Central and Southern Greece, particularly clear in the pairing of kitchen and bathroom. At Halieis and at Eretria, roughly contemporary if slightly later into the fourth century than the houses at Olynthus, which date from circa 432–348 BCE, the pairing of kitchens and baths are also found. In the absence of terracotta bathtubs, basins on stands resembling birdbaths (Greek *louterion*) could be used (Hellmann 2010, 47–49). Frequently depicted in painted pottery, an example survives in situ at

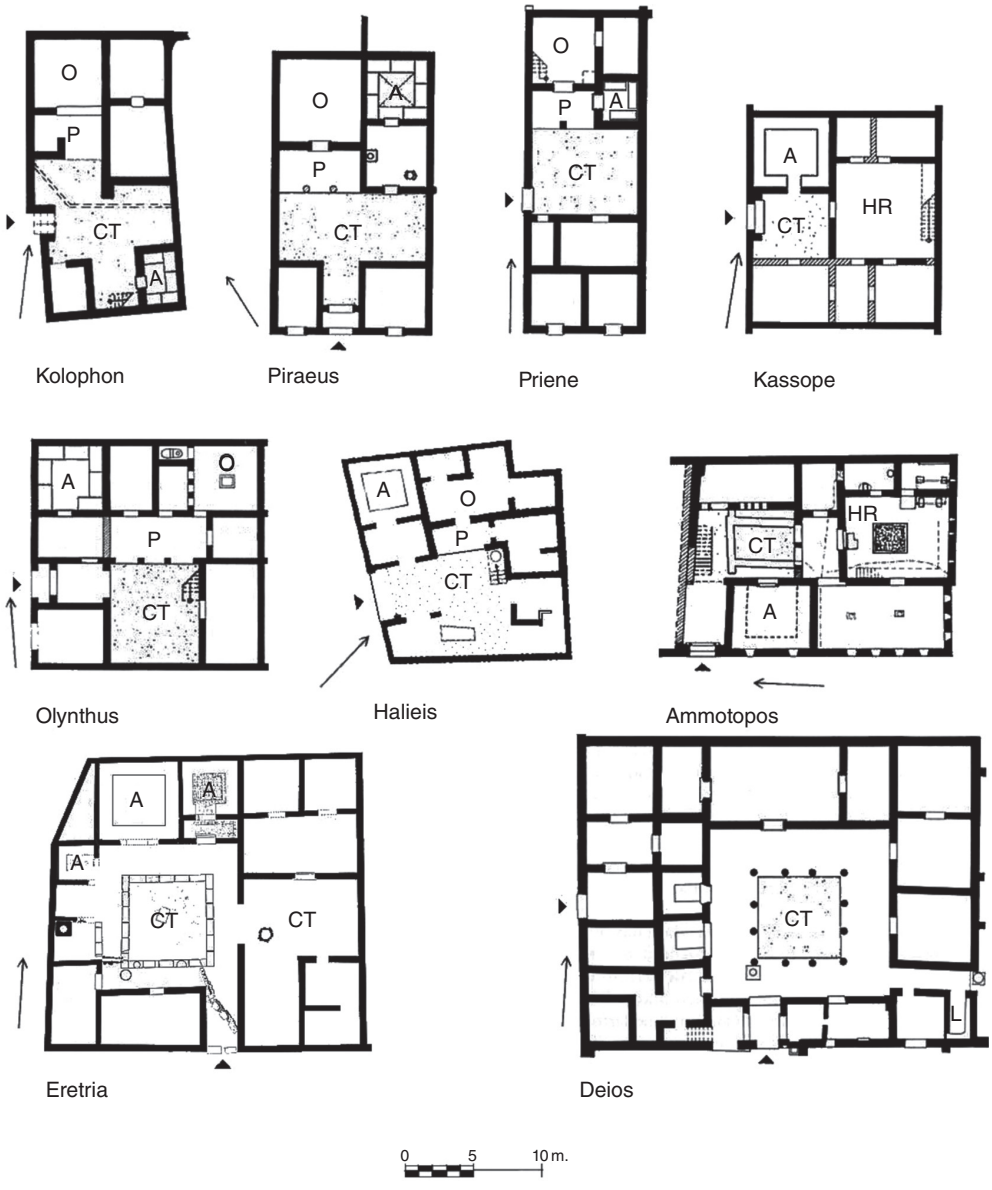


Figure 40.2 Classical and Hellenistic house plans. Key: A = *andron*, CT = court, HR = hearth-room, L = latrine, O = *oecus*, P = porch.

Halieis (Ault 2005, 50). Given the concern for hygiene along with drainage (for tile or stone-lined drains frequently mark household floors), it is notable that latrines, already pioneered in Bronze Age houses from Mohenjo Daro in the Indus Valley to Minoan Crete, were not regularly incorporated into Greek domestic architecture before examples dating to the second century can be recognized at Delos (Owens, Zuchtriegel, and Trümper 2011; cf. Ault 2005, 69, Hellmann 2010, 175–177).

In addition to the Olynthian kitchen complex, a similarly distinctive and environmentally influenced suite of living rooms has been documented at two Late Classical sites in Epirus in northwestern Greece, where the climate more closely resembles that of continental Europe. At Ammotopos and Kassope (Figure 40.2), a characteristic hearth-room dominates the plan of houses (Hoepfner et al. 1999; Hoepfner and Schwandner 1994, 145–161). Moreover, both Ammotopos and Kassope are situated at such high elevations (over 300 m [984′] above sea level) that the benefits of the south-facing house plan so important elsewhere have been omitted altogether in favor of an orientation against the prevailing winds. The courtyards, now located to the east or west of the main rooms, but still retaining their role as the primary access point for the house from the street, are consequently smaller as well, with precedence given to the eponymous hearth-room. Both Olynthian and Epirote houses, thus, show specific adaptations in plan to climatic settings, while at the same time adhering to socially and culturally determined elements of design found in Greek houses elsewhere.

Along with the courtyard giving way to a north portico which in turn leads to main living rooms, the final distinctive suite of rooms which routinely occurs in the Greek house is the men's dining room, the *andron* (Ault 2005, 69–70; Nevett 2010, 43–62). The *andron*, like the single entrance, is an element charged with social-cultural significance. For it was here that men of one family entertained those of others, fostering extra-household social, economic, and political alliances. Such commensal dining, an aristocratic, even royal tradition with roots in the Near East, is, by the fifth century, regularly manifest in domestic settings. The emergence of an "*andron* culture," the democratization and privatization of a practice formerly the purview of the elite and at public festivals (for formal dining rooms in private houses were preceded by those in sanctuaries), is an illustration of the manner in which the house also increasingly served as a vehicle for self-representation and presentation (Hoepfner 1999, 138–148).

Domestic *andrones* were the most regularly sized rooms in Greek houses, for their dimensions were set to accommodate a fixed number of standard dining couches (the reclining posture assumed by diners was the most visible legacy of the practice's Near Eastern origins) set around the room's perimeter. Seven-couch *andrones* were the norm, making the average dining room about 5 m^2 (54 $feet^2$), with an off-center doorway required to accommodate the odd, seventh couch. Yet even with the intrusion of the domestic symposium, the privacy of the household was respected. The *andron* was frequently adjacent to the street door or clearly separated from the household's domestic core. Generally the dining room proper was also screened off by an anteroom, providing an additional buffer from the rest of the house.

The character of individual households is also evident in other traces in the archaeological record. Most of these are primarily artifacts: processing facilities for grinding grain, presses for oil or wine; traces of craft production, such as weaving and stoneworking; and storage areas, among the most readily identifiable (cf. Cahill 2005; Foxhall 2007; Hellmann 2010, 113–138; Tsakirgis 2005). At the same time, such houses may also display manifestations of social pretense through the elaboration of their façade as well as elements of interior design, juxtaposing modest and egalitarian tendencies (in terms of general principles of construction, of house size, and disposition of rooms) with elements of self-presentation, depending on circumstances of time and place (Walter-Karydi 1998). The use of elaborate entrances, recessed into the house frontage or finished with cut stone jambs crowned with stone capitals, or especially large and

impressive ashlar orthostates along street-facing frontages, have only recently been recognized and articulated as statements of status (Nevett 2009).

Indeed, such expressions of self (re-)presentation continue along public sight lines and via increasingly restricted access routes into the house. Moving from the external doorway into the courtyard, it too may bear elements of status architecture, especially those adapted from religious and civic buildings, or the palatial residences of Hellenistic rulers, as in the use of trabeated elements such as columns, architraves, and architectural terracottas, particularly evident in any of the surrounding porticos. Courtyard surfaces, left as beaten earth in their most basic form, may be increasingly well finished, from plaster to stone paving to mosaics. The most exclusive room to which outsiders (i.e., non-kin group males) may be invited, the *andron*, is where the most elaborate decoration, too, may appear (see Greek Interior Decoration: Materials and Technology in the Art of Cosmesis and Display). From painted stucco walls, to plaster or even mosaic floors, and fine furnishings, the potential for domestic pretense was at its height here. It is for this reason that in aristocratic Hellenistic dwellings, such as at Delos and Pella, public reception rooms which did not necessarily serve for dining, but rather as places for receiving guests and transacting business, continued to be laid out as increasingly formal *andrones* (Trümper 2007; Westgate 2007b).

John Bintliff has recently traced the development of Greek houses from the Iron Age through the Hellenistic period and noted that their increasing size and elaboration of spatial syntax are evidence for expressions of "eu-sociality," as manifestations of "communal values" accompanying the rise of "moderate democracy," a feature of as many as half of the *poleis* in the Greek world (Bintliff 2010; cf. Westgate 2007a). The nature of representative government was transformed with the decline of the *polis* system in the Hellenistic and Roman periods, when monarchies and empires trumped democracies. While class distinctions and the gap between rich and poor widened in increasingly visible ways, not least in the realm of domestic architecture, communities continued to see an overall rise in the standard of living and success in social development (cf. Morris 2005). In the end, while the *polis* system which gave rise to the Greek house withered, it was the Greek house itself that triumphed. For its influence lingered on, continuing to impact the domestic architecture of the Mediterranean world.

Conclusion

Greek houses are on the one hand closed and self-sufficient systems, while at the same time embedded in and interacting symbiotically with the surrounding community. We have seen that the Greek house is not only an environmental construct, a literal domestication of building materials and spatial syntax, but that it is part of a fluid and flexible *koinē* of design which encapsulates nature and tradition, family and society across its manifestations in the Hellenized world of the Mediterranean. In the words of Amos Rapoport (1969, 82), "I would suggest that anyone could live in an ancient Greek house, for example, with the only needed adjustment being to the technological spaces."

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In English, the most recent books providing overviews of Greek domestic architecture are Ault and Nevett (2005), Nevett (1999), and Nevett (2010). In French, Hellmann (2002) offers an excellent consideration of ancient Greek building materials and construction techniques, although one focused primarily on monumental architecture. Her subsequent volume in the same series, *Manuels d'Art et d'Archéologie antiques*, Hellmann (2010), offers ample coverage of Greek housing. In German, Hoepfner (1999) and Hoepfner and Schwandner (1994) are indispensable.

CHAPTER 41

Greek Interior Decoration: Materials and Technology in the Art of *Cosmesis* and Display

Hariclia Brecoulaki

1. Introduction

The concept of "ordering" and "adornment" is expressed in Greek culture with the word *cosmesis*. The interior space—be it domestic or public—adapted to architectural features and building functions is transformed into a suitable setting for the human activities that are to occur there; a setting where various movable objects and fixed decorations interact to order and adorn it. The interior space becomes its own closed universe, *cosmos*, combining a variety of materials, textures, colors, and light. To enhance a temple with monumental statues, to adorn a tomb with paintings or a house with mosaics, to display domestic paraphernalia in *gynaecea* (women's quarters) or bronze armor on the walls of *andrōnēs* (men's dining rooms), to furnish a king's residence with sumptuous couches and artworks; these are acts that reflect specific social motivations and cultural behaviors, religious beliefs, political environments, and aesthetic values.

We limit our focus to the fixed elements of interior decoration in ancient Greek domestic space (wall paintings and mosaics), movable artifacts (such as freestanding sculpture and furniture), and panel painting. We shall briefly touch on the interior decoration of Greek public spaces. While the function of architectural sculpture was decorative from its origin, statues and large-scale painting in Greek public buildings assumed religious or civic roles and cannot be considered decorative in the current sense of the word (Ridgway 1971, 337). Likewise, with no primary planning, the accumulation of countless dedications within public buildings, particularly in temples (although on view for worshipers and visitors), did not reflect a predefined concept for interior decoration. The rich archaeological documentation from private funerary monuments, such as Macedonian chamber tombs, providing indirect but valuable evidence of elements of Greek interior decoration, will also be discussed briefly.

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2. The Private Interior Space: Function and Decoration

The mode of decoration of private interiors, which heavily depended on wealth, served to mediate the social identity of its occupants, according to geographical and chronological contexts (Westgate 2000; 2007). Social changes were also reflected in how an interior space was organized and furnished. Houses assumed a multifunctional character, becoming places where both domestic and ritual actions occurred, and their layout was influenced by a combination of practical and aesthetic considerations (Walter-Karydi 1998; Nevett 1999; 2010; Ault and Nevett 2005; Westgate 2010). Most "decoration" was applied to spaces that were accessible, as for example the *andrōnēs*, where banquets occurred. With the exception of figurative painting—whose role in the private sphere seems to have been almost exclusively aesthetic—sculpture, mosaics, and furniture primarily served ritual and practical functions. But how can we define the essential character of an artifact or artwork within its original frame? At which point do the notions of "utilitarian," "ritual," and "decorative" merge? Common vessels obviously had purely utilitarian functions, but a collection of metalware arranged in a *kylikeion* (cupboard) certainly became part of the interior decoration, as well as a display of status. Likewise, simple wooden couches or *diphroi* (stools) in modest houses represented part of the utilitarian furniture necessary for everyday activities, but gold and ivory furniture with elaborate sculptures and glass ornaments found in royal residences, obviously decorative, served as indicators of power and wealth (Brecoulaki et al. 2014; Athenaeus mentions Alexander the Great's golden *diphros* [*Deipnosophists* 12.539e] and Antiochus Epiphanes' ivory *diphros* [5.193]). Terracotta figurines have always been used decoratively inside houses, but the practice of setting up freestanding statues in private spaces was established rather late in the fourth century BCE. However, although herms and statuettes of gods contributed to the embellishment of noble houses, their function was mainly associated with domestic rituals and cults (Walter-Karydi 1998, 65–71). Certain forms of fixed decoration, such as mosaics and wall plastering, were primarily practical: bathrooms usually had water-resistant plastered walls; spaces exposed to open air (e.g., courtyards) or those for receiving dinner guests (*andrōnēs*) were often paved with mosaics or cement to protect them from humidity and mechanical damage. However, with the development of sophisticated techniques during the Hellenistic period, aesthetic parameters gradually became increasingly important, to the point where functionality almost became subordinate to decorative and artistic value. Although textual sources recall the decoration of King Archelaos' residence in Macedonia with paintings made by Zeuxis from as early as the late fifth century BCE (Aelian, *Historical Miscellany* 14.17), and houses at Olynthus feature colored plastered walls, not until the third and second centuries BCE do we find archaeological evidence of private houses decorated with figural wall paintings, signed mosaics, and freestanding marble sculptures, the most elaborate examples coming from Pella and Delos.

The simplicity of a typical household in democratic Athens, and its distinction from elaborate civic buildings, has been suggested from both textual evidence (Demosthenes, *Olynthiacs* 3.25–26; *On Organization* 29; *Against Aristocrates* 207) and archaeological remains of fifth-century BCE excavated houses. This modest way of dealing with the private sphere must have been, in a way, counterbalanced by the city's commitment to decorating public and religious buildings sumptuously with artworks produced by the most illustrious contemporary sculptors and painters. The Classical Greek house, built

around an open courtyard, with a physical division between *andrōn* and *gynaecon*, seems to have been poorly decorated (Xenophon, *Economics* 9.2–5). The decoration of Alcibiades' house, with its wall paintings, must have been uncommon (Plutarch, *Alcibiades* 16). By the end of the fifth century, however, Aristophanes briefly describes an elaborately decorated *andrōn* with bronze statues and painted ceilings (*Wasps* 1215).

The private display of artwork began to acquire a more decorative character toward the end of the fourth century BCE. The shift to monarchies during the Hellenistic period enhanced the role of private residences and palaces vis-à-vis public buildings, and households served as a means of self-promotion, signaling status and power through elaborate decoration and display of luxury (Kutbay 1998). The earliest and most impressive surviving example, the palace of Aegae in Macedonia, whose great *andrōnēs* could accommodate up to 230 couches, and whose huge courtyard almost assumed the role of *agora* (public meeting place) in democratic cities, marks the transition from a sumptuously decorated private building to a space for public life and political action (Kottaridi 2009). Consider the poet Simonides' words to the tyrant Hieron:

> And first, the palace: do you imagine that a building decorated in every way and most expensively could have offered you greater glory and honor than a whole city surrounded by walls and buttresses, decked with temples, stoas and colonnades, harbors and markets? (Xenophon, *Hieron* 11)

Luxurious decorations of late-fourth-century BCE Macedonian chamber tombs offer an illuminating glimpse into the material culture of the Macedonian elite: wall paintings, painted ceilings, purple textiles on the walls, copper, gold, silver, and ivory artifacts, and unusual pigments adorning magnificent couches (Brecoulaki 2006; Kottaridi 2011). Such interiors, even though in funereal contexts, offer tangible evidence of elements of interior decoration, and they illuminate literary descriptions, such as Athenaeus' banquets and the grand Seleucid and Ptolemaic pavilions where *cosmesis* and luxury surpassed the very limits of extravagance (Calandra 2011). The famous pavilion of Ptolemy Philadelphus at Alexandria, with its remarkable collection of panel paintings (Athenaeus, *Deipnosophists* 5.196a–197c), would have probably functioned in the same way as the public *Pinakothēkē* displayed on the Athenian Acropolis. The gemstone collections of Ptolemaic queens, as described by Posidippus (*Stones*, 1.1–4.6), reflected the accumulation of wealth and the social motivation to exhibit it.

3. Elements of Fixed Interior Decoration

Mosaics and the Art of Pavement Decoration

A mosaic is almost always connected to the architectural setting and purpose of the building it decorates, providing a smooth, water-resistant walking surface that is easy to clean and maintain. Plain pebble floors are already found in temples of the Archaic period, but the earliest extant decorated mosaics (fifth century BCE) are preserved almost exclusively in private houses, most often in *andrōnēs.* The overall quality and subject matter of a mosaic was determined by the function, size, and shape of the space to be decorated, as well as by personal taste, the house owner's wealth, and choice of workshop

(on workshops: Dunbabin 1999, 269–278). An exception to practical requirements is the fine Hellenistic *emblemata*, picture-mosaics prefabricated in specialized workshops as self-contained centerpieces for floors. *Emblemata* were prized luxury items, and some were signed (e.g., two at Pompeii, signed by Dioscorides of Samos: Dunbabin 1999, 32, 43, 271–272). The application of mosaics to walls and vaults is a Roman invention.

The choice of materials relied on chronology, geography, the personal style of a workshop or individual decorator, and the patron's level of affluence. Often, however, new materials were introduced as techniques were developed. Nonetheless, certain standard materials and application techniques endured from the earliest geometric pebble mosaics to the most refined Hellenistic figured scenes. Vitruvius (7.1) gives detailed instructions (Dunbabin 1999, 279–303; Roman Interior Design for further discussion of mosaic preparation and execution). Evidence attests the detailed planning of mosaic designs: lead stripes for outlining bands, colored preparatory drawings or incised preliminary guidelines on the *nucleus* to create grids, and careful measurements (a representative example of incised preliminary guidelines is attested on a Hellenistic mosaic from Samos [Gianoulli and Guimier-Sorbets 1988]). Red preliminary sketch lines are visible in places on the Hellenistic "Rape of Helen" mosaic in Pella (Petsas 1965, 44). Also attested are detailed full-colored preliminary drawings for the production of complex mosaics, executed on the lime bedding to guide the placement of colored tesserae (pigments such as Egyptian blue, hematite, and carbon black have been identified; Smirniou et al. 2010). The finished floor had to be ground with grinding stones and abrasives (Dunbabin 1999, 288). At a final stage, a thin lime stratum or marble dust could be spread over the surface to fill the tiny gaps left between the stones. Mineral pigments, usually composed of red or yellow ochres (iron-oxide-based minerals), could eventually be added to this final lime stratum. The use of applied color over the surface of stone tesserae has also been reported in a few Hellenistic mosaics at Delos and Ephesus (Guimier-Sorbets 2007).

The earliest decorated pavement mosaics in Greece (late fifth century BCE) are made with smooth natural white and black pebbles, 1–2 cm (0.4–0.8″) thick, set in a bed of lime-based plaster. The designs are usually laid in white against a dark ground. Most of the floors are bichrome, but occasionally colored stones are used: mainly yellow, red, and green randomly dispersed on the background, and less often to mark figural details. The mosaic from the Centaur Bath in Corinth (late fifth century BCE) is the earliest example of the random use of colored pebbles (Williams and Fisher 1976, 109–115, plates 13,14). The largest number of mosaics from this early period comes from the New Town at Olynthus in Eastern Macedonia. Other examples are found in Attica (Athens), Euboea (House of the Mosaics at Eretria), and the Peloponnese (Corinth and Sicyon). The basic ornamental motifs are meanders, floral and vegetal elements, concentric circles, and circles divided into quadrants to form wheel patterns. The border patterns also include wavebands, scrolls, palmette friezes, and rows of triangles, motifs also frequent in contemporary architectural decoration and vase painting. Figurative scenes are used less often to form friezes, usually with rows of animals or imaginary creatures. More complex figural compositions decorate mosaic central panels, the finest examples of which are from the House of the Mosaics at Eretria and the Villa of Good Fortune at Olynthus. An evolution toward more realistic rendering is traceable in certain conventional motifs, such as scrolls and certain more complex floral compositions, which acquire more plasticity and a three-dimensional effect that would be fully explored during the early Hellenistic period (the

examples at Sicyon are representative). Floral motifs and vegetal ornaments of extraordinary richness and vividness—recalling the "flowery floors" of the house of Demetrius Phalereus (Athenaeus, *Deipnosophists* 12.542)—reflect the progressive accumulation of pictorial acquisitions to produce naturalistic effects. The best-preserved examples include the mosaic of the Palace at Aegae, with its elaborate female *protomai* ending in scrolls at its outer corners (for recent photos in color, see Kottaridi 2009, 135–137), and the signed mosaic by Gnosis at Pella with its laborious floral compositions (for recent photos in color, see Lilimpake-Akamate 2011, 153–154).

Only at the end of the fourth century do we see mosaicists attempting to imitate the achievements of painting in figural scenes. At this time, new techniques in setting the stones and sorting pebbles were developed (rendering details with small pebbles and employing shading to model figures with more naturalism and evoke depth), and new materials were introduced. Stripes of terracotta and lead, together with colored clay beads, delineated figures and interior facial details, and they introduced a greater range of colors and gradations. The most representative examples of this development can be observed in the pictorial mythological scenes in large houses at Pella, such as the "Rape of Helen by Theseus" or "Dionysus Riding a Panther" (Figure 41.1). In elaborate hunting scenes, figures exhibit extreme plasticity and detail, pushing the laborious natural pebble mosaic technique to its limits (Figure 41.2). Although pebble mosaics continued to be produced during the third and second centuries BCE, their overall quality progressively declined. The *opus tessellatum* technique, using regularly sized tesserae of stone and glass, opened up opportunities for more realistic rendering of decorative motifs and figure scenes.



Figure 41.1 Pella, aerial photograph of the House of Dionysus with the restored peristyle in the north courtyard. *Source:* Universal Images Group/Universal History Archive/Getty Images.



Figure 41.2 Pella, detail of the mosaic decoration on the floor of the symposium hall in the House of Dionysus depicting a lion hunt, 325–300 BCE. *Source:* De Agostini Picture Library/A. Dagli Orti / Bridgeman Images.

Mosaics composed of tesserae (near-cubic pieces), appearing during the early Hellenistic period, offered a wider range of possibilities for precision and enhanced polychromy, and they allowed for more ambitious images. Transitional mosaics show both techniques: pebbles and rough marble chips (e.g., mid-third century BCE mosaics at the temples of Zeus at Olympia and Sparta). Fine examples of the mixed technique come from Ephesus and Alexandria (Guimier-Sorbets 2004), a high-quality third century BCE production center. The "Stag Hunt by Three Erotes" shows a sophisticated combination of tesserae with small pebbles, heralding more advanced experimentation with small regular tesserae. Among the masterpieces of this fully developed *vermiculatum* technique is the "Personification of Alexandria" from Thumis (Daszewski 1985, 146–158). Tiny fragments of colored stones were juxtaposed to create an optical fusion

when seen from a distance, as if of fine strokes of paint. Bright reds, purple, and gold revive the palette. And a variety of earthen hues allow for the naturalistic rendering of flesh tones and facial features. The artist's signature, Sophilus, remains, and the mosaic's high pictorial quality suggests that it was probably copied from a pre-existing painted prototype. The school of Pergamon is also distinguished by remarkable and colorful combinations of glass and minuscule stone tesserae, exhibiting *trompe l'oeil* realism, as on fruit and flowers, garlands, and figured scenes with comic masks in rooms from Palace V. However, the largest corpus of Greek mosaics (second to early first century BCE) comes from Delos, where 354 mosaic pavements exhibit a notable variety of techniques, decorative motifs, and figured subject matter (Bruneau 1973). Pebble mosaics, chip mosaics of whitish marble, mosaics using ceramic fragments, and tessellated mosaics in the *opus tessellatum* and *vermiculatum* techniques with tiny stone, glass, and faience (glazed ceramic) tesserae, are all attested in lavishly decorated Delian houses. Among the rich repertory of geometric motifs, *trompe l'oeil* cubes represent a characteristic trend of Delian pavement decoration. Fine *opus vermiculatum* technique was used for figured mosaics in the House of Dionysus and the House of the Masks. A winged Dionysiac *daimon* riding a tiger is among the finest examples, combining "pictorial" possibilities with an extraordinary wide range of colors, employing not only natural stones and terracotta, but also glass and faience tesserae, particularly for blue and green hues (Guimier-Sorbets 2007; Figure 41.3). The use of colored pigments in mortar was used to mask the interstitial joins between fine tesserae and to suggest pictorial effects more convincingly, while the occasional superimposition of a paint layer on the top aimed at enhancing



Figure 41.3 Delos, mosaic emblem from the House of Dionysus. Detail of the head of the winged god, second century BCE. *Source:* Hervé Champollion/akg-images.

the vividness of colored tesserae. The culmination of fine *opus vermiculatum* technique toward an increasingly pictorial rendering in large narrative compositions is reflected in second-century BCE masterpieces: for example, the "Alexander" mosaic from the House of the Faun in Pompeii (Moreno 2001), a transfer into stone of an earlier Hellenistic panel painting, showing extreme technical virtuosity in both the formal treatment of figures and coloristic effects.

Recent studies stress the color alteration of glass and faience tesserae in Hellenistic mosaics and the importance of color reconstruction for correctly appreciating the original polychromy (for the alteration of purple tesserae into gray on the Alexander mosaic: Guimier-Sorbets 2010).

The use of colored pigments is attested within mortar, to mask joins between tesserae, and to enhance the colors of tesserae with superimposed layers of paint. However, in certain cases paint was also used directly on white tesserae to depict geometric motifs. And painted floors, executed exclusively with mineral pigments, have survived. In most cases, painted floors were monochrome, and pigments were directly mixed with mortar.

Mural Decorations: Masonry Style and Figural Painting

The earliest literary evidence of painting in a domestic context relates to Alcibiades (450–404 BCE), the notorious Athenian general who "imprisoned" the painter Agatharchus in his house until he had adorned it with paintings (Plutarch, *Alcibiades* 16). We also know that a painter named Theophilus from Alexandria, active 300–250 BCE, received orders to paint murals and *pinakēs* for houses (Nowicka 1984). However, no large-scale figurative paintings from Greek interiors have survived. The only (extant) type of mural decoration consists of colored plaster, small-scale painted friezes, and applied stucco in various degrees of elaboration and complexity. The most common and widespread system of mural decoration was based on the so-called Masonry Style, imitating ashlar masonry walls, typically consisting of a socle zone, orthostates, the decorative string course, the main wall area, an upper zone, and a cornice band. The suggestion of volume was obtained with the use of three-dimensional plaster motifs. The structural elements of this style recall those of the Classical Greek orders. And various lapidary textures—marble, alabaster, and colorfully veined or mottled stones—were reproduced with illusionistic painting. The orthostate and isodomic zones of smaller blocks were delineated by incised lines or modeled in plaster relief and drafted margins. This method of decoration probably appeared in Greek houses sometime during the end of the fifth century BCE (Walter-Karydi 1998, 33), adopting decorative schemes and aesthetic ideals that had already been applied in the design of temples and other public buildings of the Classical period. The morphological principle of Masonry Style wall decoration became standard in elite domestic mural decoration through the Hellenistic *koinē* with specific regional traits and variations, requiring trained craftsman and expensive pigments.

Only poor evidence of early polychrome mural decorations survives in domestic contexts. The Olynthus excavations have brought to light many houses with painted plaster dating to before the mid-fourth-century BCE, but only a few walls are preserved with a height greater than 1 m (3.2′). A floral frieze was found in the House of Many Colors, and a painted garland was found in House BiV. The wall paintings at Olynthus were divided into three main categories: monochrome walls; walls with multiple horizontal divisions; and elaborate five-zone schemes, similar to the well-preserved interior of

the tomb in the west ridge. In the late-third-century House of the Colored Plaster at Pella (for recent photo in color: Lilimpake-Akamate 2011, 112), large parts of the wall feature a colorful five-zone architectural decoration (Figure 41.4). The orthostates are white, separated by vertical bands of red, black, and yellow. Above this is a zone of faux marble panels, a string course of ochre panels framed with relief moldings, and an upper part divided by low-relief white pillars, suggesting the illusion of openings to allow light and air in the rooms (for an example of a wall with actual columns in Eretria, see Reber 2007). There are no figured friezes from domestic contexts in Macedonia, but domestic



Figure 41.4 Pella, two-story façade in stucco and painting decoration of an interior wall from the so-called House of the Plaster, late fourth/third century BCE. *Source:* Carole Raddato.

architecture is producing an increasing body of wall decoration (faux marble panels have been preserved at a Hellenistic house at Petres, Florina: Adam-Veleni 1998, 59, figures 35–38). A house at Amphipolis, second century BCE, decorated in the Masonry Style, features large-scale painted lozenges on orthostates with alternating colors, stucco cornices, and garlands with Erotes (Ginouvès and Akamatis 1994, 103, figures 92–93). A figured frieze depicting a chariot race with a winged Nike as charioteer was found in a house on Rhodes, presumably third century BCE, and a narrow frieze, featuring Erotes on tendrils, is preserved in a Late Hellenistic house at Cnidus. Other examples of mural decorations survive sporadically from Hellenistic domestic contexts in Athens (Wirth 1931, plate 20.1), Macedonia, Crimea (Panticapaeum), Pergamon, Alexandria, and the Near East (Wulf-Rheidt 1998). However, the best-preserved corpus of Masonry Style decoration comes from the late-second-century BCE houses at Delos.

The standard decorative arrangement of major rooms in Delian houses replicates stone masonry by using different architectural elements in painting and stucco. The plinth and orthostates are monochrome, usually red and black, respectively. Drafted panels above the orthostates are usually rendered in solid colors or faux marble. Pictorial friezes, to emphasize the string course, constitute the major center of interest (Bruno 1969, 3, 5), subdivided into two major categories: those with decorative repeated motifs, and those with original narrative scenes (Hadzidakis 2003, 214–223). Molded bands separating distinct zones bear various geometric and floral motifs, lesbian cymatia, broken meanders, and wave patterns (Bezerra de Meneses 1970, 161, figure 117). The use of double- or triple-pattern bands below the figured frieze is a common feature on Delos. Sometimes only one band appears above and below the figured frieze, as in the courtyard of the House of the Comedians (Bezerra de Meneses 1970, 152, figure 108). In the House of the Tritons, several pattern bands appear above the isodomic zone (Bezerra de Meneses 1970, 62, figure 118). The color sequence of the usual isodomic course above the frieze is typically monochrome, either red or white. Decoration of the wall's upper zone was sometimes copious and complex. In the House of the Comedians, the blue upper zone is reconstructed with stucco affixes of palmette and lion heads (Bezerra de Meneses 1970, 154, figures 110; 1987, 78, figure 1), while the upper zone of the walls in the House of Dionysus was decorated with Ionic half columns in stucco with molded dentils, triglyphs, and metopes (Bulard 1908, plate 6a).

During the Classical and Hellenistic periods, the techniques of wall plastering for monochrome surfaces or backgrounds for wall paintings usually relied on the application of successive layers composed of lime and various inert (sand, crushed marble) and/or hydraulic aggregates (volcanic earths, crushed bricks). Local workshops often show particularities in the application of plaster, and they utilize aggregates from local minerals. Organic additives such as straw, plant fibers, or animal hair were occasionally employed to enhance the plaster's mechanical properties and reduce the contraction of the lime during setting. The number of layers, their thickness and consistency, the ratio and nature of their ingredients, and finally the modes of application (with or without polishing) determined both the durability and final appearance of the plastered surface. A thin layer of lime wash applied by a brush (whitewash) was often superimposed on top of the final layer of *intonaco* to achieve a smooth support for painting (Roman Interior Design).

The Delian houses offer the best-preserved evidence of Hellenistic domestic mural decoration, allowing us to document the entire stratigraphy of the plaster layers and to study the technology of their wall paintings (Kakoulli 2009, 33, 92–105). In the House

of the Comedians, five different plaster layers have been revealed. The first rough layer consisted of a pinkish mortar containing lime, quartz, calcareous aggregates, and large terracotta shards (1–3 cm [0.4–1.2"] thick). Over this thick layer, two layers of lime plaster mixed with crushed brick were superimposed, and a third was composed of pure lime and crushed (possibly Parian) marble fragments (thickness: 0.5 cm [0.2"] each). The uppermost plaster layer was also composed of lime and finely ground marble. Iron-based pigments (red and yellow ochre) were mixed into this final layer to obtain the wall's monochrome surface. Vitruvius (7.3.5–7) and Pliny (*NH* 35.174–177) describe the components and application of plaster, the importance of multiple layers, and the recommended use of potsherds or crushed marble to ensure the brilliance of the top surface.

The painting could be applied to walls either by the *fresco* (pigments applied on a fresh plaster) or *secco* technique (pigments mixed with organic binders, applied on a dry wall; Roman Interior Design). The identification of organic binders in the paint layers of Hellenistic funerary paintings—such as egg, animal glue, tragacanth and fruit tree gums (Brecoulaki 2006, 400–405)—has confirmed that the most common painting technique was the tempera (*secco*) method. The gamut of pigments used by late Classical and Hellenistic painters on wall decorations consists of a series of natural and artificial materials of mineral or organic origin, as reconstructed from funerary monuments, especially from Macedonia. The most frequently applied pigments in ancient Greek mural decorations include iron-based ochres of various hues (yellow, brown, and red), calcium carbonate white, carbon black, and Egyptian blue. Other less commonly identified pigments, which may also come from regional mineral sources, include copper-based greens (malachite, conichalcite, atacamite), serpentinite, cinnabar, orpiment, jarosite, madder lake, murex purple, and lead white (Brecoulaki 2006). Systematic investigations of the painting materials of domestic mural decorations in Greece have thus far only been conducted on the Delian houses (Kakoulli 2009, 92–105). Several pigments were employed to produce various colors, as identified in the Delian wall paintings. For red, orange, brown, yellow, and pink, the painter used iron-based ochres (goethite, limonite, and hematite), jarosite, and cinnabar, either pure or mixed with red ochre. Egyptian blue was applied either in single paint layers, or on top of a layer of carbon black. To produce greens, painters employed Green earth (celadonite, an iron-based green which seems to have been progressively substituted for costlier copper-based greens used in the fourth and third centuries BCE). Kaolinite, a white clay, also evident as a white pigment, was found in mixtures with red ochres. The application of pigments in successive paint layers, on top of colored backgrounds, suggests the *secco* technique. Bruno (1969; 1985) has observed mature artistic expression in both the three-dimensional rendering of floral motifs and the illusionistic suggestion of depth and light in compositions with a narrative interest, as in the "Frieze with the Actors," emphasizing the role of color and *trompe l'oeil* techniques in establishing pictorial formats which break with the conventional uses of flat backgrounds as abstract fields of color.

Although literary evidence attests domestic ceiling decoration (Walter-Karydi 1998, 54–55), archaeological evidence in Greece is limited, contrary to the more abundant documentation from Hellenistic funerary monuments and Roman-era houses (for a recent overview: Meyboom and Moormann 2013, 110–144). Delian houses again provide interesting, although fragmentary, insight. Fragments of painted plaster (found

in the first-floor rooms in the House of Seals and the House of the Sword) facilitate the restoration of patterns of bands surrounding a quadrangular field, evoking carpets stretched on the ceiling. These decorations are richer (costly pigments, gold leaf) and more complex (some fifteen motifs) than those in contemporary tombs, adopting the same "carpet" composition whose patterns are borrowed from textiles. Particularly light materials were usually employed in ceiling painting. The lower plaster was not applied to the flat wall surface, but rather on a brushwood or bulrush network, affixed to a wooden ground. Instead of the heavy sand plaster, a lighter lime-based plaster was preferred, applied on a layer of rammed earth.

4. Movable Artworks and Artifacts

Panel Painting

In his discussion of ancient painting, Pliny reports that famous painters, such as Apelles, never painted on house walls, which would likely be destroyed in fire, but only on panels (*pinakēs*: *NH* 35.118). Indeed, panel paintings must have represented a highly valued interior decorative feature in elite houses of the Classical and Hellenistic periods, while small pictures of cultic character were probably hanging on the walls of modest domestic rooms, like those depicted on red-figure vases (Walter-Karydi 1998, 50–51). According to Aelian, the renowned painter Zeuxis was hired by King Archelaus of Macedon to decorate his palace at Aegae with paintings (*Various History* 14.17), and Ptolemy Philadelphus collected drawings and paintings from the Sicyonian school (Plutarch, *Life of Aratus* 12.5; 13.4); drawings and paintings also decorated the walls of his famous pavilion at Alexandria (above, §2). Although no panel paintings are preserved from the Classical period and the few fragments of painting on wood come from the interior of Hellenistic tombs (Kottaridi 2011, 106–107), the important corpus of large-scale wall painting from Macedonia offers direct testimony to the probable appearance of the panel paintings by great masters. On the façades and interiors of Macedonian funerary monuments (fourth to second centuries BCE), painters tackled the challenge of realistically rendering human figures with complex composition and sophisticated use of line and color. It is particularly interesting that, although surviving paintings are all executed on walls or stone, their technical background relies on the practice of panel painting. This is evident in the use of organic binders, attesting *secco* and tempera techniques, and the application of color in sophisticated mixtures and superimpositions of paint layers, often reflecting dependence on pre-existing panel painting originals (as, for example, in the tombs of Philip II at Aegae and the so-called Tomb of the Palmettes at Mieza: Brecoulaki 2006, 122–123, 185–192).

The only extant ancient Greek painted panels are the four Archaic *pinakēs* found inside a cave at Pitsa in Corinthia. Although their character is votive, we may presume that similar *pinakēs* must have also been hanging on the walls of domestic rooms. Technological investigation of these *pinakēs* reveals interesting information on painting materials and techniques (Brecoulaki 2014). The texture and color of the panels resemble pine, which, along with fir, was used for writing tablets and painters' panels (Theophrastus, *HP* 2.9.7, 5.7.4; children took lessons in drawing on boxwood: Pliny, *NH* 35.77). The Pitsa *pinakēs* were covered with a thin white ground of gypsum, as a substrate for the

paint layer (*gesso*). The painter did not rigorously follow incisions that marked the preliminary design. Paint was applied directly on the ground to shape bodies with carbon black or red (cinnabar) contour lines. Egyptian blue, red ochre, and realgar (an arsenic sulfide) were originally included in the painter's palette.

Freestanding Domestic Sculpture

Domestic statuary appeared from the mid-fourth to late first centuries BCE as another cultural expression of status (Walter-Karydi 1998, 65–71). Its primary venue was in courtyards or near *andrōnēs*. Sculptural display, as a reflection of prestige and wealth, is clearly evoked in literary sources, especially in the domestic context of Hellenistic rulers. In the pavilion of Ptolemy II Philadelphus, 100 statues created by famous artists were displayed in the large dining room (Calandra 2011), while in the pleasure boats of Ptolemy IV Philopater and Hieron II of Syracuse, Parian marble portraits of the royal family and statues of Aphrodite and Dionysus decorated the *andrōnēs* and private shrines (Athenaeus, *Deipnosophists* 5.205d–207e). Recent studies based on archaeological evidence stress the complex relationship between sculptures and their display context (only a few statues have been found in situ), the associations between public and private sculpture, and statuary as an expression of piety, wealth, and taste (Barrett 2011).

Of particular importance for Hellenistic domestic marble sculpture are Olynthus, Eretria, and Delos, with interesting examples from Pella (marble statuette of Alexander the Great as Pan: Pella Museum, #ΓΛ 43) and Rhodes. The earliest known example from Olynthus is a cult statue of Asclepius found in the entrance to the *andrōn* of house B vi 7. In the House of the Mosaics in Eretria, the plinth of a late-fourth-century BCE nude male was excavated in the courtyard outside room 4. House II yielded another fourth-century example, identified as a youthful Hermes, originally belonging to a herm. Herms in houses are documented in red-figure vase painting (Walter-Karydi 1998, 68). And, in domestic contexts, herms were crowned with wreaths (Athenaeus, *Deipnosophists* 11.460e; Theophrastus, *Characters* 16.10; on herms, Wrede 1986).

Delos yields the largest corpus of domestic sculpture from the Hellenistic period. Approximately 260 statues, portraits, and reliefs have been documented so far, allowing us to investigate the types and functions of second-century BCE domestic sculpture, their display and artistic quality, and the cultural background of the house owners (Hardiman 2005, 191–242). In the courtyard of the House of the Herm (Figure 41.5), an impressive group of over thirty sculptures was found: Aphrodite, Artemis, the head of a satyr, a Heracles Farnese, herms, and numerous sculptural fragments and statue bases, including one with an inscription citing famous sculptors (Marcadé 1969). More herms, portrait statues, and fragmentary statues of men and women (possibly representing deities) were found in the House of the Masks and the House of Dionysus in the Theater Quarter. Two dedicatory statue portraits were found in situ at the House of Cleopatra and Dioscorides, where an inscription reveals that the owners were of Athenian origin (Marcadé 1969, 325–328; Figure 41.6). A sculptural group of Artemis slaying a deer was found in House Th III S, in the southern section of the Theater Quarter (Marcadé 1969, 218–219), and a total of nine sculptures in the House of Diadoumenus—perhaps a workshop (Marcadé and Hermary 1996, 82–83, 110–111, 192–193).



Figure 41.5 Delos, the House of the Herms laid out in four different levels, second century BCE. *Source:* John Hios/akg-images.

Marble carving techniques remained static from the Classical to Hellenistic periods. The major early sources of white marble were the Cyclades, mainly Naxos and Paros (see Hertz and Waelkens 1988; Classical Geology and the Mines of the Greeks and Romans). Translucent "lychnites" marble from Paros was already exploited by the sixth century BCE and still preferred for statuary until Roman times. The marble of Mount Pentelikon in Attica was widely used both in architecture and sculpture. Mt. Taygetus in Laconia and Mount Hymettus near Athens provided gray marble for sculpture, the latter being particularly popular during the Hellenistic times.



Figure 41.6 Delos, statues of Cleopatra and Dioscorides with dedicatory inscription on the statue base, House III.I, second century BCE. *Source:* Shutterstock/Evgeny Shaparin.

The process of carving is often reconstructible through tool marks on unfinished sculptures (on marble carving techniques and tools: Palagia 2006). To develop a sculpture, the Greek craftsman carved the marble directly without a model, or with the aid of models in soft materials such as wax or clay. The essential carving tool was the mallet,

used to strike the chisel or other tools, and modeling usually started with claw chisels of various sizes, as multiple gouging surfaces produced parallel lines in the stone. Finer modeling was achieved with flat and rounded chisels. A great range of drills (stationary and running) were used for cutting grooves, boring holes to insert various elements into the marble or metal, and indicating facial features, such as nostrils or ears. Tool marks were removed from the final surface with rasps (flat tools with coarse surfaces), and rasp marks were consecutively rubbed off with abrasives (pumice from Melos and Nissiros [Theophrastus, *On Stones* 21–22] and emery from Naxos [Pliny, *NH* 36.52, 54]). A protective coat of wax and olive oil was applied to unpainted nude parts of marble statues (Vitruvius 7.9.3), a process called *ganosis*, but the same treatment could also be applied on top of painted surfaces to protect them and enhance their hues. Painting was usually applied with tempera or encaustic techniques, with the aim of intensifying the shapes and volume of carved elements by accentuating the effects of light and shadow, coloring facial features (eyes, eyelashes, lips, and hair), or even painting accessories (Brinkmann et al. 2010). Gold leaf was also used occasionally for jewelry, garments, and hair, or to simulate the shine of bronze when applied all over a nude body. Added materials (bronze, lead, stucco, colored stones, glass, and ivory) were used to indicate various accessories or facial features (in particular, locks of hair and eyes). Additions in stucco and wood were common in the Hellenistic period, especially in regions poor in marble, such as Egypt.

Unfinished fragments of Delian sculptures offer interesting insights into local craftsmanship, and they enrich our knowledge of Hellenistic techniques. It was a four-step process, consisting of roughing out the piece with a point, faceting with a flat chisel, carving details with a drill, and finally polishing the surface. Delian sculpture is particularly characterized by composite carving, wherein two pieces with different physical characteristics (color, grain, and texture) are pieced together, a technique primarily employed to create statuettes from multiple fragments. White marble was used for nude parts, and gray marble was chosen for draped portions. However, differences in marble hues were rarely evident, since the entire finished sculpture was recovered with thick polychrome paint layers, masking the heterogeneity of the marble pieces. The adoption of such a procedure probably served economic requirements: gray marble was certainly less expensive than white. This rather unusual practice was applied to Classicizing types that were mixed with realistic features. The closest parallels for this composite technique come from Cos, where a few statues were carved using the same method (Jockey 1999).

The Delian statues are also the best testimony to the original polychromy. Indeed, color must have played a prominent role in catching the viewer's eye and directing it to the space adorned by the sculpture. Recent 3D reconstructions considerably enhance our understanding of the original (vivid) visual effects that polychrome statues would have produced (Bourgeois and Jockey 2010, 235–238, figure 188). Statues were examined under ultraviolet light. UV-fluorescence photography then documented the areas that preserved fluorescent pigments. A detailed surface examination using a video microscope tracked the remains of paint layers and studied their texture and modes of application. Layers of the painted and gilt areas were subsequently analyzed with in situ X-ray fluorescence spectrometry (XRF) and, on a dozen samples, destructive analyses were conducted at the laboratory to further investigate paint layers and organic pigments and binders (Bourgeois and Jockey 2010).

Very few examples of bronze statues in domestic contexts have survived. A series of twenty-one small bronze figures uncovered in Eretria, attesting the wealth of the area's decoration, have been interpreted as evidence of Hellenistic domestic religious practices. Most ancient Greek bronze statues were made using the indirect casting method, wherein the original model is preserved (see Mattusch 1988). Bronze Hellenistic statuary is rare, and only a few pieces have been technically examined. The technological examination of the "Horse and Jockey Group" from Artemision has revealed interesting insights into the combined manufacturing methods of large-scale Hellenistic bronze statuary (Hemingway 2004). Current research on the polychromy and patinas of bronze Greek statues further enriches our knowledge of the use of pigments and metal alloys in the facial features that rendered large-scale Greek bronze statues more realistic (Descamps-Léquime 2006).

Furnishings and Furniture: From Functionality to Luxury

So much of ancient Greek furniture and textiles has vanished because of the fragility of their organic materials (Textile Technology). In fact, the surviving archaeological evidence does not allow full appreciation of the aesthetic impact of the colorful textiles that once decorated elite Greek houses (essential banquet paraphernalia included cushions, bedcovers, curtains, rugs, and wall hangings of wool, linen, or leather), much less the variety and degree of elaboration of its furniture (Richter 1966; Andrianou 2009). Providing important insight into late-fifth-century BCE household equipment, the so-called "Attic Stelai" records the confiscation and public auction of the property of Alcibiades and his friends, following the notorious mutilation of the herms in 415/414 BCE. Cost evaluation of the furniture and other objects suggests that rich Athenians had little sense of personal luxury (Walter-Karydi 1998, 82). Although Greek houses in general were simply furnished with primarily functional objects for comfort (bed-couches, low tables, armchairs, chairs, and stools) or storage (boxes, chests, cupboards, shelves, and sideboards), luxurious domestic settings, with a rich gamut of precious furnishings and elaborate furniture, were equipped by Hellenistic kings and tyrants (Aelian, *Historical Miscellany* 14.17; Athenaeus, *Deipnosophists* 12.538d). Dionysius I of Syracuse is said to have had decorated the dinning rooms of his palace and pavilions at Olympia with tapestries (Polybius 12.24.1–3). Attic vase painting and sculpture from the Archaic and Classical period show furnished interiors in banquet scenes. Important iconographic evidence on the rich polychromy of furnishings and the variety of furniture in a Classical banquet scene is provided by the remarkably well-preserved façade of the Macedonian tomb of Aghios Athanassios in Thessaloniki, late fourth century BCE. Vivid hues of blue, red, yellow, purple, and light green are used for the colorful cushions and bedclothes in remarkable *poikilia*. And a *kylikeion*, displaying metallic phiale on its shelves, is painted in bright red.

Although literary and iconographic evidence allow us to reconstruct a great deal of Greek domestic furniture, only a few domestic pieces have been excavated, while the best-preserved furniture comes from funerary contexts (Andrianou 2009, 22–89). As with textiles, domestic furniture was essentially functional and finely decorated, and elaborate pieces of expensive materials were either dedicated to the gods or belonged to wealthy individuals and Hellenistic rulers. Indeed, we have no direct textual evidence of

furniture displayed in a domestic interior for its design or decoration, with the exception of a display bed in the pavilion of Ptolemy Philadelphus (Athenaeus, *Deipnosophists* 5.197c). In contrast with elaborate furniture (whose production required expert carpenters and craftsmen), simple domestic wooden furniture (seats, tables, beds, shelves, and containers) would have been built by family members (Andrianou 2009, 122). Wood was shaped by carving, steam, and the lathe, and pieces were assembled with mortise-and-tenon joinery, held together by lashings, pegs, metal nails, and animal glue (Richter 1966, 125).

Most Greek furniture was constructed from wood (maple, oak, beech, yew, and willow: Richter 1966, 122). Stone, ivory, and metal were also used decoratively for prestigious pieces: sculpted marble armchairs, richly decorated round stone table-tops with floral and meander patterns, silver *diphroi* (Andrianou 2009, 29), and sumptuous chryselephantine couches from Macedonia. These artifacts testify to the richness of materials and techniques applied to extravagant domestic furniture during the Hellenistic period. Indeed, the outstanding quality of the ivory sculptured compositions on the chryselephantine couches from the tomb of Philip II at Aegae—combining precious pigments, gold leaf, and glass—transform such "functional furniture" into true masterpieces of art (Brecoulaki 2014; Brecoulaki et al. 2014).

5. Conclusion

Xenophon lists the conventional constituents of wealth: a house, farm, slaves, cattle, and furniture (*Memorabilia* 2.4.2). And he discourages people from buying more furniture and furnishings than they really need (*Poroi* 4.7). Similarly, after identifying three common personal needs (food, dwelling, and clothing), Plato thinks that there is no point in wanting more (*Republic* 369d). He fears that the *polis'* growing luxury—as painters and embroiders decorate houses with gold and ivory—will generate warfare (*Republic* 373e). Plutarch, in his turn, despising the possession of luxury goods, considers "silver plates" as "unnecessary items" that should be sold off when cash must be raised (*Moralia* 828a). In fact, the history of Greek interior decoration seems to be traced between the "necessary" and "unnecessary": between the sobriety of the Classical *oikos*, passing through the elite peristyle house, to the extravagant luxury of Hellenistic palaces and pavilions, where the domestic interior was given a visually public character emanating from a change in mentality and a different lifestyle (Walter-Karydi 1998, 84–95). The functional elements of a house progressively acquired a more decorative character, while purely decorative elements, in certain cases, attained the quality of art.

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FURTHER READING

Nevett 2010 and Ault and Nevett 2005 are valuable sources on Greek houses and households, their function, chronology, and social diversity. Dunbabin 1999 remains the most comprehensive work on Greek and Roman mosaics. Andrianou 2009 provides a useful up-to-date study on the movable domestic objects in their contexts and new archaeological evidence on the layout of Greek houses. On domestic Hellenistic sculpture, in addition to the seminal work of J. Marcadé 1969 on Delian sculptures, the unpublished thesis of C. I. Hardiman 2005 offers interesting synthesis and interpretation of the archaeological material in connection with its function and contexts. Bourgeois and Jockey 2010 thoroughly explicate the polychromy of ancient domestic statuary in Delos. Three lavishly illustrated volumes on Delos (Hadzidakis 2003), Aegae (Lilimpake-Akamate 2011), and Pella (Kottaridi 2013) offer high-quality photographs of well-known and unpublished artifacts. The exhibition catalog on the Eretria excavations (Pruvot, Reber, and Theurillat 2010) provides an interesting overview of material found in Eretrian houses.

CHAPTER 42

Roman Monumental and Public Architecture

Duane W. Roller

1. Introduction

The Romans came late to the tradition of Mediterranean monumental architecture, long after the cultures to their east had reached or were nearing their peak. Yet the architecture of Rome provided the basis for the synthesis of the traditions of the Greek world—with some Egyptian, Levantine, and Persian influence—into a new and vital style that included significant technological innovations and laid the groundwork for the future history of European architecture.

Roman architecture diversified as did the Roman state itself. Originally limited to the city of Rome and central Italy, eventually its methodology and theory spread throughout the Empire, from the British Isles to interior Anatolia and the Levant. As with the term "Roman" itself, Roman architecture is difficult to define, has a high degree of cultural and geographical diversity, and is not limited to structures erected by Romans. Most notably, there were the allied kingdoms—from Juba's Mauretania to Herod's Judaea—that mingled forms emanating from Italy with their own local traditions, creating new architectural concepts and bringing monumental architecture into regions not previously familiar with it. This survey is far from a complete study of the Roman architectural tradition, but—in the context of the present volume—it is meant to highlight some of its important aspects, especially in terms of engineering and technology.

2. The Beginnings

The location of the city of Rome was particularly auspicious, situated at a point on the left bank of the lower Tiber several miles above its mouth, where the river could be crossed and bluffs reached its shore. The inland location protected the city from piracy,

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and the bluffs from flooding. The river crossing ensured that the emergent city lay on a major trade route between the Greek cities in the south and the Etruscans in the north. Thus, despite modest beginnings, the Romans had every advantage both to develop into an important city and to become connected at an early date with the wider world of the Mediterranean cultures.

The Roman self-image aligned it with the migrations of peoples from the east at the end of the Bronze Age. Regardless of the level of veracity of these familiar tales, Roman contact with the Greek world can only be demonstrated by the appearance of Greek pottery in the latter eighth century BCE (Boardman 1980, 209–210). This is only marginally later than the establishment of the first Greek cities in Italy, around the Bay of Naples, especially on Pithekoussai (modern Ischia) and at Kumē (or Cumae), west of Naples (Boardman 1980, 165–169). Trade routes were quickly established to the Tiber, crossing the river at Rome, and beyond to the north, where dwelled the Etruscans, probable trading partners. One of their major cities, Veii, lay only a few miles from Rome. Here (and at other Etruscan towns), monumental architecture with Hellenic-style decoration was in place by the sixth century BCE. Before long, Rome itself began to capitalize on these opportunities.

Greek artists were available to the Romans from at least the early fifth century BCE, when Damophilus and Gorgasos were involved with the construction of the Temple of Ceres on the lower Aventine (Pliny, *NH* 35.154). No remains of the structure are known (Richardson 1992, 80–81): like so much of early Roman architectural history, one must rely on literary evidence from a much later period. The two Greeks were described as *plastae*—modelers—indicating that terracotta decoration was part of the structure (Vitruvius 1.1.13, 3.3.5), presumably in the style of the extant life-size terracottas from the Portonaccio Temple at nearby Veii. The Temple of Ceres was not the first monumental temple in Rome: a generation earlier was constructed the great Temple of Jupiter on the Capitoline, allegedly dating from the last years of the Roman monarchy and its Etruscan kings (Polybius 3.22.1; Livy 2.8.6–8). The temple was presumably in the Etruscan style described by Vitruvius (4.7), on a solid foundation of local stone and built of mud brick and stucco on a high platform, with a wooden and thatch roof and a frontal colonnade. Rebuilding and enlargement over the successive centuries has obscured its details both archaeologically and through literature, but it was probably a close parallel to the somewhat earlier Portonaccio Temple at Veii. In fact, a certain Vulca of Veii was said to have been commissioned by King Tarquinius Priscus to create the cult statue (Pliny, *NH* 35.157). This temple—presumably much altered over time—was destroyed by fire in 83 BCE and replaced by a grandiose structure more in accordance with that era, commissioned by Sulla, who brought the columns of the Olympieion in Athens for the new building (Pliny, *NH* 36.45; Plutarch, *Sulla* 27.6; Richardson 1992, 221–225).

Thus by the fifth century BCE, Rome began to display monumental public architecture in the Etruscan style, but also with Greek influence. Other temples were built in the city at this time, including the famous Temple of Diana on the Aventine, attributed to King Servius Tullus and said to be an offshoot of the cult of Artemis at Ephesus (Strabo 4.1.5). On the slope of the Capitol was the Temple of Saturn (Dionysius of Halicarnassus, *Roman Antiquities* 6.1.4), and nearby was the Temple of Castor and Pollux (Livy 2.42.5). Between these two temples was the nascent Forum Romanum, which served

as a market and government center and included the Curia Hostilia, where the Senate met. All these structures were modest forerunners of the versions whose remains are visible today, with the Temple of Jupiter being the largest and most elaborate. Although there was rebuilding from time to time, there was little evolution of the city for many generations.

3. Building Materials

Since there was a lack of good building stone in central Italy, Roman architecture remained in a brick and stucco mode for many centuries, unlike the Greek world, where marble and high-quality limestone meant a swift evolution to stone architecture. Even as late as the first century BCE, brick was the preferred material (Suetonius, *Deified Augustus* 28.3; Dio 39.61.2).

The earlier monumental buildings had stone foundations, often quarried directly at the site while it was being leveled for construction. The outcrops of the Roman hills are a soft friable tufa, known locally as *capellaccio*, which was the original Roman building stone: it may first have been used in the foundations of the Temple of Jupiter (Richardson 1992, 222). Today it is most visible in the so-called Servian Wall, ascribed to the latter period of the monarchy (Livy 1.44.3; Dionysius of Halicarnassus, *Roman Antiquities* 4.13.5) but is probably from the fourth century BCE (Richardson 1992, 262). This wall made a circuit of about seven miles (11 km), and can be seen most conspicuously today outside the Stazione Centrale.

There were several other kinds of tufa available to Republican architects, all from the environs of Rome (Coarelli 1980, 371). The best was the Anio, a red tufa first used in the Aqua Marcia of 144–140 BCE (visible today at the Porta Maggiore), the tufa of choice well into the Imperial period such as in the Temple of Mars Ultor. It was quarried at Tor Cervara, northeast of the city.

By the second century BCE, travertine (*lapis tibertinus*) came into use, coming from a quarry near modern Tivoli. This was a durable limestone which today is the most visible ashlar masonry of ancient Rome. The best surviving examples are the Theater of Marcellus and the Flavian Amphitheater. Both tufa and travertine were regularly covered with painted stucco.

Marble was not quarried in Italy in early times, and the earliest use of it in Roman public buildings was only in the late Republic, beginning when Q. Caecilius Metellus Macedonicus commissioned the rebuilding of the Temple of Jupiter Stator in 146 BCE (Velleius Paterculus 1.11.3–5); his service in Greece would have familiarized him with Greek marble construction. In fact, Roman commanders in the East during the late Republic regularly brought portions of Greek buildings back to Rome, a process that acquainted the city with the material, techniques, and aesthetics of Greek architecture. Yet indigenous Italian marble only came to be exploited in the first century BCE with the opening of the quarries at Luna (Selene in Greek), the Carrara of the Renaissance that remain heavily used today (Strabo 5.2.5; Ward-Perkins 1983, 22–25; Hirt 2010, 29–30). Julius Caesar seems to have first made use of them, but they were exploited by Augustus, and Luna marble remains visible today on the Ara Pacis and in the Forum of Augustus and Temple of Divine Julius. By Imperial times, marble came to Rome from all over the known world, and the marble trade was a major industry (Fant 2008,

126–129). There were the well-known Greek and Anatolian marbles, as well as *marmor numidicum* (*giallo antico*) from Numidia, and other stones such as granite and porphyry from Egypt (Coarelli 1980, 372).

In the third century BCE, the Romans made their most important contribution to the history of building materials, *opus caementicium* (Figure 42.1), or concrete (Lancaster 2008, 260–266). A mortar (basically sand and crushed limestone) would be mixed with water, creating a cohesive building material that could be formed into any shape, thus freeing architecture from the rectilinear strictures and roofing limitations of the Greek tradition, and making possible the great vaulted structures of the Roman Imperial world. The technology was described in detail by Vitruvius (2.4–8). The best mortar came from the Bay of Naples (today called *pozzolana*, from Pozzuoli, ancient Puteoli), which had the property of creating a waterproof concrete, thus particularly useful for harbor construction. In fact, it was so esteemed that at the end of the first century BCE, Herod the Great imported it over 1250 miles (2000 km) for his harbor at Caesarea (Roller 1998, 138).

The Greeks had made rudimentary use of concrete—the earliest example seems to be at the Upper Peirene on Acrocorinth (Blegen et al. 1930, 39–42)—but it was rarely extensive or capable of bearing major loads, and thus it was the Romans who truly



Figure 42.1 *Opus Caementicium* from a tomb along the Via Appia. *Source:* MM, https://commons.wikimedia.org/wiki/File:OpusCaementiciumViaAppiaAntica.jpg. CC public domain.

developed this great innovation. *Opus caementicium* is first documented at Cosa—the Roman *colonia* established in 273 BCE (Velleius Paterculus 1.14.7) on the coast north of Rome (at modern Ansedonia in southern Tuscany)—and is visible in an arched gateway (Dyson 2013, 474–446). By the mid-second century BCE, concrete was common enough that it was taken for granted as a primary construction material (Cato, *On Agriculture* 14–15). The earliest examples in the city of Rome—as least those visible today—are in the granaries on the Tiber (known, perhaps erroneously, as the Porticus Aemilia) and in the platform of the Temple of Magna Mater on the Palatine, both from the early second century BCE (Boethius 1978, 126–129). With the development of concrete, Roman architecture made a significant departure from its Etrusco–Greek heritage.

Yet concrete was lacking in any aesthetics as a building material and had to be faced to provide a suitable exterior surface. Thus, walls constructed of a concrete core but with a higher-quality surface became the standard in Roman architecture. Originally, irregular and small stone blocks of tufa or travertine were used, but by the first century BCE, reticulate brick work, *opus reticulatum* (Figure 42.2), became normal, which was not only more attractive but also strengthened the wall, as concrete tended to crack and collapse if unsupported (Vitruvius 2.8.1–3). *Opus reticulatum* is first seen in structures such as the Theater of Pompey (the Great) in Rome (Blake 1947, 254); by the end of the first century BCE, it was used by Herod in his palace at Jericho (Roller 1998, 173) and by the kings of Commagene at Samosata (Tırpan 1989, 519–536).



Figure 42.2 *Opus reticulatum* from Hadrian's Villa at Tivoli. *Source:* Pouwerkerk, https://en.wikipedia.org/wiki/File:Opus_Reticulatum_1.jpg. Used under CC BY-SA 3.0, https://creativecommons.org/licenses/by-sa/3.0/deed.en.

4. Innovative Building Types

In the last centuries of the Republic, the Romans began to develop their own repertory of building types, a further movement away from their Greek and Etruscan origins. Some of these were significant modifications to existing types, such as the Roman version of the theater and temple, others were innovative buildings such as the basilica and amphitheater, and still others were the Roman evolution of a Greek type, such as baths and aqueducts.

The basilica (Figure 42.4), which seems to have originated in the second century BCE, is a purely Roman structure, despite its Greek name, whose origins remains enigmatic. It became an essential component of the forum of every Roman and Romanized city and provided the antecedents for the Christian church. Although details varied, it was basically a rectangular building with its front on one of the long sides and a peristyle around all or part of the structure. The interior had colonnades and often a second story. The best description is that by Vitruvius (5.1.4–10), who constructed one at the north Italian city of Fanum Fortunae (modern Fano); the earliest surviving examples are at Pompeii, Cosa, Ardea, and Alba Fucens, all from the latter second century BCE (Boethius 1978, 149–156). The long front of the basilica provided the axiality to a Roman forum and helped mark off the commercial quarter of the town. There are certain analogies with the Greek stoa, but these are more functional than formal, and there is no evidence that the Roman structure evolved from the Greek one. The term "basilica" was in use as early as the beginning of the second century BCE (Plautus, *Curculio* 472), and in 184 BCE M. Porcius Cato (the Elder) built the first basilica in Rome (Livy 39.44.7). The best surviving example in the city is the so-called Basilica Aemilia (more properly Basilica Paulii) in the Forum: the visible remains are from the Augustan and Julio-Claudian periods, the last in a series of structures on roughly the same site (Richardson 1992, 54–56).

The Roman temple was actually an Etruscan building, presumably of Greek origins but differing in that the colonnade was only on the front, and the structure sat on a high platform approached by a flight of stairs that could extend across the entire building. The interior arrangements were more simple than in the Greek ones. Life-sized statues could be placed on the pediment. The style was described by Vitruvius (4.7), and numerous examples exist throughout Rome, although what one sees today is generally the product of Imperial rebuilding.

The Roman theater evolved directly from the Greek model, as influence from the Greek towns in southern Italy spread north. Although there is a long history of temporary theatrical structures in and around Rome, the first permanent stone theater in the city was that built by Pompey the Great in the Campus Martius, dedicated in 55 BCE (Tacitus, *Annals* 14.20; Dio 39.38.1–6). A slightly earlier structure (58 BCE), that of M. Aemilius Scaurus, remains obscure, and had a marble stage building, but may not have had a permanent cavea (Pliny, *NH* 36.113–115). Pompey's theater was allegedly inspired by the one on the Greek island of Mytilene (Plutarch, *Pompey* 42.4), yet this Greek structure was, as expected, built into a hillside, whereas Pompey's was freestanding and much more elaborate. At the very least, the Roman one evolved far beyond its Greek antecedent (especially since the flat Campus Martius was hardly suitable for the traditional siting of a Greek theater) and became the freestanding enclosed structure that would define the Roman theater. Pompey's architects may have been

responsible for this change: a slightly earlier theater at Pompeii (circa 80 BCE) is built into a hillside, perhaps reflecting more direct Greek antecedents (Richardson 1988, 75–80). Like the basilica, the theater became one of the defining elements of a Roman town (Vitruvius 5.3).

Closely related to the theater was the amphitheater (Welch 2007, but see Golvin 2007). The building type may have originated in Campania to provide a venue for the local gladiatorial spectacles: the oldest extant is at Pompeii, dating from the early first century BCE (Richardson 1988, 134–138), elongated with parallel sides, seemingly the original form, although the word "amphitheater" probably did not exist at this time (the dedicatory inscription, *CIL* 10.852, does not use it). In Rome, C. Scribonius Curio built one in 53 BCE, but not for gladiators. Curio's structure was a peculiar set of paired theaters that could either stand separately (for plays) or be turned to create an arena between them (Pliny, *NH* 36.116–120). This may have been the first structure to use the term "amphitheater," which, in the first century BCE, appears almost simultaneously both in Greek and Latin (Dionysius of Halicarnassus, *Roman Antiquities* 3.68.3, 4.44.1; Strabo 5.3.8, 14.1.43; Vitruvius 1.7.1). In 29 BCE, Statilius Taurus built the first permanent amphitheater in the city (Suetonius, *Deified Augustus* 29.5), standing in the Campus Martius but destroyed in the fire of 64 CE. Most notable and visible today is the great Flavian Amphitheater, or Colosseum, dedicated in 80 CE. It and the many other prominent amphitheaters surviving throughout the Roman world have made it the defining element of Roman architecture. It was one of the first purely Roman forms to spread to the farther reaches of the Mediterranean: shortly after 25 BCE, Juba II of Mauretania built one (in the older linear form) at his Caesarea (Roller 2003, 123–124), and a few years later Herod the Great did so at his own Caesarea (Roller 1998, 140–141).

Hydraulics, including aqueducts (see also URBAN INFRASTRUCTURE IN THE ROMAN WORLD), baths, and sewers, were a special Roman concern (Strabo 5.3.8). Needless to say, the Greeks had attended to such matters but in a manner far more rudimentary than the Romans (Lawrence 1983, 308–310). The oldest Roman aqueduct was the Appia, built in 312 BCE (Livy 9.29.6); aqueducts were constructed regularly over the next several centuries, most notably the Marcia of 144–140 BCE (Pliny, *NH* 31.41–42). The aqueducts approached Rome from the volcanic territory to the east and southeast, and were a remarkably sophisticated system of hydraulic technology, with careful attention given to matters of flow and pressure. They remain one of the more visible elements of the physical landscape of the Roman world, and those of the city of Rome were described in great detail in the extant *On the Aqueducts of Rome* by Frontinus, supervisor of aqueducts at the end of the first century CE (Hodge 1992).

As the water system evolved, public baths became a feature of the city. Modest public and private baths had existed in the Hellenistic world (Lawrence 1983, 349–350), but as usual it was the Romans who developed the genre (Yegül 2013, 15–32). Vitruvius (5.10) preserved a precise description of the siting and working processes of the Roman bath. The Stabian (second century BCE) and Forum Baths (circa 80 BCE) at Pompeii are among the earliest known examples in Italy (Richardson 1988, 100–105, 147–153). In Rome, the first public bath was built by M. Vipsanius Agrippa, started in the 20s BCE (Dio 53.27.1). It was modest and simple, although notable as an art gallery (Pliny, *NH* 34.62, 35.26). Some remains of a later reconstruction are visible in the Campus Martius just south of the Pantheon.

The next public bath in the city was constructed in CE 64 by Nero (Suetonius, *Nero* 12.3), north of the Pantheon, where remains can be seen under buildings at the north end of the Piazza Navona. A third establishment was completed in CE 80, the Baths of Titus (Suetonius, *Titus* 7.3; Dio 66.25.1), as part of the project that included the Flavian Amphitheater or Colosseum. Portions of them can be seen on the southern scarp of the Oppius Hill.

All these early baths were modest when compared with the great Imperial constructions in Rome and elsewhere, the first of which was those of Trajan on the Oppius (Richardson 1992, 397–398), whose great platform and various walls are still visible. These huge buildings—among the largest in the Roman architectural repertory—included not only the baths themselves but libraries and public rooms in a massive enclosed precinct. The Antonine Baths, popularly the Baths of Caracalla, at the southern edge of the city, preserve the form at its best.

5. The Arch, Vault, and Dome

Three constructional elements typify Roman architecture: the arch, vault, and dome (Lancaster 2008, 257–269). These, accompanied by the design possibilities of molded concrete, were the epitome of the Imperial architectural style. The arch is a Greek invention: the earliest examples are from the end of the fourth century BCE (Lawrence 1983, 294–297). Although a Roman arch could be used in a building, they are most famous as freestanding commemorative structures, perhaps originally temporary, but eventually evolving into the familiar triumphal arch. In 196 BCE, L. Stertinius commemorated his service in Spain by erecting in Rome three arches that supported gilded statues (Livy 33.27.3–5). Four years later, P. Cornelius Scipio Africanus constructed one on the Capitol, also surmounted by statues (Livy 37.3.7). In Rome, arches were part of the physical display of the return of a victorious commander from overseas; outside the city, they tended to be merely commemorative. The earliest extant are probably two in northwest Italy, at Segusium (modern Susa) and Augusta Praetoria (modern Aosta), dating from the Augustan period (Ward-Perkins 1981, 171–174). Significantly, the one at Segusium was commissioned not by a Roman but by the local allied king, Cottius (*CIL* 5.7231). In Rome, there are fragments of the arches dedicated to Augustus in 29 and 19 BCE next to the Temple of the Divine Julius at the southeastern corner of the Forum (Dio 51.19.1, 54.8.3; Platner 1926, 34–35), although the first extant standing arch in the city is that of Titus, from the 80s CE, between the Forum and Flavian Amphitheater, much altered from its ancient form.

Vaulting appeared in the fourth century BCE, in tombs in northern Greece and Macedonia, becoming common in Rome by the end of the Republic. Concrete made great vaulted ceilings possible, especially in the Imperial baths: as Roman buildings became larger, vaulted roofs became more common, freeing interiors from the closely spaced colonnades and dimensional limitations that had plagued Greek architecture (Höcker 2010, 243–247). Both the arch and the vault allowed the stresses of a structure to be directed downward and outward, with tension and potential collapse relieved by the use of keystones.

Although arches and vaulting had Hellenistic origins, the dome seems to be a purely Roman invention, probably from the first century CE. The so-called Temple of Mercury at Baiae on the Bay of Naples may be the earliest extant, but its date is not certain (Ward-

Perkins 1981, 166–168). At Rome, there may have been one in Nero's first palace, the Domus Transitoria, in the portion now located under Hadrian's Temple of Venus and Roma, although this is disputed (Richardson 1992, 138–139). In Nero's Domus Aurea, the octagonal central room of the eastern complex, generally thought to be used for dining, has a large dome of concrete securely dated to just after CE 64 (Suetonius, *Nero* 31). The huge dome of the Pantheon, from the early second century CE, is the most conspicuous today. It follows the constructional precepts laid out by Vitruvius over a century earlier (4.8.3, 5.10.5), and, at 142′ across (40 m), is the largest before the Renaissance.

6. Architecture as Power: Rome in the Last Years of the Republic

In the last years of the Roman Republic, there was constant building in the city of Rome, making full use of the new materials and techniques. As competing commanders and political leaders sought both to reform the Roman system and to acquire power, architecture became a conspicuous element of their efforts. The spreading of Rome's political reach—beginning as early as the third century BCE with the Punic Wars—more than ever exposed Romans of wealth and power to the architectural traditions of the Hellenistic Greek world, and they returned to Rome anxious to implement building efforts that were based both on what they had seen in Greece as well as the current state of indigenous Roman architecture, creating a combined form that was to establish the architectural tradition for the Imperial period. There was even cross-fertilization, as Roman architects began to ply their trade in the Greek world, most notably the mysterious Cossutius, who, in the first half of the second century BCE, was commissioned by the Seleucid king Antiochus IV to complete the Olympieion in Athens (Vitruvius 7 preface 15–17).

In the summer of 83 BCE, the great Temple of Jupiter on the Capitol burned down (Plutarch, *Sulla* 27.6). It was rebuilt by L. Cornelius Sulla, then entering the period of his greatest influence (Pliny, *NH* 36.45). He used columns from the Athenian Olympieion (perhaps material left over from Cossutius' work of a century earlier), thus inaugurating half a century of intense building in the city as the Republic collapsed. A generation later, Pompey the Great and Julius Caesar, competing in politics and on the battlefield, also competed architecturally. In answer to Pompey's theater (55 BCE), Caesar immediately began construction of his own just to the southeast, although the project was only completed 35 years later by Augustus and dedicated to his late nephew M. Claudius Marcellus (Augustus, *Res Gestae* 21; Suetonius, *Deified Julius* 44; Dio 43.49.2–3). During the last decade of his life, Caesar began to implement the first major building program within the city. Most important was the Forum Julium (just north of the Forum Romanum), begun in 54 BCE (Cicero, *To Atticus* #89.8 [4.16]) and dedicated in 46 BCE (Dio 42.22.2). It was a Hellenistic-style enclosed temple precinct—the first Roman example of this genre long familiar in the Greek world—with a temple to Venus, the ancestor of the Julian family, and was famous for its golden statue of Kleopatra (Cleopatra) VII (Appian, *Civil Wars* 2.102; Dio 51.22.3). Many other projects of Caesar's were started during these years, most left incomplete (or even merely in the planning stage) at the time of his death in 44 BCE, and finished by the triumvirs, or by Augustus alone. These included the Saepta Julia (the voting precinct in the Campus

Martius: Cicero, *To Atticus* #89.8 [4.16]; Dio 53.23.1–2), and the Curia Julia (Dio 44.5.2, 45.17.8) and Basilica Julia (Augustus, *Res Gestae* 20.3; Dio 56.27.5) in the Forum. At least one Greek architect was involved in these projects, incurring the wrath of Cicero (*To Atticus* #334 [13.35–36]).

Despite increasing political chaos after Caesar's assassination, building activity continued during the triumvirate of M. Aemilius Lepidus, M. Antonius, and C. Octavian. The most important new project was a memorial to Caesar, perhaps started by Antonius but completed by Augustus many years later (Roller 2007, 90–91), eventually becoming the extant Temple of Divine Julius at the east end of the Forum. Antonius may have started the Temple of Mars Ultor (Roller 2007, 93–98). But Octavian completed most of Caesar's projects: including the Temple of Mars Ultor, vowed at the Battle of Philippi, probably by Antonius (Ovid, *Fasti* 5.69–78; Augustus, *Res Gestae* 21.1; Suetonius, *Deified Augustus* 29.2), but completed 40 years later (Simpson 1977, 21–24), when its original purpose had long since become irrelevant. It bore little resemblance to the original concept. After Antonius' death in 30 BCE—Lepidus had long since been marginalized—Octavian as the winner could slowly complete the unfinished projects (and add many of his own), as he became Augustus and the new regime fell into place. Architecture as a political instrument of those in power was no longer questioned.

7. Early Roman Building outside Rome

As the Roman horizon expanded and Romans began to spend time in the Greek world, they became exposed to the rich environment of Hellenistic Greek culture. This began as early as the end of the third century BCE, when, during the Second Punic War, Romans spent a lengthy time in the Greek city of Syracuse and eagerly absorbed its artistic and intellectual wealth. When the city fell to M. Claudius Marcellus in 212 BCE, much of its art was removed to Rome, awakening interest there in all things Greek, and encouraging the attitude that the Greek world existed for the Romans to acquire (Livy 25.40.2). Twenty-five years later, when Romans had actually been on the Greek mainland, "foreign extravagance" (*luxuria peregrina*) began to become commonplace in Rome (Livy 39.6.7). Yet the influence was not all in one direction. From the very beginning of Greco-Roman political interaction, Romans were influencing the architecture of the Greek world, for example, Cossutius mentioned above (§6). By the first century BCE, Romans were actively building in Greece, Anatolia, and the Levant. Around 50 BCE, Appius Claudius Pulcher (consul BCE 54) rebuilt the Lesser Propylaia at Eleusis (Clinton 1997, 164–165). Somewhat earlier, Pompey the Great was busy restoring as many as 40 cities (Dreizehnter 1975, 213–245), including the ancient city of Soloi in Cilicia, which he renamed Pompeiopolis (Strabo 14.3.3, 14.5.8). Although such efforts probably remained within the existing architectural repertory of the Greek world—and in some cases may have been limited to monetary donations—it established the Romans as an architectural factor in the ancient cities of the eastern Mediterranean.

In 47 BCE, Julius Caesar visited Antioch-on-the-Orontes. This famous city had recently come under Roman control owing to the collapse of the Seleucid Empire. Contemporary with his extensive efforts in the city of Rome, Caesar inaugurated a building program in Antioch, most notably constructing a Kaisareion, the first known Roman basilical structure outside of Italy, featuring an open courtyard with an apse containing a statue of Caesar himself (Sjöqvist 1954, 94–95). He also provided the city with

an amphitheater (also probably the first outside Italy), aqueduct, and other structures (Roller 1998, 82–83). Caesar's building program in Antioch and the placing of Roman architecture in this venerable Greek city continued the tradition of innovation that was then occurring in Rome: in particular, the Kaisareion was a close parallel to the Forum Julium, a fine example of cross-fertilization, since a form that was originally Hellenistic Greek had been carried to Rome, modified, and now returned to the Greek world. There was also a Kaisareion in Alexandria, although its origins are uncertain, and it has been variously attributed to Caesar himself, Cleopatra VII, Antonius, or Augustus (McKenzie 2007, 177–178).

8. Augustan and Julio-Claudian Rome

With the end of the Roman Civil War in 30 BCE, the subsequent peace and prosperity inaugurated a lengthy period of construction in the city of Rome that continued almost without break until the early third century CE. At first, efforts by the emperor Augustus and his colleagues were directed toward completing the plans of Julius Caesar and the triumvirs, fitting them into the aspirations and policies of the new regime. But Augustus and his immediate successors also embarked on their own programs, making use of the technological innovations, new building materials, and Greek inspiration that had developed during the earlier part of the first century BCE. Augustus' famous comment that he had found Rome a city of brick but left it one of marble (Suetonius, *Deified Augustus* 28.3) was no idle boast, but an astute statement of the transformation of the city during his era, a process particularly enhanced by the exploitation of the Luna marble quarries. Augustus himself left a detailed list of over 20 structures that he built, restored, or completed, with an additional 82 unspecified temples (*Res Gestae* 19–21). Much of this was merely restoration or repair—surely the 82 temples fall in this category—but there were a number of genuinely new projects, or completion of ones that had not been far advanced when he took power.

Most notable was the Forum of Augustus, continuing Caesar's policy of providing additional public space adjacent to the ancient Forum Romanum. It was an impressive colonnaded precinct that adjoined the Forum Julium on the north (Richardson 1992, 160–162), with the Temple of Mars Ultor at its far end, vowed (probably by Antonius) at the Battle of Philippi in 42 BCE and worked into the Augustan project, which far exceeded the concept of the original temple. Like the Forum Julium, the Forum of Augustus was a Hellenistic-style enclosed portico (over 400′ [120 m] deep), with extensive marble details, especially on the temple, but also travertine as well as colored marbles from Africa and Greece. It served as a memorial to the history of Rome, with niches for statues of the great men of Roman history as well as members of the Julian family (Suetonius, *Deified Augustus* 31.5; Dio 55.10.3). It became a notable art gallery (Pliny, *NH* 35.27) and a place where certain elements of state business could be conducted.

Another Augustan achievement was further development of the Campus Martius as a monumental quarter, rather than the grassy field it had been since earliest times (Strabo 5.3.8; Ovid, *Letters from Pontus* 1.8.37–38). Encroachment into the Campus had begun with the Theater of Pompey the Great and then Caesar's Saepta (only completed in 26 BCE: Dio 53.23.1–2). Augustus used the long west wall of the Saepta (over 1000′ [300 m] in length) to define a new district. Near its northwest corner, he located the Pantheon whose Greek name reveals the continuing impact of Greek architectural

thought even in the Imperial period. The dedicatory inscription now visible on the façade of the extant building (second century CE) dates the original to 27 BCE (Dio 53.27.2). It was probably similar to the Temple of Mars Ultor; among its famous artifacts were the earrings on its statue of Venus, made from a pearl that had been owned by Cleopatra VII (Pliny, *NH* 9.121; Macrobius, *Saturnalia* 3.17.17). To the south of the Pantheon was the Basilica of Neptune (Dio 53.27.1), some of which is visible today, and then, farther south, the Baths of Agrippa, previously discussed. All these buildings related to one another and created a public precinct in the Campus, an early example of methodical urban planning in the Roman world.

In the Augustan period, Roman architecture was still eclectic. The Theater of Marcellus—the final version of the theater started by Caesar in the 50s BCE—was in a conservative Roman style, built of tufa, travertine, and brick; its only use of marble may have been a few columns (Asconius, *Commentary on Cicero's Pro Scauro* 45). On the other hand, the Ara Pacis, dedicated in 9 BCE in the northern Campus Martius, a monumental outdoor altar, almost entirely of Luna marble, and without precedent in Rome, derived from such Greek models as the altars of the Twelve Gods at Athens or Zeus at Pergamon. Beyond the Ara Pacis, Augustus built his mausoleum (Strabo 5.3.8; Dio 53.30.5), based in part on Etruscan tumuli, but also on the royal tombs of the East: he began it just after his return from Egypt in 29 BCE, where he had supervised the burial of Cleopatra VII and Antonius in their own mausoleum (Plutarch, *Antonius* 86.4; Dio 51.15.1). The Ara Pacis and Mausoleum of Augustus represent the Hellenized side of contemporary Roman architecture, whereas the Theater of Marcellus is in an indigenous tradition.

Augustus' immediate successors paid less attention to building, perhaps reflecting a break from the intensity of construction of the previous century, but nevertheless the city of Rome continued to see a steady stream of projects. Many of these were relatively minor, but of particular note was the Castra Praetoria (underwritten by Tiberius, CE 21–23) at the northern edge of the city, important both in the history of architecture and in the evolution of the Roman political system (Suetonius, *Tiberius* 37.1; Tacitus, *Annals* 4.2; Dio 57.19.6). It was a legionary camp of the type that had only existed previously outside Rome, such as the one at Augusta Praetoria (Aosta) in northwest Italy, dating from 24 BCE. Tiberius' structure is a rectangle, 1440′ by 1250′ (440 × 380 m), with rounded corners; the walls still stand to their full height of nearly 16′ (5 m). The exterior of this utilitarian structure shows no ornamentation and is merely brick-faced concrete. The arrangement of the interior is unknown.

The successive emperors, Gaius Caligula and Claudius, produced little public building, although both improved the city's water supply (Suetonius, *Gaius* 21; Frontinus, *Aqueducts* 1.13). Claudius was also responsible for the new harbor at Ostia, the port of Rome. Claudius' successor Nero is an important figure in the history of architecture, but in terms of domestic, not public, constructions. His contributions were discussed above (§5): notably the Campus Martius baths and use of domes.

9. The Role of the Allied Kings

An important factor in the dissemination of Roman architecture was the phenomenon known as the friendly or allied king. These were indigenous monarchs who had been trained and often educated by the Romans, and who eventually ruled their kingdoms with Roman support, having an unofficial obligation to mix Roman ways with their own

needs. Generally ruling at the margins of the Empire, they served as a buffer between Roman territory and the lands beyond. The concept was at its peak in the Augustan and Julio-Claudian periods (Braund 1984; Roller 2003, 267–275). These kings demonstrated their Roman qualities in several ways, including commissioning elaborate architectural programs, and thus they served as a means by which Roman architectural theory spread across the Mediterranean.

The two outstanding examples of kings as patrons of architecture are Herod the Great of Judaea and Juba II of Mauretania. Herod (ruled 40–4 BCE) commissioned the most extensive building program of Classical antiquity other than those of a few Roman emperors. He built many places within his own territories, as well as throughout Syria, Anatolia, and as far as the Greek heartland (Roller 1998, 85–124). Some 40 sites are known. Herod was in Rome as early as the winter of 40–39 BCE, and also spent time in Antioch, where Julius Caesar had first brought Roman architectural styles to the East. Herod's program was profoundly innovative, spreading the indigenous Italian forms of the theater (Figure 42.3), Roman-style temple, amphitheater, and residential structures to the Levant. He used Roman construction materials such as *opus reticulatum* and hydraulic concrete. He also was directly involved in the Augustan program, building Nikopolis, Augustus' victory city near the site of the Battle of Actium. Herod was not limited to using purely Italian forms: traditional Greek



Figure 42.3 The Italian-style temple at Sebasteia (formerly Samaria), built by Herod the Great, one of the first of its type outside Italy. *Source:* Shuki, https://commons.wikimedia.org/wiki/File:Augusteum.JPG. Used under CC BY 3.0, http://creativecommons.org/licenses/by/3.0/.

structures such as the gymnasium and stadium were also part of his program, and his Temple in Jerusalem made use of typical Levantine religious elements. All this came together in his great city of Caesarea (Kaisareia in Greek), at the northern edge of his kingdom, completed in 10 BCE, and which would become second only to Alexandria as the major city of the eastern Mediterranean. Especially important was its port, Sebastos Harbor, which used *pozzolana* imported from the Bay of Naples as well as the most modern construction techniques available. It inspired Claudius when he built his own port at Ostia below Rome.

On a somewhat more modest scale, but nevertheless innovative, was Herod's younger contemporary Juba II of Mauretania. The displaced heir to the Numidian kingdom, raised and educated in Rome, married Cleopatra Selene, the sole surviving child of Cleopatra VII and Marcus Antonius, and was sent in 25 BCE to rule Mauretania, the unorganized part of Africa west of his (now provincialized) ancestral territory of Numidia. He settled at the ancient indigenous city of Iol, which he promptly renamed Caesarea or Kaisareia, constructing for his royal capital there a Roman city, including a theater, amphitheater, and other structures, and importing Luna marble for decoration (Roller 2003, 119–137). To the east of the city was his tomb, known today as the Mauretanian Royal Mausoleum, similar to Augustus' mausoleum at Rome, although with certain indigenous features. Juba and Herod created show cities (although no less functional) which could demonstrate both to their subjects and the Roman power elite that they were firmly within the new Roman architectural (and political) tradition, cities as civilized and modern as Rome.

10. Roman Architecture in the Provinces

As noted above (§3), Roman architecture began to spread beyond Italy in the first century BCE. Its impact varied: in the west, there was no tradition of sophisticated building, and Roman architects had virtually a free hand, but in the East the new buildings had to fit into the existing repertory of cities that often were much older than Rome.

In Iberia and Gaul, completely new Roman cities were founded as early as the first century BCE. For example, in the Baitis (modern Guadalquivir) valley of southern Spain, formally organized as the province of Baetica in 27 BCE (although a Roman political presence dated back to the early second century BCE), the small provincial cities of the earlier era were totally rebuilt in the Augustan period. Italica (north of Seville) and Corduba (modern Córdoba) define the Roman presence (Collins 1998, 148–155, 117–122). In the more remote areas farther north, Augustus established two new cities, whose names carried with them that of the new regime. In the west was Augusta Emerita (modern Mérida), founded in 25 BCE, containing one of the first Roman theaters extant from the Iberian peninsula and an early amphitheater (Collins 1998, 185–199). To the east, on the Iberus River (modern Ebro), was Caesaraugusta (modern Zaragoza), founded at the same time (Collins 1998, 290–293). Both these cities served as outposts for the Romanization of central Iberia, and had all the trappings of proper Roman towns.

In modern France, the ancient Celtic territory, Lugdunum (modern Lyon) was founded in 43 BCE at the junction of the Arar (modern Saône) and the Rhodanus (modern Rhone). The city was developed in the Augustan and early Julio-Claudian periods, with an amphitheater, theater, various temples, and, importantly, the Ara Romae et Augusti (the Altar of Rome and Augustus) of 12 BCE (Strabo 4.3.2; Deglay 1976, 529),

a monumental outdoor altar in the style of the exactly contemporary Ara Pacis in Rome, serving to demonstrate to the indigenous population (which had long gathered at this important river junction) the validity and significance of the new regime.

Twenty miles (30 km) downstream was Vienna (modern Vienne), whose history parallels that of Lugdunum, but which perhaps served more as a commercial than religious and political center. Here local traders and merchants could mingle with those from Rome, and through the visible medium of Roman architecture (especially a temple of Rome and Augustus) they could become accustomed to Roman ways (Ward-Perkins 1981, 226–227). Eventually western Europe was dotted with such Roman centers.

In the East, matters were different. There were few new cities (Herod's Caesarea is an exception), yet Roman architecture was regularly inserted into the ancient centers of the Greek world, often having a symbolic demonstration of the existence of a Roman presence, or in order to implement the new prosperous commercial environment. Athens is a good example (Ward-Perkins 1981, 263–271), where a circular temple of Rome and Augustus was built at the east end of the Acropolis during the Augustan period, reflecting an Italian tradition of small round temples (such as the so-called "Temple of Vesta" in the Forum Boarum at Rome), but with decoration inspired by the nearby Classical buildings on the Acropolis. In the ancient Agora itself, Agrippa built a large odeion around 15 BCE, a peculiar mixture of local form and detail with Roman monumentality. To the east of the Agora, a new quarter was laid out, the Market of Caesar and Augustus, around the late Hellenistic horologium known as the Tower of the Winds (Time-Telling Devices). The market is an enclosed portico with a monumental entrance toward the Agora, a conservative structure almost pedantic in style, but nevertheless reflecting the improved economy of Roman Athens. This mixture of the innovative and ordinary, the local and Roman, with an emphasis on commerce, was repeated in numerous existing cities throughout the eastern Roman world.

11. Later Roman Architecture

With the invention of the dome in the mid-first century CE, and its transference from domestic to public building in the following century, there were few further innovations in Roman architecture. The styles, methodologies, and techniques remained relatively stable until the changes of late antiquity that led to Byzantine architecture. Sheer size often became the dominating factor. The dome of the Pantheon in Rome, built in the years after CE 118 (Richardson 1992, 283–286), remained the largest in existence for a thousand years. The great Imperial baths that began with the one constructed by Trajan after CE 104, and which continued through those of Caracalla (the Antonine) and Diocletian, are impressive even today for their magnitude. The latter, whose remains are in and around the Piazza del Cinquecento and Piazza della Repubblica in Rome, remains astonishingly well integrated into the plan and buildings of the modern city. An enormous basilica, completed by Constantine in CE 313 and popularly named after him, stands east of the Forum Romanum (Figure 42.4). It features one of the few architectural innovations of late Roman times, the flying buttress, and is a masterpiece of the era, with extensive use of cross vaulting. The basilica was thoroughly studied in early modern times and provided a transition between Roman public architecture and the ecclesiastical architecture of the Renaissance.

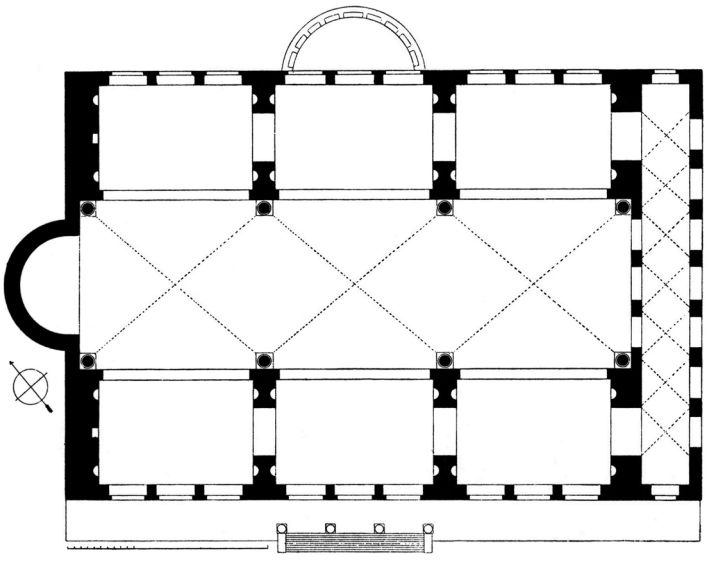


Figure 42.4 Plan of the Roman basilica in its most developed form (the so-called Basilica of Constantine in Rome). Adapted from Georg Dehio/Gustav von Bezold: Kirchliche Baukunst des Abendlandes. Stuttgart: Verlag der Cotta'schen Buchhandlung 1887-1901, Plate No. 6.

Yet, despite these impressive structures, building in the city of Rome began to diminish after the middle of the second century CE, and except for occasional and sporadic periods, there was little further construction in the city, although most emperors honored it with a minimal effort. This lessening of building activity was in part due to a new emphasis on repair (early Imperial buildings were now hundreds of years old), and a feeling that few further buildings were needed in this architecturally rich city. Moreover, political reality saw a shift away from Rome toward the provinces, where vigorous building continued. The occasional spurts of effort were limited, in large part, to the baths and Constantinian basilica already mentioned, and occasional temples. With the establishment of Constantinople in CE 324, Rome was hardly of any further interest.

As building in the city declined, that in the provinces increased. In Asia Minor, particularly, a vigorous new mixed Greco-Roman style emerged, using the excellent indigenous building stone rather than concrete and *opus reticulatum*. Incorporating Italian forms such as the basilica remained a viable approach, but in a richer and more decorative manner than the sometimes austere forms of the west. An excellent example is the library built by C. Julius Celsus at Ephesus in the early second century CE, whose articulated façade with alternating triangular and curved pediments is highly aesthetic (Ward-Perkins 1981, 288–291). Farther east, the groundwork laid by Herod the Great led to great cultic complexes honoring Hellenized and Romanized local divinities, such as the sanctuary of Jupiter Heliopolitanus at Baalbek, of the first century CE, an accumulation of a monumental façade, Hellenistic enclosed portico, and Italian style temple.

Roman architecture penetrated beyond the farthest limits of the Empire, as remote cities such as Palmyra in the Syrian desert and Volubilis in western Mauretania were rebuilt in such a way to provide Roman architecture (and the symbolism it implied) to

an indigenous population that may have been only slightly Romanized. As the Roman system became more fragile and less cohesive, from the fourth century CE, its architecture remained the most visual aspect of Roman society—as it does in many places today—and it provided the basis for Byzantine, Islamic, and European styles.

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FURTHER READING

Ward-Perkins 1981 remains the best overall handbook on the topic of Imperial architecture. For the Republic, see Boethius 1978. Both these works are lavishly illustrated with many useful plans. For the city of Rome, see Richardson 1992. Although old, Blake 1947 is an excellent summary of construction materials. The many *Oxford Archaeological Guides* to various portions of the Roman Empire are excellent catalogs of the actual remains at individual sites. For specific building types, see the following: for the amphitheater, Welch 2007 (with the cautions advanced by Golvin 2007); for baths, Yegül 2013; and for aqueducts and water supply, Hodge 1992.

CHAPTER 43

Roman Domestic Architecture

Nathalie de Haan

But my house is, as you say, a forum (Cicero, *To Atticus* 12.23)

1. Introduction

This chapter sets out to explore Roman domestic architecture under the Republic and Empire, a vast topic both chronologically and geographically. Scholarly literature on Roman housing is abundant, especially from the eighteenth century onward since the rediscovery and excavations of Herculaneum and Pompeii in 1738 and 1748, respectively.

Our starting point will be the writings of Roman authors on domestic building, notably Vitruvius. These treatises reflect the opinions behind ancient building practices and help us to create an interpretative framework. From there, constructional, social, functional, and regional aspects of Roman domestic buildings will be addressed. Both material and literary sources help to shed more light on the use of Roman houses. Inevitably, elite housing receives much attention as the majority of our sources, material and literary, reflect the world of the elite, both in the center and peripheries of the Roman sphere of influence. Relatively well-preserved ruins throughout the Roman world contain the houses of well-to-do citizens, whereas the poorly built dwellings of the lower classes leave hardly any trace, not to mention the shelters of homeless people living on the streets that are invisible in the archaeological strata.

2. Treatises on Architecture and Building Manuals

In the preface to Book 7 of his *Ten Books on Architecture*, probably written and published in 30–20 BCE, the Roman architectural writer Vitruvius lists the authors that he studied to achieve architectural expertise. The impressive list contains mostly Greek names, with

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just a few Roman authorities: Fufius (perhaps Quintus Fufius Calenus, serving under Caesar) and Marcus Terentius Varro, whose *On the Nine Disciplines* is now lost (Gros 1997; Rowland and Noble Howe 1999, 1–18). Thus, Vitruvius presents himself not only as a well-read man of learning, but also as the first Roman who devotes himself "to this kind of writing beyond one or two volumes." Moreover, this preface offers an interesting insight into the kind of treatises and manuals available in the late first century BCE (SCIENTIFIC ENCYCLOPEDIAS).

Vitruvius devotes Book 6 to domestic architecture, but he did not offer a general overview of Roman housing. According to recent interpretations, Vitruvius does not describe architectural phenomena but instead prescribes sets of rules for the design of buildings and devices. It is important to keep in mind that Vitruvius was writing for an elite audience, "not only for those who intend to build, but also for all learned men" (1.1.18). Hence, his Book 6 focuses mainly on the design of the *domus* (singular and plural), the house of the late Republic's Roman elite. But we do not find here any description of a "standard *domus*." On the contrary, part of this book deals with the influence of climate on man's very existence and the necessity to adjust housing to climatological circumstances (6.1). Hence, as Vitruvius explains:

> Under the northern sky buildings should be entirely roofed over and be as enclosed as possible, oriented toward the warmer regions but not open to them. By contrast, under the onslaught of the sun in southern regions, because they are assailed by heat, buildings should be made more open and should face north and northeast. Thus, whatever Nature exaggerates will have to be restored by art. In the remaining regions the placement of the buildings should be adjusted in the same way, according to the way the heavens are oriented because of the inclination of the cosmos. (6.1.2; all translations of Vitruvius are from Rowland)

Moreover, the various rooms of a house should be oriented according to their function (6.4). Winter dining rooms and private baths, for example, should face southwest or west, whereas bedrooms and libraries should profit from the morning sun and therefore be oriented to the east. Consequently, a house plan should be designed or adjusted to the building plot and its orientation. Even if "proportion" is the keyword in the design of any Roman building, including houses (6.2, 6.3), the rules of design could not always be made to conform to unruly reality. In other words, many grand houses were customized according to the possibilities of the allotted space and orientation, a fact that Vitruvius acknowledges (6.3.11). Vitruvius was not the first author to stress the importance of climate and proper orientation of rooms (see also ANTHROPOLOGY: KNOWLEDGE OF MAN; "ECOLOGY" IN THE ANCIENT MEDITERRANEAN; PHYSICIANS AND "SCHOOLS"; PSYCHOLOGY AND PHYSIOGNOMICS). This must have been common knowledge in the Hellenistic building manuals. Moreover, many excavated Greco-Roman houses reflect how building practices employed these rules.

The design depended on the commissioner's social position as well. A house should meet the needs of its owner in an appropriate way, a concept referred to as "suitability" (*decor*; 6.5). Here Vitruvius distinguishes between the personal areas (*propria loca*) and public areas (*loca communia*) (6.5.1; see below, §4).

Vitruvius essentially focuses on urban residences of the Italian elite, and only briefly discusses countryside villas (6.6). Here too, however, he stresses the orientation of rooms toward the directions of the winds. Moreover:

> If the villa is going to be on the more refined side, it should be designed according to the symmetries that have been recorded earlier for urban buildings, so long as this does not interfere with its serviceability as a country house. (6.6.5)

Various treatises on agriculture by Cato the Elder, Varro, Columella, and Palladius (late fourth or fifth century CE) provide additional information. These authors briefly discuss building materials and design, as well as how to choose the right place for building (of course, easier in the country than in the context of an existing urban settlement). Cato's *On Agriculture* (14–17) provides useful information on the building process (see below). He also mentions prices.

Vitruvius dedicated his work to Augustus, who in the late twenties BCE was responsible for an ambitious building program in the city of Rome: "I have set down these instructions, complete with technical terms, so that by observing them you could teach yourself how to evaluate the works already brought into being and those yet to be" (1 preface 3). We are ill-informed on his direct influence in antiquity, but the very fact that the treatise was copied during the Carolingian Renaissance suggests that *On Architecture* still circulated in the Late Antique period. Pliny the Elder and Frontinus both name Vitruvius without, however, referring to his work, even though Frontinus adds "*architectus*" to Vitruvius' name. But we do know that at least two later authors used Vitruvius: Faventinus and Palladius.

Marcus Cetius Faventinus (late third century CE) loosely adapts parts of Vitruvius' text, whom he cites as Vitruvius Polio [*sic*] among unnamed "other authors" (1). Faventinus chose to focus exclusively on domestic buildings (29). Offering a practical guide for villa owners, Faventinus discusses finding water, digging wells, and (extensively) the location of various parts of the villa. It is clear that the villa is conceived as a farm, not as a country house for relaxation. "If you wish to build something better and more artistic, you will take your pattern from buildings in town" (13). Only a few of the 29 chapters are devoted to town houses. In chapter 14, Faventinus stresses the proper disposition of rooms in an urban house, and then briefly discusses the proportions of dining rooms and other rooms that can be closed (*conclavia*), *exedrae* and *oeci* ("living rooms" in a broad sense), and finally the location and heating arrangements of the bathrooms.

Remarkably, Faventinus paid little attention to different types of walls and masonry, a topic prominent in Vitruvius, apparently, falling under the domain of public building in Faventinus' view. As for building material, only timber is treated at length, possibly indicating the region(s) that Faventinus had in mind, for example, parts of Gaul.

Palladius employs Faventinus' "abridged version" of Vitruvius in his own fourteen books on agriculture. This handbook for an estate owner contains, in the first book, practical advice on the location of the villa and of specific rooms and buildings. Again, much space is devoted to the adjustment of rooms according to the directions of the winds. Instructions are given for building a bath suite, including detailed descriptions of the arrangements for heating and water supply. Moreover, advice for finishing walls is given. But, generally speaking, instructions on walling, wall types or roofing, as well as a discussion on building materials are lacking.

3. Design

It is obvious that large and sophisticated projects, both public and private, could only be built according to a design and that a trained architect would have to be involved in some way. With reference to Greek theory, Vitruvius explicates that design itself was divided into various parts: *ordinatio* (ordering), *dispositio* (design), *eurythmia* (harmony), *symmetria* (symmetry), *decor* (suitability), and *distributio* (allocation) (1.2.1). His phrasing, however, is vague and problematic, since *ordinatio*, *dispositio* and *distributio* belong to the tasks of the architect, while *eurythmia*, *symmetria,* and *decor* are qualities of the finished building (Geertman 1994). In the process of ordering and design, the careful establishing of *moduli* (measuring units) is crucial for the right proportions and symmetry of the building.

No ancient building plan or drawing has survived, but Vitruvius (1.2.2) describes various types: ichnography (plan), orthography (elevation), and scenography (perspective drawing). In other literary sources, various terms for architectural plans occur: *forma* ("design:" Aulus Gellius, *Attic Nights* 19.10.3; Faventinus 1) and *species* ("figure:" Aulus Gellius, *Attic Nights* 19.10.3); the written specifications of a building plan were called *aedificandi descriptio* ("specifications of building:" Cicero, *On Duties* 1.138).

Architectural design and building practice (*aedificatio*) are often contrasted (e.g., Thébert 1987; cf. de Haan 2004). The demarcation, however, between the experienced contractor and the architect seem to have been flimsy. "Architect" was not a registered profession protected by official titles or privileges. Cato (*On Agriculture* 14) names a *faber* (craftsman, contractor) for the building of a new villa, without citing a design or an architect. Aulus Gellius (*Attic Nights* 19.10.1–4) refers to various contractors when discussing the building of a new bath suite in a private house, but he omits mention of an architect or experienced craftsmen, who, one might expect, should oversee the construction of a bath suite, including the arrangements for heating, water supply, and sewage. Many heads of households, trusting in their own reading, built according to their own wishes for themselves (Vitruvius 6 preface 6). In sum, we have a sliding scale. On the one end, we find elaborate original designs and the sophisticated adaptation of existing plans for larger buildings. On the other end, humble dwellings were very likely built without any plan. The importance of proportions and symmetry—often facilitated by standard measurements—however, is obvious in the majority of Roman period buildings. Research in Britain, for example, reveals that standardized lengths for timber used in Roman period houses were of 1, 1.5, and 3 Roman feet (Perring 2002, 81).

4. Construction Techniques and Building Materials

As now, construction was highly dependent on available building materials. In the Mediterranean, stone building was the norm. In parts of the northwestern provinces where stone was scarce and had to be imported, other material and construction techniques prevailed, most notably timber, terra pisé, mud brick, and wattle and daub. Acknowledging the importance of solid knowledge of building material and construction techniques, Vitruvius devotes the second book of *On Architecture* to building material and the various techniques employed for walls.

Mud bricks (*lateres*, hence *opus latericium*) were still common in the first century BCE and could be applied in properly roofed buildings where no water could harm the unbaked bricks (Vitruvius 2.8.16, 18). But since Roman law regulated the thickness of party walls to a maximum of a foot and a half, walls built of mud bricks could only sustain one story. Consequently, this building technique was unpopular in Rome, where space was precious.

Baked brick, developed in Magna Graecia and adopted by the Romans in the late second century BCE (Wilson 1979; Coarelli 2000), was widely used to face concrete walls (see below). From the first century CE onward, the manufacture of brick and tile became an Imperial monopoly (Adam 1994). In the provinces, the army seems to have been responsible for local brick and tile production, as proved by kilns found near many Roman camps. The dimensions of brick and tile were standardized, seemingly early on, as implied by Cato the Elder's suggestion that the price of building a villa was calculated according to the number of tiles employed (*On Agriculture* 14). Such standardization is confirmed by archaeological evidence throughout the Roman Empire.

Roman concrete (*opus caementicium*) was gradually developed from the late third century BCE and allowed for constructions that were before impossible (see Vitruvius 2.6; Pliny, *NH* 16.202; Roman Monumental and Public Architecture). *Opus caementicium* built the core of walls that were enclosed with *opus incertum* (irregular work) of ashlar stone (limestone, tufa or lava stone). In the first century BCE, small tufa blocks of pyramidal form (*opus reticulatum*: "net-work"; Figure 43.1) replaced the rough *incertum* facing. These prefabricated tufa blocks increased the speed with which even



Figure 43.1 Pompeii, House VIII 2.16. Entrance of the house ("*fauces*"), walls faced with *opus reticulatum*, posts of *opus testaceum*. Photo by author.

unskilled masons could wall up the shells on both sides of a concrete wall. The diagonal lines thus created in the facing of the concrete walls, however, were potential lines of fracture during earthquakes (cf. Vitruvius 2.8.1). This problem was solved in the second century CE when horizontal layers of brick alternated with the *reticulatum* parts of the facing of the wall. In the course of the first century CE, enclosing the wall's concrete core with baked brick (*testae*, hence *opus testaceum*) became the standard (Figure 43.2).

The advantages of building in concrete were enormous. Walls of *opus caementicium* faced with *opus testaceum* could reach great heights and enabled buildings with up to six floors. Owing to the hydraulic properties of the mortar, it even became possible to build under water (piers, embankments, etc.; see URBAN INFRASTRUCTURE IN THE ROMAN WORLD). Moreover, the static quality of Roman concrete allowed for the spanning of rooms of huge dimensions



Figure 43.2 Ostia, *regio* I Insula III, "Caseggiato di Diana" (I.iii.3-4), second century CE. Photo by author.

with barrel vaults, cross vaults, and walls with convex or concave forms (ROMAN MONUMENTAL AND PUBLIC ARCHITECTURE). Logistics was important, and, if properly organized, imposed efficiency on the building process. Moreover, a large part of the work could be done with the help of unskilled labor. Mixing mortar, hauling stones and sand, hewing stones to smaller *caementa*, and carrying concrete to the masons working high up on the scaffolding were all tasks that unskilled laborers could fulfill under the supervision of an experienced foreman.

The number of skilled craftsman, masons, and carpenters, in particular, was relatively low. Carpenters were responsible for the wooden molds necessary for the construction of arches, vaults, and coffered ceilings. Experienced masons created elegant solutions for corners, windowsills, doorjambs, and window frames, whereas less skilled bricklayers did most of the walling up.

Window glass was invented in the course of the first century CE, and from the middle of the century onward, window openings became substantially larger, compared to earlier window openings without glass. Square windowpanes (circa 30–45 cm in length, 1–1.5 Roman feet) were set in a frame of wood or lead. Double-glazed windows were a common feature of baths, both public and private (Figure 43.3).



Figure 43.3 Roman villa in Borg, Saarland (Germany). Double-glazed windows in the *caldarium* (warm room) of the private bath suite (reconstruction, 1997). Photo by author.

Heating rooms, most notably bathing rooms, became possible owing to the development of the hypocaust system, where, ideally, standardized, two-foot square (60 × 60 cm) heat-resistant tiles were used (Vitruvius 5.10). Wall heating using modified tiles (*tegulae mammatae*) or box tiles (*tubuli*) that increased the room temperature substantially. Some contractors possibly specialized in building bath suites which had particular technical arrangements for the provision and disposal of water and heating.

5. The Roman *Domus*: Between Theory and Practice

The Myth of the Roman Atrium House

In many ways, "the Roman atrium house" is an invention of the nineteenth century. Scholars were eager to link recently excavated dwellings in Pompeii to well-known textual sources in general and to Vitruvius' writings in particular (Jolivet 2011, 7–18). Some of these scholars, for example, the German archaeologists Johannes Overbeck and August Mau (1884), carefully addressed the problematic relation between the Vitruvian text and the architectural remains of Pompeii. They were the authors of a highly influential monograph on Pompeii in which they established one of the first plans of the "standard Roman house" (Figure 43.4). Copies or slightly adapted versions of this "standard plan" soon found their way into both scholarly publications and popular representations of the Roman world, including widespread guide books on Pompeii. Subsequently, a myth arose about standardized Roman elite houses characterized by a central hall, the *atrium* (Figure 43.5), in the front part of the house and a Hellenistic peristyle in the back, replacing the small garden (*hortus*) that characterized the original atrium house.

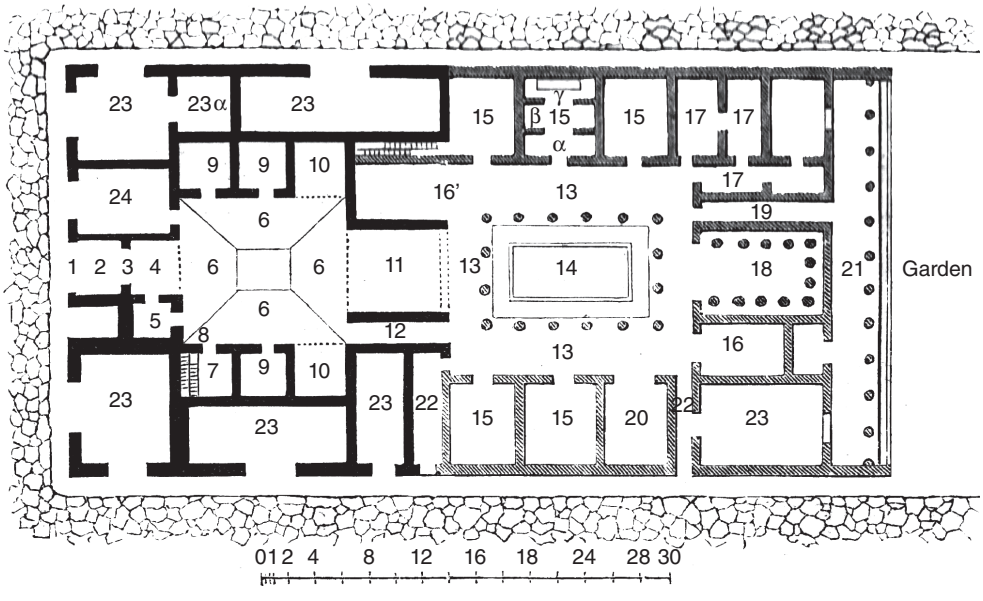


Figure 43.4 Plan of the "standard Roman house" ("Plan des römischen Normalhouses"). *Source:* Overbeck/Mau 1884.



Figure 43.5 Pompeii, House of the Silver Wedding (Casa delle Nozze d'Argento, V 2,i), atrium. Photo by author.

Consequently, almost every Latin schoolbook and most handbooks on (Roman) architecture present the "standard Roman atrium house" with a fixed order of rooms labeled with Latin names such as *fauces* (entrance), *atrium* (central room), *tablinum* (often translated as "office"), and *cubiculum* (bedroom). Moreover, the plan of this standard atrium house is always presented with an imaginary central axis around which rooms are arranged in a symmetrical manner. There is, however, not a single atrium house that corresponds in every detail to such a strict axial symmetrical design. This standard plan is often presented with parts of Vitruvius' text on domestic architecture, which was in no way intended as an exhaustive description (6.5).

Labeling rooms with Latin or Latinized Greek names stemming from a variety of written sources constitutes a further problem (cf. Leach 1997; Dickmann 1999, 23–39). Whereas *fauces* (literally "throat") or *vestibulum* (vestibule) for the entrance of a house may seem unproblematic, it is hard to attach labels such as *cubiculum* or *oecus* to single rooms if decorations and artifacts are lacking to help us to detect the functions of that specific room. Moreover, recent research has shown that many rooms served multiple purposes, changing during the course of the day (Allison 2004).

Even more problematic is the implicit assumption that every Roman house was an atrium house. This type of elite house never became a widespread phenomenon outside of the Italian peninsula, with the exception of some regions in Gaul and Spain. Moreover, the atrium house almost completely disappeared from the second half of the first century CE onward (e.g., Ellis 2000). The trend is sharply illuminated by surveys of *domus* in, for example, North-Italy and Africa (Gros 2001, 93–102; Carucci 2007). Furthermore, several Pompeian dwellings renovated in the decade before 79 CE show the growing importance of the back part of the house over the atrium area in the front.

For example, during the last phase the atrium in the House of the Gilded Cupids (Pompeii, VI 16.7) became the passageway to the peristyle and adjacent rooms, an area that occupies some 75% of the floor plan.

The origins of the atrium house are highly debated as well. Excavations on the slope of the Palatine Hill in Rome have brought to light various atrium houses, whose dates are highly disputed: late sixth century BCE according to the excavators, based, according to critics, on flimsy evidence (Carandini and Carafa 1995, 2012; Wiseman 2001, 2013; Moormann 2001; Jolivet 2011, 68–72). Strangely enough, at least part of the discussion centers on the search for the early "prototype" of the atrium house, often implicitly suggesting that this "prototype" resulted from only one homogeneous ethnic, social, and cultural context. The multifaceted evidence from various archaeological contexts in the Italian peninsula seems to suggest the opposite, showing the dynamics of cultural processes. Nonetheless, the myth of the ubiquitous atrium house as a timeless phenomenon of the Roman world has proved tenacious.

The Domus as a Status Symbol

"But my house is, as you say, a forum," wrote Cicero in a letter to Atticus (12.23), recapitulating the essence of the Roman elite dwelling. The Roman elite house (*domus* or *aedes*) was neither a "temple of privacy" nor exclusively the seat of family life as it is in the modern Western world. The house was primarily a useful instrument in the public and social life of its owner (Wiseman 1987). Of course, the needs of the inhabitants of a *domus* should be met as well. But even then, there was always direct or indirect interaction with the outside world. Rituals connected to family life and the well-being of the *familia* took place in the front part of the house, the "public" area of the atrium (Hales 2003, 2–3). Making a sacrifice to the household gods (*Lares*) who had their shrine (*lararium*) in or near the atrium was a daily ritual. The birth of a child was marked by putting flowers on the threshold of the house, so passers-by would notice. A new bride would be brought in procession to her new home where she would adorn the doorposts with wool (wool-working was regarded as a proper activity for freeborn women).

In a telling passage, Vitruvius clarifies the distinction between the "public" and "private" areas within the house:

> Personal areas are those into which there is no possibility of entrance except by invitation, like *cubicula*, *triclinia* (dining rooms), baths, and the other rooms that have such functions. Public areas are those into which even uninvited members of the public may also come by right, that is, vestibules, *cavaedia*, peristyles, and any rooms that may perform this sort of function. (6.5.1)

The keyword here is accessibility: the distinction of rooms of the house lies between an explicit invitation to enter a particular room or not. The reception ("public") areas are open to the owner's clients as they awaited reception by their patron. The sources speak of a morning ritual when clients would visit their patron's house for the daily salutation, that is, "to pay their respects." The salutation itself occurred in the atrium or *tablinum*. Afterward the patron would leave the house surrounded by his clients as a sign of his high social status.

The *invitati*, those allowed to enter bedrooms, baths, and dining rooms, were (male) citizens of equal rank to the house owner. In the late afternoon and evening, these "friends" (*amici*) were invited to enjoy supper (*cena*) with the head of the household (*pater familias*). A visit to the private bath suite of the house in the late afternoon, before the *cena* began, could be the starting point (de Haan 2010, 119–126). These *cenae* were strictly organized to affirm social hierarchies at Rome and elsewhere. Etiquette and the proper placement of guests were extremely important. Such dining parties took place in the back area of the house, in the rooms adjacent to the peristyle: *triclinia*, *oeci*, *diaetae* (garden rooms), etc. Since drinking in bars was regarded as an activity unworthy for high-rank persons, dining and drinking parties in the private sphere were popular among the elite. A *cubiculum* could be used for more intimate conversations on politics, business matters, and so on (Riggsby 1997; Anguissola 2010).

Thus, the house was instrumental in underlining the status of its owner. House owners who did not receive other people did not need large reception areas. Space was a luxury, and only the rich could afford large areas designed for the reception of many people, as Cicero confirms:

> And, as in everything else, a man must have regard not for himself alone but for others also, so in the home of a distinguished man, in which numerous guests must be entertained and crowds of every sort of people received, care must be taken to have it spacious. (*On Duties* 139)

Cicero also explains the relationship between a grand elite house and the social standing of its owner:

> I must discuss also what sort of house a man of rank and station should, in my opinion, have. Its prime object is serviceableness. To this the plan of the building should be adapted; and yet careful attention should be paid to its convenience and distinction. (*On Duties* 138)

In a pioneering article, Andrew Wallace-Hadrill discusses the functioning of the Roman elite house (Wallace-Hadrill 1987, reprinted in Wallace-Hadrill 1994). Various signs were immediately "read" by visitors to help them fully appreciate the social status of the owners. The very entrances of grand houses were designed to impress and make clear that a family of high rank inhabited that particular dwelling. The dimensions of *atria* indicated the number of persons (clients) that the commissioner received on a regular basis. Within the house, the decorations and furnishing helped to establish what kind of area one was visiting (see also Roman Interior Design).

Moreover, the prestige of the *gens* (clan) to which the house owner belonged was emphasized by the display of portraits of renowned ancestors in the "public" area of the house. According to Pliny (*NH* 34.17), "the forum" (as the heart of municipal commemoration) "was established in private houses as well, notably in *atria*." Even outside the house, the deeds of illustrious forefathers were celebrated—their portraits and spoils of war were affixed to the outer wall near the entrance (*NH* 35.7). Thus, the house provided individuals with a visible past (Hales 2003, 47; cf. Flower 1996). Pliny adds that new owners were not allowed to remove these signs of other people's glory. Hence, the elite house was fundamentally the extension of the public life of the *pater familias* and his relatives, and visibility was of utmost importance (Cicero, *On his Own House* 100–101; Velleius Paterculus 2.14).

The opposite was also true. The destruction of a house diminished the owner's reputation (Cicero, *On his own House* 101; *To his Friends* 14.2.3; *To Atticus* 3.15; Dionysius Halicarnassus, *Roman Antiquities* 12.4.6). The loss of the memorial of one's ancestors was regarded as a serious blow to one's public persona. For the same reason, selling a *domus*, that is, the "place of memory" of a family, was regarded as an undesirable, in fact, a reprehensible, act. (In practice, buying and selling elite property in Rome was common.) Moreover, a *domus* could also reflect the lack of morals of its inhabitants. In his second *Philippic* (2.68–69), Cicero accuses Marc Antony of converting Pompey's confiscated house into a brothel. Precisely because the house was part of the public life of the *pater familias,* too much showing-off of one's wealth and power was detrimental to the balance of power among the Roman elite and therefore undesirable. In fact, the accusation of opulence was an effective weapon to destroy an opponent's reputation. Members of the Roman elite were expected to invest their money in public building and eugertism, not in private luxury—at least according to the rhetoric of the political arena (cf. Cicero, *In Defense of Murena* 76). Practice, of course, was different.

The *domus* was subjected to a set of unwritten rules that shaped social hierarchies among the extremely competitive elite classes during the Late Republic and Principate. Moreover, by adapting "the Roman way of life," elites outside of Rome assumed this mind-set in part and created their houses similarly.

Roman Housing: A Functional Approach

Apart from social purpose and symbolic value, all dwellings share basic functions: shelter, safety, and the storage of one's belongings. But clear distinctions between the houses or apartments of the lower classes and the upper class exist. Rooms of smaller houses and apartments must have had multiple functions, as archaeological evidence from the Vesuvian cities suggests. The variety of finds indicates that rooms served the basic needs of their inhabitants: eating, sleeping, and storage (Mols 1999; Allison 2004). Moreover, working (handicraft and/or selling of goods) and living space was often combined in one or two rooms, either the front rooms of a *domus* rented out by the owner, or parts of an *insula* ("apartment block;" Pirson 1999). A shop (*taberna*) in Herculaneum, where wine and grain were sold, offers a fine example: a downstairs room opening onto the street features large counters and shelves attached to the wall; the shop owner and his relatives lived in two small upstairs rooms (Figure 43.6). Nearly all trades—even dangerous activities, such as forging—were small-scale businesses that were performed in parts of inhabited buildings. Recent research on fulling workshops (where clothes were cleaned) shows that combining spaces for both fulling and living on the ground floor of an urban dwelling was not uncommon (Figure 43.7; Flohr 2011 and 2013).

It is generally assumed that some of the activities usually connected to a domestic environment were performed elsewhere by inhabitants of small, dark, cramped apartments in overcrowded urban quarters. Bathing, for example, could occur in one of the urban bathing complexes found in every Roman town, even in small settlements. Moreover, instead of preparing meals at home, people usually ate inexpensive food sold on the streets. Common use latrines were often part of apartment buildings and could be found elsewhere as well, notably attached to bath buildings, often directly accessible from the street via a separate entrance.



Figure 43.6 Herculaneum, *taberna* (shop) V.6 with two upstairs rooms. Photo by Stephan Mols.



Figure 43.7 Pompeii, House VI 14.21-22 ("Fullonica di Marcus Vesonius Primus"). Plan: courtesy Miko Flohr.

In the larger houses of the more privileged Romans, room functions seem to have been more widely spread, with, for example, separate rooms for sleeping, cooking, bathing, and relaxing. Literary sources mention libraries, picture galleries, dining rooms used in different seasons, and different types of reception rooms (*oecus* and *diaeta*). Yet even in elite dwellings, rooms served multiple functions.

Service quarters, usually isolated from the family's part of the house, often had separate entrances, as, for example, the House of the Centenary in Pompeii, where a separate entrance leads to the kitchen and service area. Moreover, since the private bath was heated from the service quarter, the fuel could be easily brought into the house (de Haan 2010, 223–228).

6. Beyond the Atrium House

Insulae

The various uses of the term *insula* (plural *insulae*) require explanation. Vitruvius employs the word only in his discussion of urban development, where *insula* means "block" (1.6.8, 2.9.16); elsewhere he uses *habitatio* (dwelling) and *aedificium* (building), usually in the plural, for apartment buildings. Modern authors, however, denote apartment buildings as *insulae*, that is, buildings divided into units inhabited by different tenants or owners. The meanings of "group of buildings surrounded by streets" ("building block") or "a building divided in various units" (*partes* or *portiones* in legal texts) both apply. Essentially, in both cases the plot with buildings was originally owned by a single individual and hence often called after this first owner, for example, *insula Sertoriana* in Rome, after Sertorius (*CIL* 6.29791 [*ILS* 6034]). The term *insula*, in fact, was originally used for a plot with buildings in the land register (Gros 2001, 112).

Literary sources suggest that, at least from the late third century BCE onward, Rome's population increase was met by multi-story apartment buildings. Livy tells of a cow, in great panic, that advanced to the third floor (*contignatio*, literally "roof beams") of an *insula* as early as 218 BCE (21.62.3). Plautus refers to a protagonist as living *in cenaculo* (a small apartment or attic: *Amphitryo* 863). In the second century BCE, Ptolemy VI Philometor, forced to flee Egypt, found a shelter in Rome, staying in a narrow upper-floor apartment "since the rents in Rome were so high" (Diodorus Siculus 31.18.2). Cicero describes Rome as "situated among mountains and valleys, stuck up, as it were, and raised aloft, amid garrets, with not very good roads, and with very narrow streets" (*On the Agrarian Law* 2.96, 63 BCE). Cicero also recalls the case of Tiberius Claudius Centumalus, "who owned a house on the Caelian Hill" and was ordered by the augurs "to pull down such parts of the building that obstructed the augurs' view because of their height" (*On Duties* 3.66). Vitruvius (2.8.17) explains that population density in the city forced the inhabitants to live in multi-story buildings. Thus "the Roman people have excellent dwellings without hindrance" and even "with fine views." Other authors, however, are less positive. Martial and Juvenal (late first to early second century CE), for instance, repeatedly complain about the poor living conditions in *insulae*. But it is dangerous to generalize their complaints. Evidence from Ostia shows that spacious apartments consisting of as many as twelve rooms, equipped with large glazed windows and amenities such as running water, could be comfortable dwellings. The Ostian *insulae*, in

fact, exhibit the diversity and wide range in dimensions and qualities that are hidden by the single label *insula* (Mols 2000; cf. Priester 2002).

Growing populations caused the building of *insulae* in other places as well, most notably in Ostia (Figure 43.2), from the second century CE onward when the booming city underwent major alterations. But the phenomenon was in itself more widely known. When Carthage was captured in 146 BCE, the densely populated Punic capital boasted buildings of six floors (Appian 8.128). In Herculaneum, the so-called Insula Orientalis II, an apartment building consisting of four stories and designed to house a large number of people, was built shortly before 79 CE.

As a rule, apartment buildings rose several stories, up to seven or eight floors. Legislation under Augustus restricted the total height of *insulae* to 70′ (circa 20 m), suggesting a fear of instability (Strabo 5.3.7). Under Trajan, the maximum height was reduced further, to 60′ (circa 18 m: *Epitome of the Caesars* 13.13).

Densely populated areas were especially vulnerable to the continuous risk of fire. The use of highly inflammable material in timber-built upper stories made it hazardous, and many fires resulted (Aulus Gellius, *Attic Nights* 15.1.2–3). It is precisely for this reason that Vitruvius disapproves of timber-framed buildings (*opus craticium*), a building technique widely employed, however, because it was cheap, quick, and easy (Vitruvius 2.18.20). After the devastating fire of 64 CE, Nero is reported to have taken drastic actions, issuing rules regarding the height of buildings, width of streets, utilization of less flammable tufa stone, accessibility of water, building of porticoes, and the obligation that every building should have its own exterior walls instead of partition walls shared with adjacent buildings (Tacitus, *Annals* 15.43; Suetonius, *Nero* 16.1).

Apartment buildings were, however, absent in large parts of the Empire, likely because of lower population densities. Neither knowledge nor materials were lacking, as large public works (baths and aqueducts) were built in concrete throughout the Empire.

"Domus" of the Imperial Period

There is, likewise, no standard Roman *domus* for the Imperial Period. Houses differed considerably in layout, size, building materials, and sophistication of design and amenities. Apart from the size of the plot and the owner's financial means and social position, climate and availability of building materials determined how houses were built. Consequently, a house considered "outstanding" in one part of the Empire, because of its size, design, amenities, etc., might be regarded as "mediocre" in another region. Chronology also plays a role. Settlements flourishing in one period could suffer from decay and depopulation in another era. Such changes would have a major impact on all aspects of life, including housing. In some regions, local architecture had long been part of the Mediterranean *koinē*; in other parts, notably in the northwestern provinces, the army played an important role in introducing new building methods and design (Peterse 2005).

Many *domus* share characteristics rooted in the Roman way of life, reflecting Roman values. The layout of *triclinia* and the presence of private baths are good examples. Much discussion centers on the question of how "Roman" a given house was, contrasting "Roman" characteristics to local native traditions or comparing the house with building traditions in central Italy. But perhaps this is the wrong question. First of all, "Roman" is a complex and multi-layered concept (Woolf 1998). Moreover, the very fact

that house owners made the effort to have their houses built according to Roman design suggests that they would consider themselves as "Roman," at least to some extent, since their houses would reflect (part of) a Roman lifestyle. In the end, a house should serve the needs of its inhabitants and thus would have to meet the requirements that public life imposed on local elites.

A characteristic shared by the large majority of Imperial *domus* is the arrangement of rooms around a central courtyard or peristyle. The arrangement could be radial or axial. The axial layout with a *vestibulum*, *peristylium*, and *triclinium* along a central axis seems to have been introduced in the second half of the first century CE, predominantly in the western part of the Empire (Meyer 1999; Gros 2001, 148–213). The *vestibulum* fulfilled the same function as the now obsolete atrium: clients would gather here in the morning to greet their patrons. In fact, the ritual, far from disappearing during the Empire (as many scholars have maintained), remained an important sign of status. For the same reason, entrances of elite houses were usually grand. To a visitor standing in the vestibule, the vista created by the axial arrangement allowed for a glimpse through the peristyle of the most important reception room, the *triclinium*, where the owner received "friends" of equal rank. The peristyle's gardenlike embellishment, with flowerbeds, fountains, and water basins, contributed to the impression of opulence, turning the house into a pleasant spot. Especially in arid regions, "showing off" by the conspicuous consumption of water must have been a statement well understood by both clients and guests.

The radially organized peristyle houses that were more prevalent in the eastern part of the Empire (possibly because their layout was essentially a continuation of Hellenistic models) shared many of these features. Moreover, trends in late antiquity can be followed here more closely, since peristyle houses continued to be built, rebuilt, and inhabited until the middle of the sixth century CE. These houses show a tendency of having increasingly elaborate reception rooms, reflecting a growing dichotomy between elite and non-elite, partly resulting from the abandonment of public buildings and facilities (Ellis 1988).

We are less well informed about the houses of the lower classes, often built of perishable material and hence archaeologically underrepresented, especially in the West. Moreover, Imperial-era written sources hardly mention lower-class housing. Plutarch, the exception, offers a glimpse of the kind of dark and damp dwellings that must have formed the homes of large numbers of people (*On Curiosity* 1).

Country Houses

In the villas where the upper classes spent their free time (*otium*), luxurious facilities were more freely incorporated. It was easier to have a variety of amenities in these villas, where only friends of equal social rank would visit. (Villa culture developed in the course of the second century BCE.) Land owners maintained several properties: remote luxury villas, where they spent part of the year, town homes in Rome, and other villas in the hills near Rome, on the coast, or in mountainous regions. Agriculture was sometimes of minor importance, but usually the elite, whose wealth was based on land-holding, had a number of villas and farms with land cultivation as the major objective. Owning villas in various regions of the peninsula and abroad, additionally, meant spreading the risk of losing all one's possessions.

Harsh on the lazy life of luxury of fellow Roman aristocrats, Varro condemns the indulgence in vogue in his own time, contrasting such frivolities with the rustic backgrounds of Rome's ancestors:

> (…) and they do not think they have a real villa unless it rings with many resounding Greek names, places severally called *procoetion* (ante-room), *palaestra* (exercise-room), *apodyterion* (dressing-room), *peristylon* (colonnade), *ornithon* (aviary), *peripteros* (pergola), *oporotheca* (fruit-room). (*On Agriculture* 2 preface 2)

The passage shows once again the fierce competition among members of the Roman elite in the late Republic. But, apart from luxury, the villa was, just like the town house, a place of display, stressing the high rank and successes of its owner. Pliny (*NH* 22.6.12) records, for example, that Sulla's villa in Tusculum featured a wall painting that depicted the moment when his soldiers awarded him with a grass crown, a high military distinction. In the same period (second–first century BCE), the influence of Hellenistic building and decorative practices were at their height, with the introduction of the peristyle and private baths. By the first century CE, this had changed. During the Principate, the taboo on excessive luxury faded and finally disappeared completely.

Paul Zanker (1995) shows how villa culture and upper-class houses greatly influenced middle-class urban dwellings. Inspired by the amenities offered in villas, new elements were copied in urban houses. Fountains, for example, or even elaborate *nymphaea* with running water and surrounding canals were built into small gardens and *triclinia* in order to create the pastoral atmosphere of landed life and leisure.

Villas of the Late Antique period, especially in the West, show comparable trends to their urban counterparts. From open structures designed for both agriculture and the aristocratic life of leisure, many villas became heavily fortified retreats, where autarchy was the ultimate goal. As such, the layout of these large estates reflects the clear-cut hierarchies and the widening gap between elite and non-elite that characterize late antiquity.

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FURTHER READING

Excellent general overviews are offered by De Albentiis 1990, Ellis 2000, and Gros 2001; the latter study is very detailed, richly illustrated, and treats various regions separately. Hoepfner 1999 contains fine contributions on Roman housing by renowned specialists. For the Republican period, see Hales 2013. Literature on the houses of Pompeii and Herculaneum is abundant. Clarke 1991 treats Roman Italy, mainly focusing on Pompeii, Herculaneum, and Ostia. Fine studies on villas, with many references to older and specialist studies: Mielsch 1987, Smith 1997, and Jeffrey A. Becker and Nicola Terrenato, eds. (*Roman Republican Villas: Architecture, Context, and Ideology*. Ann Arbor: University of Michigan Press). The best study of Roman construction is Adam 1994, whereas building processes are analyzed by Taylor 2003.

CHAPTER 44*

Roman Interior Design†

Sarah Lepinski

1. Introduction

Scientific knowledge as applied in artistic practices in the Roman world drew from many sources, from accumulated bodies of knowledge adapted and augmented over centuries, in various cultural contexts in the ancient Mediterranean and Near East. In the Roman world, this knowledge was further developed: artisans refined and enhanced existing technologies, techniques, and materials for purposes specific to their time and place.

In general, Roman architecture and design practices display a deep understanding of three-dimensional space, proportion, and geometry and, as with Roman art and artifacts, they embody craftsmanship that demonstrates a sophisticated understanding of visual qualities and also the physical properties of natural and synthetic materials. This material and technological knowledge is evident in many occupations in the Roman world, including those employed by, for example, fullers, weavers, farmers, glassmakers, and metalworkers. When considering the scientific applications of technical and material knowledge in artistic production, it is important to underscore the interconnected nature of technological know-how and material use among artists and other professionals in the mining, metallurgy, glass, dyeing, and fermenting industries.

* The research for this chapter was completed during my time as a Visiting Scholar at the Bard Graduate Center for Decorative Arts, Design History, and Material Culture in 2012–2013. The BGC was an ideal place to undertake a study of Roman interior decoration through the lens of science and technology, and this work benefited tremendously from the invigorating program directed by Peter Miller and from many critical and inspiring conversations with Nicola Sharratt and Abigail Balbale.

† Interior design is a modern term, relating to professional decorating activities that became more fully commercialized at the turn of the twentieth century. Unlike contemporary roles for interior designers, similar professions are not securely identifiable in Classical antiquity.

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Artistic and architectural applications of this knowledge are broadly documented in Roman sources (of various genres); the most influential for Roman design and materials are the architect and engineer Vitruvius and the statesman and naturalist Pliny the Elder. Scientific inquiries of Roman-era thinkers also contribute to our written source material, for example, Ptolemy and Galen. Archaeological data and scientific analyses of the technical and material characteristics of art, objects, and raw materials form a second large body of information. Visual representations of artistic occupations (on objects such as grave stele and wall paintings) constitute a third source. Here we focus on the objects and works of art rather than ancient written documents or visual representations, and we approach the discussion of scientific and technological knowledge utilized in decorative media by integrating archaeological data with visual and material analyses.

Before engaging with these sources, though, it is important to highlight a few overarching questions regarding the relationship of art, technology, and science in antiquity and how we can understand these relationships. To begin, following Lehoux's title *What Did the Romans Know?* (2012), …what did Roman artisans know? Furthermore, how is our understanding of scientific knowledge in the Roman world reflected in the working knowledge of ancient artisans? These questions underscore an uncertainty in our comprehension of the relationship between artistic endeavors and contemporary philosophical and scientific practices. While constraints of space prevent exploration of these questions, they have significant implications for how this chapter fits within the context of this volume and also, perhaps, for how to approach future work on the application of science in Roman artistic practices.

With these complexities in mind, I offer a synthesis of scientific knowledge evident in design methods and material use for the execution of interior decorative media. We specifically address painting, stucco, and mosaics on walls, ceilings, and floors; sculpture in stone and metal; furniture and furnishings in metal, glass, and wood. A broader discussion of decorative media would also address textiles and ceramic, silver, and glass vessels more extensively.

2. Roman Rooms

The interiors of Roman elite structures (such as civic and domestic buildings) were extensively adorned with decorative objects and materials that reinforced the status of the homeowners and represented themes highlighting their fortune, wealth, and prosperity. The decorations also reflected current trends and fashions. For instance, late-first-century BCE interior décor in Campanian houses demonstrates the homeowners' tastes for Hellenic art and mythology, tastes that were fueled by the influx of Greek art objects resulting from Roman political and military expansion in the Greek east. Similarly, later in the early first century CE, Campanian decorative styles followed current Roman international relations with Egypt, integrating Egyptian motifs and designs into interior furnishing such as wall paintings and furniture decoration.

In terms of design methods, the permanent decorative media in Campanian structures, that is the decoration that adorned ceilings, walls, and floors, were inter-coordinated. These media were designed in ensemble and fashioned in situ according to particular interior spaces and room functions (Clarke 2007). Floors, walls, and ceilings were prepared with a coating (tamped earth, cement, or plaster), articulated to determine the character of the interior space. These articulations developed directly from construction

techniques and can be categorized into two distinct approaches to surface decoration: enhancing solid surfaces by "sheathing them with real or painted imitations of precious colored marbles (the First Style), or opening them up with perspective schemes seeming to recede behind the physical boundary of the wall (Second Style)" (Clarke 2007, 323). Similarly, mosaic floors were either decorated as flat surfaces or illusionistic representations. Stuccowork, on both architectural and ornamental elements, further articulated ceilings and walls three-dimensionally.

The conception and execution of decorative media on floors and walls were realized according to the principles of proportion relating to room size. Following the planning of the overall design, perhaps approached collectively by patron, painter, and mosaicist, the preparatory work was executed in phases (Ling 2000, 56–57). In theory, room decoration would have occurred from top to bottom, with the ceiling executed first, then walls, and finally the floors, although evidence of working procedures show that this theory was not necessarily always in line with actual practices (Zimmermann and Ladstätter 2011).

In many cases, a framework for the decorative designs on ceilings and walls was drawn with ochre or incised in preparatory layers of plaster and then carefully measured with a plumb bob and straight edge to ensure accuracy (Ling and Ling 2000, 56–57). Similar procedures were performed on mosaic floors, where designs were marked into mortar bedding with drawn or incised guidelines. For example, blue sinopia was used in the *Domus Aurea* (Lavagne 1970, 693–694), but red sinopia was far more common (Dunbabin 1999, 283). Techniques used to plan decorative designs both on walls and floors were not universal and, in some cases, multiple techniques were combined.

With excavations of Roman structures it is possible not only to study the finished decorations, but also to look beneath the surface, so to speak, to analyze fragmentary decorative media (fallen from walls, destroyed, or re-deposited) as well as evidence of production activities such as deposits of raw materials (*tesserae* scraps, lime/gypsum mixing areas, pigments) and other artifacts discarded during the execution of the surface decorations.

Collectively, this work reveals that Roman artisans had extensive knowledge of the plastering materials used for covering and decorating surfaces, and that they fully understood the physical and aesthetic properties necessary to render successful surface media. In many ways plastering materials unite interior surface decoration, serving as the support for media on ceiling, wall, and floor.

The technologies involved in making plaster during the Roman era were remarkably sophisticated and, while drawing on earlier traditions, methods of application, and qualities (most significantly the development of hydraulic cements), they were further advanced over this period of time (Wright 2005, 143–180). As in earlier practices, Roman plasters were primarily lime based, although gypsum was used in some parts of the Roman world (in particular North Africa, Egypt, and the eastern Mediterranean). Lime and gypsum are similar in appearance and composition, but each had distinctive characteristics that dictated how they were used in decorative media (Wright 2005, 144). Widespread throughout the Mediterranean and Europe, lime is a white caustic earth (calcium oxide) derived from commonly occurring limestone (i.e., calcium carbonate). Generically termed rock gypsum and found throughout the Middle East and Mediterranean region, gypsum refers to both calcium sulfate and the material acquired from sedimentary rocks such as alabaster, selenite, and satin spar.

There is also a close relationship between the modes of procurement and preparation of lime and gypsum and those employed in mining and processing other minerals

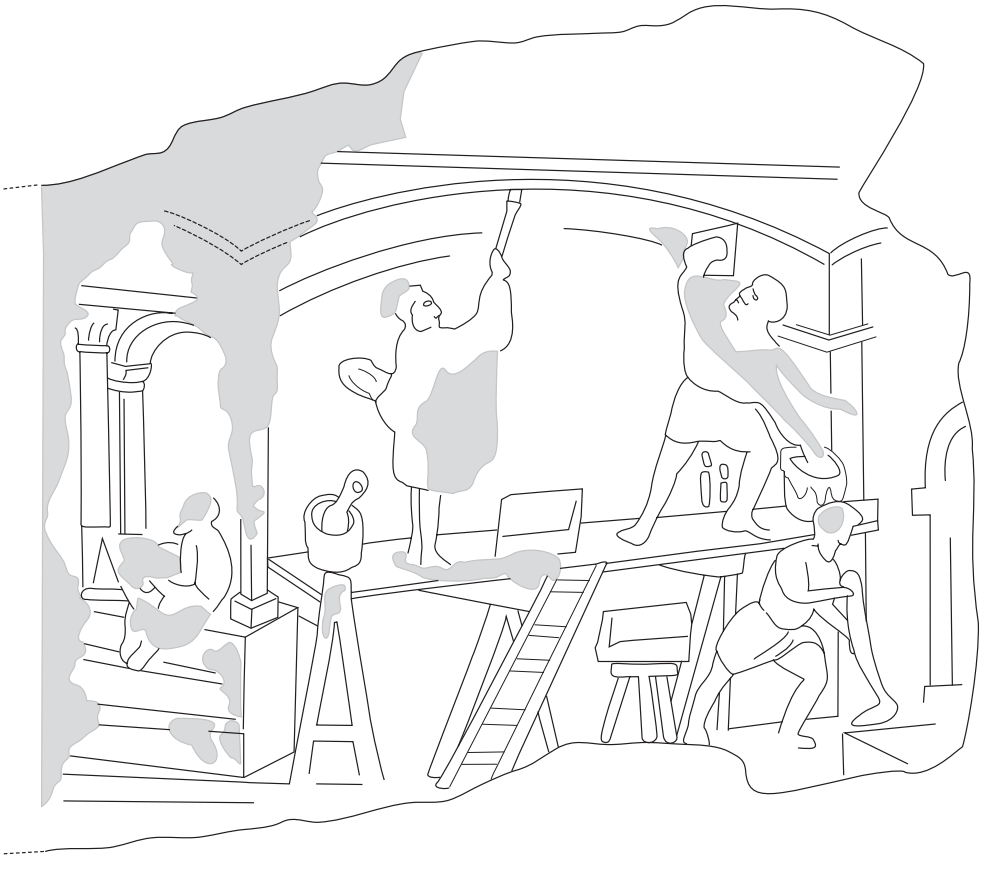


Figure 44.1 Reconstruction of the stages of wall preparation derived from stele from Sens, Lyon.

and metals. Both lime and gypsum are derived from sedimentary rocks and were likely acquired by digging and/or collecting from surface finds rather than through quarrying (Wright 2005, 149). In the Roman period, procurement of lime and gypsum for building and decorative purposes was likely carried out primarily on a local scale for immediate use and probably included extensive re-use of stones from earlier buildings. This is in contrast to the importation of luxury marbles during the Roman period. Preparations for both lime and gypsum plaster require burning the stone to produce a powdered substance, but there are differences in temperatures and process. It is necessary to burn limestone at a temperature of 1000° C (1832° F) over several days, while rock gypsum can be burned at a much lower temperature (100–200° C [212–392° F]) and for only twenty-four hours (Wright 2005, 156). Limestone, burned to a powder, is caustic and generates heat when mixed with water. In contrast, gypsum powder does not generate excessive heat when mixed with water and can be quickly applied. Other characteristics of the two manufactured materials also differ. When slaked and combined with other material aggregates (one part lime and two parts sand is a common recipe), lime mortar sets slowly and shrinks as it dries; when dry, it is hard and durable and does not dissolve easily; in some circumstances (and with specific types of aggregates) it can set underwater. Gypsum sets quickly and expands slightly as it dries.

Other materials were added to lime or gypsum to make plaster, and these ingredients differ according to region, period, and purpose. In general, the aggregates used for both lime and gypsum plasters typically comprised minerals and, sometimes, previously manufactured materials such as ground-up ceramic and/or recycled plaster. The mixing of lime and gypsum with water and aggregates occurred at the building site and, once mixed, there was a limited amount of time to use the plaster: quick-drying gypsum mandates swift use, and slaked lime is unusable after about two weeks.

The application of plaster to ceilings, walls, and floors was a stepped process; for each decorative medium (mosaic, painting, stuccowork) artisans built up layers of plaster. The final strata typically consisted of finer coats, with fewer and/or specific aggregates specifically selected to enhance the visual characteristics of the painting, stucco, or mosaic layer. In some instances, the final (or penultimate) plaster coats for Roman mosaic production were colored to enhance their ultimate appearance (Guimier-Sorbets and Nenna 1992; Dunbabin 1999, 288; Guimier-Sorbets 2000). Furthermore, recent work at Oplontis has furthered the identification of painted decoration on floors in the Roman period (Cline 2015).

3. Painting

The physical science involved in plastering technologies in the Roman period is particularly evident in mural painting practices—executed in both dry (*secco*) and wet (*fresco*) techniques. *Secco* is a general term to describe mural paintings that use a binding medium (typically organic) to apply pigments onto a dry substrate. *Fresco*, referring to mural paintings wherein pigments are applied to a semi-wet and thin plaster layer, requires multiple lime-rich plaster sub-layers to mitigate drying. In this process, the calcium hydroxide of the slaked lime reacts with atmospheric carbon dioxide to form calcium carbonate. Extant paintings show that the number of layers was not consistent.

The types of aggregates used in plasters varied and typically reflect the local geology. Their selection and preparation influence the texture and appearance of the painting, in some cases improving the properties of the plaster or the ability to polish the surface. For example, aerial plasters (like *opus signinum,* using terracotta fragments as an aggregate) and hydraulic plasters were both employed on surfaces in humid or moist areas, such as cisterns, or on the lower parts of walls and floors (Kakoulli 2009a, 29–30). Also, the use of marble in the final layer (or layers) influences both the porosity of the plasters and the effects of polishing. Marble aggregates in the final coats also impart a reflective quality to the color of the paintings' surfaces.

4. Stucco

Like the plaster layers employed for painting, stuccowork required extensive understanding of plaster and aggregate interactions to achieve the necessary specifications for adhering both molded and hand-formed stucco decoration to walls and ceilings. The same craftsmen likely prepared surfaces for painting and stucco decoration. And, in many cases, as with fresco painting, the final stucco layer consisted of finely prepared plaster that was frequently painted; the optical qualities of the applied pigments were integral to the process of forming preparing the stucco plaster.

5. Color (Pigments and Dyes)

Like plaster technology, the use of natural minerals and other inorganic and organic materials as coloring agents in Roman decorative media demonstrates that Roman artisans had vast knowledge of material properties and characteristics. In wall paintings and stuccowork (and also for marble and metal sculptures), common sources for pigments include iron oxides and silicates such as ochre (including purple, reds, orange, and yellows), green earth, chalk white, carbon black, mercuric sulfide (cinnabar), artificially produced red and white lead, and copper-based composites like verdigris and Egyptian blue and lakes (coloring materials of organic origin) (Eastaugh 2004; Kakoulli 2009b).

Most of these pigments were water-dispersible, and they were applied without difficulty to the damp plaster used in *fresco* technique, but other materials (carbon black, lakes, or dyes) require a binder. The skill of the artisans as colorists and the extent of both their creative abilities and chemical knowledge are especially apparent in the use of artificially fabricated materials. These were manufactured through chemical processes and related to technologies employed in other ancient industries. For instance, the production of red lead is linked to mining and metallurgical technologies. Also, the fabrication of white lead and possibly verdigris (green) are connected with the production of vinegar through grape fermentation (Kakoulli and Lepinski 2012).

The use of dyes in Roman decorative media also links artistic practices with other industries and technologies. Dyes created from plants (like madder and indigo) and animals (murex and possibly kermes) were used by artists to enhance both the color and visual qualities of pigments. These dyes were used as lake pigments, that is, an organic material rendered insoluble with the reaction of a metal ion to form an organometallic complex (Gettens and Stout 1966).

The dyestuff is extracted into an aqueous solution to which an inorganic substrate was added, such as alum (potassium aluminum sulfate). The hue and degree of transparency are both influenced by the substrate material. The type of binding media (typically proteins derived from egg or plant/tree gums) was also responsible for a pigment's transparency, and further affected aesthetic qualities (Kakoulli 2009a, 75–81; Kakoulli and Lepinski 2012).

Various technologies, especially the pyrotechnologies involved in ceramic production and glassmaking, are intricately connected to materials and practices involved in making mosaics and paintings. The highly fired vitreous material known as Egyptian blue was used extensively in the Roman period. A synthetic compound, calcium carbonate silicate consists of silica, lime, copper, and alkali. There are some inconsistencies in our understanding of the various methods of making Egyptian blue, which likely derive from differences in regional practices and available materials, as well as innovations and experimentation over the millennia (Kakoulli 2009b, 83–84). As practiced in Roman Italy, the process consisted of preparing balls of sand, natron, and copper shavings, which were then fired in a ceramic vessel.

Recent analyses of Roman examples reveal that Egyptian blue was made specifically for use as a pigment during this time, and that the fabrication processes likely drew from Hellenistic traditions. Production sites in Italy dating to the late first century BCE have been identified in areas around Cumae and Liternum (Platania et al. 1998; Caputo and Cavassa 2009). Modern experimental trials in making Egyptian blue have yielded various results, depending on recipes, preparation of raw materials, and firing conditions.

Drawing from her experimental work, Kakoulli (2009b, 89) reports that significant differences in the nature (color) of the pigment were due to distinctive sources of copper (malachite, metallic copper, or bronze) and sand. Also, the particle size of sand (the optimal size was between 0.25 and 0.125 mm [0.009–0.005"]), amount of flux, and firing conditions (temperature, length of time that the maximum temperature was maintained, and the number of firings) all played important roles in achieving richly colored Egyptian blue.

Egyptian blue was at times painted over base colors (such as gray), to achieve depth, or over red, to attain purple. Other pigments were used in combination and with advanced understanding of aesthetic results in terms of hue, intensity, brilliance, and perception of depth and dimension. Adding to these complex applications of color, gold pigments were used to highlight specific details in figural paintings and accentuate specific forms, such as metallic bosses and/or architectural elements.

6. Mosaics

The variation and complex combination of colors and materials are also evident in Roman mosaics, which frequently covered floors as well as special interior and exterior surfaces, like fountain niches and pools. These mosaics represented elaborate geometric patterns, figured friezes, and mythological scenes that were carefully planned and integrated into larger decorative ensembles along with painted and stuccoed walls and ceilings. Like stucco and paintings, mosaics and other surface incrustation (such as *opus sectile*, marble paneling) were primarily fabricated on site. Intricate designs were executed with stone, glass, terracotta, and sometimes shell fragments cut into different shapes, primarily cubes (*tesserae*), and then pressed into plaster mortar layers to form various patterns and compositions.

Preparation techniques for mosaics varied according to region and period of time; but generally thick, well-prepared layers were necessary to mitigate environmental elements and provide a solid ground for the decorative media. Well preserved in Roman structures, the layers typically consisted of a number of strata including the *statumen* (a bedding of fist-sized stones), the *rudus* (a mix of rubble and lime beaten solid to a thickness of around 23 cm [9″]), and finally the *nucleus* (upper layer: a finer mortar mixed with three parts crushed tile or potsherds to one of lime, approximately 15 cm [6″] thick).

Levels and rulers were used to measure and map designs marked into the upper layer of mortar bedding with incised, painted, or impressed guidelines, snapped into wet plaster with a string line (Dunbabin 1999, 282–286). Another technique employed strings connected between nails (Dunbabin 1999, 283 note 19). The *tesserae* were set by hand into the thin setting-bed. As one area was completed, an adjacent section was prepared with mortar and then completed (Dunbabin 1999, 286; Wootton 2012, 161). The *tesserae* were polished, and sometimes a thin wash of diluted plaster (at times colored with pigment and added marble dust) was spread over the floor to fill up the interstices (Guimier-Sorbets 1992, 626). *Emblemata*, smaller central representations of humans, animals, or other motifs were executed with much finer *tesserae* (*opus vermiculatum*). These were typically fixed in a tray, likely off-site, and inserted into the mosaic in a final phase (Guimier-Sorbets 2000).

Tesserae materials link the production of mosaics to other artistic endeavors, such as stoneworking, ceramics, and glassmaking. Stone *tesserae* were cut from various types of

stone panels and fragments, either to fulfill certain commissions or fashioned from stone left over from other masonry projects or the quarrying process. *Tesserae* were formed by hammering pieces of stone onto a chisel-like blade (a bolster-blade or knapping blade, hardie) set in a block of wood. This process requires extensive practice and a solid understanding of the qualities of specific stones (as well as other materials, such as glass and ceramic) to know how the pieces would fracture when hit and how to cut the stone to amplify a material's aesthetic qualities.

7. Glass

Glass was prevalent in Roman interior decoration, used for mosaic *tesserae*, windowpanes, lamps, and tableware (Wright 2011; Rasmussen 2012). Made by heating silica, lime, and soda, glass is classified as neither a solid nor a liquid (Forbes 1966; Henderson 1985). With a long history, glass is linked to other types of silicate materials (faience, Egyptian blue) by composite materials and the pyrotechnologies involved in their manufacture (Henderson 1985; Fiori and Vandini 2004; Beretta 2004b). By the Roman era, specific developments in casting and blowing glass led to new uses.

The raw materials of silica, lime, and soda function in the following manner. Silica produces the requisite random (non-crystalline) structure, the definitive feature of glass. Oxides, such as phosphorus, are intermediate in forming the glassy state. Soda (potash) modifies color and transparency. Both oxides and soda act as fluxes (to promote the melting of the glass at reduced temperatures) or stabilizers in certain conditions. Additional minerals and metals, such as cobalt, copper, and manganese, were used as colorants.

There are two basic processes involved in the manufacture of glass. The first is to change the physical state and chemical composition of raw materials so that they coalesce to form a new substance. The second is to fashion an object from this substance. Sometimes the processes were carried out in succession as part of one project; other times they were separated. Glass could also be remelted, reformed, and recolored. It is generally understood that, when separated, the initial process (or "primary production") manufactured bulk glass to be used as raw material in the second process of producing finished glass forms and objects (Kowathli et al. 2006).

In many ways, glass manufacture is related to both metallurgy and ceramic technologies. Metal objects could be molded or wrought (hammered) into shape; ceramic vessels could be molded and modeled, and also turned on a wheel, as in ceramic production. Glass, too, could be molded or shaped by blowing. As Wright points out (2005, 285), there is a close relationship between throwing pottery and blowing glass: both activities entail the use of centrifugal force in creating hollow voids from a single plane. Furthermore, the pyrotechnologies involved in smelting metals and firing ceramics also link these industries. Glass making requires high temperatures of approximately 1100° C –1500° C (2012° F –2730° F) to produce the viscous matrix that can be formed into glass objects. For this, a kiln similar to those used with lime, pottery, brick, and metal furnaces was used, although differences in manufacturing glass affected the design and functioning of kilns. Furnaces for making bulk glass likely differed from those that produced finished glass objects.

There are still many questions regarding the scale and organization of the Roman glass industry, especially for the early Roman Empire. Some evidence exists for glass production and trade in the later Roman period. For example, large kilns for primary

glass production have been excavated in northern Israel. Shipwrecks also dating from the later Roman Imperial period (circa third century CE) testify to extensive trade in both large-scale and organized production of glass as well as extensive glass recycling, but there is less substantial evidence for earlier networks and processes (Silvestri, Molin, and Salviulo 2008).

Roman artisans employed well-established methods to make molded glass vessels and other objects, but they also furthered glass technology by developing methods for blowing glass. At some point in the mid-first century BCE, glassmakers learned how to inflate glass utilizing a tube to blow air into a bubble. With this technique, glass vessels could be made more quickly and cheaply. The vessels were formed and decorated by pinching, pressing, and pulling the glass when still workable. The surfaces were decorated by rolling glass chips into the exterior (creating splash ware) or by applying threads of glass. When cool, glass could also be painted or cut to imitate rock crystal. Slightly later, glassmakers also combined techniques and began blowing glass into molds that were incised with intricate designs.

Developments in glass vessel production in the late second and early first centuries BCE directly influenced other decorative media (Boschetti 2011). In mosaic decoration, the use of glass seems to have originated in Italy with the practice of reusing fragments of finished forms, such as glass cast vessels, glass canes (Guimier-Sorbets and Nenna 1992), glass jewelry, and Egyptian blue pigment balls (Boschetti 2011) in mosaic decoration.

Producing glass specifically for *tesserae* became prominent in the early first century CE and coincides with what is understood to be a shift in glass production and distribution in the Roman Mediterranean (Boschetti 2011, 76). At this time, there was an increase in the quantity of naturally colored raw glass in the Roman market, and glass may have been destined for secondary workshops where the coloring processes would occur (Boschetti 2011, 90). Overall these changes reflect the expansion of the glass industry and adaptation of glass technology specifically for use in decorative media, like mosaics, and also for window glass (Boschetti et al 2008).

8. Windows

Glass panes—used in wooden and metal window frames, opening casements, and protective grilles—were likely fastened with glue or plaster (Whitehouse 1999). Archaeological evidence from the Bay of Naples demonstrates that the use of window glass was commonplace by the end of the first century CE. While few panes are preserved in their entirety, it is possible to estimate size and production techniques from fragmentary remains. Panes typically measure 22–30 cm (3.5–4.5″) square, although the largest were around a meter square (10.5' square) (Mackay 1975, 61). In the early Roman period, glass panes were produced with blowing techniques, most commonly the cylinder blown method, wherein glass was blown in a cylinder form that was later cut and flattened with heat. A second blown method, producing crown glass, is attested from the fourth century CE on.

In many cases, surface textures indicate what technique was used. With cylinder glass, one side was commonly glossy and the other matte. The matte side frequently retains impressions of the texture of the sand or wooden surface onto which it was pressed for flattening, and the edges are usually straight with a rounded profile. The glossy side sometimes has tool marks at the corners, from lifting or manipulating the semi-cooled glass sheet.

Like glass *tesserae*, window glass became widespread in Italy in the early first century CE, and ubiquitous later. With all glass media, light was the primary consideration. Glass enhanced surfaces and interiors, specifically areas with watery functions like fountains, niches, and bathhouses, which were fitted with glass windows to provide insulation. The significance of light in Roman structures is also evident with the use of, for example, transparent stones (*petra specularis*).

9. Stone

Movable objects like sculpture, serving vessels, and furniture further embellished decorated interior and exterior spaces like gardens. Similar to the stones used in mosaics and marble paneling, Roman sculpture both in the round and in relief, utilized variously colored marbles and limestones. White stones primarily came from Greece, Turkey, and Italy; colored marbles and other stones were imported from quarries throughout the Mediterranean, especially from North Africa, Egypt, Southern Greece, and central Turkey (Claridge 1988, 139; Durnan 2000, 18–22). Remarkably well organized and maintained, and supported by the Imperial administration, this trade ensured access to select stones for certain levels of society and large metropolitan areas (Ward-Perkins 1980; Waelkens et al. 1988; Claridge 1988).

White marbles, in particular, were valued for Roman sculpture. These marbles were carved into monumental figures representing deities, Imperial and elite portraits, and dynastic groups, and into small-scale statuettes and relief compositions. As in earlier Greek sculptural practices, facial features, hair, and clothing were augmented with paint (Grossman 2003, 81–82; Brinkmann, Primavesi, and Hollein 2010; Greek Interior Decoration: Materials and Technology in the Art of *Cosmesis* and Display). Recent work on polychromy in both Greek and Roman sculpture reveals the technical and chemical sophistication with which artisans worked with coloring materials, including organic and inorganic pigments and gilding.

In the early first century CE, color in Roman sculpture was also achieved by combining colored and white marbles in composite forms. This practice was refined after the expansion of Roman control over quarries in North Africa, Egypt, and Asia Minor. In the second century CE, practices again changed. With Roman control of quarries and organized networks, the size and quantity of available marble blocks improved, resulting in monolithic sculpture and a wider range of figural types (Claridge 1988, 149–152).

In addition to availability and color, other characteristics, such as workability, also dictated which stones were employed for Roman sculpture. Fine marbles were valued because they could be carved with intricate detail. Sculptors carved away material to create a form using a traditional mason tools, including rasps and chisels with variously shaped heads. Roman practices differed from Greek techniques, however, by working the block from front to back rather than carving from all sides (Van Voorhis 1998; Grossman 2003, vii). In this approach, a Roman sculptor worked out the whole pose from the block's front plane and transferred the image to the marble with measuring devices and, perhaps, drawings. While there is no consensus regarding measuring techniques, analyses of extant sculpture in the round, especially by Rockwell (2008) and Pfanner (1998, 157–257), has shown that many Roman sculptors used a system of triangulation with measurements taken from three raised bosses (*punti*) (cf. Touchette

2000, 344–353). A related system was employed in relief carving, where circles formed the organizing principle (Birk 2012, 23). Variability in applying these techniques (as evidenced in the placement and use of *punti* and/or circles) further emphasizes the skill of many Roman artisans and their ability to adapt visual forms and work in multiple scales.

10. Metals

Sculptures and other decorative elements in metal, such as bronze, silver, and gold, adorned both the interiors and exteriors of Roman structures. Bronze was used in large-scale statuary, smaller sculpture, and as decorative appliqués on furnishings such as chests, doors, chairs, beds, and lamps (Mattusch 1996). Tablewares (vessels and serving implements) were fashioned out of silver, gold, bronze, and iron.

Metals (gold, copper, tin, lead, and zinc) were mined in a number of ways (Classical Geology and the Mines of the Greeks and Romans). Bronze, an alloy typically composed of 90% copper and 10% tin, was the most commonly used in interior decorative media. Sourced in a number of forms and/or conditions (as ore, smelted raw metal, scrap metal, and manufactured objects), bronze is harder and stronger than copper and has good casting properties. It also maintains a lower melting point than pure copper. It therefore remains liquid longer and thus facilitates pouring into molds, and it readily accepts plating and gilding (Hemingway 2000, 37).

In general, ancient metallurgical practices involved separating the metal from the other substances in which it was contained. For this, heat was used to extract the metal from the compound mineral. Two processes were involved: roasting and smelting. Roasting releases volatile elements (gases) in the ores by heating them to a temperature below their melting point. Smelting extracts the metal from the solid mineral residue by heating the compound to its melting point, resulting either in residue (slag) or run-off of the metal. The metal is then collected either as it runs off or from the bottom of the crucible (Wright 2005, 243–244).

Metal was worked in two different ways: hammering (forging) and casting. The process of hammering metal is dictated by the physical qualities of the metal, particularly its malleability. Gold, for example, is highly malleable, but alloy bronze is not. Hammering had three related purposes: to re-form the metal; to increase the metal's hardness and strength; and to reduce malleability (making the metal brittle). Reducing the malleability of a metal is counter-productive and thus is reversed by the process of annealing (or heating metal to make it workable again). Lead, for water pipes, for instance, was hammered out into sheets and then folded and seamed.

In the Roman period, in contrast with Greek and Etruscan practice, both iron and bronze were cast into sculptures and statuettes in varying sizes, and into other shapes and objects, such as vessels, lamps, and doors (Wright 2005, 250). Bronze statuettes and other objects were remarkably widespread; their small size made them easily transportable. Bronze ornamentation also adorned chests and beds. Used as appliqués or plastic attachments (like finials on chairs), these bronze ornaments were frequently apotropaic. Finials, for example, usually represented animal heads (hounds, horses, mules, and geese) and evoked the forms represented in the furniture's legs, which frequently terminated in animal protomes. Figural motifs also decorated lamps, either on the handles or in the general body (Menzel 1968, 227; Doeringer, Mitten, and Steinberg 1970).

Metal casting technologies include three general methods established by the Greeks and improved in the Roman period: the solid lost wax methods, and the direct and indirect methods of hollow lost wax casting. In the solid lost wax method, a model of the final product is made in solid wax. This model is surrounded with clay and heated. Heat melts the wax, which drains away, and hardens the clay. The hollow mold is filled with molten metal. When the metal cools, the clay model is broken away from solid object. Solid bronze sculptures were small scale.

Hollow lost wax casting techniques were used for larger sculptures and objects cast in pieces. Two methods were used: direct and indirect. The direct method also begins with a clay core in the shape of the final product. This core is covered with wax vents so that gases can escape and molten metal can flow completely over the core. A second coating of coarser clay is layered over the core and wax, and the entire mold is heated. As the mold heats, the wax melts away, creating a hollow area between the two clay layers, and the interior core hardens. Once the wax is completely melted and the core is hard, molten metal is poured into the hollow. When cool, the exterior mold layer is broken away, the sculpture is assembled, and its surface is finished (Hemingway 2000).

In the indirect method of lost wax casting, the initial clay model is maintained and therefore can be used again. In this process, the model of the final object is made in clay (or another material), and then a mold of the model is made in either clay or plaster. The mold is cut into sections so that it can be removed easily while still preserving details. When dry, the segments are reassembled and secured. A wax layer is applied to the inside of the segments and removed when dry. These layers reflect details of the original model, but other details can be added or changed. When the wax model is complete, it is further prepared for the molten metal: vents, channels, and funnels are attached to the wax, which is then covered with clay. The clay mold is heated, and the wax is poured out. The mold is heated again to harden it, and then a third time to receive the molten metal. After the metal cools, the mold is removed, and the surface is smoothed. For large-scale metal sculpture, the various cast parts are fitted together mechanically, with pins and rivets, or metallurgically, by soldering pieces with metal (i.e., spreading melted metal over a reheated surface), or with glue (animal or vegetable).

Various techniques were used in the Roman period to finish the surface and add decoration and details. After casting, the surface marks frequently needed to be smoothed, and several tools, of stone and metal, were used to remove imperfections: rasps, scrapers, files, polishers, burnishers, and smoothing tools, and perhaps also pumice and abrasive powders (Boucher 1990). After the surface was finished, Roman bronze pieces were further decorated and embellished with other media (Born 1990; Oddy et al. 1990). Physical features and clothing were added by mounting metal elements onto the surface with chiseling lines and by inlaying metals like copper or silver. Eyes were inlaid with glass, ivory, metal, and precious stones and embellished with metal eyelashes, fastened separately. Sometimes, too, lips were accentuated with other metals, either prefabricated and inserted into the mold before casting or inlaid after casting. Silver and ivory were used for teeth and fingernails, and red bronze accented nipples (Boucher 1990; Mattusch 1996).

Intricate decorative techniques—embossing, chasing, and enameling—were also used to enhance Roman statue bases and other objects, including lamps, vessels, silverware, furniture, and architectural elements (Bol 1985). Most commonly prized in the Roman period, however, were bronze and silver objects that were plated and gilded.

Bronze sculpture was not gilded before the Roman period (Mattusch 1996, 26–27). For this, Roman artisans drew from earlier practices for plating and gilding bronze vessels and other objects: revetting or overlaying silver or gold plates and adhering them with pressure (hammering) or glue. The main technical challenge was oxidation; silver was more susceptible than gold, and therefore thicker sheets of silver were used, although primarily on bronze vessels (Boucher 1990).

Gold sheets were cold gilded and sometimes adhered to bronze with egg white (Bol 1985, 159–160; Boucher 1990, 177). One cold gilding technique employed an amalgam of quicksilver (mercury) and gold plates, pressed firmly onto a clean and heated bronze surface. Fire gilding was another technique for small objects: the bronze surface was cleaned, scored, and heated and then applied with a heated mixture of gold dust and mercury. After application, the object was heated, causing the mercury to evaporate and leaving the gold attached to the bronze surface (Boucher 1990, 173).

Other surface treatments were also used to color Roman bronze sculpture. While today it is challenging to identify such treatments, owing to the deterioration of bronze surfaces, patinated and painted bronze surfaces may have been common in Roman antiquity. Resulting from differing oxidizing levels of copper alloys during the forging process, patinas ranged in color from red to black. Roman artisans made use of these "chromatic permutations" for aesthetic purposes, either leaving patinated areas to contrast with other surface colors, shapes, or forms or using them as a "ground" for added pigmentation with paint (Boucher 1990, 173; Born 1990, 184).

11. Wood

Wood was also common in Roman interior spaces, complementing marble, bronze, iron, glass, and terracotta decorative elements. It was used for built-in elements (*opus intestinum* or inside work) such as door and window frames, cornice moldings, decorative paneling, balcony screens and balustrades, and for furniture, including stools, benches, chairs, beds, tables, chests, cupboards, and shrines (*aedicula*—typically in the form of freestanding cupboards; for an overview: Ulrich 2007). Poor preservation has hindered the study of wooden objects, although certain groups of wooden materials have been spared deterioration: for example, carbonized wooden furnishings at Herculaneum and Pompeii. To date, this area retains the most extensive wooden furnishings. Chemical analyses on Roman wooden furniture from Herculaneum demonstrate a range of woods used for furniture: silver fir, oak, walnut, box, hornbeam, maple, and beech (Mols 1999, 79–83).

Roman carpentry tools (saw, adze, auger, compass, plumb line, drill, hammer, chisel, rasp, file, glue and fish-glue, square, libella, lathe, and metal clamp) were used to fell and prepare trees and to trim, shape, cut, bore, drill, smooth, and model surfaces (Mols 1999, 83–91). Calipers (dividers), levels, and rulers were used as measuring devices. Technical sophistication in Roman woodworking is evident in fabrication techniques and wood preparation, including joining techniques and the use of lathes to produce bed legs, which were further strengthened with interior iron rods. At Herculaneum, angle joints (two pieces joined at an angle—commonly 90°) primarily include mortise-and-tenon joints. Mols (1999) states that an adhesive (glue) was likely used in strengthening the joins, as no other fasteners—dowels, nails, cords, or straps—were employed

in this body of furniture. While traces of proteins have yet to be detected on furniture samples, these glues likely derived from either bovine bones (*gluten taurinum*) or fish skin (*ichthyocolla*, cf. Pliny, *NH* 32.73; Dioscorides 3.88).

Wooden architectural elements, such as capitals flanking *aedicula* and doorframes, and decorative details on furniture (couches, chairs, and tables) were carved into various shapes—heads of animals and decorative geometric or floral friezes. Many of these elements were painted or covered with veneer or parquetry (Mols 1999, 97–98). Veneer utilized thin wood pieces with distinctive grains to cover a wooden surface. These pieces were cut in uniform dimensions from larger planks, using either flat cut (plain sawn) or quarter-sawn. The different cuts produced veneers with distinctive patterns: the flat cut highlighted wavy or elliptical patterns of wood grain; the quarter-sawn produced a pattern of parallel lines resulting from growth rings visible on the interior plane. In a technique now known as parquetry, pieces, adhered with glue, were placed to create intricate geometric patterns such as stars, meander friezes. As today, oil and wax were used to finish the surfaces (Mols 1999, 98–99).

Wooden furniture was also painted, gilded, and decorated with appliqués and fittings of bronze, iron, bone, ivory, glass, and other precious materials (Mols 1999, 98–110). These multi-media pieces, like other forms of decorative media, demonstrate a technical and material adaptability which seems to characterize Roman interior decoration, and underscores the inter-related nature of materials and technologies in Roman artistic production.

12. Summary

Roman artisans had extensive understanding of the physical properties of their materials, and scientific and technical knowledge was widely applied in Roman decorative media. Also striking is the close relationship of artistic production to other professional activities, in terms of both material use and the application of technological skills. Whether a similar relationship existed between artistic activities and contemporary scientific and philosophical endeavors is a question for further work. In fact, it is my hope that this broad overview may serve as a prolegomenon for more scholarship along these lines or others.

Another fruitful direction may be the economies of materials in the Roman world from a social perspective, perhaps in the same vein as Meiggs (1982) or Russell's (2013) broad approach to trade and society. Color science, as we now call it, encompasses the perception of color by humans, the sources or origins of color in materials, color theory in the visual arts, and the study (or physics) of light. Work in any of these directions would necessarily build on the solid foundation forged by Bradley (2009a–b) on literary and philosophical aspects of color in early Imperial Rome.

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FURTHER READING

http://www.artofmaking.ac.uk. A remarkable resource for stone working in the Roman world including tools, with videos showing techniques, essays, and links to projects on topics such as color and conservation.

http://www.ancientpolychromynetwork.com (University of Georgia) A portal to multidisciplinary research on color and materiality in the Mediterranean world.

Adam, J.-P. 1999. *Roman Building: Materials and Techniques*. London: Routledge. Provides an English translation of foundational and wide-perspective of Roman building materials and techniques. Along with Wright 2005 and Forbes 1966, Adam offers expansive resource for information on building, technology, and materials.

CHAPTER 45

Textile Technology

Ellen Harlizius-Klück

1. Introduction

In his contribution to the *Handbook of Engineering and Technology in the Classical World*, John Peter Wild writes: "The metaphorical use of textile terminology is a characteristic of the Classical language that reflects the ubiquity of textile crafts in contemporary life … To us, however, such textile concepts may seem obscure" (2008, 465). Examples for such use stem from Philo of Alexandria, who called the universe a wonderful weave and the inventor of weaving, a scientist (*On Dreams* 1.203–207), or from Plato, who explained the true knowledge of the statesman with the paradigm of weaving (*Statesman* 311c), and in the *Republic,* he described the universe as a spindle with the planets sitting on the edges of rotating whorls with different diameters (10.614–621).

Rudolf Eisler investigated Presocratic concepts of the *cosmos* that employ weaving terms. He was convinced that cosmic weaving was not a metaphor but a complex technical paradigm that showed the world and its matter as an ordered fabric of elements (1910, 222–223). Yet, Eisler considered weaving a very simple technique and assumed the Greeks used elaborate embroidery to produce real pictures on fabrics. This assumption might have been induced by the remark of Blümner (1912, 158), who, in his comprehensive book on ancient technology, wrote that a work like the pictured textile on the famous Clusium (Chiusi) skyphos, where Penelope is sitting in front of a warp-weighted loom, could never have been woven with such a primitive device. From recent textile studies, we have learned that this is technically incorrect, although the tools are simple. But the prejudice against the primitiveness of weaving and its techniques persists.

Since our knowledge of ancient technology from 600 BCE to 600 CE has increased considerably, the contribution of craft to the development of science and technology is now being reconsidered. Several recent publications point out that, for the ancient

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world, crafts made the order of the *cosmos* visible in a non-scientific way (Hahn 2001; McEwen 1993) and that practical knowledge of materials might have influenced early theories about matter and change (Rihll and Tucker 2002, 275). In the recent history of mathematics, textile technology is considered as a possible source for the development of mathematics: weaving structures are grounded on a strict dual logic that was mechanized in the course of history and eventually controlled by punched cards, a technology that was transferred to calculating machines and explored further in the development of computer technology (Harlizius-Klück 2012, 63; Essinger 2004). Since Penrose tilings were discovered in Islamic art, patterning is more and more conceived of as a mathematical practice. Furthermore, ethno-mathematics contributed considerably to this development through the analysis of the knotted strings of the Inca (the *khipu)*, which proved to be arithmetical tallies, and even the tunic patterns include arithmetical values of some kind (Brezine 2009; Urton and Llanos 1997, 203; Harlizius-Klück, 2015).

Carrie Brezine, who worked on the technical algorithms used with the loom of the Andes (2009), attributes high intellectual activity to the weavers because the framed textiles made on the Andean looms have remarkable mathematical claims for the construction of patterns. On the contrary, she views the western loom, which can produce long runs of cloth, as a repetitive tool requiring only low intellectual ability to operate. But in antiquity there were no long runs of cloth, and weaving was similarly framed. Therefore, the level of intellectual activity in constructing patterns in antiquity was not very different from Brezine's Andean examples (Harlizius-Klück 2004, 126–130; Harlizius-Klück, 2015). Only later were mechanisms added where the mathematical algorithm was part of the loom, and there was less need for the weaver to think about the patterns while weaving. This is actually discussed for the end of our period, when—archaeologists assume—a horizontal loom with mechanized patterning implements was invented.

Weaves provide a distinct structure where patterns are to be considered as a visual algebra: a generalization of arithmetical constraints that are to be pondered when constructing patterns on the loom. The dualism of odd and even, inherent in the shedding of the warp, is accountable for this, plus the fact that patterns always consist of positive integers. Weaving, therefore, may serve as a model for algebraic considerations, especially in plain geometry. To weave a geometric shape, it has to be transformed into ratios of positive integers (the thread counts in the rectangular grid of the weave), and even the problem of the incommensurability in the square may arise. The pattern of the square in a square, famous for its appearance in Plato's lesson in geometry (*Meno* 82b–85c), is frequent in depictions of fabrics (Harlizius-Klück 2004, 120–125).

2. Historiographical Note

The specific historic situation and development of archaeological textile studies reflects regional and academic preferences of the past. In the nineteenth century, Classical archaeology was mainly concerned with objects of Greek art like vase paintings and sculptures. It was a philologist, James Yates, who in 1843 collected the references to textile manufacture made by Classical authors and the Danish archaeologist J. J. A. Worsaae, who started systematic excavations of textiles in 1861. On the basis of Yates

and his interest in ancient economy, the German Hugo Blümner wrote four volumes on ancient technology that include a considerable section on textile production. At that time, there was broad discussion in Germany concerning the professionalization of engineering as a scientific discipline, and the history of technology came up as a new subject. Blümner's books, perceived as the first contributions, were newly revised and edited in 1912. Only one year later, Franz M. Feldhaus, one of the first historians of technology, published his technology of antiquity and the Middle Ages. Textile production is still mentioned there, but reduced to the very first rotation technology, that is, spinning. The rotation principle was intensely discussed as one of the scientific features of mechanics, and in 1934 Hugo Horwitz closed the discussion of spinning as its origin with an article showing that the rotation produced by spinning is minor in comparison with the true rotation principle.

Blümner's statement on the primitiveness of the loom and the impossibility of woven pictures probably started the discussion of the ancient loom that took place around the turn of the century. The Austrian art historian Alois Riegl was the first to discuss the warp-weighted loom for German scholars in 1893, presenting a model derived from an Icelandic loom displayed at the Royal Museum in Copenhagen. Luise Schinnerer followed in 1895, under the patronage of Riegl, with a publication on sprang, tablet weaving, and needle binding (*nålebinding*) in ancient textile finds from Egypt. Later Margrethe Hald (1950) worked with the Danish finds in Copenhagen and, supported by the monograph of Martha Hoffmann on the warp-weighted loom (1964), established a lasting tradition of textile research through textile analysis of archaeological finds, reconstructions, and experiments with the help of ethnographic parallels in Denmark.

Further important contributions are the book by Forbes, who, in 1956 presented a survey of ancient textile production by bringing together the written and archaeological sources (Wild 2007, 2), as well as John Peter Wild's publication on the Roman textile industry (1970) and Barber's book on prehistoric textiles in the Mediterranean (1991), which still gives the best overview of Mediterranean textile production.

Today the experimental approach and analysis of the Danish archaeological textiles, in good condition, sometimes consisting of complete garments and outfits, are promising sources for the investigation of textile technology of the past. Since 2005, the Centre for Textile Research in Copenhagen has connected international research in this field (Gillis and Nosch 2007; Gleba and Mannering 2012; Andersson Strand and Nosch, 2015).

2. Sources, Methods, and Advances

Finds

Evidence for textile technology is elusive. Both the textiles and the tools that produced them are perishable. Only spindle whorls and loom weights survive to give direct evidence on technological details. However, clay loom weights disappear from Greek and Roman urban sites by the first century CE. We do not know what loom was used after that period, and there are speculations about the occurrence of the horizontal treadle loom. In such cases, a combination of sources and reconstructions is applied (on sources for textile production, see Gleba 2008, 23–36).

Owing to decay, textiles from antiquity are mostly found as scraps. Exceptions are clothes from burial contexts, where we sometimes find valuable textiles such as the gold and purple tapestry from Vergina (Andrianou 2012, 46; Barber 1991, 3; Spantidaki and Moulherat 2012, 196). The majority of textile finds from Greece occur as mineralized remains, while the eastern Roman world is rich in textile finds (Wild 2003b, 110). There are large groups of finds from Syria, Palestine, Egypt, and Nubia, where the majority are wool textiles in tabby weave as well as felts and rarer techniques such as taqueté, Coptic knitting, tablet weaving, damask twills, and silks from Palmyra (Wild 2003b, 103; Bender Jørgensen and Mannering 2001, 2–7).

Visual Representations

Archaic and Classical Greek vase paintings depict a huge variety of textiles and textile patterns. They are a valuable source, though not always easy to read clearly. Sculptures often depict clothing in a way that does not allow one to distinguish between specific cloth properties. There are, however, some exceptions. The bronze statue of Marcus Aurelius (second century CE) shows a mantle with visible fold lines that do not indicate storage folds but rather deliberate fashioning by a cloth press (Granger-Taylor 1987). Painting on sculptures can also indicate textile design and patterns (Brinkmann and Wünsche 2003). Scenes on stelae from Daunia dated to the seventh–sixth centuries BCE show women seated in front of vertical looms (Gleba 2008, 30–31), probably weaving bands with meander patterns. The depictions are highly formalized. The best source for images on Greek textile technology is the *lekythos* of the Amasis painter in New York, showing all stages of textile production from spinning to folding. For Roman textile technology, it is a monument erected in the German town Igel, showing Roman textile trade to the Provinces in the North (Drinkwater 1982).

Written Sources

Some Greek and Roman authors write on textile topics, but not always reliably. Such texts, not meant as technical descriptions, serve various purposes that have to be considered. Sources like the Price Edict of Diocletian or the Mycenaean Palace archives are without such a bias, but the terminology is sometimes impenetrable and challenging (Wild 2003, 9–10). This is a general difficulty of technological terms (Landels 2000, 7; Hodges 1970, 7), but textiles vocabulary seems to be a special case. Regarding weaves—the structure of a textile (tabby, twill, satin, etc.) that gives the best information on technology—technical terms are completely absent. Textile terminology traditionally uses non-verbal conceptual representations (thought to be a fundamental characteristic of textile terminology) to generate and convey definitions (Lervad, Nosch, and Dury 2011, 214–216; Michel and Nosch 2010, ix–xix).

Aristophanes uses descriptions of wool-working in the *Lysistrata* (574–586), and Plato later gives a similar list of wool-working activities in the *Sophist* (226b–c). Examples of written sources on textile craft in Italy are Catullus (64.311–319), who describes spinning, and Ovid (*Metamorphoses* 6.53–60) on weaving. Further sources are Pliny the Elder and Varro as well as funerary inscriptions. Dyeing receipts are recorded in some papyri, but the main source is the dyestuff identified on the textile remains themselves (Wild 2003b, 114).

Reconstruction and Experimental Archaeology

Because of the unique construction of ancient garments, where bands and borders are integrated in fabric construction, it is possible to reconstruct whole garments from small pieces (Cardon 2001, 17; Wild 1970, 55–56). From such reconstructions, we have learned that faults in woven textiles might also serve as evidence of production methods. Entering-errors indicate the use of heddles because they repeat over the fabric, whereas faults made by hand do not repeat (Cardon 2001, 16; Rosenfeld 1958). Mathematical analysis induced by such repeating warp faults is used to reconstruct the shedding mechanism of looms (De Jonghe 2001). Such reconstructions go beyond the copies of ancient objects for display, and this method developed into a broader approach where experiments with reconstructed objects and tools help to gain knowledge about the production processes. The Centre for Textile Research in Copenhagen has conducted experiments with textile tools and techniques since 2005 (Andersson Strand and Nosch, 2015).

Stone-built boilers supporting lead vats excavated at Pompeii were used for reconstructing the entire dyeing process in order to answer the question of whether Pompeian dye works were able to produce enough goods to serve local demand or even a surplus for export (Hopkins 2011). Other approaches investigate breeding ancient sheep species, processing fibers, estimations of time, loss of material from fleece to thread, and the relation between the weight of the spindle whorl and the range of yarn thickness (Andersson Strand 2012).

Experimental archaeology makes practical attempts to reconstruct past conditions and circumstances. It relies on archaeological data, pictorial and descriptive sources, and sometimes on ethnological parallels. Besides tangible and measurable evidence, experimental archaeology also allows for conceptual exploration (Hurcombe 2008, 85) as it changes the role of the researcher, who often has to become skilled in the craft itself and therefore applies both explicit and tacit knowledge (Ciszuk 2007; Harlizius-Klück 2013).

3. State of the Art of Knowledge on Textile and Clothing Technologies

Chaîne Opératoire or Taskscape

The operational sequence from gaining raw material to producing cloth, the *chaîne opératoire* (Figure 45.1), is described at length in Barber (1991), Gleba (2008, 37–89), Andersson Strand (2010 and 2012), and Grömer (2010, 43–220). In Classical times, the treatment of raw material and the processing of fibers, already known for millennia, did not change considerably. There are, however, cultural differences in treatment methods and regional differences in the availability of raw material.

The operational sequence is often divided into three stages: converting fibers into yarn, interlacing yarn to make a fabric, and finishing (Wild 2008, 465). The challenge in investigating ancient textile technology lies in the fact that these stages are not so clearly defined. Dyeing can appear at different points in the textile chain (Wild 2003, 10), and most garments are shaped and decorated while still on the loom.

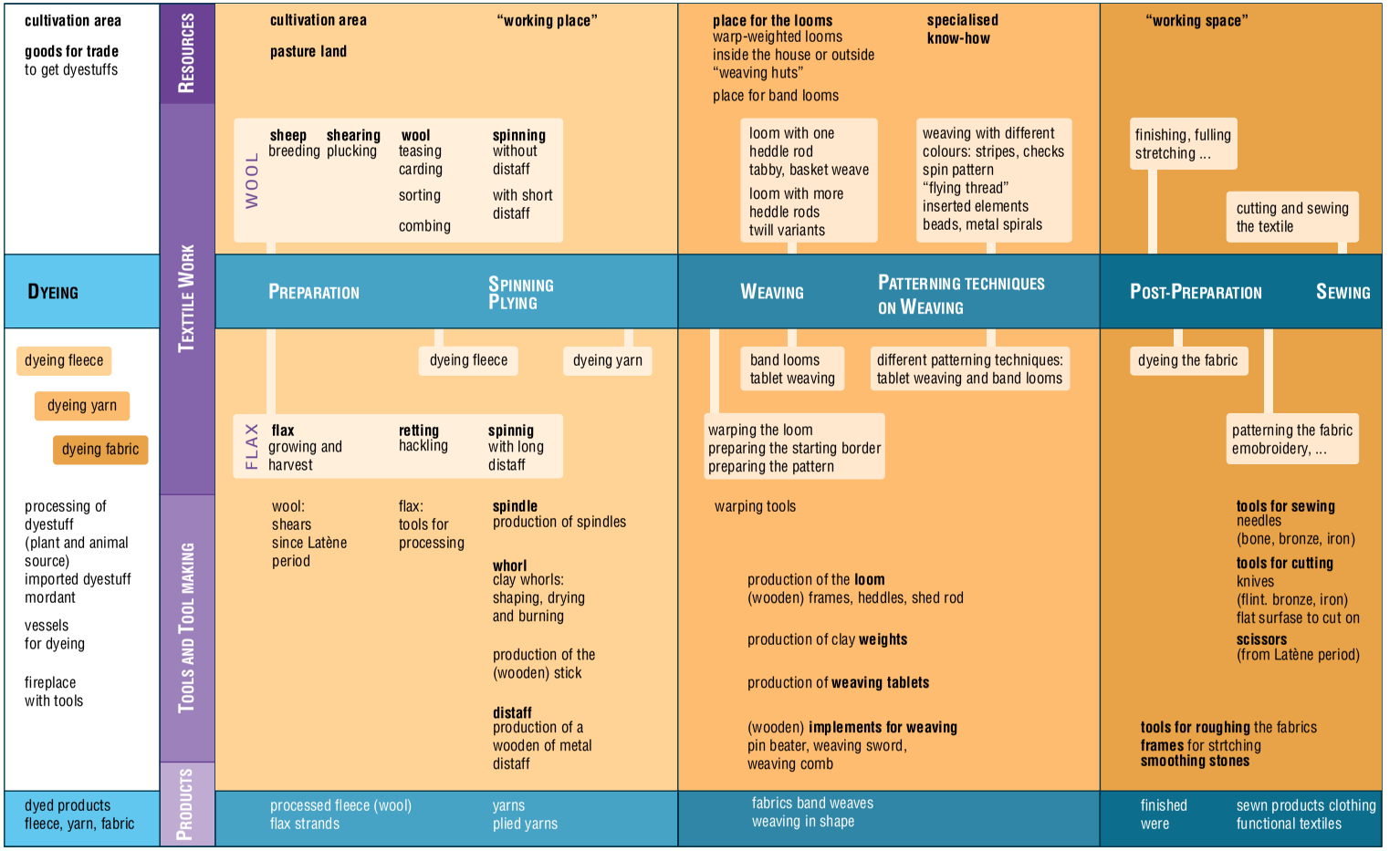


Figure 45.1 Taskscape of textile technology including tool production. Source: © Karina Grömer.

The flowchart of the operational sequence should be read as one path through a landscape of different potential capacities, regional resources, needs, cultural preferences, and technologies. The term "taskscape," coined by anthropologist Tim Ingold for the totality of tasks making up the pattern of an activity carried out in a community (2000, 325), serves well for the following description of several parts of the textile production process.

The Textiles

Textiles make up a considerable part of everyday goods in antiquity, ranging from cushions, blankets, carpets, tents, mantles, tunics, hair-nets, girdles, ribbons, braids, and cloth to sails, ropes, etc. It is impossible to present the entire range of textile technologies in detail. Our discussion is of necessity general, but the data itself, archaeological or textual, is never that clear. Regional and cultural differences are frequent, and interested readers should consult the Further Reading section at the end of this chapter.

Greek dress mainly consisted of a tunic and/or cloak. Vase paintings show garments elaborately patterned until the first half of the fifth century BCE, when they are mainly white. The textiles available in the Roman world are described as simple wool tabbies ranging from coarse, simple webs to luxurious light materials, and twills that display an equally sophisticated variety. Some fabrics were weatherproof or wind-resistant, and others protected against heat and dehydration. Simple stripes or checks, tapestry *clavi* or *gammas*, and various patterned weaves or piled fabrics were available (Bender Jørgensen and Mannering 2001, 7). The toga, the official Roman dress, consisted of a long woolen fabric draped around the body. The measurements and shapes of the toga varied over times, and it became a commercial item at least after 300 CE (Wild 2003a, 92), but it does not occur in the Price Edict of Diocletian.

Raw Material

Raw material for yarns and fabrics, the fibers, come from plants and animals. Wool and flax were primarily used to produce textiles, but esparto, hemp, nettle, papyrus, goat and rabbit hair, silk, cotton, fibers of mussels, and even asbestos were among the rare textile finds either excavated or mentioned in ancient texts.

Animals have two distinct types of hair: long, coarse hairs and a shorter and finer underwool. Already domesticated, sheep gradually carried more wool than coarse hair owing to selective breeding (Wild 1970, 4–10; Wild 2008, 466). Textile finds expose a distinct consciousness of wool qualities, and we find them sorted neatly. However, there is no written account of wool sorting in the Mediterranean area (Wild 2008, 467; further on wool: Blümner 1912, 106–120; Wild 1970, 22–26; Forbes 1987, 2–26; Barber 1991, 20–30; Gleba 2008, 65–75; Grömer 2010, 71–74; Andersson Strand 2010, 10–13).

Flax is one of the most common plant fibers. Recent investigations show considerable flax production in Greece (Nosch 2013). Small-scale flax cultivation might have been widespread in Italy as well. Domesticated flax provides fiber for textiles we know as linen. In Roman times, Spanish linens were highly reputed (Wild 2003a, 80). Hemp and esparto were used for ropes, nets, and tents (Wild 1970, 29–30; Wild 2003a, 81; Andersson Strand 2012, 23).

Silk and cotton were known and imported, but were not common. Wild silk moths (which, we presume, have died out) were known to produce a fine fiber. Before the sixth century, the cultivated silk of *bombyx mori* that provides a long and fine filament was only available from China or India. Then in 553–54 CE Justinian acquired silk moth eggs and started local production (Wild 1970, 26–27; Wild 2003b, 108). The Romans held silk in high regard for clothes, but its use was restricted. A mussel of the Mediterranean Sea, the *pinna nobilis*, produces long filaments to attach itself to the seabed. These silk-like filaments were spun and woven into smooth but resistant shiny golden-brown fabric, the color being the natural color of the filaments. This so-called sea-silk was produced in Italy and was listed in Diocletian's Price Edict as wool from the sea (Maeder 2008, 116). The oldest find is from the fourth century BCE (Wild 1970, 20; 2003a, 82; Maeder 2008). Even asbestos was spun and woven into napkins, which were burned clean instead of being washed (Pliny, *NH* 19.4).

Fiber Preparation

Fleeces of wool were plucked from sheep or shorn with a knife. The use of iron shears began in the second half of the fourth century BCE (Barber 1991, 260). Sometimes the fleece was washed and presumably sorted into different qualities.

In Greece and Rome, wool was combed to prepare it for spinning, or sometimes just teased (Wild 1970, 24–26). From Greece we know that wool was prepared for spinning in a different way. Rovings were made by stretching and slightly rolling fibers on the naked thigh or by using an *epinetron*, a pottery implement put on the thigh over clothing; the *epinetron* was unknown in the Roman world (Wild 2008, 470).

All bast fibers have a similar production process (for experiments in flax cultivation, see Andersson Strand 2012, 25). Flax is pulled according to the fiber characteristics one hopes to achieve: yet green flax gives thin and fine fibers; slightly older stalks give coarser material; and yellow stalks make coarse material that is good for ropes and cordage requiring strength. Ripe seeds are rippled, and stalks are retted either in water or by placing them on the ground (Andersson Strand 2012, 26). Pectin is then dissolved from different parts of the plant. Afterward, the stalks are dried again and then broken to separate the sheaves from fibers. Then the fibers are scutched with a wooden knife so that all parts of the bark are removed. Not all of these steps are always done. In the end, fibers are combed in preparation for spinning (Forbes 1987, 27–43 on flax and linen, 43–49 on cotton).

Dyeing

Dyeing is said to be a skilled craft requiring certain knowledge of applied chemistry (Walton Rodgers 2003, 25–29; Wild 2003b, 114 and 2008, 476; Forbes 1987, 127–143; Cardon 2007; Gleba 2008, 75–81). The natural shades of wool from black over red and brown to white served as colors for patterning. Wool was also dyed in the fleece and as yarn (Wild 2003a, 91). Plants, insects, and mussels were used for dyeing a full range of colors available in the Roman Empire. Plant dyestuff included woad, madder, bedstraw, cochenille, brazilwood, safflower, barks, nuts, roots, and more. True purple came from a mollusk, other reds from scale insects like kermes. In Roman times, purple was popular for *clavi*, the stripes that distinguish Roman citizens, but few of them were

likely genuine murex purple. Finds from Mons Claudianus show an imitation of true shellfish purple, obtained by first dyeing wool in blue in a vat where the source of indigotin was most probably woad, then by dipping into a madder-bath after mordanting with alum. Iron salts may also have been added to obtain the precise shade of purple required (Cardon 2001). Purple, *purpura*, is the name both for the precious color from murex shells, extracted from the ink glands, and the widely traded purple-dyed raw wool. Phoenician sites had the best reputation for purple (Wild 2003b, 115).

Spinning

Spinning, which is the process of twisting fibers into a long thread, is done with a range of methods (Bender Jørgensen 2012, 129). Most commonly, spinning is accomplished with a spindle consisting of a shaft usually made from wood and a whorl of stone or clay, shaped as a torus or truncated cone and functioning as a flywheel to enhance the momentum of rotation. The whorl is usually placed on the lower end of the spindle, but sometimes on top. The weight of the whorl influences the fineness of the thread (Barber 1991, 9; Andersson Strand 2012, 33–34). Wild (2003b, 108; 1998, 223) says that the spindle, where the whorl is fastened on the top of the shaft, used with counter-clockwise rotation gives s-spun thread, which then is plied into yarn with a Z-twist (Figure 45.2). But experiments show that the choice of spinning tool does not predict the spin direction (Andersson Strand 2012, 33; Bender Jørgensen 2012). Spinning can be done by twisting rovings into firm thread or by twisting fibers from a combed fiber mass into single threads. The mass of fibers could be held in the left hand with or without a stick or other support (distaff). Two strands of thread can be plied together into a firm thread, which then has the opposite twist. In the Roman west, plied yarn was only used as sewing thread (Wild 2003a, 82).

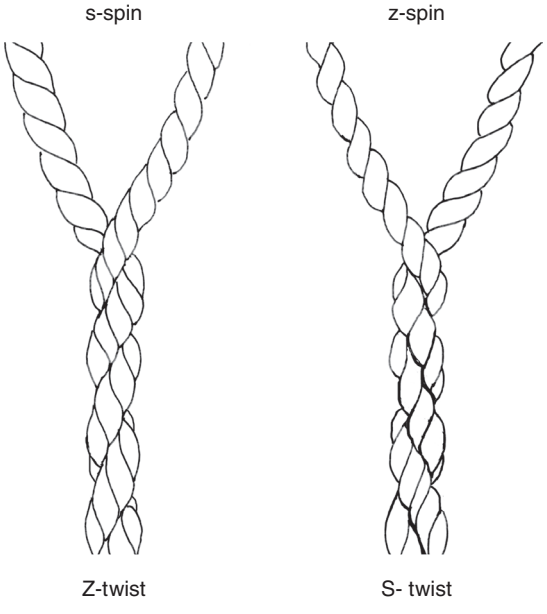


Figure 45.2 Spin and twist of yarns.

Weaving and Loom Types

In principle, weaving is the interlacing of yarn, but wool or linen thread is not stiff enough to be interlaced as it is. Limp yarn needs tension to achieve the stiffness required for weaving. Elizabeth Barber therefore defines weaving as follows: the tensioned set of threads, set up first, constitutes the warp, while the threads introduced by interlacing constitute the weft. This interlacing process is called weaving, and the device that provides the tension is the loom (Barber 1991, 5).

Two principal possibilities for tensioning the warp were used in antiquity: stretching by weight or stretching between two beams. In the latter case, the beams might also run parallel to the ground, which has advantages for implements like heddles. But both loom types used in Greece and Italy were vertical: the warp-weighted loom and the two-beam loom.

Weaves

In a tabby weave (Figure 45.3), the weft threads go over and under every second warp thread and the opposite way in the next row. Twill weave has weft threads going over more than one warp thread with a translation of one thread in every row. In a 2/1 twill, the weft goes over two and under one warp thread. Twill can also be made in several number combinations by changing the direction of translation. In the Roman West, twills were often a combination of z-spun warp with s-spun weft. 2/2 twill is dominant, and diamond twill, a more complex variant, is frequent among finds (Wild 2003a, 87).

Weaves can be open, with a considerable and balanced distance of threads in the warp and weft direction, or have threads packed closely with only warp or weft threads

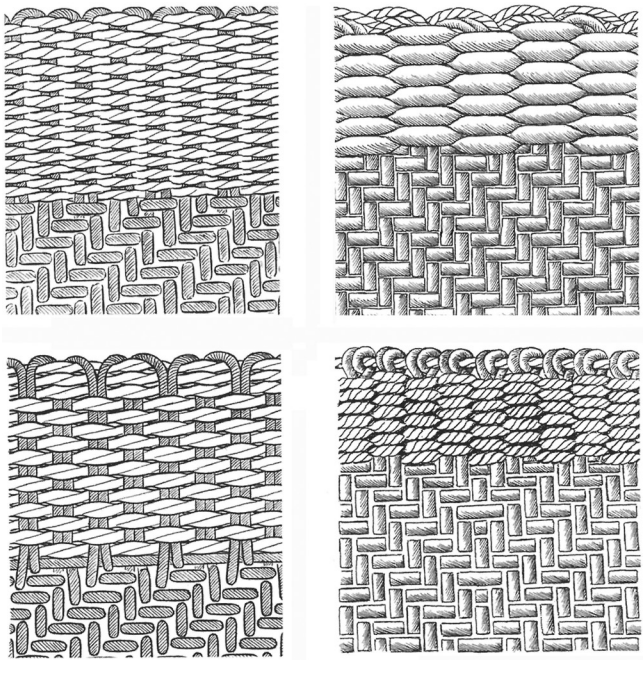


Figure 45.3 Diagrams of basic weaves.

visible (warp- or weft-faced fabrics). Tapestry is a weft-faced technique in which weft threads do not reach over the entire width of the fabric but only as far as the color is needed for the motif pattern. Tapestry remains are rare among textile finds in Greece, but the few we have (Vergina, Sampula) show a highly developed craft. Literary sources often mention pictured weaves (Homer, *Iliad* 3.125–127; Ovid, *Metamorphoses* 6.53–82), and vase paintings show figured garments, the depiction of Penelope's web on the *skyphos* from Clusium being among the most famous. In Hellenistic and early Roman times, tapestry-woven fabrics like hangings and blankets showed shades of colors giving the three-dimensional impression of bands sewn on the fabric. In the eastern Roman Empire, tapestry bands or medallions were woven into plain wool or linen tabby. Fabrics can have loops and piles on the surface to enhance qualities like warmth or smoothness. Pile techniques are common in the eastern Roman Empire, especially in Egypt (Wild 2003b, 113).

In the east, simple geometric damasks in wool made use of the full range of 2/1 and 3/1 twill structures with alternating warp-faced and weft-faced effects. Such fabrics were made at least before the end of the first century CE. A little later, we find weft-faced compound tabby weaves (taqueté) with figurative designs, a technique that opens the discussion of complex devices for opening the shed (Wild 2003b, 109).

Bands and Starting Borders

Before threads are attached to a loom to make a garment, many decisions have to be made to achieve the desired result: yarn thickness, quality, and length, but also details like the twist direction of yarn, the distribution of colored threads, the number of threads necessary to achieve certain patterns and complete pattern repetitions. The most common loom in antiquity, the warp-weighted loom, works with a distinct feature that allows many constructive decisions to be made beforehand: the starting border (Figure 45.4). This is a band or cord that collects, orders, and distributes the later warp threads, which

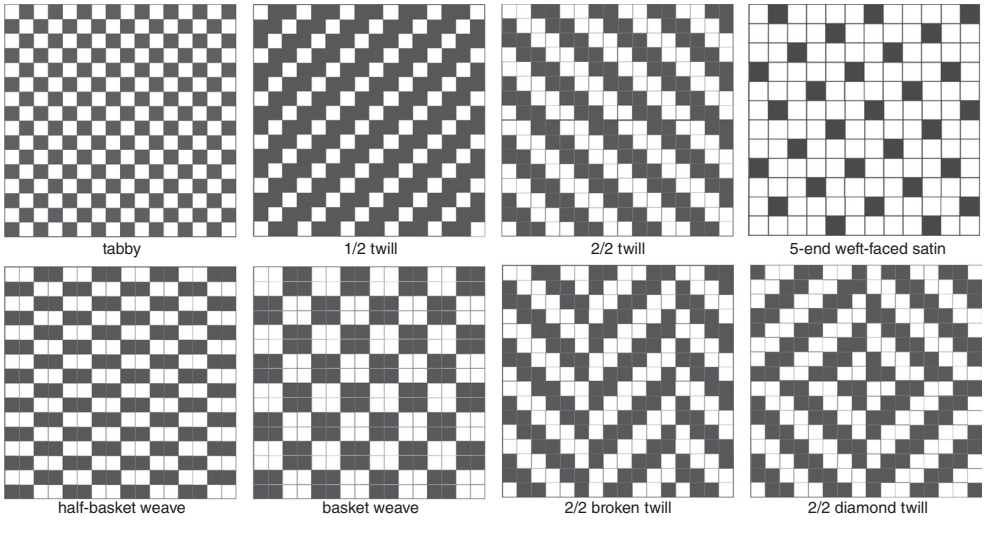


Figure 45.4 Diagrams of starting borders. Adapted from Grömer 2010, 126.

are fixed in the cord or band as a weft. This band or cord can be made by plaiting, twining, or true weaving, but most commonly by tablet weaving.

Tablet weaving is done with cards of triangular, square, or other polygonal shape with holes in the corners. The warp threads are entered through these holes, and the distance between the holes forms a shed. Packs of such tablets carrying the threads form the warp, and turning the pack makes alternate sheds, so that the holes change position. This technique produces cords in the warp direction (four-hole-tablets produce four-strand-cords, hexagonal tablets produce six-strand cords, and so on). The weft is not visible but secures these parallel cords, giving a warp-faced fabric. The pattern is provided by different colors of the warp strands and different twist directions, forming the impression of lines or other motifs. Bands and borders patterned with this technique were found all over Europe, and the variety of designs is broad (Grömer 2010, 172–177; Ræder Knudsen 2012). It is also possible to weave figures, letters, and other designs.

The Warp-Weighted Loom

The warp-weighted loom has two uprights with an upper cloth beam and a lower beam used for shedding. The starting border is attached to the upper beam, and the warp is divided into odd and even numbered threads. One set of threads is laid in front of the lower beam, the other half behind. Attaching loom weights provides the warp's tension. And, by leaning the loom against a wall at a slight angle, a natural shed (the space where the weft is introduced) is produced. Loom weights are usually the only direct archaeological evidence, and their distribution can tell much about the setup used by the weaver (Wild 2008, 471; Mårtensson, Nosch, and Andersson Strand 2009). Some looms did have a stand providing the angle (see Hoffmann 1964; figures 126, 127, 128). Providing the countershed is a heddle rod to which the other half of the warp threads is tied. In this form (with one heddle rod) the loom is prepared for weaving tabby, but additional heddles make it possible to weave twills and satins.

In the case of vertical looms, it is not possible for a shuttle (the tool that introduces the weft) to slide through the shed; it must be carried by hand. It seems that the Greek tool for this operation, the *kerkis*, fulfilled several purposes and was not shaped like the shuttle we use today (Edmunds 2012).

The weaver must consider the complex functional interrelationships among size, weight, and shape of loom weights in producing textiles of a certain type (Mårtensson, Nosch, and Andersson Strand 2007). The range of possible techniques on the loom is wide, from simple tabby and twill to damask twills and other compound weaves like taqueté, but also tablet weaving, tapestry, flying needle, and brocades.

The Two-Beam Loom

After the first century CE, loom weights are no longer found in urban sites in Greece, suggesting that the warp-weighted loom went out of use; and literary sources suggest the two-beam loom was now common (Wild 2003b, 109; Walton Rodgers 2001, 160).

For the two-beam loom, two uprights are set in a stand with upper and lower cross beams. It can work with a tubular warp (Wild 2003, 317; Hald 1950) or a warp with stretched out threads as on the modern handloom. The weave structure is picked out by

hand, but the loom may also have heddle rods. Walton Rodgers (2001, 159) writes: "It would be hard to attach any elaborate patterning device to this loom, and it is generally associated with simple weaves" (cf. Wild 2003a, 84). But this estimation is misleading, as this was the preferred loom for the precious figured tapestries.

Treadle and Draw Loom as Possible Inventions?

The only significant change in loom technology in Roman times might have been the development of the horizontal treadle loom or foot-powered loom, which made the work more efficient by freeing the hands but in turn gave way to complicated harnesses that made damask patterns easy to weave. Evidence for this technology comes from interpretations of texts or reconstructions by combining excavation results and analysis of weave structures. Patterning of textiles is easier with the help of several heddles, but it is not clear if and how this works on a warp-weighted loom when more than three heddles are required. Experts assume a horizontal loom for this purpose (Wild 1987).

Carroll reports that excavations at the monastery of Epiphanius in Thebes point to pits for harness looms with treadles as early as the seventh century CE (1985, 169). She concludes that the development of this fully equipped draw loom occurred in Egypt over several centuries (Carroll 1985, 173). Also, De Jonghe states that the looms for weaving complex 3/1 twill damasks were "equipped with a 'permanent memory' so that the pattern and weaving faults repeat at regular intervals" (2001, 141).

However, systematic studies of weave faults and technical possibilities have shown that horizontal treadle looms or draw looms were not employed for Roman silk damask weaves. They were probably produced on a horizontal loom with sheds opened by two sets of four heddle rods. An example of this use is the tunic discussed by Cardon (2001). Wild later indicated that ethnographic evidence from Iran shows complex patterned compound weaves still being made on vertical looms (2007, 4). Therefore, evidence for the horizontal treadle loom with a programming device as a Roman-era innovation is still pending.

Primitiveness and Innovation

Wild resumes his discussion of the proposed complex Roman heddle loom: "The Roman master weaver must have had the mental agility of a modern computer programmer, along with a prodigious memory" (2008, 473). However, the mental agility must be even higher, when the loom has no permanent memory, as Brezine has shown for the algorithms of Andean weavers (2009). A skilled weaver can indeed work the beams and rods that he or she knits together to a loom by using cords to make anything from coarse rugs to the finest and elaborately patterned fabrics (Bender Jørgensen 2012, 131). The primitive hardware of ancient textile technology is misleading. The implication of primitive production processes might explain the search for a horizontal treadle loom as the first innovation toward the production of long pieces of fabric woven with the help of mechanisms controlling the patterning. The software of ancient textile technology is not at all primitive: that is, the weavers' skills already visible in the products as well as in their ability to generate patterns fitting into various mathematical constraints of the utilized technology.

Finishing Techniques

One of the textile tools sometimes mentioned in histories of technological inventions of antiquity is the cloth press, developed from simple lever presses that employed ropes and weights as described by Hero (*Mechanics* 3, 2, 13–21; Cech 2010, 147). From the first century BCE onward, the lever press, combined with a spindle or screw (Pliny, *NH* 18.317; Cech 2010, 148), served for laundry or other purposes where fabrics or garments were pressed (Cech 2010, 149; Granger-Taylor 1987).

Woven wool was fulled to improve its warming properties. This was accomplished by trodding fabrics in a solution of water and fuller's earth or urine. The fabric then shrank, and the hairy wool became entangled to produce a smooth, dense surface. Another technique for finishing woven woolen fabrics was to raise the nap with teasels and then shave that surface to give a smooth finish. Many fuller workshops have been excavated in Pompeii and Ostia, but the archaeological evidence is scant for the eastern provinces (Wild 2003a, 90). Felt is produced in a similar way but made from wool fleece.

Most of the garment shaping was done on the loom, but some parts still had to be sewn together (Cardon 2001; Rösel-Mautendorfer 2010, 172–177; Wild 1970, 57–58). Presumably cutting and tailoring fabrics started as a technique of reuse (Sumner 2009, 13). A good example is the tapestry trousers from Sampula (Xinjiang, China). The tapestry, probably manufactured in Bactria during the third and early second century BCE, shows a centaur, a Greek motif. Originally measuring 2.3 × 4.8 m (7.5 × 15.7′), the tapestry might have decorated a palace hall. Later it was cut and sewn into trousers (Mayke Wagner et al. 2009, 1073). Stitching and applications were also in use, and a great variety of stitches were known (Grömer 2010, 187–190).

Sprang and Nålebinding

For textiles that needed to be elastic, like caps, headdresses, or socks, sprang or *nålebinding* were used (Schinnerer 1895; Wild 2003, 22–25; Andersson Strand 2010, 12–15). Sprang is worked on a frame where threads are stretched out vertically like a warp on a two-beam loom. Then neighboring threads are twined in rows. Sticks at both ends of the threads keep the twining in place. When the work is finished, a thread replaces these sticks. In textile finds, this thread can identify the technique. Most sprang frames on vase paintings are small and held by hand.

Recently it was proposed that tight-fitting trousers, represented in vase paintings and by newly discovered color traces on marble (Brinkmann and Wünsche 2003), were made in sprang (Drinkler 2009). The frame for this work must have been considerably larger.

In Roman Egypt, socks were made from *nålebinding*, a type of knotless netting produced by interlocking loop rows with a needle. The loop size determines the density of the fabric. This technique was probably not used by western Romans (Wild 2003a, 88). A textile find in nålebinding from Dura-Europos dated to the mid-third century CE was considered knitting (Barber 1991, 122), but the first examples of two-needle knitting date to 1000 CE. Sprang as well as *nålebinding* are modern Scandinavian terms, whose respective Greek or Latin words are unknown.

4. Weaving into Shape and the Necessity of Order

Cloth today is associated with a textile produced and traded in considerable length, then cut and sewn into shape. Such textiles have a neat outer side and a rarely seen inner side. This is not the case for ancient times, when most garments were woven into shape and often show no clear recto or verso side. This might be why painting on fabrics is uncommon in antiquity. Techniques with inverse, complementary, or neat patterns on both sides were preferred.

The warp-weighted and two-beam loom are well adapted for weaving into shape. On the warp-weighted loom, the starting border provides a preliminary operation of ordering a textile by a band that predicts the measure, and often the quality, density, and the numbers of warp threads for the whole weave.

Consideration for fitting patterns begins with the starting border. At this stage, two factors are important: the distribution of colors and the divisibility of the total number of warp threads. If the latter were a prime number, no pattern repeat would ever fit. Knowledge of divisibility rules and of number features (such as odd, even, prime, relatively prime), as well as knowledge of common measures, least common multiples, and greatest common divisors was necessary to weave the elaborate patterns we see in the visual representations. Patterns like the meander depicted by Exekias on a funeral plate (Figure 45.5) result from an in(ter)ference of binding structure and color distribution that must be carefully planned (Figures 45.6–9).



Figure 45.5 Exekias, Fragment of black-figured funerary plaque with meander patterned dress on the right (circa 540 bce). *Source:* Courtesy Staatliche Museen zu Berlin, Preußischer Kulturbesitz.

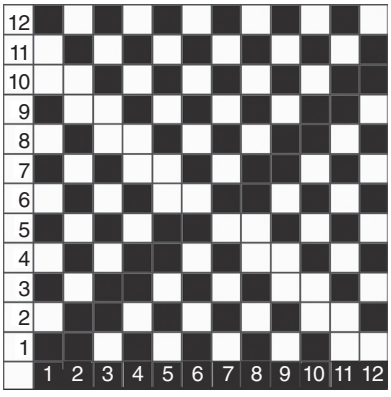


Figure 45.6 Weave structure of meander pattern in Figure 45.5. Dark squares indicate lifted warp threads. Repeat after eight threads in each direction.

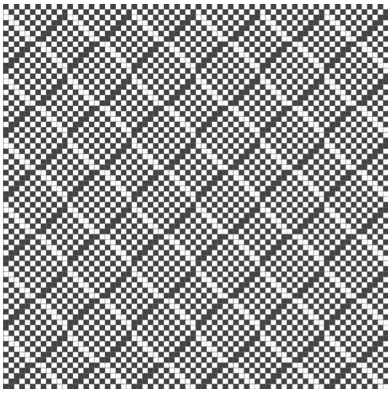


Figure 45.7 Appearance of the weave with all warp threads dark and all weft threads white.

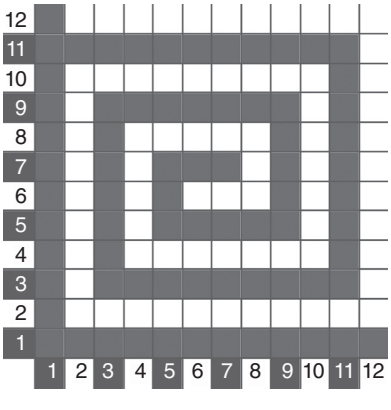


Figure 45.8 The same structure with a color change in each warp and weft thread: all odd threads are dark, all even threads are white.

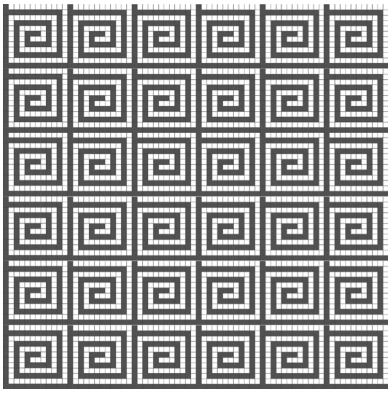


Figure 45.9 With this new color distribution a completely different pattern appears, but the weave structure is still the same as the one in Figures 45.6 and 45.7.

The mathematics favored by Plato as pure knowledge is an arithmetic that distinguishes numbers as odd or even and explores the properties that are generated by combining them (see Euclid, *Elements* books 7, 9). Yet some features are mathematically puzzling: the concrete value of integers is absent, and arguments concerning geometrical magnitudes "are expressed in the language of ratio and proportion, without assuming any numerical values" (Saito 2009, 804). Some philosophical reason, giving rise to such mathematical imperfection, is often assumed.

Mathematically it is possible and satisfying to attribute such features to a "concern with the generality of proof" (Saito 2009, 805). But what if this way of thinking about numbers comes from a practice that was itself concerned with generality and not, initially, mathematics? The word "line" shows its origin from the "linen" thread via Greek *linon* and Latin *linum*. *Radius* was the Latin word for the shuttle, later also denoting the compass. The weaver is constructing figures with *radius* and *regula*, just like the geometrician with compass and straight edge. *Regula*, the ruler or straight edge, *kanon* in Greek, denotes the heddle rod that controls the regular repeat of the pattern.

The Greek *arithmoi*, numbers, are only positive integers greater than one and not part of an infinite continuum, but "rather a set of discrete entities" (Lloyd 2009, 9) like the threads on a loom. Mueller writes that Euclid defined the unit in a mathematically useless way and phrased the few arithmetical problems he solves in terms of "finding number satisfying a condition rather than generating them" (1981, 60). A weaver indeed has no need to calculate with only one thread. Finding numbers satisfying required conditions is exactly what the weaver does when planning the pattern.

In the *Statesman*, where Plato clearly distinguishes between pure and applied knowledge, he gives the example of "arithmetic and other kindred arts" for the former. We naturally think of mathematical examples like geometry. But this arithmetic is characterized by a dualistic number concept that concentrates on oddness and evenness, halves and doubles, and divisibility. The kindred ancient art, then, is not geometry but the visual algebra of weaving patterns.

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CHAPTER 46

Urban Infrastructure in the Roman World

Klaus Grewe
Translated by Johanna K. Sandrock

1. Introduction

Humankind has always endeavored to create a safe, livable, efficient, and comfortable living environment. And we have long understood how to improve living conditions by harnessing resources and labor (human and animal) under the arc of the human capacity for rational thought. Over time, demands on resources increased, the requirements and expectations of society grew more complex, and human solutions to those challenges became more innovative and impressive as the natural environment was increasingly adapted to human needs, tastes, and whims.

Highly qualified Roman military engineers brought their typical efficiency to road construction. Wherever natural obstacles interfered, the Romans found highly technical solutions for their ambitious infrastructure. They built bridges with heretofore unfathomable measurements. Perfectly conceived structures soar up to 50 m (164′) over rivers that—until then—were impassable, and they even seem to defy the law of gravity. Not only are these bridges perfect technical constructions, but they are impressive aesthetic achievements as well.

In hydraulic engineering, Roman achievements were unrivalled until the twentieth century. For cities like Cologne, Constantinople, or Carthage, aqueducts were built, each boasting a length of more than 100 km (62 miles)—this alone is an achievement in the history of technology. Up to the time of Frontinus, nine water delivery systems were built for Rome, bringing water to the city in extravagant amounts. To realize such goals, water delivery systems were built with a decline as slight as a finger's breadth per 30.5 m (100′), and this demonstrates the masterful skill of ancient surveyors, who had only simple tools at their disposal. Aqueduct bridges, up to 50 m high, spanned valleys

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that were difficult to cross; and mountains, which obstructed routes, were tunneled through. The construction of tunnels, among the most difficult of engineering feats, likewise testifies to the high level of ancient technology. We find tunnels in both aqueduct and roads, and those that were constructed for draining large lakes and for flood control are especially impressive.

In general, the Romans created a living environment that allowed the greatest luxury and standard of living, both in their own country and the provinces. Expansion of urban infrastructure followed, permitting a hygienic lifestyle even outside Italy. The Roman way of life was all but defined by city streets, substantial residential developments, public water supply, sewage systems, and, notably, the large bath complexes that fleck the Roman sphere of influence. We also note that only rarely did major epidemics develop in Roman cities.

2. Water Supply

The Roman water supply system of cities, military camps, or other settlements was an outstanding achievement in engineering technology. If a water source was not expedient in a particular location, water was then transported from afar. Extraordinarily complex, such water delivery systems were constructed from individual modules, each posing its own challenges (for aqueducts, see also Grewe 2014; Roman Monumental and Public Architecture).

This construction begins with locating suitable sources of water. The Roman engineer had to consider topography and local challenges, and then look for feasible, endemic solutions. Consequently we find varying techniques in different regions of the Roman Empire. Where water was plentiful year-round and available within an easily accessible distance, a natural spring might be used (as in a remote region north of the Alps), groundwater might be tapped, or water might be taken from a flowing source. In other regions, for example in arid and semi-arid zones, other techniques had to be employed, and here we find magnificent dams and water pumping facilities.

Once a water source was chosen, the engineer next had to determine whether a pipeline to the intended delivery area was possible with the technology at his disposal. The engineer also had to consider how to plan the route. The first task was to calculate the elevation differential and the distance between the source and its destination, which alone could determine the feasibility of the project. The Romans may indeed have been masters in surveying, but even in Roman times water flowed downhill. And although only simple instruments for measuring land were available, architects were able to achieve surveying measurements of incredible accuracy. The surveying tools employed by Vitruvius were capable of yielding almost error-free measurements with the easiest application (see 8.5). Set on supporting legs (like a sawhorse), the *chorobates* was a beam from which were suspended plumb lines that functioned like levels, with a groove or channel at the top of the beam. The *groma*, a vertical staff with horizontal cross-beams from which plumb lines were suspended, was useful for surveying straight lines and for fixing right angles. One could use plumb lines on a *chorobates* or *groma* to determine the height of a surface. If conditions were too windy for a plumb line, the carpenter could then check the level of water poured into the *chorobates'* groove. Such instruments were built to be used by trained laborers, and their accuracy lay in the fact that, with repeated measurements at different locations with the same equipment, errors were eliminated, which—for all practical purposes—produced error-free results.

In the simplest case, one could build a pipeline to conduct water by means of an unobstructed slope into a valley. As a rule, the channel consisted of a U-shaped stone canal (*specus*), laid underground and covered with slabs or a vault. The dimensions of this channel varied according to the amount of water being transported. A country estate obviously needed a smaller pipeline than a provincial capital. The general dimensions for the pipeline system from Eifel to Cologne were 0.70 m × 1.35 m (2.3′ × 4.4′), which allowed inspectors to check for damage on the pipeline, even if they might have to crouch. For this purpose, the pipeline's path was designed with access/entry points at regular intervals (as at Lyon) or irregular (as at Cologne). If the ratio of the difference in height and distance appeared to allow for a sloped gravity pipeline but topographical features hindered its development, further planning was brought to bear. In this regard, the chief concerns were mountains and valleys, which could hinder the planning of a route.

For crossing tributary valleys (both small and large), bridges were the first solution. Gravity pipelines had to simultaneously follow both the natural slope and the contours of the topography; thus it becomes clear why aqueduct routes were not straight, and also why such a large number of bridges were employed in their construction. In general, where tributaries emptied into larger valleys or rivers, it was necessary to construct small bridges. Larger rivers and valleys naturally had to be crossed with correspondingly larger bridges. If valleys were more than 50 m (164′) deep, bridges were a technical impossibility. Pressure lines were employed, as at Lyon. Here a giant lead siphon was built for crossing the 123 m (403′) deep Yzeron Valley, bringing 25 m^3/day from the Gier pipeline into the city. Smaller valleys, however, could also necessitate the construction of a pressure pipeline. And locally sourced materials were preferred. So we find 35,000–40,000 tons of lead used for the pipes of the eight constructed pressure lines in Lyon. In Almunécar in Spain, terracotta pipes were lined with a thick *Opus caementicium* (concrete) lining to withstand the line pressure. In other places, wooden pipelines were also laid.

Large stone pipes were the rule in constructing pressure lines in Turkey, where we find a picturesque example of this type in Aspendos. The pressure pipeline was part of a long-distance water delivery system, crossing a hollow that lay on the side facing the mountain range. To reach the 40 m (131′) high acropolis, a bridge of corresponding height would have to be laid across the 1700 m (1 mile) wide valley. Opting to construct a pressure pipeline, the locals used stone blocks with overall dimensions of 90 × 90 × 50 cm (35 × 35 × 19.5″) and an interior diameter of 27 cm (10.6″).

Vitruvius wrote that such a pressure line ought to cross the floor of the valley on a horizontal foundation (8.6.5); for this purpose, a correspondingly massive stone bridge was also built in Aspendos. Along the course of this bridge, two changes of direction had to be accommodated, and precautions were taken to avoid problems caused by the pressure at the break point: pressure release towers were built (40 m [131′] tall), equipped on each side with ramps on which the stone pipeline could lead to an elevated *freispiegelbecken* (leveling basin). Subsequently a pipeline was conducted over a ramp to the valley, so that water could pass through the next part of the pressure pipeline. As a result, two pressure relief towers had to be built within three stretches of the valley pipeline, which even today dominate the landscape behind the acropolis of Aspendos. Completely different problems arise when a mountain ridge obstructs a water supply route. In such a case a tunnel is essential (see below, §5).

The endpoint of a water pipeline was generally a *castellum aquae* (water structure), where the transition to the municipal water mains were made, or even a *castellum divisorium*



Figure 46.1 Pont du Gard. Photo by author.

(distribution structure) for the purpose of distributing water to various branches of a municipal pipeline network. We find an excellent example in Pompeii, where the water towers are still preserved. Pompeian water towers were fed by the *castellum divisorium* via lead pressure pipelines, and water flowed from them through lead pipes under the roads to individual connections across the city. Branch pipes led from the main line at intervals to supply public and private buildings (fountains, baths, elite private homes, and commercial businesses)—for the use of which there were fees to the city (Frontinus notes cases of hacking into the system at Rome: *On Aqueducts* 2.103). The water supply was continuous and could not be stopped. However, it was possible to divert the flow by the use of taps and valves. It was also possible to rig a temporary bypass for conducting repairs on short sections without cutting off the main supply (Frontinus, *On Aqueducts* 2.124). Unused water flowed as surplus from public fountains through gutters in the street and, finally, into the canal system. Here, along with fecal matter and other sewage, it was directed into the outlet channels. While water pipelines were, as a rule, laid underground, they emerged as bridges for short segments, most conspicuously the iconic Pont du Gard at Nîmes (France; Figure 46.1) and the Puente del Diable at Tarragona (Spain).

3. Road Construction

This catchy motto that "All roads lead to Rome" is, in fact, an invention of medieval literature, but it vividly captures the sheer achievement that linked the Roman Empire, making it accessible by all forms of transport. The Roman highway system alone is

estimated to have covered a total distance of 80,000–100,000 km (49,710–62,140 miles), and—if one adds in secondary, linking, and local roads—the number of constructed roadways increases exponentially.

Over the millennia, roads were the most important means of human communication. They served for the exchange of news and commercial goods, for transportation of infantry, and as "information highways" for administrative officials. And yet not every form of road involves civil engineering. Only after a junction between two locations is systematically laid out (i.e., plan and route preceded construction) can the structure be seen as an engineered "artificial" road, as differentiated from a "natural" road. The latter may fulfill the same purpose—a path makes traffic between two locations possible—but the technical features are, for the most part, completely different. Such paths evolved simply through continuous use. Thus courses are therefore generally dependent on topography, so that natural obstacles, like mountains and valleys, are bypassed and artificial constructions are not a factor.

In this regard, road builders were always pragmatic. Only when the construction of a traffic route was absolutely necessary did one resort to planning and relying on technology. If a mountain ridge had to be crossed or a mountain face had to be circumvented, it might indeed be inevitable to cut into the cliff itself. A road's incline could also be reduced by planning a serpentine (or switchback) path, wherein the engineer could manage the road's grade.

Sunken paths, although falling under the purview of engineered roads, usually resulted from continuous travel in irregular attempts to deepen roadways, especially in hilly areas. Among other things, sunken paths may have been caused by a softer or more crumbly subsurface, the effects of weather, lack of road maintenance, erosion, or frequent use.

On the other hand, roadway cutting and terracing are regular elements of road construction. In this way the obstacles of mountain ridges and faces could be mitigated. Steep hills, in particular, could be reconfigured to make the slopes more manageable. If a steep sloping mountain ridge had to be bypassed with a planned roadway, the construction of a tunnel was in some cases avoidable if a terrace could feasibly be constructed along the steep cliff where the road was to be built.

Near Donnas in the Aosta Valley (Italy), an ancient road was constructed as a terrace cut from a steep bluff for a distance of more than 100 m (328′). Nearly 5 m (16.4′) wide, at the beginning, the road climbs to the north, so that the slope would become smoother later in its course. Two elements of construction left by the stone workers in the existing cliff are noteworthy: an archway, marking the change in the road's slope, as well as a milestone visible in the vertical rock face. Scratched 2.4 m (7.9′) above the extant roadway, a line is conspicuous for the entire stretch. Apparently the roadway was first crudely carved out of the wall during the terrace's installation. Then the surveyor marked out the intended slope and sketched a line in the cliff as a guide for construction workers.

An extraordinary feature of this part of the road is a milestone, not erected next to the roadway, but carved out of the smooth cliff wall. Crude mason's marks at the base of the milestone prove that the road surface was laid even deeper over the course of time. Because the recent surface with its distinctive lanes must naturally arise from the last phase of use, it should probably no longer be classified as Roman.

Along the course of the Via Appia, traces of a similar building project near Terracina (Italy) are observable. Only the dimensions are more impressive. Here in 109 CE under Trajan, a difficult mountain crossing was constructed by means of a terrace at the level

of the coast, for which extensive stonework on the promontory of Pesco Montana was necessary. Today the 36 m (118′) high cliff, cut back in antiquity, looms large, and a commemorative arch at the end of the stretch underscores the significance of this engineering feat. Although not well-preserved, the accompanying inscription is recognizable from a distance through the measuring marks in the cliff wall itself, which specified—in Roman numerals—the progress of quarrying from the top to bottom. The highest number is CXX (120 Roman feet).

If a mountain ledge was small and the cliff there was stable, it was then possible to establish a breakthrough, or short tunnel. In such a construction, the necessary incline of the roadway was accommodated without difficulty during the work. This was of great advantage for road construction in the mountains, since roads that extended over passes for a great part of their distance either had to be built on a steep incline or decline.

The Col de Pierre Pertuis ("*Petra Pertusa*") on the Roman road near Tavannes in Switzerland is perhaps the clearest example of such a breakthrough. A traveler can easily see that the breakthrough, only about 6 m (19.6′) long, follows the oblique position of the existing limestone layers. The height of the breakthrough diminishes from 7 m (23′) on one side to 5 m (16.4′) on the other. Where the breakthrough occurs, a width of 9 m (29.5′) is available for threading the Roman road. An inscription chiseled over the lower entrance names Marcus Dunius Paternus as commissioning the road construction, suggesting a date of circa 200 CE. This road also incorporates genuine tunnels.

Other roads immortalized their builders, most famously the Via Appia, one of the first great national roads. Begun during the censorship of Appius Claudius Caecus in 312 BCE, upon its completion it covered a distance of nearly 500 km (310 miles) to the important port cities of Tarentum and Brundisium in southern Italy.

Milestones, prototypes of today's mile markers, furthermore, were extremely important for travelers. They indicated the correct path and how much of the road still lay ahead. Often, milestones are the only evidence for the construction of roads, especially when they give us the names of those responsible for commissioning or repairing roads (Greek and Roman Cartography).

There were also signposts. Among these are the stone from Tongeren (Belgium) and the so-called *Stadiasmus* from Patara (Turkey; Figure 46.2). The distance marker, now in the Musées royaux d`Art et d`Histoire in Brussels, found in 1817 near Tongeren, dates to around 200 CE. It indicates the distances—measured in *legulae* (leagues), the usual unit of distance in Roman Gaul—from Tongeren to other important cities in Roman Gaul including Bonn and Mainz. The *Stadiasmus* from Patara (surviving in fifty-nine stone blocks and so-named because its distances are listed in *stadia*) was once 5.5 m (18′) tall, measuring 1.6 m × 1.35 m (5.2 × 4.42′) at the base, crowned with an equestrian statue, probably depicting Claudius. In addition to the dedicatory inscription, seventy locations with accompanying distances were listed, corresponding approximately to the area of Roman Lycia, and including some previously unattested toponyms.

As we can see in the case of the Via Agrippa from Cologne to Trier, no rule mandated that a highway had to be built with large paving stones. While these may be appropriate for roads within a city, highways were built according to simpler methods. At the same time, highways needed to be solid, and it was also essential that they withstand heavy travel. Picturesque paving stones, as seen on the Via Appia to the south of Rome or also on a Roman road in Tell al-Kharama in Syria, were not the norm in any case.



Figure 46.2 Roman road, Tarsus, Turkey. Photo by author.

4. Bridge Construction

In places where fords were inadequate for crossing rivers, bridges had to be constructed. That the dimensions of these Roman bridges often exceeded actual requirements suggests that Roman engineers took advantage of opportunities to demonstrate their technical abilities.

The use of arches and vaults in architecture was perfected by the Romans, as we see in the Pantheon or Baths of Caracalla in Rome (see Roman Monumental and Public Architecture). Arches also feature in bridge construction. Although arches were known to the Greeks, who only rarely used them, it was the Etruscans who taught this technology to the Romans who, in their turn, perfected the structure. Purely Etruscan arched bridges, such as that in Blera, and Roman reconstructions on Etruscan foundations (as at Vulci) attest to this transfer of technology.

Before the semicircular arch came into use, bridges could be constructed only with small spans. As the simplest form of conquering a dip in the landscape or a brook,

the beam bridge allowed easy spans of 3–4 m (9.8–13.1′) with stone slabs or 5–10 m (16.4–32.8′) with wooden beams for spanning the gap.

The development from simple timbers to true vaults as roadway support is traceable in various ways. One, perhaps minor, development can be seen in the gabled arch: two stone pillars set at an angle against each other. In this way the obstacle (e.g., a brook) could be spanned with a rather large opening. The corbeled vault (using a corbel or console, a type of bracket that juts along the wall to support the weight above) also offered this possibility. The dimensions of bridges first built with this simple technology were increased through the use of the semicircular arch.

The concept of the arched bridge with semicircular (or rounded) arches relies on the transfer of forces acting on the arch to the abutments and piers. The self-supporting function of the arch is only achieved when the centered semicircle has been closed at the apex with a keystone (Figure 46.1). The weight of the keystone is transferred to the adjoining voussoirs and from there the weight is increased from one voussoir to the next. This transfer of force continues to the supports where, in each case, the weight of one half of the arch is transferred to the impost and then to the piers or the abutments.

Also built were wooden bridges that also attest the superior carpentry skills of Roman architects. Caesar's bridges over the Saône (Arar) and the Rhine deserve mention. Caesar himself must have regarded the first of his two Rhine crossings (in 55 BCE) a technical and tactical masterpiece, because he describes it in detail (see Figure 46.3):

> Caesar had resolved to cross the Rhine; but he did not consider it safe to cross by ships nor did he regard it to be in accord with his own dignity or that of the Roman people. So, although there was the greatest difficulty of constructing a bridge because of the river's breadth, swiftness, and depth, he nevertheless considered that it ought to be attempted, or that his army ought not cross at all. He devised this plan of a bridge. At a distance of two feet, he joined two piles together, each a foot and a half thick, sharpened a little at the



Figure 46.3 Caesar's Rhine Bridge. *Source:* John Soane, 1814.

> lower end, and proportioned in length, to the depth of the river. When he had fitted these piles into the river-bed with machinery and had driven them in with mallets, the piles, not quite vertical, like stakes, but bending forward and sloping, so that they leaned forward according the river's nature (i.e., in the direction of the river's current). Forty feet lower down, he also placed two other piles opposite these, fastened together in the same manner, but directed against the force and current of the river. Each of these, besides, were kept firmly apart by cross-beams two feet thick, fitted in at their extremities between two braces on each side to fill the gap and join them together into trestles. Thus, the main piles were arranged in different directions and fastened on sides the one opposite to the other, so great was the strength of the work, and such the arrangement of the materials, that—where the greater force of water dashed itself—the beams were held together bound all the more tightly. These beams were woven together by timber overlaid in the direction of the length of the bridge, and they were then covered over with poles and wickerwork; and in addition to this, at the lower side of the bridge, driven into the water obliquely were wooden stakes, which, serving as a buttress, and joined with the whole construction, sustained the force of the river. And there were others likewise above the bridge, at a moderate span so that—if tree-trunks or ships were sent down the river by the barbarians for the purpose of destroying the work—the violence of these things might be diminished by these defenses and might not injure the bridge.
>
> Within ten days after the timber began to be collected, the whole work was completed, and the whole army led over … having spent altogether eighteen days beyond the Rhine… Caesar returned into Gaul and cut down the bridge. (*Gallic War* 4.17–19)

Caesar's tactical deliberation here is unmistakable, and his description is notably rich with technical details (Figure 46.3). Caesar's engineers clearly understood the hydraulic forces at work on this stretch of the Rhine (possibly between Andernach and Neuwied). And the army-built wooden beam bridge, constructed from double timber pilings, proved effective. The upstream and downstream pilings, at oblique slants and secured by cross-beams, together were able to withstand the forces of the river's current. This was an impressive show of engineering and force, taking only 10 days (and countless troops) to complete.

Trajan's column in Rome represents another contemporary document for the history of bridge construction. Trajan's expeditions against the Dacians are vividly depicted on the 200 m (655′) spiral frieze, including an illustration of a bridge being built over the Danube, planned and executed by Trajan's architect Apollodorus in 106 CE. The combined timber and stone bridge features a compact structure, like Caesar's Rhine bridge, ostensibly serving only to transfer Roman troops across the Danube.

At the same time, the technology of constructing bridges from wooden trusses on massive stone pilings was also used for permanent bridges such as, for example, the bridge over the Mosel at Trier (Germany) or Constantine the Great's bridge over the Rhine at Cologne. Remains are still visible in Trier. The road bridges of southern Spain were completely constructed of stone, and many of them continue to serve their original function. Because Roman highways are often only recognizable through their vestigial routes, the bridges testify to the standard framework of Roman Imperial traffic. Only through bridges was it possible to effectively interlink the Roman transportation system, thus expediting the quick and efficient movement of troops and the transmission of messages. That is to say, the most direct route possible facilitated the speed of travel. The Romans

recognized this necessity, and thus they did not avoid topographic obstacles such as valleys or rivers, but instead they bridged them.

Magnificent Roman-era constructions outside of Italy are often better preserved than those in Italy itself. In Alcántara, located at the farthest end of Spain, we find one of the most beautiful Roman bridges of all. And road bridges remained important components of an extensive post-Roman transportation network. The fact that the Arabic toponym *Al Kantara* (bridge) frequently occurs in this or similar form in Moorish place names of towns near Roman bridges shows the enduring influence of these infrastructures into the Arab period.

We find Roman bridges throughout the Empire in every possible state of preservation. Many appear cast in one piece, and we recognize in this a unique hallmark of the Roman architect. Elsewhere the traces of time are unmistakable, and post-Roman renovations reveal the interests of contemporary ruling powers and how their architectural measures preserved bridges. Medieval constructions, in no way inferior to their Roman predecessors, were also erected on the foundations of Roman bridges that had been completely destroyed, as at Aspendos (Turkey), where the Seljuk Turks made the Eurymedon River crossable again at the beginning of the thirteenth century with an exceptionally good medieval bridge.

5. Tunnel Construction

Tunnel construction is perhaps the most difficult of all feats of engineering. Until the introduction of modern drift technology, the essential problem in tunnel construction was maintaining the intended path underground. Therefore, in three thousand years of tunnel construction, two tunneling procedures were employed: the so-called *Gegenortverfahren* (drilling a tunnel from two sides and meeting in the middle), and the qanat, or light shaft, procedure.

According to the *Gegenortverfahren* procedure, two teams of workers began constructing the tunnel at each end, and the two tunnels met more or less exactly in the middle, as with the sixth-century BCE Tunnel of Eupalinos on Samos (Herodotus 3.60). The exceptional difficulty of this method lay in maintaining the intended direction underground over the long drift distance. Engineers could correct deviations from the planned path through a change in drift direction in the subsequent section. It is precisely these corrections which are easily recognizable today in tunnels built using this procedure.

To minimize this type of drift error, from the earliest times tunnels were built according to the qanat procedure, in which the section is divided into several building lots. The path of the tunnel is marked off above the mountain, and shafts are dug at regular distances. In each shaft, workers begin at a predetermined depth with the drift of a tunnel, and then they try to align one shaft with the one directly next to it. In this way, short drift sections are completed, and drift errors are minimized. The connection of all the sections completes the tunnel. This procedure comes from ancient Persia, where water often had to be supplied from far away. The underground source was tapped and conducted in kilometer-long qanats into the service area. These qanats were nothing more than connections of numerous sections of tunnel segments. After its establishment around 1000 BCE, the qanat procedure soon spread across Asia Minor and North Africa. Under designations like Kahris, Käris (Iran), Foggara (Sahara), Khiras (Afghanistan),

Sahrig (Yemen), Falaj (Oman), Ngoula, Kriga or Chegga (North Africa), Khattara (southern Morocco) or Mambo (Japan), qanats are common and widespread throughout the world, including in Europe, and especially in Italy. The Romans employed this method to build countless tunnels for roads, aqueducts, and spillways. And the Etruscan, or rather the Etruscan–Roman, tunnels used for lowering the level of lakes in the Alban mountains are partly still in use.

Many ancient tunnels survive, and some continue to serve their original function. A spectacular example is the Claudius Tunnel on the Fucine Lake (Italy) with its 5.6 km (3.5 mile) length. Just as stunningly picturesque is the Titus Tunnel near Çevlik (Turkey), through which an entire river has been rerouted. Near Montefurado (Spain), through one of the river-encircled mountain spurs, a tunnel was built as a gold sluice on the Sil River, where small amounts of gold were transported from the slag of the goldmines in the area around Las Medulas. And a pit was added where the heavier gold could be separated from other fluvial material and then collected.

Road tunnels were also built, although rarely. We find them relatively frequently around Naples, perhaps because of the endeavors of a single architect, Lucius Cocceius Auctus, active under Agrippa, and to whom a tunnel on the island of Ponza has been attributed. Two ancient road tunnels stand in direct connection with the expansion of an ancient naval base, the Portus Julius. One of these, the Grotta della Sibilla, enabled a connection between Lake Avernus and the port basin, the remains of which are preserved as the Lucrine Lake. The second, larger tunnel (Grotta di Cocceio, also known as the Grotta della Pace) facilitated access from Cumae to the naval base which lay behind the port on Lake Avernus. The port systems were arranged by Agrippa in 37 BCE, and soon proved unsuitable because of the shallowness of the sea, for which reason a replacement was created at Cape Misenum. With its nearly 1,000 m (3,280′) length and equipped with reinforced entrances and paved drives, the Cocceius Tunnel between Avernus and Cumae is one of the few ancient structures which makes reference to one of its architects (Strabo 5.4.5).

Also attributed to Cocceius, the Cripta Neapolitana, the tunnel from Naples to Pozzuoli, is supposed to have supported heavy traffic. Two ancient sources discuss it. First, Seneca's description gives us a glimpse into the transportation significance of ancient tunnels. He writes in a letter to his friend Lucilius:

> Nothing is longer than this dungeon, nothing more gloomy than these torches, which don't let us see through the darkness, rather only allow the torches themselves to be seen. Moreover, even if the location had light, the dust would swallow it up, which itself is a difficult and burdensome nuisance in an open space, all the more so in that place, where it spins around on itself and it is bottled up without any breath of air, and falls back on those who stirred it up in the first place. (*Letter* 57)

The tunnel has a length of 705 m (2,313′). In antiquity it was 3–4 m (9.8–13′) wide and 3–5 m (9.8–16.4′) high. In the fifteenth/sixteenth century, it was enlarged nearly four times, and replaced only in 1885 with a new construction right next to it. It is probably this Cripta Neapolitana that is the only ancient tunnel indicated on the *Peutinger Map* (GREEK AND ROMAN CARTOGRAPHY). In the Posillipo neighborhood of Naples, yet another tunnel was constructed: the Grotta di Seiano, said to have received its name from Tiberius' praetorian prefect, but also attributed to Cocceius. However,

its period of construction cannot be confirmed, and Sejanus (20 BCE–31 CE) could have been responsible for later repair work. The close-laid predecessor of a road tunnel at Furlo-Pass on the Via Flaminia is more like a breakthrough. The inscription over the north portal (*CIL* 11.6106) dates the structure to the later years of Vespasian's reign (69–79 CE).

Because architectural drawings, descriptions, measurements, and other documents from the time of the construction of such projects in antiquity and the Middle Ages have been lost, we must rely on the tunnels themselves. However, there is one important (but late) literary source: *Kitab inbat al-miyah al-khafiya (Book on the Extraction of Hidden Waters),* composed by the Arabian mathematician Mohamed Al Karaji at the beginning of the eleventh century in Persia. Al Karaji discusses in detail how to find water levels, he describes instruments for surveying, and he elaborates on water conduits, including their construction, lining, how to guard against decay and how to clean and maintain them. His description of qanat construction is so vivid that he gives us insight into the technical problems, explaining the tools, construction practices, and even the methodologies underlying line layout. Al Karagi often offers several solutions for one problem, and we assume that he preserves the state of technology at the turn of the first millennium CE as well as experiences from more recent generations, as is clear from passages such as "The ancient Persians used to …" (see Grewe 1998, 33–40).

6. Shipping Canals

Even today the most economical form of commercial transport is along waterways. This was especially true in antiquity, when overland routes were badly constructed and often in poor condition. For heavy loads, for example, construction material for city infrastructure, no other method of transport was even considered. In earlier times, these types of loads could only be transported along waterways, such as navigable rivers. If waterways were not readily accessible, loads then had to be conveyed over the shortest possible land route, or artificial waterways (canals) were added to facilitate transport (see Strabo 3.2.5, 5.3.6, 17.1.4; Land Transport and Vehicles). Canals served to connect a production center or delivery destination to an existing navigable waterway, and, more importantly, canals linked bodies of water, thus making large geographical areas accessible to marine and riverine transportation.

The history of shipping canal construction has its roots in the advanced civilizations of the ancient world. The earliest canals, found in Egypt, Mesopotamia, and China, are part of the essential cultural fabric of these lands. The canal between the Nile and Red Sea, built around 600 BCE by Necho, was repeatedly renovated by Darius I, the Ptolemies, and Trajan. The canal was wide enough to allow two ships to pass, side by side, and Herodotus reports that it took four days to travel the entire distance (2.158).

An early canal system (483–480 BCE), built by Xerxes as a canal breakthrough near Mt. Athos, seemed more an object of prestige than a utilitarian construction:

> From what I can gather, Xerxes ordered the canal to be dug because of his arrogant pride. He wanted to display his power and leave behind a memorial to himself. For they could easily have drawn the ships across the isthmus, but instead he ordered that this canal be dug to connect with the sea sufficiently wide for two triremes to row side by side on it. The same

> men who excavated the canal were assigned also to bridge the Strymon River. (Herodotus 7.24; trans. Purvis)

Herodotus also reports on the details of this canal's construction. Xerxes had divided the entire project into several sections, assigning the work to various tribes. In most sections, the bed of the canal had to be excavated with vertical walls:

> Now the barbarians divided up the ground along the canal route among their nations and dug the channel as follows. They drew a straight line along the border of the city of Sane, and when they had dug the trench deep enough, some of them kept digging at the bottom of the channel while others continuously carried the excavated soil up to another group of men standing on scaffolds above; these in turn passed it up to yet others, until it reached those at the very top, who carried it away and deposited it elsewhere. At the sites assigned to all except the Phoenicians, the banks of the trench kept caving in, doubling their work. (7.23.1–2; trans. Purvis)

This was presumably because the steeply designed walls had no support and kept collapsing. Such was not the case in the Phoenician section. In contrast to all other workers, the Phoenicians employed a technique of graduated canal walls. This "bench-cut" method of building created extensive earthworks in the upper part of the canal construction zone, but with progressive construction management one reached the bottom of the canal with the same width as in the other segments. Herodotus praised this achievement:

> But the Phoenicians, whose expertise is evident in many situations, displayed it here in particular, for on all the land that fell to them to dig, they made the top of the trench twice as wide as it was supposed to be and reduced the width as they dug farther down, so that when they reached the bottom, the trench was equal in width to what had been dug by the others. (7.23.3, trans. Purvis)

The naturally occurring Isthmus of Corinth, a 6 km (3.7 miles) wide, 75–80 m (246–262.5′) deep link between central Greece and the Peloponnese, encouraged the early building of a canal there to replace the *Diolkos*, an artificially built towline canal (for smaller ships) which had existed since the sixth century BCE. Serious attempts at canal building continued there into the time of Nero, who ultimately failed. The plentiful traces of this former attempt are no longer visible, covered up by the modern canal (1881–1893).

In Europe the first shipping canals were built by the Romans. But sources report both successfully completed and abandoned canal projects. The Mosel–Saône canal mentioned in Tacitus (*Annals* 13.53) was not completed until 1881–1882 as the Canal de l'Est. In the Roman period, this canal was probably considered an artificial river branch from the Mosel, that is to say, a drainage channel, conceived without locks. One canal built by Drusus on the Lower Rhine about 12 BCE no longer survives. But two ancient authors bear witness to this structure. Suetonius extolled this work:

> On the right bank of the Rhine, he commissioned completely new canal work, an impressive construction that still carries his name today." (*Deified Claudius* 1)

Similarly, the course of the *Fossa Drusinae* is no longer reconstructible, but because the canal lay on the other side, the right side of the Rhine, it can only have encompassed

a Rhine–Ijssel link, to arrive at the North Sea by way of the Zuiderzee. This reconstruction of the section makes sense when we follow Germanicus' campaign against the Batavi, as described by Tacitus:

> He entered the conduit which has the name "Drusian;" and he prayed to his father Drusus that, by the example and memory of his plans and achievements, he should gladly and propitiously help one who was now engaged in the same bold enterprise. From there he traveled across lakes and Ocean on a favorable voyage as far as the Amisius River. (*Annals* 2.8.1; trans., Woodman)

This mere 3 km (1.86 mile) shipping lane probably spared the Romans the dangerous crossing of the North Sea at the delta of the Rhine.

A second canal, creating a link on the other side of the Rhine between that river and the Maas, served the same purpose. In reference to this canal, constructed under Corbulo, we gather from Tacitus that its construction was motivated not just by transportational considerations:

> Nevertheless so that his soldiery might be divested of their inactivity, he ran a conduit of 23 miles (35 km) in length between the Mosa and the Rhône, by means of which the uncertainties of the Ocean could be avoided. (*Annals* 11.20; trans., Woodman)

Moreover, a certain amount of occupational therapy for the troops is not to be overlooked as a motivation in the construction of the *Fossa Marianae* between Arles (France) and the Mediterranean Sea (Strabo 4.1.8; Pliny, *NH* 3.34). A further, more important reason for building the *Fossa Marianae* was more practical, because it was said that, in this way, a replacement shipping lane could be built for the permanently silted Rhône Delta. With the construction of the Marius Canal, leading to the Mediterranean along the eastern side of the Rhône, Arelate (Arles) was established as an easily reachable port city along this waterway. Thus the Mediterranean Sea, at that time already entirely navigable, would have been linked with the North Sea by means of the intended Mosel–Saône Canal.

Professionals from the military had to be contracted for the most difficult phases of building. Such was the case with Nonius Datus, chosen from the third legion to plan and build an aqueduct at Saldae (Algeria) in 152 CE. This is no different in the construction of shipping canals, because these difficult works required a high level of technical ability. This assertion is emphatically supported through the exchange of letters between Trajan and his governor in Bithynia-Pontus, Pliny the Younger (111–113 CE). Pliny aimed to connect an interior lake near Nicomedia with the sea and asked Trajan for the assignment of a *librator*, a professional planner and surveyor. Trajan advised him to appeal to the governor of Lower Moesia, where such professionals were in abundance. He then advised that the *librator* might check whether the lake would not be drained dry by the planned canal construction (*Letter* 10.41–42).

7. Summary

The achievements of Roman engineers in solving infrastructural challenges are extraordinary. But we are handicapped by the fact that blueprints, building descriptions, and many important written sources have not survived. Ancient authors, such as Vitruvius



Figure 46.4 Tombstone of Ammianus, Hieroplis. Photo by author.

and Frontinus, report technical details, but in order to accurately decode the technology, we must engage with the perspective of the ancient engineer, for only in this way are we able to comprehend ancient building strategies. Recent research reveals new insights into aqueduct construction and, in particular, how measuring tools, such the *chorobates* and *groma*, were used. But technological discoveries go further. For example, a recently decoded tombstone relief in Hierapolis (Pamukkale, Turkey) proves that, by the third century CE, a gearbox for transferring circular to horizontal movements had already been developed. Ammianus, otherwise unknown, preserved this invention for the propulsion of a water-driven double masonry sawmill on his gravestone (Figure 46.4).

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CHAPTER 47

Siegeworks and Fortifications

Raffaele D'Amato

1. Fortifications

From the beginning of human history, settlements were linked with the problems of defense and survival. Men circumscribed territory to create a space delimited by some sort of natural protection, as a defense against wild animals or human attack. With the advent of civilization, people used wood, stone, and earth to demarcate space. Civilization brought organized war, conquest, and expansion. One of the primary purposes of the development of permanent inhabited sites was defense, as illustrated by the preponderance of settlements on naturally defensible terrain. Provisions (food and water), in addition to the walls themselves, were needed to ensure self-sufficiency under siege, and they also influenced the structure of the defense walls.

Bronze Age Greece

As technology advanced, powerful military defenses arose in the Mediterranean. The first major Aegean urban settlements, with their elaborate fortification systems, flourished on the Greek mainland and Cycladic islands by the second half of the fourth millennium BCE (D'Amato and Salimbeti 2013, 46). On the Greek mainland, strong fortifications were built from about 5000 BCE, for example, at Sesklo and Dimini in Thessaly. Primitive organized defensive warfare was already present in fortified pre-Minoan settlements, as at Kastri on Syros and Panormos on Naxos (D'Amato and Salimbeti 2013), and Lerna in Argolis (Ekonomidou 1993, 274; Wiencke 2000, 91–92, plates 3–8, figures 1.15–1.19).

The settlement that developed on "Kastraki" hill (Sesklo) and the surrounding area, covered an area of at least 100 km² (38.5 miles²) during the Middle Neolithic period.

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All the houses had stone foundations and were surrounded by large walls, perhaps simple retaining walls or possibly defensive or privacy walls (Liritzis and Dixon 1984; Karykas 2003, 7–13 with reconstruction). At Dimini, six curvilinear enclosures (0.6–1.4 m [2–4.6′] wide) were built of local slate. With a height of 1.5 m (4.9′) where they were freestanding, these structures reached 1.7 m (5.5′) where they functioned as house walls. Arranged radially, they were interrupted at four points by passages 0.85–1.10 m (2.7–3.6′) wide, leading to the settlement's interior (Adrimi-Sismani 2008).

During the most significant period, 2700–2000 BCE, Aegean inhabitants lived in organized settlements which had small citadels with fortification walls, bulwarks, towers, and gates providing protection against sea invaders or neighboring populations. Despite the apparent absence of conflict or destruction, small Cycladic forts presumably reflected contemporary insecurity (Ivanova 2007, 253–255). This architecture may be viewed as a miniaturized version of the great defensive circuits of earlier stages at sites such as Troy I–II (Korfmann 2005, 48–51, 99) and Lerna. In the Kastri citadel on Syros, located on a steep hilltop, the fortifications are formed by a wall with six hollow projecting bastions built of small to medium slabs, with the presence of a second defensive breastwork outside the wall (Louyot 2007, 9–33, 19–20; Sahoğlu 2008, 488). Entrance is gained through one of the bastions. The internal settlement consists of clusters of small rooms. Another small fortification, Panormos on Naxos, has an irregular interior with several roughly semicircular bastions and a single entrance from east (Doumas 1972, 151–170, figures 17–18).

Defensive towers show a development toward more advanced warfare strategy. Towers appear at Lerna on the mainland during the Early Helladic II (EH II) period (2500–2300 BCE). Lerna, with one of the largest prehistoric mounds in southern Greece (circa 180 m^2 [1937.5 ft^2]), probably owed its importance to its position on the narrow isthmus that formed the route from Argolis to the South Peloponnese (Wiencke 2000, 1; Caskey 1960, 285–303). Early Bronze Age Lerna had substantial fortification walls and a palace or administrative center in a central building (the "House of Tiles"). The EH II settlement at Lerna was surrounded by fortifications consisting of a double wall with interior rooms and towers flanking at least one gateway (Caskey 1968, 114). The older part of this circuit wall, altered and rebuilt several times, is east oriented (Caskey 1997, 2, 11 [areas Q-T in figure 10]; Peperaki 2004, 214–231, figure 12.1). From room 11 there was access to a U-shaped tower. Beyond this, a stepped stone roadway came up from the southeast, probably from the shore, to a gateway (Caskey 1997, figure 10). This tower was soon demolished and replaced by the heavier and solid tower that covered parts of the old steps (Wiencke 2000, 99, plans 5, 6, 8, 18, figures 1.11, 1.16, 1.18). The towers themselves were hollow, allowing the space to be utilized during attacks. The sole purpose of these towers was to fire projectiles from an elevated position (Caskey 1958, 125–44, 132–33, plates 22–24). A similar defensive system is visible at Aegina Kolonna, providing a comparandum for defensive architecture during the Early and Middle Bronze Age with the Near East, mainly with Jericho.

The major Cyprus settlements, about 1600–1450 BCE, located along the coast and in the central part of the island, were structured as defensive fortresses. They were generally square or rectangular, surrounded by massive walls, about 6 m (19.5′) high, closed on all four sides by defensive ramparts (Karageorghis 2002, 31, figure 17). Around the fortress were soldiers' barracks, and a rectangular tower occasionally protected the access gate.

Towers first appear on Crete at Hagia Photia during the Middle Minoan IA period (2000–1925 BCE), somewhat later than on the Greek mainland and further east (Tsipopoulou 1992, 66–69, 66, plates 9–10). The large building complex consists of 37 rooms defended by protective walls on three sides (Tsipopoulou 1999, 182–183, plates XXVIIIa, XXXa–XXXIIc). The defensive walls, 1.3–1.5 m (4.2–4.9′) thick, are preserved as foundations of undressed stones: there are three apsidal buttresses on the north side of the complex facing the sea, and another at the southwest corner, likely near an entrance from the plain. Serving much the same purpose as defensive towers, these buttresses increased the defensive character of the site (Tsipopoulou 1988, plates 6, 10). The large enclosure walls would have likely protected inhabitants from sea-borne threats, because projectiles and other long-range weapons would have been ineffective against the large walls. If, however, attackers anchored, the walls could then be overtaken, climbed, or possibly destroyed. Consequently, the tactics of massed and concentrated assaults were sufficient inducements to stimulate new strategies for defense. These large bastions probably served also as barracks, storage facilities, and administrative buildings, and they could be regarded as symbols of an incipient military state (D'Amato and Salimbeti 2013, 60).

Archaeology shows that inhabited sites on Crete were more likely to be located away from the coast, as the early inhabitants likely felt vulnerable to attack from the sea. Further, "guard houses" or "guard-posts," both in the countryside and adjacent to settlements, appear to have had defensive functions. In addition, "refuge sites" were placed strategically to offer inhabitants safe haven in times of danger and insecurity (Chryssoulaki 1999, 78–83).

The first Greek citadels were a mix of practice and efficacy. When tracing out walls to encompass a town, there was a natural tendency to try to employ natural defenses such as cliffs or steep slopes: citadels were usually built on hilltops and surrounded by walls following the contours of hills (Jakovidis 1999, 199–204, 202; Demakopolou and Divari-Valakou 1999, 205). This is still evident in the Athenian Acropolis, which formed the first Bronze Age nucleus of that city, and in the first hub of Menelaus' Sparta (Figure 47.1). Parts of the defensive walls and a thirteenth-century BCE underground cistern have been found in Athens, revealing a complex system of fortifications. A first wall, coinciding with the Acropolis, surrounded the palace, while a second defensive wall was erected around the lower town (Iakovidis 2006, 69–70, 79–83, 105–07, 150–57, 227). An underground spring at the north edge of the Acropolis, linked to the cistern, was essential for surviving a siege (see map in Anderson Immerwahr 1973, figure 6).

The citadel of Mycenae, rich in gold (*Iliad* 11.46 *et passim*), is the most striking example of this age, especially in its final shape, circa thirteenth century BCE, with the Lion Gate flanked on the right by its powerful protective bastion (Jakovidis 1999, 201–223). The city was protected by cyclopic walls 900 m (2950′) in total length. The Palace, closed within these walls, was erected on the rocky hillock which dominated Argolis (Jakovidis 1988, 21, 28–29, 40–45). These walls are typical of late Bronze Age fortifications in Greece, made of massive stones, some as large as 12 tons, inspiring the belief that they must have built by the mythical Cyclopses (Pausanias 2.25.8). With a medium average thickness of about 5 m (16.5′), these impressive walls still reach a height of 7.5 m (24.5′), but were originally 10–12 m (33–39′: Jakovidis 1999, 200).

Two gates were built into the walls at right angles, such that enemies could be attacked from high ramparts before reaching the gate. This was the function of the



Figure 47.1 The thirteenth-century BCE site of the *Menelaion*, near Sparta. Photo by author.

bastion erected at the far side of the main gate: it dominated the gate, so that the defenders could hurl missiles at exposed attackers. The famous Lion gate was built, pseudo-ashlar style, from four massive blocks (Kontorlis 1985, 43). The lintel stone alone weighs 20 tons (Campbell 2010, 25), and the gate's opening still measures 3 m^2 (32 ft^2). Two narrow sally ports punctuated the walls, and the towers were crenellated.

Tiryns was probably the most strongly fortified citadel. Built on a low rock rising some 18 m (59′) above the surrounding plain (Kontorlis 1985, 60), the first nucleus was built around 1500 BCE. Fortifications were added to north and south circa 1425 BCE, and finally, around 1300 BCE, the south and east walls were reinforced by galleries (fitted with vaulted roofs) which also show evidence of mud brick battlements. Chambers in the walls, furthermore, allowed archers to beat off besiegers.

Dark Age Greece

Fortifications of the Greek Dark and Archaic eras closely resembled late Bronze Age fortifications: the seventh-century walls at Emporio on Chios, almost identical to Bronze Age walls, are even inferior (Frederiksen 2011, 8–9). The citadel or acropolis remained the focal point of town defense, and Emporio's fortified hilltop was probably only used for refuge. Until the early sixth century BCE, the defenses of the Athenian Acropolis were in stone and wood, that is, much like those of the Bronze Age (Papadopoulos 2008, 31–46). Despite well over a century of excavations in and around Athens, there is absolutely no evidence for a fortification wall of the Archaic period other than the

Achaean fortifications, until the construction of the Themistoclean wall. But, from the sixth century on, Greeks began to fortify not just the defensive center but entire towns, especially in the colonies of Asia Minor. Under pressure from Lydia and then Persia, Ionians were compelled to improve their fortifications (Connolly 2006, 274), and there were clear criteria for choosing city sites according to the needs of defense (Aristotle, *Politics* 1327a, 1330a–b).

Classical and Hellenistic Greek Defenses

According to Thucydides (1.4.89; 2.15.3, 4), Athens had a circuit wall before the Persian invasion, probably dating from the Bronze Age. After the Persian sack in 480 BCE, the Athenians rebuilt the city walls to encompass the whole populated area and to connect the walls with the fortifications of the Piraeus port. Athens was, in fact, totally dependent on food brought in by sea, and the long walls enabled the Athenians to maintain contact with their fleet even while under siege (Herodotus 6.116; Thucydides 1.107.1; Plutarch, *Cimon* 13.7; Conwell 2008). Initially there were two long walls, one running from the city to the Piraeus, the other to Phaleron, a broad open bay where the first Athenian harbor was situated. Later, a third long wall was added to the south, built during the war with Sparta, parallel to the first, giving the city a defended corridor to the port, and rendering the Phaleron wall superfluous (Fields 2006a, 18 with reconstruction). All these fortifications were dismantled in 404 BCE at the end of Peloponnesian War.

The development of siege engines during the fourth and third centuries BCE brought to bear new defensive systems, able to defend against new siege techniques (Connolly 2006, 288). It was desirable to keep besiegers as far as possible from the walls: any defense would have been useless against an enemy who had breached the walls. Catapults were used for defense, and, from the fourth century BCE onward, walls and towers were designed to hold such artillery. Both walls and towers were bored with arrow slits and artillery ports, as at the Dipylon Gate in Athens (Fields 2006a, 26 with reconstruction). Towers were often as many as four or five stories high with heavy artillery located at the second level and lighter pieces at the top. A pitched roof replaced crenellations, primarily to protect defenders from enemy missiles, as, for example, tower L in Messene (Fields 2006a, 39 with reconstruction). At Paestum, the towers had shuttered windows and arrow slits for catapults, but not crenellations (Winter 1971, 88).

Towers also featured postern gates for sallies against attempted encroachment, as at Gyphtokastro. A large ditch, or series of ditches, was usually dug in front of the walls as a precaution against sappers and also to make it difficult to bring up siege machines. Outer ditches were usually fronted with palisades or thorn hedges (Connolly 1986a, 68). The inner ditch was protected by stone outworks behind which were artillery emplacements. Beyond the trenches were covered holes and artificial marshes to trap enemy machines.

There was a tendency to thicken and heighten walls, built with well-squared polygonal stone or mud brick. The old walls with crenellated battlements (*epalxion*) were sometimes replaced by screen walls with shuttered artillery ports and arrow slits or windows (*epalxis*), often built according to the "saw tooth" system, as at Samikon in the Peloponnese or at Miletus in Asia Minor (Nossov 2009, 18–19; Warry 1981, 91; Philo, *Poliorcetica* 1.44 in Marsden 1971, 105–184). Vaulted rooms, reminiscent of Bronze Age citadel casemates, were sometimes built into the walls for the troops quarters.

Roman City Walls

Roman walls and defensive systems evolved over many centuries (Lander 1984; Säflund 1998; Coarelli 2000, 20–25). The earliest ditches and banks were replaced in the sixth century BCE by an Etruscan-style fortification under the Romano-Etruscan King Servius Tullus (ruled 578–535 BCE). After the Gallic sack of Rome (387 BCE), the consul Camillus rebuilt the Servian Wall in tufa—11 km (6.8 miles) long with a parallel ditch 29.6 m (97′) wide and 9 m (29.5′) deep—and fitted it with several gates (Melani 2000, 20). Around the turn of the millennium, the city grew and expanded well beyond the limits of the Servian Walls. For three centuries, Rome did not need walls. But in the third century CE, new waves of barbarian raiders exposed the city to enemy incursion for the first time since the Gallic sack of Rome in 390 BCE. With this new menace, cities empire-wide began to reinforce old walls or build new ones. Valerian (ruled 253–259 CE) erected a new defensive wall around the Athenian Agora (the Herulian wall), and in 280 CE the Athenian citizens completed a second one, portions of which are still visible (Hurwit 1999, 253–254).

Recognizing Rome's new vulnerability, Aurelian (ruled 271–275 CE) commissioned a new, monumental defensive structure, the Aurelian Wall, still surrounding a large part of the old Roman urban circuit (Zosimus 1.25; Chaillet and Martin 1999, 52–53). The circuit was studded at regular intervals, about every 30 m (98.5′), by a system of 381 towers (Fields 2008, 33). Walls and towers were built of a compact core of irregularly shaped pieces of tufa and travertine held together with *caementa* of lime and pozzolana (*opus caementicium*), faced, inside and out, with bricks or tile set in mortar (*opus latericium*): these walls, originally only 6.1 m (20′) high and 3.65 cm (1.4″) thick, were restored by Maxentius (ruled 306–312 CE: Mancini 2001, 26–32). He did this by doubling their height, blocking several minor entrances, and strengthening a number of gateways. According to Lactantius (27.2), Maxentius began to excavate a ditch in front of the walls, never completed. A century later, these walls were again reinforced by Stilicho, the Vandal *Magister Militum* ("Master of Soldiers") of the Emperor Honorius (ruled 395–432 CE). The walls proved effective twice against the Goths, but they were not strong enough in 410 CE, when Alaric sacked the city (Procopius 3.2.7–39). But the walls continued to play a significant role in late antiquity: strengthened twice in the fifth century, they were the kernel of the victorious Roman resistance of Justinian's *Magister Militum*, Belisarius, against the Goth Vitiges who besieged the city in 537–538. Belisarius restored a good portion of the walls and opened a sally port, which is still visible (Procopius 5.19.13,18).

Roman Imperial Defenses

Such fortifications spread throughout the Roman Empire. The need to defend the huge Empire inspired the creation of a system of fortresses and walls along the borders, sometimes combined with natural defenses like rivers, deserts, and mountains and always reinforcing Rome's superiority. In Germany, temporary military installations (marching camps) were replaced with permanent stone camps. Prosperous fortified sites were promoted to colonial status, for example, Colonia Agrippina (Cologne) and Moguntiacum (Mainz) (Tacitus, *Annals* 12.27; Carroll 2001,123;

Klein 1998, 60–66, 61). Under Hadrian, Germany was defended by a palisade fronted by a ditch, replacing an earlier earthen bank. The Rhine provided a partial barrier to tribal movement which the Romans could control through naval squadrons and by supervising crossing points (D'Amato 2009, 7; Pitassi 2011, 117, 139, plate XX). In Raetia, roughly Switzerland and Austria, a stone curtain wall was built. The second major European river frontier, along the Danube, was joined to the Rhine frontier by linear fortifications which protected a sensitive triangle of territory to the south-east of Argentoratum (Strasbourg). In other parts of the Empire, the *limites* (boundaries) were completely open, or simply marked by a military road or river. In the east, small client kingdoms buffered Roman territory in Anatolia and the Levant against the Parthians and Sassanids. Thereafter the upper and middle Euphrates provided a suitable line on which to base legionary fortresses. Between the Euphrates and the Arabian Gulf, the desert offered a reliable buffer, although indigenous tribes who knew this inhospitable terrain intermittently troubled Roman holdings to the west. North Africa, annexed gradually (circa 150 BCE–50 CE), was the southern portion of the eastern frontier. Under Hadrian, however, dry-stone walls were built, strengthening the African *limes*. Other sections were left open but not unguarded. Desert, supplemented by occasional physical barriers and forts still active in the seventh century CE, played a significant part in marking the boundaries of Roman authority (Ravegnani 1983, 45–46, 55–68). In Britain, in contrast to the other major frontiers, Romans relied primarily on linear defenses, such as the walls of Hadrian (stone) and Antoninus (turf-block) that combined protection with propaganda in order to separate the hostile Caledonian tribes from Roman areas. Hadrian's Wall, extending about 120 km (75 miles: from Bowness to South Shields), was composed of three separate defensive features: a ditch to the north, the wide stone curtain with towers, eighteen forts, mile castles, and a large earthwork to the south. At some points, the stone curtain was 2.96 m (9.7′) wide and about 4.4 m (14.4′) high. In the west, parts of the Wall were built in turf blocks with a width of 5.9 m (19.3′) at the base. Fort defenses were conceived for the use of hand-thrown weapons, javelins, and throwing spears, or arrows and stones. The effective range of javelins is estimated to have been 25–30 m (82–98′: Fields 2003, 16).

It is ironic that the best-studied Roman defenses—between the Rhine and Danube in south-western Germany and the walls of northern Britain—are not typical of the Roman frontier. These frontiers were maintained to delimit and protect Roman territory by barring entry to foreigners, but they served also as places of exchange and transmission of goods and customs. The dimensions of Roman fortified centers depended upon the number of troops stationed there. Fortresses, permanent bases for two legions before Domitian, were later reduced in size to accommodate one legion or one legion and cohorts of auxiliary troops (Fields 2003, 6). Forts were permanent bases for auxiliary units, protected by an earth rampart, bored by four gateways, each with a timber tower. The earth rampart was encased with timber or turf and built over a bed of logs or a stone base. Fortresses and forts on Hadrian's Wall still show the remains of centrally placed headquarters buildings (*principia*) facing the main road (*via principalis*). On the side of the *principia* was the garrison commander's residence (*praetorium*). Situated near one of the side gateways (*porta principalis dextra* or *porta principalis sinistra*) were the granaries (*horrea*). Gateways, as at Birdoswald on Hadrian's Wall, had double portals and sometimes springers for an arch.

Smaller installations for accommodating auxiliary cohorts, fortlets were placed at intermediate points along the frontier: river crossings or along roads. They had just a single gate with a timber tower and one or two ditches beyond. Watchtowers were even smaller installations, made of timber and managed by a *contubernium* of eight men.

During the third century, a new fortress system was erected at sensible points: the fortification design now clearly reflected a radical change from simpler models, revealing a fortification technique that was emphatically defensive (Connolly 2006, 300). At the turn of the second century CE, military architecture produced systems with a combination of stone curtain and earthen bank, sometimes narrow, as still seen in many sites, for example, Reculver (Regulbium in Kent). Here the foundation consists of a trench filled entirely with small flint cobbles. The curtain is 3 m (9.8′) at the base, reduced by two internal offsets to 2.4 m (7.8′). The wall's core is composed of flint-rubble; the outside is faced by neatly squared local blocks. Behind the curtain there is a sloping bank of clay and earth, built largely of earth excavated from the two external ditches, some as much as 15 m (49′) wide. Providing a substantial back for the curtain, this gives defenders access to the rampart walk.

Late Roman Defenses

When the Anglo-Saxons raids began across the North Sea and down the Channel, Saxon Shore fortifications were built, some of which remain well preserved and visible (e.g., at Portchester, Burgh Castle). The later massive freestanding fortress walls reveal a more elaborate construction technique. At Pevensey (Anderitum), successive layers of flint and crushed chalk were laid down and rammed above vertical piles driven deep into the trench base (Pearson 1999). Chalk was packed into the spaces between the timbers, and a layer of mortar was spread over the top, sealing the foundations and ensuring a level platform for the superstructure. Resting on the top chalk layer, just below ground level, was a lattice of large timber balks. The core mainly comprised flint (Pearson 1999, 26–27 with reconstruction). A small earthen bank extended a short distance up the wall's inner face. The wall, constructed of sandstone blocks painted with pink crushed brick mortar, had horizontal bonding courses of brick and sandstone slabs at intervals, typical of the late Roman fortifications and still visible today, for instance, in the walls of Carcassonne in France (Figure 47.2).

2. Siegeworks

Fortifications and siegeworks were always inextricably combined, and the development of one inevitably stimulates changes in the other. We note the parallel evolution of fortifications and siegeworks from the rudimentary to elaborate and complex systems. Most military engagements of any period were not fought on the battlefield but rather against fortified sites (Kern 1999, 3–4). Without capturing these fortifications, the conquest of foreign lands was impossible. The science of siege weapons (*poliorcetica*) is attested in biblical texts and Egyptian artwork which shows fortified cities under siege (Herzog and Gichon 1997, 46–54, 218–224). Early evidence for siege methods is found in illustrations of wheeled ladders to mount walls, dating from around 2000 BCE. From about 1900 BCE, we note representations of familiar siege weapons such as battering rams and wheeled towers (e.g., belfries: Kern 1999, 12, 16, figure 4; Yadin 1963, 16–27). The



Figure 47.2 Late Roman tower of the Carcassonne fortress, fifth century CE. Photo by author.

Hittites and Assyrians made improvements in siege technology, including the construction of siege camps, mounds from which to mount attacks, moats, wall towers, citadels, and raised entrances to fortifications (Bennett 2005, 171–172).

Bronze Age Greece

In the Aegean, we have archaeological evidence of centers quickly fortified for emergencies and violent attacks, especially during the late Middle Minoan II (circa 1800–1700 BCE), when defensive squared walls were constructed at Pyrgus, and two cisterns were brought in. At Malia, metallic tripods were buried, as if the inhabitants feared a raid and tried to secure their valuables (Godart 1999, 39–45, 39; D'Amato and Salimbeti 2013, 49). The complexity and size of these Achaean citadels suggest equally sophisticated siege methods (Connolly 2006, 276). Scant evidence in Homer and from archaeology—like the famous siege *rhyton* from Mycenae (Grguric 2005, 20)—suggests skirmishes and forced starvation at besieged sites. Depending on food supplies and relief troops, a siege by starvation could be protracted (as at Troy, according to legend), sometimes for several years. Treachery was a proven means of ending a siege (Kern 1999, 30: Rahab in Jericho: *Joshua* 2).

Let us consider the legendary ten-year long Greek siege of Troy, celebrated in epic but based on historical reality. The Greeks primarily used a blockading tactic but were unable to take the heavily fortified city until they used a siege engine, the Trojan horse.



Figure 47.3 Roman tortoise battering ram, siege of Seleucia or Babylonia by Septimius Severus, 203 CE, Arch of Septimius Severus, Rome. Photo by author.

Connolly (2006, 277) and Fields (2004, 51–56) propose that an Assyrian war machine could imitate or replicate the Trojan horse: either a battering ram raised on wooden legs, elevating the ram to the upper wall, or a "tortoise" (tank) fitted with wheels (see Figure 47.3). A possible ram would be hung from the roof beam and operated by men within the hide-covered housing, to ward off incendiary missiles. The machine could have been moved by wheels or rollers (Connolly 1986b, 78). Connolly suggests that the horse-shaped machine would have needed a housing that could raise the ram about 4 m (13′) so that it could be brought to bear on the wall's superstructure, and the upright beams could have been extended to form legs. Battering rams, in continuous use since 2000 BCE, were improved in western Asia, especially by the Assyrians (Yadin 1963, 314–315). They were surely known to the Greeks, although unattested in Greek sources until the fifth century BCE.

Classical and Hellenistic Greek Siegeworks

True war machines were introduced to the Greek world only in the Classical age when the science of poliorcetics was fully developed into a *technē* (art) with the construction of artillery engines, composition of technical treatises, and development of technical terminology.

The Greeks copied siege machines from Assyrian and Persian models, including battering rams (*crious*: Warry 1981, 63). According to Diodorus Siculus, Pericles was the first "of all men" to use rams and tortoises, at the siege of Samos, 440 BCE, but his engineer, Artemon from Clazomenae, had experience with Persian machines (12.28.3; Plutarch, *Pericles* 27). In the west, as early as the late fifth century BCE, the Carthaginians were building sophisticated siege machinery—wheeled siege towers and battering rams—which they used against Italiote Greeks, who in turn soon adopted this new technology (Kern 1999, 134). As early as the fourth century BCE, Greek military engineers recognized the need to construct heavy artillery with enough power to breach fortification gates and walls. Dionysius, tyrant of Syracuse, was instrumental in developing perhaps the most important siege weapon, the catapult (Warry 1981, 78–79). In 399 BCE, Dionysius brought together a large number of craftsmen with the specific goal of developing new military technology (Diodorus Siculus 14.41–42). Hero of Alexandria explained that Dionysius' catapult was derived from the so-called *gastraphetēs*, "belly shooter," a hand-held composite bow that was cocked by pressing the stock with the belly (Marsden 1971, 17–60; Schiefsky 2005, 253–270, 254). These machines, and successive designs—the *oxybelēs* (a larger version of the *gastraphetēs*) and the stone-throwing *lithobolos* (which volleyed stones of 10–180 lbs [4.5–81.5kg] like a sling-shot)—were not torsion engines, whose force issued from a bow (Connolly 2006, 281–283).

Eventually developed was the torsion catapult, whose force arose from the application of torque as based on the principle of the rope spring—whereby the release of a tightly coiled rope (at the end of the catapult's throwing arm) results in a great force. A missile, typically a large stone or bolt, could be launched from a torsion catapult with enough force to weaken or breach a wall. The spring frame (*plinthion*) of an arrow-firing catapult was designed to hold two torsion springs under extreme stress, and the pipe fitted into the gap between the two springs formed a window (*dioptra*) through which a man could target his objective (Campbell 2003b, 8 with reconstruction). The goal was not for complete destruction, but rather for surrender after a display of force, as often happened (de Vries and Smith 2007, 41).

At the siege of Tyre in 332 BCE, Alexander employed gigantic siege towers against the city's hilltop defenses. Although the terrain did not permit wheeled machines to approach the wall's foot, the upper stories of such machines were well within missile range of the Phoenician battlements. Posidonius' *helepolis* ("city-taker"), described by Biton (51.6–56.8; Marsden 1971, 66–77), was built for Alexander presumably in 330 BCE. Measuring 18.5 × 15.5 m (60.7′ × 51′), the tower's axles were supported by an iron strapped joist. Two joists, side by side, sandwiched the wheels in between. There were likely also crossbeams, as in late Roman siege towers (Campbell 2003a, 37). The bottom story probably sat on posts fixed to the joists above the axles, with a gap between the axles and first floor timbers. With the posts in position, the wheel rims rubbed against the floor above, and men could push the machine without cramping (Campbell 2003a, 42).

In the fourth century, machines of this kind were often quite large. Among Alexander's successors, Demetrius Poliorcetes was best known for his elaborate siege machines, including the battering ram built by Hegetor of Byzantium, mounted on the top of a massive wheeled shed (Athenaeus, *Mechanica* pp. 21–22W; Vitruvius 10.15). Built by Epimachus in 304 BCE, Demetrius' *helepolis* was an iron clad siege tower, 40 m (131′) tall, armed with artillery (Athenaeus, *Mechanica* p. 27W; Vitruvius 10.16.4). The frame

was constructed of squared timbers, bound with iron. Placed across the center at one cubit (1/2 m = 1.5′) intervals, bars pushed forward the tower, which was mounted on eight solid wheels, each nearly a meter (3.2′) thick, also covered with iron plates. The wheels were mounted on pivots so the tower could move in any direction. The main body of the tower was divided into nine storys, each with two stairways, allowing for two-way traffic without congestion. The front and sides were covered with iron plates nailed on to protect the tower from burning missiles. Portals at the front, at each level, covered by mechanical shutters made from hides stitched together and stuffed with wool, provided excellent protection against enemy missiles. The sides of the machine's undercarriage or grid-iron (*escharion*) measured 23 m (75.5′). Its base was 22 m (72′) square. Crossbeams—against which the men pushed to move the machine—partitioned the interior of the undercarriage at one cubit intervals (Diodorus Siculus 20.48).

Roman Siegeworks

In conducting sieges, the Romans combined practical genius with ruthless thoroughness. If initial assaults did not elicit surrender, the Roman army surrounded the area with defensive walls and ditches, patrolled by Roman troops. No supplies or reinforcements could be brought in, and no sorties could be launched against the besieging army.

The Romans also made efforts to cut off water supply. At the iron age hill fort at Uxellodunum (near modern Vayrac), Caesar first stationed archers to fire on those collecting water from the river at the foot of the hill (*Gallic War* 8.40). The besieged peoples then had to rely entirely on a spring (at the foot of their wall) which Caesar's engineers were able to subvert, thus forcing the town to surrender.

Other methods of overcoming fortified sites were also time consuming. Chief among these was a tactic wherein the attacking force tunneled under the walls and then collapsed the tunnels to bring down sections of the walls above (as at Dura Europos in the third century CE: James 2011). Direct assault of fortifications with scaling ladders and battering rams (easily countered by defenders) rarely brought success. Some fortifications were built on terrain that was not easily surmounted, such as at Masada where the Judeans resisted under siege for nearly three years before the Romans constructed an earthen ramp that breached the walls in 73 CE.

The Romans further developed Greek *poliorcetica* (Gravett 1990, 3), largely with the help of Greek engineers. One of the hallmarks of the Roman army was its versatility, and little distinction was made between machines used for defense and those for attack. Siege weapons (including the familiar towers, *helepoleis*, tortoises, battering rams, and the *onager* or "wild ass") were used both for hurling missiles in battle and attacking fortresses.

The *aries* ("ram"), battering ram, consisted of a large tree-trunk beam, frequently 30.5 m (100′) in length. At one end, an iron or bronze ram's head was fastened. This first beam was suspended from a transverse beam, like a balance, by ropes around its middle. Posts at both ends supported the balance beam (Josephus, *Jewish Wars* 3.19; Vitruvius 10.13.1). Hence soldiers did not have to support the entire weight. Operating the *aries* required the combined effort of several men pushing the machine forward to strike an enemy wall. A well-trained team could give it a rapid and forcible swinging motion backward and forward. Many battering rams were equipped with protective shells or "tortoises" of plank and wicker covered with uncured hides or other fireproof material from which the *aries* seemed to swing like a tortoise's head emerging from its shell (Vegetius 4.14).

The Roman *helepolis* closely resembled its Greek prototype as did the *turris* (tower). Taller than city walls and other fortifications—Mithridates VI's tower at the siege of Cyzicus in 73 BCE was 45.7 m (150′) high—these formidable engines were generally made of wooden beams covered on three sides with iron, and sometimes with rawhides. Archers and slingers were stationed in the upper stories, and the lower story contained a battering ram. The *turris* was also equipped with ladders, sometimes on wheels, that facilitated scaling enemy walls. The only defenses against the *turris* included burning them, sabotaging the underlying ground, or overturning them by means of battering rams suspended from masts on the city walls.

The Romans also adopted Greek torsion catapults—the larger *ballistae*, and smaller, more portable *cheiroballistae*—significantly improved during the campaigns of Philip II (382–336 BCE) and his son Alexander (356–323 BCE). The *ballista* or scorpion, developed from the *gastraphetēs*, could project missiles weighing from 22.6–136 kg (50–300 lbs). The technology evolved, and finds from Spain (Ampuria, Teruel) shed light on catapults used during the Republic (Russo 2009, 142–145), whereas evidence from Mainz and Cremona gives insight into early Imperial catapults (Campbell 2003a, 34). These catapults had arms fastened to two tightly twisted sinew skeins. Set on a heavy stock, the arms were fitted with a slider that was placed in a dovetailed groove and could slide freely back and forth. On each side of the stock was a straight ratchet with two pawls fitted into them and attached to a claw-like trigger mechanism. A missile would be placed against a thick bowstring strung between the two arms. To fire the catapult, the bowstring was drawn back by the ratchets, and a missile would be shot by releasing the trigger. In time, the *ballista* was rigged with wheels for greater motility.

To these catapults the Romans added the *onager* (see Figure 47.4), which consisted of only a single horizontal spring and a single arm mounted on two large, heavy horizontal beams connected by crossbeams. At the end of the *onager's* arm was a sling from



Figure 47.4 Hypothetical reconstruction of an *Onager*, Salzburg Museum. Photo by author.

which to launch missiles, usually stone balls. The *onager* was fired by a rope trigger that anchored the arm to the base. Technologically simpler than *ballistae* or *cheiroballistae,* and perhaps more powerful, *onagers* are attested only by Ammianus Marcellinus (23.4) during his account of the Alamanni incursions into Gaul (355–57 CE). At least once, despite hitting no one, a single large stone fired from an *onager* caused such mass confusion that it eventually routed the attackers. At the time, the Romans still seemed to have had a large amount of artillery, with catapults defending nearly every Roman fortification, and arms factories continued to supply artillery.

Late Antiquity

Such torsion machines continued to be used into late antiquity. Marsden (1971, 236) concluded that torsion artillery—both single and double-spring—was still produced in late antiquity and that this artillery was comparable in form to earlier Greek and Roman ordnance. According to Marsden (1969, 189), Vegetius (circa 450 CE), Ammianus Marcellinus, the anonymous author of *De Rebus Bellicis* ("On Military Matters," circa 375 CE; see Cameron 1979), and Procopius (500–565 CE) provide "sufficient indirect or implied evidence" to indicate that the standard bolt projector of late antiquity was the two-armed torsion catapult. Indeed, it appears that between the fourth and sixth centuries the use of the older, more technologically complicated two-armed torsion catapult gave way to the cruder, but more easily constructed tension catapult typical of the Middle Ages. This change does not necessarily imply a decline in technological expertise. It could reflect, for example, changing tactical priorities, since what the newer catapult lost in accuracy it more than made up for in greater rapidity of fire. Blockades, however, remained the usual procedure for sieges: Totila's siege of Rome lasted for a nearly a full year (546/7) until one of the wealthy families responsible for the city's security decided to open a gate to the Ostrogoth besiegers in the vain hope of protecting their riches.

Unlike in the West, where cities were in decline after the fifth century, urban life flourished in the East, at Byzantium, and Greco-Roman poliorcetic traditions and the *fabricae*, the workshops that produced war machines, were thriving. Classical sources continued to influence siege techniques as revealed by contemporary poliorcetic treatises, and Classical siege technologies survived. Written accounts of sieges, however, accorded much less attention to the intricate war machines used in antiquity, in part because defense technologies had become more formidable. Even so, this relative absence of advanced technology did not render medieval Roman methods of siege warfare any less sophisticated. In theory as well as practice, the emphasis shifted instead to logistics and politics in the struggle to win or hold fortified towns (Corfys and Wolfe 1999, 7). But this is another matter.

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CHAPTER 48

Arms and Weapons

Raffaele D'Amato

1. Introduction

The importance of warfare in Greek society is nowhere better symbolized than by the fact that its first great literary product is a monumental epic poem, the *Iliad,* which is almost wholly concerned with warfare (Snodgrass 1999, 14; Sage 2002, XII–XIII, 1–3). Though recorded in its final form about 700 BCE, the epic is ultimately the product of a long period of oral composition with roots reaching back to the Greek Bronze Age (circa 1600–1200 BCE). With connotations both negative (men killing other men) and positive (defense of noble ideals, camaraderie, and sacrifice for the defense of common values), war became a real virtue (*aretē*) and the cornerstone of Greek civilization (D'Amato 2013, 47). An integral part of the Hellenic competitive lifestyle and culture, warfare was an *agōn*, a competition (whose etymological connection to "agony" well suggests the intensity of the passion of this practice among the Hellenes), and it delimited the boundaries of citizenship, as in Sparta, whose citizens were warriors par excellence.

2. The Bronze Age

The weaponry of Homer's Achaeans (referring collectively to the Greeks) represented the best available military technology in the Mediterranean basin from 1500 to 1200 BCE (D'Amato and Salimbeti 2013, 4, 12).

Confirmed by archaeology, the use of spears and javelins is well attested on pottery, frescoes, and engraved seals or rings. Longer spears (3 m [10′] or longer), used for thrusting, were normally wielded with both hands (D'Amato and Salimbeti 2011, 13; Grguric 2005, 12). Short spears could have been used both for thrusting or throwing in

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close combat or hunting. Javelins, mainly used for throwing, were normally shorter and equipped with smaller tips (Grguric 2005, 30). The javelin or spear butt (*saurōtēr*) was a further Greek innovation that allowed for a reserve weapon if the shaft was broken: the spear tip could stick in the ground without compromising the spear head.

As high-status offensive weapons, many swords and daggers survive from the Greek Bronze Age (Grguric 2005, 15–16; D'Amato and Salimbeti 2011, 13–16). The earliest swords were fashioned as a very sharp blade, similar to a long spit, with a central strong marked rib. From the sixteenth century BCE, swords were manufactured with a rounded top and a grip that was the extension of the blade (D'Amato and Salimbeti 2013, 30–31). The slashing or grip-tongue sword, described by Homer and able to cut through bodies and armor, marked a revolution in bladed weapons. One of the most enduring of all sword types (Kilian-Dirlmeier 1993, 94–126), this weapon, made either in bronze or iron, first appeared in the late Bronze Age and continued in use for 500–700 years, well into the Iron Age. This model, the so-called Naue sword type, diffused first into central Europe, Scandinavia, and the British Isles. By 1300–1200 BCE, it had spread to Greece, Crete, the Aegean Islands, the Levant, Palestine, and Egypt (Jung and Mehofer 2009, 114, 117–121). Ranging in length from 50 to 85 cm (20–33″), most had straight sides that narrowed to the point. A few examples in both bronze and iron swelled slightly toward the tip giving them a leaf shape (Jung and Mehofer 2009, 125–126). Some featured midribs, often consisting of most of the blade's width, others were lens shaped, and a few were diamond in cross section. The hilt (tang) was flanged, and hilt plates were set within the flanges and riveted (Jung and Mehofer 2009, figure 5). Warriors suspended their swords from a baldric (sword belt), often described by Homer as decorated by silver bosses. In shaft grave V at Mycenae, a bossed gold shoulder belt (the decorative cover of a leather baldric) measuring about 130 cm (4′) by 3 cm (1.75″) was found near a bronze sword (Schuchhardt 1890, 293, figure 259).

Several short single-edged swords and highly decorated daggers have also been found in shaft graves at Mycenae and other Achaean sites. The ritual double or quadruple-axe, an iconic Minoan image symbolizing a powerful female deity, was also employed by the Achaeans as a weapon (D'Amato and Salimbeti 2011, 17–18). Several bronze double axes, hatchets, and pickaxes are attested at various Achaean settlements (Mycenae, Pylos, Thebes), while bronze axes with semi-circular blades (thirteenth to eleventh centuries BCE) have been found in Crete. Bronze, sandstone, and limestone maces or hammers of various shapes and dimensions have been found at Drakotrypa, Paralimni-Teichos, and Cyprus (D'Amato and Salimbeti 2011, 18). A crater fragment from Kynos (LH [Late Helladic] IIIC [1400–1050 BCE]: Fields 2006, 40) depicts a warrior brandishing such a bronze axe in a naval battle. The utilization of metal maces is also cited by Homer (*Iliad* 7.138–141).

The famous silver rhyton from Mycenae shaft grave IV (circa 1550 BCE) shows an organized group of lightly armed slingers (Grguric 2005, 20) in accord with Homer's Locrian slingers, who were armed only with bows and slings of twisted wool (*Iliad* 13.712–719). Sling bullets could be made of metal as at Maa-Palaeokastro (Cyprus)—where bronze sling bullets (4.8 cm [2″] long; circa 1200–1100 BCE) have been found—and other late Bronze Age sites, particularly at Enkomi.

The bow is well known in Linear B tablets, and artisans specialized in bow construction (Melena –1995, 273, tablet AN207+360). Lightly armed archers without defensive weaponry are also indicated (*Iliad* 15.471–473; *Odyssey* 22.116–125): for example, in

the battle scene on the Mycenaean silver rhyton (above). The bowmen here throw their arrows from behind the first lines, and Odysseus, the Locrians, and Philoctetes' lightly armed troops (*Iliad* 2.716–20) are renowned for their use of the bow. Archaeology supports the fact that the Homeric poems are referring to the late Bronze Age, as arrowheads are rare among the finds from the Greek mainland in Dark Ages and Geometric period, but common among the finds of Late Bronze Age Greece.

Although an important element of Achaean weaponry, the bow's status in the *Iliad* was mixed. Agamemnon promised the honor of second place in the division of booty to Teucer, who had adroitly killed the enemy with his bow (*Iliad* 7.266–334), thus qualifying the archer as clever. On the other hand, Diomedes condemns bowmen as "unheroic" because they fight from a distance (*Iliad* 11.385–395). The bow is also associated with defensive weaponry as attested in Achaean archaeological sources. The bowman Teucer takes shelter behind Ajax' full body shield (*Iliad* 8.266–268), and Odysseus famously wears a boar tusk helmet (*Iliad* 10.261–265). And as the Trojan ally Dolon embarks on a nocturnal raid of the Greek camp, he is armed with both javelin and bow (*Iliad* 9.333–336; cf. *Iliad* 7.136–141, 11.191, 13.311). Odysseus wields a double torsion-composite bow (*Odyssey* 21.12), difficult to string unless the stringer sits or squats while bracing the bow over one knee and under the other thigh. Characteristic of Scythian archers, the weapon became familiar in the Classical era (shown on fifth century coins), but was unfamiliar to Penelope's suitors who could not string the bow—not because they lacked the strength, but because they lacked knowledge of this unfamiliar weapon (Hexter 1993, xci, figures 5–6 and 264–265).

Defensive weapons (shields, armor, and helmets) were devised to resist offensive armaments. Shields were mainly of two types: the very large ones which covered almost the entire body and the medium/small ones (Cassola Guida 1973, 13–50). Larger shields, comprising several layers of bull hide (sometimes reinforced with bronze plates), assumed two main shapes: figure-eight and tower. Small shields were either completely circular or had a lens cut from the bottom (D'Amato and Salimbeti 2011, 19–23; 2013, 38–40). A handle on the inside allowed the warrior to hold the shield with his left arm while fighting. Made of several layers of leather with bronze bosses and reinforcements, or sometimes completely of bronze, these models were sometimes suspended from a baldric (D'Amato and Salimbeti 2011, plates A, B, G).

In the late period, large or medium-size squared shields—generally with fringes and two large cuts on the sides—are depicted in pottery fragments recalling those used by Anatolians and Hittites. These shields were sometimes reinforced with metal elements and bosses as verified by the "trapezoidal/tailcoat shaped" specimen found in Cyprus (D'Amato and Salimbeti 2011, plate C).

During the LH I (1550–1500 BCE), different type of helmets were used. The most famous was the conical helmet, reinforced with rows of boar tusks, and probably introduced by the populations migrating into the Aegean from Central/North Europe around 1800 BCE (D'Amato and Salimbeti 2011, 23–24). These helmets were made of perishable material—leather according to Homer (*Iliad* 10.261–265)—on which rows of boar tusk plates were horizontally sewn. The upper plates had a triangular shape. On the top of the helmet was a circular ivory or bronze button, sometimes used to hold a crest (Grguric 2005, 12–13). The neck protection and crest holder were likely made with the same leather that made up the helmet's internal structure. Achaean boar tusk helmets were still in use, but declining, during the final phases of the Late Helladic

period, as corroborated archaeologically at Pylos and Olympia, and in art (Borchhardt 1972, 18–28, 31–37; Vonhoff 2008, catalog 69, 92, 94).

Helmets made completely of bronze were also used. Near Knossos, a bronze helmet (circa 1450 BCE), discovered in one of the so-called "warriors' graves," has two large cheek guards probably stitched or riveted to the helmet (Borchhardt 1972, 55–60, plate 37.1.4). Found in grave XXVIII from Tiryns is a beautiful example of a transitional late Achaean bronze helmet (circa 1050 BCE). The composition of this helmet with four parts and two cheek guards agrees with Linear B tablets from Pylos dated around 1200 BCE where the helmet is described as constructed of four elements and two cheek pieces (Cassola Guida 1973, 97–99, plate 30.3). The famous late Achaean helmets represented on the warrior's vase from Mycenae (circa 1200 BCE) have a similar shape, horns, upper crest holders, plumes, and embossed or reinforced elements. But at least three variants are shown. Even if these helmets are generally interpreted as made of leather or other perishable material reinforced with bronze bosses, we cannot exclude the possibility that similar helmets could also have been made of embossed bronze (Connolly 1997, 28–29).

Metal rings and bands were a typical feature of the so-called "Feather Headgear" in use during the last period of the Bronze Age, mainly depicted on Aegean "Sea People" warriors represented in the Medinet Habu reliefs (*The Epigraphic Survey* 1930, plates 8, 9, 19, 32–34, 37–45; *The Epigraphic Survey* 1932, 71–72, 99–100). This helmet was probably constructed in much the same way as the boar tusk helmets but with the leather thongs turned up at the ends and held in place by one or more metal rings. These "Feather Headgear" helmets were sometimes equipped with neck protection and secured by a leather chin strap (*The Epigraphic Survey* 1930, plates 51–52). Important findings of bronze reinforcements of such helmets come, among others, from the warrior grave A in *Kallithea* dated about LH IIIC (1400–1050 BCE). The finds show remains of strip-embossed pieces, flat strips, and small bronze bosses: all these elements have long nails with which they were once fastened to the helmet's core (Moschos 2009, 356–359, figures1–2). Bronze "rings," serving as part of the helmets' lower edges, are also mentioned in the *Iliad* (7.12, 10.30, 11.96).

The earliest complete bronze defensive armor was found at Dendra, Argolis (Figure 48.1; 1450–1400 BCE). Its composition shows that the Greeks gave priority to protecting the most vulnerable body parts (see EPIDEMIOLOGY AND PATHOLOGY): two bronze plates (about 1 mm thick) protected the warrior's torso and back. To these were added two bronze shoulder guards. Two curved bronze plates were fixed to the underside of the shoulder guards to protect the upper arms. Two triangular bronze pieces were secured to the shoulder guards for additional protection at chest level. A bronze throat guard and six bronze belts connected to the bottom edge of the cuirass, three in front and three at the back (Àström 1977, 28–34, plates XII–XX: all parts show a series of small holes of 2 mm diameter along the edges for attaching a lining to the inside of the cuirass; larger holes, about 4 mm, near the edge of all the elements, were used to connect various plates with laces). A lower arm guard, 20.5 cm (8″) long, shaped like a pipe and tapering toward the bottom, and a pair of greaves (the most ancient until now found in bronze) completed the defensive protection. Reconstructions demonstrate how this panoply, despite its size, was sufficiently flexible and comfortable for use by both infantry and warriors fighting from chariots (D'Amato and Salimbeti 2011, 28).



Figure 48.1 The Dendra panoply, Greece, circa 1450 BCE, Archaeological Museum of Nauplion. Photo by author.

The Dendra panoply marks an evolutionary turning point for metal body corselets. Numerous fragments of bronze armor from the fourteenth to thirteenth centuries BCE have been found in various sites. But the most complete suite of Achaean armor, from the citadel of Thebes (the Cadmeion), represents a new model in terms of flexibility and lightness, without sacrificing defensive protection (Andrikou 2007). From the Dendra specimen, widely used in the fifteenth to fourteenth centuries BCE, the Greeks developed a simpler and more comfortable variant, following the same paradigm of construction but smaller in size. The torso and back protections, to which other pieces were attached, evolved into the bronze belly bell cuirass of the Archaic period, probably already used in the final phase of the Late Helladic, as illustrated on pottery (D'Amato and Salimbeti 2011, 30–31).

Light corselets, often organic or reinforced with metallic elements, and breastplates are well known in the Aegean from the seventeenth to the thirteenth century BCE. Also known is metallic scale armor from the Near East (D'Amato and Salimbeti 2011, 34–35), attested iconographically and archaeologically and utilized during the final phase of the Late Helladic. (At Kanakia, on the south-western tip of Salamina, a single bronze scale from an armor was found. The scale, bearing the stamp of Ramesses II, thirteenth century BCE, possibly suggests that Salamina warriors had fought as mercenaries in his army.)

Depicted in art and literature, greaves on the lower legs, continuing the Dendra paradigm, were usually of linen or other organic material (Rodenwaldt 1921, plate V). Bronze specimens have been found in Enkomi (1200 BCE), Callithea (LH IIIC), Portes (twelfth century BCE), and recently near the town of Amphilochia and at Kouvaràs near Akarnania (Moschos 2009, 356; Jung and Mehofer 2012, 251, 255 figure 7).

3. The Dark Ages, Geometric, and Archaic Periods

After 1200 BCE, vast changes occurred in every aspect of Greek life. The great palace complexes of the late Bronze Age were destroyed or abandoned (Sage 2002, 18). A general decline in technical skills was accompanied by a drastic fall in population and the abandonment of many previously occupied sites (Snodgrass 1971, 365). In contrast, the islands and western coast of Asia Minor experienced large-scale immigration into the early ninth century, when again a measure of stability returned to the Greek mainland (Fine 1983, 30–36).

Archaeology proves a crucial aid to reconstructing the military technology of the Dark Ages, which is obscured by our lack of written and iconographical material (Snodgrass 1999, 35–36). Grip swords of the late Bronze Age are still present in great number in graves (Hiller 1991, 138–139), but from the eleventh century iron replaces bronze.

From about 800 BCE, warrior figures begin to reappear on pottery, providing additional evidence, especially from Athens. In later writers, we have scattered and often mythologized literary references (Sage 2002, 19). Great care must be exercised in disentangling Bronze Age military technology from later practices in Homer. The focus of Homer's near contemporary Hesiod is on the farmer, not the soldier.

Already by the late Bronze Age, iron began to be utilized in place of bronze in the manufacture of weapons, especially swords. By about 1000 BCE, the transition to iron weapons was complete (Georganas 2005, 68–73) with the production of spears and other weapons in iron by the end of the century.

Cited in the Homeric poems, javelin-like weapons are already visible on late Bronze Age representations of warriors fighting from chariots in the Peloponnese. Missile warfare grows in importance, and javelins become prominent in the archaeological record between 900 and 700 BCE when the typical warrior burial included two or three spears (Snodgrass 1971, figure 93; 1999, 38–40; Rawlings 2007, 26).This type of warfare is also illustrated on late Geometric Attic painted pottery (circa 750–725: Brann 1962, 18, 20, 65, 83, plate/catalog 17/304,19/336, 22/383, 26/418). A plausible style of fighting can be deduced: an initial phase of casting spears at long range is followed by close combat of smaller units fighting with swords, as shown on the Dipylon vases (Greenhalgh 1973, 67, figure 40).

Surviving the Dark Ages, the chariot, the prerogative of aristocrats in the *Iliad*, is depicted again on painted pottery about 800 BCE. The rail chariot of the Homeric poems

and late Bronze Age iconography was still in use, together with a square-box four-wheeled chariot known from Dipylon pottery (D'Amato and Salimbeti 2011, 46). A magnificent burial discovered at Lefkandi in Euboea (750–600) contains four horses (and a warrior's concubine) buried as tokens of his prestige (Dressen and Crieelard 1994, 253). Chariots continued to play an active role in combat, although they were also used in ceremonial contexts. Mounted warriors, shown on Greek vases from the late Bronze Age into the seventh century, were more likely heavily armed elite troops than a true cavalry, intended to complement the infantry on the battlefield, which may not have been developed until the sixth century.

The period of warfare depicted in Homer is contested. Some argue for 800–600 BCE. We prefer an earlier era. The *oikos*-based society of the Dark Ages and Geometric period developed from late Bronze Age settlements and social models described by Homer, that is, a society headed by a class of aristocrats who dominated all major aspects of community life, including warfare (Sage 2002, 19–20). Given the limited resources and practiced on a narrow scale, warfare largely consisted of raids for livestock and other booty under the leadership of aristocratic warriors seeking both to acquire goods and to defend and enhance personal power. According to Thucydides:

> There was no war on land that led to the development of any considerable power. All wars were fought against neighboring peoples and the Greeks mounted no foreign expeditions with the aim of subduing others. The smaller communities did not ally with the most powerful nor did these less powerful states join on an equal basis to make expeditions in common. Rather warfare was waged between neighbors. (1.15.2)

Aristocrats of the Geometric and Archaic eras fought with military accoutrements similar to late Bronze Age weaponry: shields, armor, and helmets, made of iron and leather (or other organic material, as linen) on bronze (Snodgrass 1971, 213–295). Widely represented in Dipylon pottery and sometimes confused with the figure-of-eight shield, the so-called "Dipylon shield" was circular or oval with two cuts on each side—this allowed for better maneuverability during combat with sword or spear (Rawlings 2007, 27). Like tower and figure-of-eight shields, this body shield was made of several layers of hide sewn to a wicker frame and sometimes reinforced with metal bosses or plates at shield's external edge.

Similar but later "Boeotian" shields are represented into the fifth century BCE (D'Amato 2010, 244). The Boeotian helmet was constructed either of organic material or bronze, and representations from Crete show an Illyrian (Balkan) prototype that was in use from at least the tenth century BCE, together with the near-eastern conical helmet. Concurrent were hybrid types, as in helmets from Tiryns with both European and Aegean features, together with "purer" Illyrian types, as in the Argos Helmet (Hencken 1971, 8).

Founded during the same era, in 753 BCE according to legend, Rome was militaristic from the beginning. The weapons of the early Roman warrior were inspired by Homeric weaponry, and even into the historical era archaic figure-of-eight shields (*ancila*) were brandished by special priests of Mars, the *Salii* (Livy 5.52.7). Early Roman armor, derived from Villanovan culture, consisted of bronze pot helmets, sometimes surmounted by crests, bronze circular shields, and squared or circular breastplates. Leather armor was widely used, as likely in contemporary Greece (Snodgrass 1999, 41–42).

By the mid-eighth century BCE, a series of crucial political, economic, and social changes occurred in the Greek world. Monarchy was replaced first by aristocratic rule and then by a new governmental construct: the city-state (*polis*). In this context, there developed a new style of infantry warfare, based on a group of heavily armed infantrymen organized in a *phalanx* of close rectangular formation at least several ranks deep. This formation predominated in land warfare in Greece until Philip of Macedon vanquished the allied city-states at Chaeronea in 338 BCE. In a slightly altered form, the Macedonian *phalanx* dominated the Mediterranean battlefield until the battle of Pydna in 168 BCE, when the Roman army, comprising heavily and lightly armed soldiers, vanquished Perseus, the last King of Macedon.

The heavily armed infantryman was called a hoplite, after his shield (*hoplon*), and his equipment followed a standardized pattern. There survives a complete set of armor, the Argo Panoply (700–675 BCE), whose cuirass derives directly from late Bronze Age corselets, strongly influenced by Unrnfield models (Connolly 2006, 54–55, figures 1–3). This defensive armor consisted of a metal Illyrian-type helmet, in use until the time of Alexander the Great. The Illyrian helmet was primitive in shape, open at the face but with extended flaps to protect cheeks and neck. The hoplite also wore a bronze bell-shaped plate corselet composed of two sections, a breastplate and a back plate, like its Achaean prototypes (Figure 48.2). Despite inconveniences, this model endured for two centuries until lighter varieties were adopted at the beginning of the fifth century (just before the Persian Wars). Bronze greaves to protect shins and calves evolved to envelope the leg completely (Sage 2002, 26). Further, sundry armor for ankles, forearms, and thighs was gradually abandoned, although use varied greatly among individual hoplites.

The single most important piece of defensive equipment was the shield (Connolly 2006, 51–54), which by now had evolved into a large circular shield (0.9–1.2 m [3–4′]



Figure 48.2 Detail of the Argos panoply, Greece, circa 750–675 BCE. Archaeological Museum of Argos. Photo by author.

in diameter), extremely convex (D'Amato 2013, 230), constructed from a wooden core initially covered in leather and rimmed with bronze. Eventually, the entire shield tended to be faced with bronze. The grip was a specific Greek invention. The shield had a detachable central armband, the *porpax,* through which the left arm was normally thrust up to the elbow (Kagan and Viggiano 2013, 13.38). The left hand then grasped the second element, the *antilabe,* normally a leather thong which ran around the periphery of the shield's rim. This gripping mechanism allowed a firmer and more rigid grip than possible with a single central handle, and it distributed the weight of the shield more evenly between the elbow and the hand, allowing it to be held more securely in front of the body and for a longer time. But the holding system created problems in protecting the right side of the body, which in turn strongly influenced phalanx tactics.

The major offensive weapon was the heavy thrusting spear (2–3 m [6.5–10′]: Connolly 2006, 63) with a heavy iron or bronze head and a butt spike both for supporting the spear in the ground at rest and as a secondary weapon when the point was broken off (D'Amato 2013, 233). The hoplite also carried a short stabbing sword useful for close fighting.

In all probability the great expense of bronze armor limited the number of troops that any state could field since individual fighters were generally responsible for supplying and underwriting their own equipment (Rawlings 2007, 45–47).

4. The Classical and Hellenistic Age

In Greece and Rome, the heavy hoplite dominated the battlefield until the early fourth century. In Rome, however, tactics varied with the enemy, and the warrior's armament became gradually lighter and specialized (Connolly 2006, 126–127).

In Greece, new forms of body armor were developed. The linen corselet, *linothōrax*, made of pressed linen folded in several layers, was dispersed throughout the eastern Mediterranean by the late sixth century BCE. Also noted are the leather corselet (covered by metal bosses or simply made of hardened leather), lamellar armor (of plates of bronze or leather), and many other composite armors, combining bronze scales with linen and painted leather (D'Amato 2013, 245–246; Connolly 1986, 38–39). Meanwhile the hoplite's metal armor, following the contours of a human torso, became the more anatomically shaped *statos.* Beautiful specimens of this muscled cuirass, the final stage in the evolution of the Dendra cuirass, were worn by Roman, Greek, and Italic hoplites from the fifth to the second centuries BCE (Connolly 2006, 54–59, 100, 110). Fastened on the sides, this armor was often embossed and decorated with silver and gold, and even painted, as were helmets and cuirasses of organic materials.

Although there was a tendency to eschew heavy panoply in Greece shortly before the Peloponnesian War (431–404 BCE), contemporary artwork shows heavily armored hoplites alongside nude warriors or those defended lightly with only shield, helmet, and tunic. Roman legionaries and officers were often protected with anatomical armor (*lorica*). By the third century BCE, also in use was chainmail armor of interlaced rings (*lorica conserta hamis* or *lorica hamata*), a Celtic invention (Robinson 1975, 164; Feugère 2002, 74–76; Connolly 2006, 122–123, 132–133). The more lightly armed legionaries wore breastplates, the *cardiophylax* ("heart-protector") mentioned by Polybius (6.23.2–5), but linen and composite armor remained in use.

Heavily armed cavalry also fought with elegant anatomical armor, javelins, and curved swords (*machaira*), as substantiated at a gravesite at Lanuvium near Rome (early fifth

century BCE) and on numerous Greek vases (fifth to fourth centuries BCE: Connolly 1986, 56–57, 62–63; Chiarucci 2003, 14). Armor for horses dates back to at least 2500 BCE, and by the sixth century BCE the Greeks were using chest guards and chamfrons in metal or leather to protect horses' heads during battle (Gamber 1968, 11; Junkelmann 1992, 204). Arrian (*Tactica* 4) distinguishes both armored and unarmored horses in the Roman cavalry of the 130s CE—armored horses were equipped with protection for their sides and foreheads.

Under the Athenian general Iphicrates (418–353 BCE), the light Thracian *Peltastai* equipment was adapted to the hoplite (Nelson 1975, 40, figure 60): a padded or quilted corselet, and a new longer spear—the prototype of the Macedonian *sarissa*. This equipment, used alongside the heavy *statos* and the lighter *linothōrax*, became the standard equipment of the Macedonian phalangite of Philip II and Alexander the Great (Connolly 1986, 60–61), yet many phalangites fought without corselets (Snodgrass 1999, 117).

The bronze helmet evolved from the full-faced Corinthian type to the Chalcidian (with a strip for a nose guard). The simple conical *pilos* was quickly adopted late in the fifth century BCE (Connolly 2006, 60–62). Introduced in the fourth century BCE was a design that proved popular with the Macedonian army: a new bronze mask helmet, inspired by the Thracian model, featuring check-guards (Connolly 1986, 70; Figure 48.3).

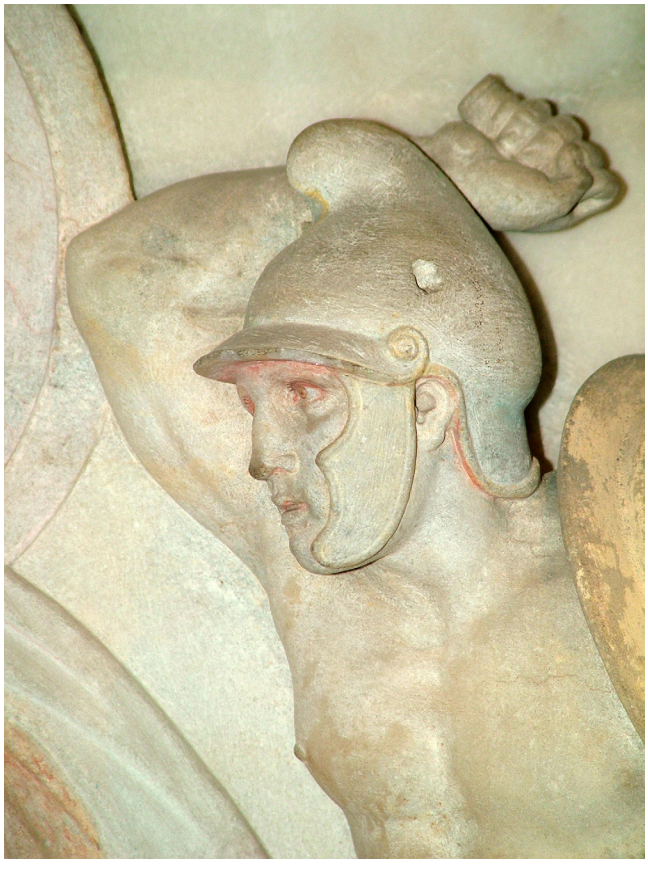


Figure 48.3 Detail of Senior Rank Macedonian warrior from the so-called Alexander Sarcophagus, Greece, circa 323 bce, from Sidon, Istanbul. Istanbul Archaeology Museum. Photo by author.

5. The Roman Empire

From the late first century BCE onward, Rome maintained a professional standing army of citizens and allied auxiliary troops. Training was efficient, pay and equipment were regularized, and soldiers were outfitted with standardized uniforms and equipment that was mass-produced at factories (*fabricae*) throughout the Empire, manned by skilled legionary specialists and civilian artisans (see Vegetius 2.11; Bishop 1985).

The superiority of the Roman army was based partly on a new military formation—the maniple, a formation of 120 soldiers arrayed in 3 ranks of 40 men who engaged the enemy sequentially—perfected during long years of war against Italian neighbors (e.g., the Samnites, 341–290 BCE) and foreign enemies (Pyrrhus of Epirus, 279 BCE; Carthage, 264–146 BCE). A new weapon, the *gladius hispaniensis*, adapted perhaps from Iberian models, was the most effective weapon in the Roman arsenal (Connolly 2006, 130–131), a two-edged blade (50 cm [about 1′]) with a long point. With improved practices in metallurgy during the early Imperial period, this sword evolved from the broader Mainz type into a thinner, more effective "Pompeii type" model, well adapted for stabbing or chopping and represented on Trajan's column (the earliest examples were found inside the gladiatorial barracks at Pompeii: Miks 2007, plate 29, catalog A591-A592-A593, 706–707). These short swords, worn on the right side, were slowly supplanted under Septimius Severus (193–211 CE) by the longer cavalry *spatha* (0.75–1 m [30–39″]), a slashing, fencing sword, eventually worn on the left side (Coulston and Bishop 2006, 154–163). From the fourth century CE the *gladius* was completely substituted by the longer *spatha*. Shorter swords (*semi-spathae*: Vegetius 2.15) were also widely employed, some decorated with splendid cloisonné, probably in the *fabricae* at Constantinople.

Also prevalent were the legionary long spear and throwing javelin, the *pilum*, derived from Etruscan prototypes. The *pilum* was composed of a thin iron point, attached to a wooden shaft that bent at impact, rendering it unusable. The *pilum*, spears, and various types of javelins were employed by Roman infantry and auxiliaries throughout the Imperial age. By the fourth to fifth centuries, new missile designs were developed: *plumbatae* or *martiobarbuli*, whose heads, reinforced and balanced with lead spheres, were kept inside the shields and could be thrown by hand or mounted upon shafts (Vegetius 2.23, 3.14, 4.21.44). These new missiles could be deployed quickly against the legs of the enemy's cavalry, especially in the East, and were especially effective in 531 CE at Callinicum, saving Belisarius' soldiers from a complete defeat.

The Roman soldier carried a *scutum*, a huge curved shield (1.2 × 0.75 m [4 × 2.5′]). Under Augustus, in the late first century BCE, the polygonal *scutum* evolved slightly into a rectangular semi-cylindrical shield (Feugère 2002, 76–78, 88–89) and remained in use until the third century (although iconography still attests it for the sixth century) when it was eventually replaced by the oval shield. The best examples of Roman shields survive at Dura-Europos, 252–253 CE. The frame of each shield was composed from 12–15 thin yellow-poplar (*populus euphratica*) planks or laths (13–35 cm [5–14″] wide and 8–12 mm [0.3–0.5″] thick), carefully arranged and glued together edge to edge, following the length of the shield (James 2004, 160–161, figure 42). The joints were carefully planed to leave no gaps. Ammianus Marcellinus also speaks of shields "built by planks (*axiculi*)," clearly suggesting a round or oval *scutum* (21.2.1). The construction was joined with a leather border, while the grip included nails for a baldric (at least for

one specimen) and an iron transverse bar. The decoration of such shields, as painted on the external leather layer, suggests that regiments and units were thus distinguished as a matter of course, a practice that continued, with local variants, in both the east and west (Kolias 1988, 124–125).

Little changed in weapon design. Reserved for high-ranking officers were the Hellenistic *thōracēs* (shorter versions of the complete *statos*) and highly polished and lavishly embossed muscled cuirasses worn over padded linen or coarse silk *subarmales* (undergarments) with strips hanging down to protect the upper shoulders and groins. From the Punic Wars onward, Roman and Hellenistic officers wore beautiful helmets of the Attic-Chalcidian type, often embossed (Wise 1982, 34–35, plate B). Caesar's troops wore the simpler, more practical Buggenum-type helmets (evolved from the Montefortino), the Coolus-Haguenau type (derived from Celtic prototypes and similar to the Buggenum helmet without the knob), helmets of Hellenistic origin (sometimes mixed with Coolus-Haguenau elements: Antonucci 1996, 28, figure 48.4), and the new Agen-Port type with extended cheek pieces, a Romano-Celtic hybrid, the prototype of the Imperial legionary helmet (D'Amato 2009, 32–38). The Imperial legionary helmet, of the Weisenau type, featured wide cheek guards (*bucculae*), a large and flat neck guard, and a reinforcement strip forming the brow protection (Robinson 1975, 45–51, 62–65). In the early second century CE under Trajan, this helmet was fitted with two crossbars on the top, probably to strengthen the helmet against the Dacian *falces* (a scythe-like weapon), a concept borrowed perhaps from the conical segmented helmets used by Danubian and Sarmatian *auxilia* (D'Amato 2012, 16–17).

The helmet was a simple design—the so-called *Montefortino* model—influenced by Celtic models: a conical/round helmet with a raised central knob, and a protruding



Figure 48.4 Helmet of Coolus-Haguenau typology with elements of Hellenistic typologies, Rome, from Pompeii, first century BCE–79 CE, Naples, Museo Archeologico Nazionale. Photo by author.

neck guard and cheek plates. Roman Julio-Claudian cavalry helmets, dominated by the Attic Koblenz-Weiler-Bubenheim typology, featured embossed metallic crests and wide cheek guards often fitted with ears in relief, as confirmed by Trajanic iconography. Also extant are Attic pseudo-Weiler models which enclose the head (D'Amato 2009, 185–187, figure 269). In the third century, the elegant Guisborough (typically Attic in shape) and the more rounded Hedderneim types (or Niederbieber) types became prevalent: the helmet now completely covered the head, cheek guards were (sometimes) fastened at chin level through a pivot and the protective crossbars were retained, leaving only a small T-opening for the face. These styles soon became universally employed by cavalry and infantry, and traces of their continued use endure into the sixth century. A mysterious vestige appears in the fourteenth-century frescoes at the monastery of Staro Nagoričane, Macedonia, which could confirm a re-employment of antique helmets during the Middle Ages (Coulston and Bishop 2006, 174–178).

With declining metallurgical skills in the third century CE (as conflicts between Rome and the Sassanids escalated), a simpler helmet design, the ridge helmet, was developed: separate cheek and neck guards were fixed to the two halves of the head piece which were connected by a metallic comb. Two primary varieties are known: a lighter style with openings over the ears (to aid hearing) worn by infantry, and a heavier model worn by cavalry (James 1986, 107–113, 131–134). From the fourth century onward, special craftsmen, *barbaricarii*, manufactured ridge helmets that were elaborately decorated with pearls, gems, and stones, and custom-fitted to guardsmen, officers, and emperors. The ridge helmet, in different styles, remained in use in the Eastern Empire during the Middle Ages and, in the west, by the Sub-Roman kingdoms and cities, especially in Italy, Brittany, Wales, and southern France (Nicolle 2002, 307).

Also widely employed during the third and fourth centuries (and used well into the fifth and sixth centuries CE in both East and West: Vogt 2006, 1–14) was the *Spangenhelm* and its offshoots, made of different segments of metal, influenced by Danubian models used by Iranian tribes like the Sarmatians and the Alans, and worn by the *Joviani* and *Herculiani* legionaries on the Arch of Galerius (James 1986, 128–131, figure 21).

The Roman soldier was protected by chainmail, *linothōrax*, or an anatomical cuirass. The most widely utilized armor was *Gallica* chainmail, but specimens in scale, leather, linen, and other organic materials were also common (Coulston and Bishop 2006, 95–100; Antonucci 1996, 10–12, 16, 25, 28–30, 39, 44; D'Amato 2009, 38–43, 122–129, 135–142, 191–192). During the third century CE, chainmail became the most common armor, but also in use were scale, segmented, and lamellar (plate) cuirasses, derived from Eastern models. Iconography confirms muscled leather armor, made of *cuir-bouilli*, and models in organic materials (Giuliano 1955, plates 37–38). It was probably during the Augustan Age that the old segmented Etruscan *lorica* in leather was transformed into *lorica segmentata*, manufactured in iron and entirely enclosing the trunk, perhaps in imitation of Parthian armor, and worn widely by infantry, auxiliary troops, and even cavalry into the fourth century CE. The small arrows of these formidable Parthian mounted archers could penetrate the tiny rings of the *lorica conserta hamis*, but not metallic *segmentata* bands (D'Amato 2009, 130–134; Bishop 2002). Specimens in leather are attested only in the iconography, apart from a mysterious banded fragment in the British Museum (D'Amato 2009, 142–144).

The cavalry also began to wear body armor from the late first century CE. Contingents of *Catafractarii* and Sassanid-Persian *Clibanarii*, employed to counter the Parthian

incursions of the fourth century CE, were completely covered in flexible iron armor (Ammianus Marcellinus 16.10.8; Julian, *Orations* I, *Panegyric of Constantius*, 37d). In addition, more mobile and versatile light cavalry contingents, the *Promoti* and *Dalmati* cavalrymen, were especially created under Gallienus (ruled 253–68 CE) as a bulwark against invaders in the Eastern Empire (SHA, *Life of Gallienus* 14.4).

In 217 BCE, a thousand Syracusan archers and slingers fought for Rome against Hannibal (Livy 22.37.8), and the mounted archer long remained part of the Roman auxiliary military engine, outfitting themselves but serving under Roman command. During the fifth century CE, these mounted archers became the main force of the Roman army in the east. Fully armored (leg and arm defense, body armor, and helmets) and fighting skillfully from horseback, they employed a new weapon, the smaller and more powerful composite bow comprising multiple pieces of wood and horn, and always recurve (that is, curving away from the archer), imported from the Central Asian Steppes (Syvänne 2013, 11–15). The Roman Empire survived in the Middle Ages because of the skill and training of its cavalry, together with the efficiency of its armament, continuing the tradition of a military expertise established 2500 years before!

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PART VIII

Travel

CHAPTER 49

Greek and Roman Cartography

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1. Introduction

At *The Art of Love* 2.125–142, Ovid recounts a charming vignette of Odysseus and Calypso spending a lazy seaside afternoon together. Calypso asks, again and again, that her captive lover recount his adventures in the Trojan War. Again and again, Odysseus "finds fresh words for the same old tale." As they stroll, Calypso asks about one battle or another, while Odysseus, in answer, sketches out the scenes for her in the wet sand. "This, he says, is Troy (he made walls on the shore). This is the Simois. Let's consider this spot my camp."

The allure of maps is universal: the arrangement of places, how one's home fits into the scheme of the larger world, the extent of the inhabited world (*oikoumenē*). Like earlier Babylonian and Egyptian endeavors, early Greek maps depicted city plans, mine tunnels, geographical regions, the entire *oikoumenē*. Although the actual maps rarely survive—and maps were almost never included in manuscripts (see Neugebauer 1975 for an incomplete world map included in a thirteenth/fourteenth century manuscript of Ptolemy's *Handy Tables*)—some descriptions do: the information was considered useful, worth copying, and even entertaining. Ptolemy defines the art of cartography, inextricably intertwined with geography, as "an imitation through drafting of the entire known world together with the things that are, broadly speaking, connected with it" (*Geography* 1.1.1). He further distinguishes between world and regional cartography. The smaller scale of the latter allows for the inclusion of topographical details, such as harbors, rivers, and towns. It is also contested whether maps as we conceive of them existed at all in antiquity: Janni 1984 argues that graphic maps never extended beyond the initial stages, primarily because the ancients lacked a concept of scale. But the concept of "map" is fluid, and they took many forms, both pictorial and (more widely) verbal.

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To the Greeks and Romans, maps were both practical (e.g., a cadastral mine plan at Thorikus east of Attica: Dilke 1985, 26) and symbolic (i.e., the Peutinger Map, below, §11). Large-scale maps were known at least by the fifth century. In Aristophanes' *Clouds* 200–18, first produced in 423 BCE in the thick of the Peloponnesian War, Strepsiades, an everyman Athenian farmer, takes a tour of Socrates' college, the *Phrontisterion* (a creation of Aristophanes' imagination), where his student guide points to a map of the Greek world. Strepsiades asks the student to indicate places on the map: Athens, his deme, his friend Cicynna. The exasperated student obliges, ignoring the query about Cicynna, but also calling attention to Euboea a "long island lying off the coast." When Strepsiades asks where Sparta is, our farmer, alarmed at the proximity of the enemy state, vehemently demands that Sparta be moved further away. Here, we see a map as an effective focal point of contemporary political events.

Socrates is featured in another anecdote illustrating the symbolic power of maps (Aelian, *Historical Miscellany* 3.28). As Alcibiades boasts about his own immense wealth and estates, Socrates shows his friend a map of the world that was publicly displayed in Athens. Socrates first asks Alcibiades to find Attica, easy enough, and then his own fields, which, Alcibiades notes, are not depicted on the map. Socrates then rejoins that the statesman has no right to boast of estates "which are not even part of the earth."

Monumental, political, and artistic, maps were displayed privately and publicly. In his will, Theophrastus requested that a world map painted on wooden panels be displayed at the Lyceum, the school where he taught, founded by Aristotle (Diogenes Laërtius 5.51). In the *Argonautica* (4.729–781), Apollonius of Rhodes refers to maps displayed on pillars in Aeëtes' court at Cholcis, "on which are all the roads and paths of the sea and land flowing all around." Colony founders drafted maps to demarcate the lands and resources allotted to the *polis*, gods, and settlers. At Rome, Agrippa's map of the world was displayed in the Portico of Vipsania.

Maps reflect the prejudices and philosophies of those who make them. Geometrical aesthetics and philosophical beliefs dictate the shape of the entire world (circular or spherical) and of the inhabited portion of it. At the center usually was the mapmaker's home *polis* or a site of particular cultural importance. The *Phrontisterion* map, for use by students in Athens, likely showed Athens at its center, or one of the particularly important religious centers, Delphi or Delos, through whose treasury the Athenian Empire grew, sparking the Peloponnesian War.

Pictorial maps *may* have accompanied geographical treatises. Anaximander, famous for drawing the first Greek map in the formal sense, is credited with a *Circuit of the Earth* (possibly accompanied by a map). Anaximander's successor Hecataeus improved upon this first map to the extent that the new edition was proclaimed "more accurate so that it became a source of wonder" (*TEGP* 6). The lost *Description of the World* by Democritus may also have included a map (*TEGP* 7). Strabo's praise of Eudoxus for his skill in rendering figures implies geometrically informed sketches accompanying his *Circuit of the Earth* (Dilke 1985, 26–27). And Eudoxus' contemporary, the historian Ephorus of Cyme (405–330 BCE), who decoupled geography from history, illustrated his arguments "with the help of the enclosed drawings" (see Dilke 1985, 27).

In producing physical maps, early cartographers relied on mathematics and astronomy as well as a variety of written and oral sources, including the informal accounts of sailors in dock. Cartographic data are integral to expeditionary treatises as well as *Periploi* and *Periegeses*—which list and describe sites encountered along a road or coast. Cartography

is also prominent in historical texts (Herodotus, Thucydides, Caesar, Tacitus). Cartographical advances are especially noteworthy during times of intense colonization (700–500 BCE) and foreign warfare (500–480 BCE: Persian War; 340–323 BCE: Alexander's expeditions). At such times, new data become available as new places are visited. Success, commercial or military, depends upon accurate terrestrial and topographical data.

2. Challenges

Greek maps were probably sketched on perishable materials, such as papyrus or vellum. Our reconstructions depend upon interpreting written descriptions, and, although these data are abundant, consensus is not forthcoming. These second- and third-hand sources are removed from the originals often by centuries; details are distorted, and context is lost in this paleographic game of "telephone." How precisely Strabo quotes Eratosthenes we cannot say with absolute certainty (Roller 2010, 20–21). We are further hindered by issues of scale and perspective. Mapmakers often exaggerated the size and importance of their own countries, placing their homelands at the center, and providing ample details of surrounding environs. As cartographers described places further from home and less well known, the scale becomes smaller and the details become attenuated. Strabo even indicates that the need to know about remote places is minimal (2.5.8), and Tacitus bluntly declares that, beyond a certain point, our information is "the stuff of tall tales (*fabulosa*)" (*Germany* 46.4). Moreover, measurements were not standardized: one *stadion* was 600 Greek feet, but there was no standard "foot:" the *stadion* at Olympia was 192.8 m (633′), the length of the stadium there; the Athenian *stadion* measured 185 m (607′). And, finally, at least before Alexander, there were no coordinated efforts to plot the Mediterranean world.

3. Utility

Maps are politically expedient: useful to empire builders and administrators for the purpose of knowing the people and customs of a place. Alexander had engaged bematists to measure distances between places to be conquered and those already subdued (Pliny, *NH* 6.61–64); Agrippa's map was intended in part to aid in vanquishing and taxing mapped areas (Pliny, *NH* 3.17; Rihll 1999, 83–84). Strabo tells us that maps are useful to governors who can manage affairs better if they know the size of a country, lay of the land, peculiarities of sky and soil; to hunters for understanding the character and extent of forest; and to commanders for pitching camp, setting ambushes, and marching in unfamiliar territory (2.5.8). But the Greek interest in mapmaking and describing the contours of the land and the arrangement of settlements predates the first formal illustrative maps, and in Homer we find a particularly rich cartographic resource.

4. Homer

Homer was called the "father of geography" by Strabo (1.1.11), and his *Iliad* and *Odyssey* (circa 750 BCE) are replete with geographical curiosity and awareness. Of particular cartographic interest is the *Odyssey*, recounting Odysseus' post-Trojan War adventures by sea. The work reads a great deal like a *periplus* (a coasting guide), rich in maritime data (anchorages and harbors), and navigational details. Like any sailor, Odysseus pays

close attention to the winds, which he knows well, and his observations suggest burgeoning efforts to map the winds, a critical step to nautical cartography (Irby 2012, 86).

Although some deny that Homer used or knew of maps (Severin 1987, 235–245), the opulent artwork on Achilles' shield (*Iliad* 18.486–492) strongly suggests an early attempt at mapmaking. The shield shows the earth in its relationship to celestial bodies, two cities, one of peace, another of war, and around the "uttermost rim," Ocean, which was thought to circle the earth. In short, the shield is a synthesized microcosm of Homer's world and represents an early cosmological map (Hardie 1985, 11).

Although Heidel (1937, 56) argues that Homer's geography lacks a frame within which to delimit boundaries and by which to create a map, Harley and Woodward (1987, 132) counter that Ocean, delimiting the world on Achilles' shield, is, in fact, a geometric frame that bounds the Homeric *oikoumenē*. The paradigm presented on Achilles' shield and the Homeric circular *cosmos*, framed by Ocean, would guide early efforts to produce "scientific" maps.

5. Milesian Maps

The first Greek rational, theoretical approaches to mapping the world, or parts of it, found expression in Asia Minor, where Homer reputedly dwelled. Miletus, where Greek science was born, was a wealthy trade center through which the scientific and artistic achievements of the Near East (including Mesopotamia and Egypt) percolated into the Archaic Greek world. As a vigorous center of commercial and colonial activity, Miletus would also have been a hub for sailors disseminating cartographic information in port (KRS 105). Lacking an empirical tradition, early terrestrial maps simply sketched the geographical outlines of the *oikoumenē*. The purpose of these early maps, however, was not to provide practical directions between places, but instead to show a sense of order, imposed or projected, onto the physical landscape and, more importantly, to show human control over that world order (Rochberg 2012, 12). Further, such maps were likely intended as rational, critical accounts of the origin of the *cosmos* and spread of human civilization (Couprie, Hahn, and Naddaf 2003, 32). This harmonizes with Presocratic cosmogonies which sought to explain the world as an ordered system (*cosmos*) emerging from chaos (The Creation and Destruction of the World). In contrast, direct observation and careful records of the risings and settings of stars informed the development of celestial maps, important both in theory (The Creation and Destruction of the World) and practice (Astrology; Greek Calendars; Roman Calendars). But early celestial cartography, like its terrestrial counterpart, relied on abstract principles (geometry) rather than empirical metrology (Harley and Woodward 1987, 130). Contemporary textual evidence for these early maps is fragmentary, redacted through second- and third-hand sources whose accounts are often as interpretive as they are descriptive (Lloyd 1973, 10, note 1). Writers employ similes and evoke familiar geometrical shapes and objects from daily life to describe places, including *comparanda* from furniture, weapons, and letters of the alphabet (Dueck 2005): the Nile Delta is so-called because it resembles that letter (Strabo 17.1.4); Attica is crescent shaped (Strabo 9.1.3); and Italy resembles an oak leaf (Pliny, *NH* 3.43). The manuscript tradition may further distort the data relayed by the original maps or their descriptions of them.

Three of Anaximander's titles imply an interest in both celestial and terrestrial cartography: *Circuit of the Earth, On Fixed Stars*, and *Celestial Globe*. His terrestrial map may

have been little more than an outline of the earth and sea, drawn on a *pinax* (painted panel or bronze tablet: Diogenes Laërtius 2.1–2; Dilke 1985, 23). Anaximander's map, its shape and size, as well as his written account cannot be reconstructed with any reliability. On the paradigm of later geographically infused writings, we surmise that *Circuit of the Earth* began with a cosmological introduction, weaving together history, astronomy, and geography, likely proceeding in lecture format to explicate the arrangement of natural and manmade landmarks, cities, and climate according to the pictorial map (Naddaf in Couprie, Hahn, and Naddaf 2003, 49). Such issues inform the cartographically charged writings of Herodotus, Strabo, and others.

Anaximander's earth was a broad, shallow cylinder, with a depth a third of its width, "like a stone column," equidistant from other celestial objects and hanging freely mid-air (*TEGP* 20; Roller 1989). This provides the framework: a flat circular earth surrounded by Ocean, resembling Homer's *cosmos* and a roughly contemporaneous neo-Babylonian clay tablet showing a circular map of the "New Empire" (Raaflaub and Talbert 2009, 147). Disputed are the relative sizes of the land masses (equal or not), the map's center (Delphi, Delos, or Miletus), and even the shape of the *oikoumenē* (circle, parallelogram, parallelogram inscribed in a circle). Hahn (2001, 204) suggests that the map incorporated a three-point coordinate system, corresponding to the sun's equinoctial and solsticial risings and settings, points that can be determined with a seasonal sundial. Most ancient maps were more or less symmetrical, and Herodotus states that such circular maps appear to have been drawn with a compass (or turned on a lathe, 4.36). Plato's employment of a spindle whorl to describe the geocentric *cosmos* as the orbits of the celestial bodies (Myth of Er: *Republic* 10.14) may be cartographically motivated (Harley and Woodward 1987, 138; see Astronomy). Anaximander may also have founded a colony (perhaps on the Black Sea: Hahn 2001, 202–203), and his map may have responded to practical considerations.

About fifty years later, Aristagoras, tyrant of Miletus, toured the Greek mainland in 499–498 BCE, searching for allies against Darius I (Herodotus 5.36, 126). The tyrant brought a portable map engraved on a *pinax* to persuade potential allies of the proximity and imminent danger of the Persian empire. Herodotus described the map, a circular "going-round" (*periodos*), when Aristagoras showed it to the Spartan king Cleomenes (Hecataeus, who was actively engaged in the Ionian revolt, may have promoted Aristagoras' map: Dilke 1985, 23–24; Couprie, Hahn, and Naddaf 2003, 33):

> A bronze tablet, on which a map of the entire world was engraved, including all rivers and every sea … "I shall now show you the sequence of lands in which [the Persians] live. Next to the Ionians dwell the Lydians; their land is fertile and richest in silver." As Aristagoras said this, he pointed to the map engraved on the tablet he had brought along. "And next to the Lydians," Aristagoras continued, "the Phrygians live here, to the east; they have the greatest abundance of flocks of anyone I know, as well as the most abundant crops. Next to the Phrygians are the Cappadocians, whom we call Syrians. Bordering them are the Cilicians, whose land extends down right here to this sea in which lies the island of Cyprus; the Cilicians pay the king an annual tribute of fifty talents. Next to the Cilicians are the Armenians, who also have an abundance of flocks; and next to them the Matienians, who dwell in this area here. The land next to them belongs to the Kissians; Susa is located right here within it, along this river Choaspses. It is here that the Great King makes his home, and where his stores of wealth are kept." (Herodotus 5.49.1, 5; trans., Purvis)

The narrative makes clear that Aristagoras refers to a physical map as he indicates the lands between Laconia, Ionia, and Persia ("I show," "here"). As was typical, the map lacked any measurable scale. Upon inquiring about the length of the march between Sparta and Asia, Cleomenes was told "three months," an ambiguous though standard length of measurement. Aristagoras' map may also have included the Persian Royal Road, which Herodotus recounted in detail, offering the short distances between staging posts in both Persian *parasangs* and Greek *stadia* (5.52–54; Casson 1994, 53–56).

6. Herodotus

Criticizing the work of his cartographic predecessors, Herodotus raised several geographical questions: why are three names (Europe, Libya, Asia) given to the Earth, which is one single unit? Why are these landmasses named after women? (A feature of inflected languages—most Greek toponyms are grammatically feminine in gender). Who fixed the boundary between Asia and Africa at the Nile, or between Asia and Europe at the Phasis River? (Herodotus thought such boundaries arbitrary). Does water surround Europe to the west and north?

Herodotus' interest in cartography was keen. Although no evidence suggests that he included maps, his ideas influenced the development of Greek cartography. Herodotus' criticism of the cartographic paradigm—circular maps showing land masses symmetrically and equally divided by the Mediterranean Sea—implies a high but repetitive level of map production by his own day (Dilke 1985, 24; Harley and Woodward 1987, 135). His advice for drawing maps was unequivocal (4.36): "I will show by a brief description the actual size of the each [continent: Europe, Asia, Libya], and what they should look like and how they should be drawn." To improve the accuracy of maps, Herodotus preferred data derived from *empirical* accounts. For example, the three-year circumnavigation of Africa (Libya) sponsored by the Phoenician Pharaoh Neco (609–594 BCE) proved that the continent is almost completely surrounded by water, excepting the Isthmus of Suez (Herodotus 4.42). Neco's sailors, incidentally, were not believed when they claimed to have seen the midday sun to their right—proof that they had sailed well south of the equator. Since no empirical evidence supported the theory of an encircling Ocean, Herodotus, consequently, rejected that model. The historian valued data from exploration and travel, and he chastised cartographers who utilized only geometry. He himself refused to make a map of the *oikoumenē* when the "outlines were so uncertain."

Herodotus' geographical diversions are as entertaining as they are informative, and a cartographic framework of the *oikoumenē* is well in place (4.37–45). Herodotus reprimanded cartographers for dividing Europe, Libya, and Asia into three roughly equal landmasses, "since these lands actually differ quite a bit in size." He gave 100,000 *stadia* as the length of Libya, and asserted that Europe is as broad as Asia and Libya together.

Like Homer, Herodotus included cardinal directions and topographical landmarks: bounding Egypt beyond Heliopolis are the north–south running mountains of Arabia, quarried to build the pyramids in Egypt (2.8). Unlike Homer, Herodotus indicated rough distances between places: the Scythian port of the Borysthenites lies at the midpoint of the Scythian coast (4.17); at its widest, Egypt's breadth is traversable in two months, by foot or camel makes little difference. Some distances given for Egypt are precise: Egypt's seacoast reaches 60 "ropes" (*schoinoi*), or 3,600 *stadia* (2.6); Heliopolis lies 4,860 *stadia* (81 *schoinoi*) upriver from Thebes, which is 6,120 *stadia* inland from the Red Sea (2.10; see Irby 2012, 94).

7. Eratosthenes and Hipparchus

Although philosophy continued to guide cartography, empirical data accreted vigorously under Alexander the Great and during the scientific Golden Age immediately following his death, especially at the Museum in Alexandria. For centuries, geographers continued to draw from the information gleaned during Alexander's expeditions (Harley and Woodward 1987, 149: e.g., Isidorus of Charax). And these data were soon employed by geographers to draw maps of Asia and to complete the contours of the *oikoumenē*, inspiring in part even Eratosthenes' ambitious world map (Strabo 1.2.1; see GEOGRAPHY).

Although Pytheas of Massilia (GEOGRAPHY) was scorned for his efforts, he extended the geographical knowledge of the west (as Alexander did of the east), especially the coasts along the English Channel. Furthermore, Pytheas computed latitudes from his astronomical observations, an advance in mathematical cartography. Pytheas' contemporary, Aristotle's student Dicaearchus of Messene (circa 340–290 BCE) was the first to divide the *oikoumenē* with a meridian (through Rhodes) and a parallel (*diaphragma*). Likely intending his *diaphragma* to divide the *oikoumenē* into two equal halves, Dicaearchus in effect produced an east–west coordinate axis (Strabo 1.1.1; Dilke 1985, 30; Harley and Woodward 1987, 152), an important step in producing maps to scale.

Eratosthenes' contributions to theoretical cartography included both his estimate of the earth's circumference and a world map, described in the third book of his *Geographica*. Building on Dicaearchus' *diaphragma*, Eratosthenes divided the *oikoumenē* into two equal halves with a parallel from the Pillars of Heracles to the easternmost limit of the Taurus Mountains (Strabo 2.1.1). He then subdivided the northern and southern portions into "seals" or *sphragides*, irregular quadrilateral shapes resembling document seals: bounded by oceans on two sides, the Taurus Mountains to the north, and the Indus River to the west. India was rhomboidal; Ariana was a parallelogram delimited by the Caspian, the capes of Carmania, and the Persian Gulf (2.1.21–24). Eratosthenes divided the northwestern segment, Europe, on the basis of three promontories projecting into the Mediterranean: the Peloponnese, Italy, and the Ligurnian promontory of Corsica and Sardinia. Hipparchus and Strabo sharply criticized these excessive generalizations. We cannot know if actual maps were included. Nonetheless, Eratosthenes' theories regarding the shape and deployment of the *oikoumenē* remained the paradigm of both textual and pictorial maps well into the Roman period, a trend which culminated, via Marinus of Tyre, in Ptolemy's *Geography* (Jones 2008).

Hipparchus was primarily an astronomer and mathematician whose interest in cartography was theoretical. Deeply critical of Eratosthenes' measurements, his own geographical treatise was tellingly entitled *Against the "Geography" of Eratosthenes*. Contrary to Herodotus, Hipparchus believed that cartography (and geography) must be advanced on strictly mathematical, astronomical grounds, and that the arbitrary distances reported by non-mathematically trained merchants and travelers were useless. Hipparchus consequently developed a theoretical system of map projections on grids of parallels and meridians, with some points fixed by stellar coordinates. Accepting Eratosthenes' figure of 252,000 *stadia*, Hipparchus divided the earth's circumference by the number of units in a circle, 360°, giving a distance of 700 *stadia*

between each degree of latitude or longitude at the equator (the Greeks believed the earth was a perfect sphere). Approximately 8,750 *stadia* separated Rhodes, at 36°N, and Syene (which Eratosthenes assumed was on the Tropic of Cancer, 23°5N, the most northerly point at which the sun appears directly overhead on the summer solstice), yielding a difference in degree of 12°5′. Multiplied by 700 *stadia* per degree of latitude, we get 8,750 *stadia*, the ancient estimate of that distance. For Rhodes, whose parallel was 195,000 *stadia* in circumference, each degree of longitude was 541 2/3 *stadia*. Hipparchus also compiled a table of latitudes, appended to his astronomical table in book 3. This coordinate system of parallels and meridians, whose foundations were established by Eratosthenes and whose practical development was advanced by Hipparchus, was to prove influential on subsequent efforts, both theoretical and pragmatic, to map regions, the *oikoumenē*, or the entire world (Shcheglov 2004; Geus 2002, 277).

8. Ptolemy

The shape of the world affects the deployment of a map as well as the cultural understanding of the spatial relationship between places. The question was tackled by many Greek thinkers, from Homer onward. Although the flat earth theory noted in the early maps and cosmographies of Anaximander and others was quickly abandoned, symmetry, geographical determinism, and Hellenocentricism persisted, bolstered by philosophical and ethnic prejudices of Greek superiority. The Pythagoreans in Croton (circa 450 BCE) may have been the first to suggest a spherical earth (Aristotle, *On the Heavens* 285b25–7, 293b25–30), and the theory gained philosophical currency because the sphere was thought to be the "perfect" shape (Plato, *Timaeus* 31b4–34b9; Dicks 1970, 72–73; Dilke 1985, 25). Nonetheless, representing the earth on a three-dimensional sphere was impractical at best, and cartographers continued to employ a facile two-dimensional medium on papyrus, wood, or bronze.

Ptolemy tackled the challenge in his *Guide to Drawing Maps of the World* (more commonly known as *Geography*), our only extant cartographical treatise from antiquity and based on the work of Ptolemy's slightly older contemporary Marinus of Tyre, circa 100 CE (Berggren and Jones 2000, 23–24). Nearly six of the eight books are essentially lists of map coordinates of about 8,000 known places, with their accepted latitudes (in degrees north or south of the equator) and longitudes (in degrees east of the meridian through the Isles of the Blest, i.e., the Canaries). Much of this data was simply copied, uncorrected, from earlier sources, thus errors were perpetuated. Recognizing that, given the earth's sphericity, cartographic data become distorted in two-dimensional formats, Ptolemy gave instructions for generating a map of the *oikoumenē* on flat surfaces and large globes. Ingeniously, he devised a sophisticated grid of curved meridians and parallels that would improve the accuracy of the positions of distant locales. Maps did accompany late Roman and Islamic manuscripts, but we cannot be certain if these were copies of Ptolemy's original maps, or even if he generated his own maps (Berggren and Jones 2000, 48–49; Jones 2012). The extant manuscripts of Ptolemy, with their lush maps, date to no earlier than about 1300 CE. But these maps seem to have been informed by Ptolemy's instructions (Figure 49.1).



Figure 49.1 Ptolemy's worldview (1482, engraved by Johannes Schnitzer). *Source:* © www.BibleLandPictures.com/Alamy.

9. Periploi, Itineraries, and Chorographies

The *Itinerary* and its nautical counterpart, the *periplus*, were practical guides, useful especially for traders and administrators (Dueck 2012, 51–67). Listing cities along a coast, *periploi* gave details about sailing conditions, harbors, what the area imported or exported, what tariffs to expect, whether the people were friendly or not, and what noteworthy landmarks and marvels (*mirabilia*) one might expect to see. Hanno, whose *periplus* of Africa (circa 480 BCE) was aborted when supplies ran out, described strange peoples and animals, including Trogodytes clad in animal skins and wild men, called "gorillas." Arrian's *Periplus of the Black Sea*, written for Hadrian (ruled 117–38 CE), reads much like a tourist guide, describing natural wonders (the unusually sweet waters of the Phasis River: 8), artifacts (an anchor on display that once belonged to the Argo: 9.2), and religious sites (an island sacred to Achilles, whose temple was cleansed daily by dutiful birds, and whence the hero aided sailors at sea: 21–23). Other *periploi* covered Anatolia (Turkey: authored by Alexander's historian Callisthenes) and India (one by Alexander's admiral Nearchus, another by the helmsman Onesicritus: Pearson 1960; Pédech 1984), surviving in scant fragments.

Chorographies are, in a word, land versions of the *periplus*, with places listed in the order that one would come to them on a journey. They included much the same types of information. The earliest extant chorography, though hardly the first such text, which also happens to be the first extant systematic geographic description of the world in Latin, was penned by Pomponius Mela (30–60 CE), who described the Mediterranean

world in three books (Africa and Asia, Europe, outer coasts and islands—replicating the tripartite *oikoumenē* accepted by Herodotus' time). Mela's work owed as much to the Greek tradition of ethnographic geography as to his own literary environment, when grotesque hybridism was in vogue. Mela's treatment is selective. He omits well-known sites of historical importance (battle sites in Germany), but includes the paradoxical and marvelous (phoenix: 3.83; Psammeticus' labyrinth: 1.56; the Catabathmian fountain, that boils at midnight and freezes at midday: 1.39). Pliny's geographical books (*NH* 3–6) follow the same paradigm. In addition, painted chorographies were also known to the Romans, and probably widely distributed. Varro (*On Agriculture* 1.2.1) refers to them off-handedly, as does Vitruvius when discussing the sources of rivers (8.2.6).

Whereas the *periplus* was a Greek innovation, the land-loving Romans developed terrestrial *Itineraries* that were closely linked to the road network. Vegetius, advising commanders in the field of their utility, refers to itineraries that are so well illustrated that conscientious generals can choose the best routes on the basis of visual data (3.6). Ordinarily, these documents did little more than list the toponyms of stops on a journey and their intervening distances, recorded in Roman miles (except in Gaul where the local metric *leuga* prevailed), and the total distance for the journey. As with *periploi*, the stops along the route were meant to indicate a day's travel that rarely exceeded 20–25 miles (32–40 km). Itineraries were sometimes inscribed on stone tablets erected at city gates. Portable versions, etched onto small silver cups, often in the shape of milestones, listed over 100 intermediate points between Gades (Cadiz) and Rome, a journey of 1,840 miles (2,960 km). Vegetius refers to collections of regional itineraries in the arsenal of a good general (or other Imperial administrators), and the so-called *Antonine Itinerary*, circa 300 CE, may have been intended to replicate such an anthology. Post-dating the Antonine era, this document is a hodgepodge of miscellaneous routes, not all direct (Talbert 2008a).

10. Celestial and Terrestrial Globes

Literary evidence suggests that "maps" were rendered also in three dimensions, on globes. As we have seen, Anaximander's interests extended to celestial cartography, and he is said to have constructed a celestial globe, placing the earth at the center, following the pattern established on Achilles' shield. The construction of such a globe is highly dubious (Harley and Woodward 1987, 134). Nonetheless, we have also seen how important celestial cartography is to terrestrial mapmaking efforts: astral data proved expedient in estimating the circumference of the earth, fixing latitudes and meridians, and for determining the spatial relationship between locations.

Parmenides, on the Italian coast south of Naples, seems to have been the first to divide the spherical world into five symmetrically balanced zones (Strabo 2.2.1–2): a hot zone at the equator, two temperate zones, and two cold. Dilke (1985, 25) believes that Parmenides illustrated this division on a map or a globe. Documentation is lacking, but sphere-making flourished, in general, in southern Italy and its cultural cousin, Sicily, in the third century BCE. Such efforts may represent the culmination of a long tradition (Harley and Woodward 1987, 136).

Eudoxus is also said to have drawn the positions of the stars on a globe representing the sky from the outside (not from the vantage point of an observer on earth). Eudoxus' *Phaenomena* and *Mirror*, respectively describing the geometry of the heavens and giving an interpretation of his globe, are both lost. But Aratus' *Phaenomena* renders Eudoxus'

treatise in verse. The Farnese Atlas, a second-century CE Roman marble copy of a third/second-century BCE Greek statue, shows Atlas supporting the celestial circles and 43 constellations in bas-relief. This is likely a direct descendant of Eudoxus' efforts (Harley and Woodward 1987, 141–142).

In the *Argonautica* (3.132–141), Aphrodite bribes her son Eros with a toy, "a perfect ball of golden hoops laced together which when tossed in the air leaves a fiery trail behind like a meteor in the sky," part mechanical wonder, part celestial globe. The golden hoops laced together may represent the celestial circles: ecliptic, equator, etc. That Apollonius compares the toy to a meteorite suggests that he intended the image to invoke the celestial sphere.

Finally, one terrestrial globe was on display in Pergamon about 150 BCE. At least three meters (10′) in diameter, the globe, the brainchild of Crates of Mallos (circa 170–120 BCE), who sought to illustrate Odysseus' journey, showed two intersecting belts of Ocean which separated four symmetrical land masses, a stark divergence from previous maps. Strabo (2.5.10) approves the globe as a more realistic rendering of the world since the globe, like the earth, is spherical. Crates thus applied geometry to his interpretation of Homer, demonstrating that maps could be intrinsically valuable in academic (literary) debate. Cicero incorporates Crates' vision into the Dream of Scipio (*Republic* 6.20–21). Macrobius (*Commentary* 5.31–36) augments Crates' theory, which came to influence Medieval cartography (Dilke 1985, 37).

11. Physical Maps

Much more than we can ever know has perished, yet some maps survive from early antiquity, with evidence from Çatalhöyük (Ankara, Turkey) and Babylon (Rochberg 2012, 9–11), and Egypt (O'Connor 2012). Even Greek maps survive in a variety of media: frescoes, coin issues, and stone. Fragments of three frescoes, found in the House of the Admiral at Akrotiri in Santorini, circa 1500 BCE, show clearly delineated locations and nascent color conventions that anticipate the conventions of later Roman and Medieval picture maps. For example, in the Peutinger Map, rivers are in blue, outlined in gold; and mountains are suggested by double blue lines. The longest Santorini fresco (4 m [13′]) illustrates the maritime journey of a fleet from one port town (left), traversing a body of water, to another (right). A second fresco (3.5 m [11.5′]) shows the plan of a river with the contours of the waterway, hillocks, clumps of vegetation, and native fauna. The frescoes may show Libya (Marinatos 1973, 231–237; 1974, 237) or a military expedition, perhaps to North Africa (Davis 1983, 3–14).

Physical relief maps are also known, the earliest being an Akkadian map found at Nuzi, datable to circa 2300 BCE. With north at the top, the relief shows the course of the Euphrates from its source in the Armenian mountains to its debouche into the Persian Gulf (Thrower 1972, 15–16, 18, figure 2.3). An Ionian coin issued circa 335 BCE (thirty five Rhodian-weight tetradrachmas and six bronzes) has the Persian king running or kneeling on the obverse. The reverse is characterized by a regular incuse with heavy stippling; although the style changes, the type is regular. Johnston (1967) identified the reverse as a physical relief map of the Ephesian hinterlands. The coins were probably struck to pay troops on the orders of Memnon of Rhodes, a Persian general in Ephesus before Alexander's arrival. The map, hence, would have made a strong symbolic statement regarding the general's authority, and its propaganda value is inestimable. Maps are also known on Sicilian coin issues: from the city of Messana coins show

the sickle-shaped sandpit projecting into the harbor, and thought to have given the city its original name, "Zankle" (Hill 1903, 38–39, plate 1.2; Seltman 1955, plate 14.5).

The fragmentary and poorly preserved Artemidorus Papyrus, 32.5 cm × 250 cm (12.7 × 98.5″), discovered in a funeral mask, was most likely intended for a luxury edition of Artemidorus of Ephesus (circa 100 BCE), who composed a geography of the *oikoumenē* in eleven books. The papyrus preserves one complete and four fragmentary columns of Artemidorus (book 11, the Iberian peninsula), a geographical map, and sketches of gods, humans, animals, and body parts, all stylistically Hellenic (Kramer 2001, 115). Never completed, the edition may have been abandoned because the artist had drawn the wrong map. The roll, then, was put to other purposes, as an artist's exercise book, the sketches possibly serving as models for painting or mosaic projects. The papyrus was discovered in a cache of documents dating between the reigns of Nero and Domitian (54–96 CE).

The map is unique. We have here a landscape anticipating (or reminiscent of) the maps of Iberia included in manuscripts of Ptolemy's *Geography*: wavy and roughly horizontal and parallel lines may suggest rivers. Fainter lines may suggest roads. Assuming that the artist employed the (now standard) layout of maps, with north at the top, the horizontal lines may represent the Iberian waterways, where the primary rivers flow into the Atlantic roughly east to west. The map also shows complex vignettes of larger settlements, approximating a realistic spatial arrangement, and several isolated solid rectangles, which Kramer (2001, 118) interprets as representing Roman way stations, *mansiones*. These resemble the symbols for settlements used in the Peutinger Map and Medieval maps of Ptolemy's *Geography*. The map seems incomplete—about 40% of the settlements are rendered. If the papyrus is authentic (Canfora 2006 argues that it is a nineteenth-century forgery), and its text and map are genuine, the Artemidorus map would then be the only regional Roman provincial map that has come down to us, apart from the 45 × 18 cm (17.7 × 7″) Dura-Europos parchment shield cover, datable to just before 260 CE. The Dura shield cover (Figure 49.2), illustrating a section of the Black Sea coast, shows two disproportionately

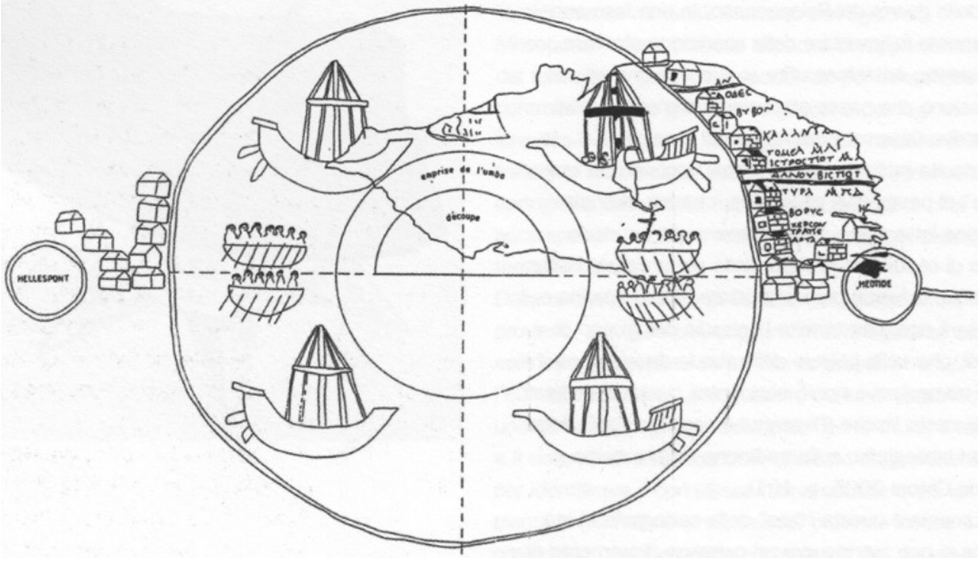


Figure 49.2 The Dura-Europos Shield map reconstructed. Source: Pascal, Arnaud. 1989. "Une deuxième lecture du bouclier de Doura-Europos." *CRAI* 373–89, figure 1. Courtesy Editions de Boccard.

large ships, the heads of four sailors, and stylized towns labeled in Greek. A pale curved line indicates the coast, studded with staging points. Principal rivers are depicted, and distances recorded (Cumont 1926, 323–327, plates CIX, CX; Dilke 1985, 120–121).

The so-called "Soleto Map," on an Attic black-glazed *ostrakon* uncovered in 2003 is almost certainly a hoax. The fragment shows the coastline of Apulia, locales indicated with points and labeled in Greek or Messalian script (Gallazzi 2006, 95).

Julius Caesar and Agrippa

In 46 BCE, Julius Caesar commissioned four Greek surveyors (one for each of the cardinal directions) to survey the world as the foundation for a narrative map of the world. The project was never completed. Caesar's heir, his great-nephew Augustus, eventually took up the challenge. He engaged Marcus Vipsanius Agrippa to continue Caesar's program. Agrippa's map, a pictorial enterprise, was completed by Augustus after Agrippa's death, and it was subsequently rendered in marble on the walls of the Portico of Vipsania, near Augustus' Altar of Peace. The map may have been updated to document the Roman conquest of Britain, Dacia, and Mesopotamia. Unfortunately, the map is lost. But it probably represented the entire inhabited world as known to the Romans in the 20s BCE. It was likely erected to show that Rome (that is to say, Augustus) had unified the world. Agrippa's map probably looked something the Peutinger Map (see below).

The "Forma Urbis" (Marble Plan)

Agrippa's map was not the only large-scale marble map of the city of Rome. A Julio-Claudian fragment (32 × 29.5 cm [12.5 × 11.6″]) shows a section of the city around the Circus Flaminius, including the temple of Castor and Pollux (Vitruvius 4.8.4; Rosada 2007, 152–153; Rathmann 2013, 206). We cannot say if this is a fragment of Agrippa's map. This fragment, however, anticipates the third-century *Forma Urbis*, carved onto 150 marble slabs, arranged in eleven rows. Measuring about 18.1 × 13 m (60 × 43′), the *Forma Urbis* was displayed on the wall inside the Temple of Peace, which was destroyed by fire in 192 (Cassius Dio 72.24.1–2) and restored by Septimius Severus (203–211 CE), who commissioned the map, quite possibly to demonstrate the recovery of city and empire after a tumultuous period of civil war. With a scale of about 1 to 240, the ratio in common use for cadastral records, and oriented with southeast at the top, the *Forma Urbis* showed in remarkable detail every architectural feature in Severan Rome—apartment buildings, temples, and baths. The plan seems to follow a key: single lines are walls of buildings; breaks in the lines of walls are doorways; dashed lines are arcades; lines of dots are colonnades; Vs or triangles represent interior staircases; and short perpendicular lines between two long parallel lines indicate exterior stairways. Some walls and column bases (e.g., Porticus Aemilia) are recessed and outlined, and further highlighted with red paint. The plan shows no geographical or political features: a blank space indicates the Tibur, which may have been painted in blue or red; the city's sacred boundary, the *pomerium*, is omitted.

The plan's function is unclear. Its intricacy suggests a practical cadastral or locator map. It is, however, too large and too awkwardly displayed—the topmost features would have been forty feet (12 m) above ground level (Reynolds 1997, 115–123). More likely,

the plan was a decorative showpiece (Reynolds, 1997, 124–134), like Agrippa's map and the Peutinger Tablet. Reynolds suggests that the Plan was a marble version of official papyrus-scroll cadastral records, updated and annotated with measurements and ownership data.

By the late Medieval period, the Temple of Castor and Pollux was abandoned, and the plan began to deteriorate. Soon, opportunistic locals repurposed the conveniently squared and handy slabs in their building projects. 1,186 extant fragments represent about 10%–15% of the original map, which scholars have been working to reconstruct since 1562. Launched in 2003, the Stanford Digital Forma Urbis Romae Project is the first complete publication of photographs and 3D models of all fragments, including 87 lost fragments, known only from Renaissance drawings (http://formaurbis.stanford.edu/docs/FURmap.html).

Tabula Peutingerina

The Peutinger Map, drawn around 1200 CE, is a copy of a monumental map of the Mediterranean world under the Tetrarchy, spearheaded by Diocletian (293 CE; see Talbert 2010). This map was ultimately thought to derive from the cartographical projects of Caesar and Agrippa some three centuries earlier. Omitted from the extant map, however, are some major Imperial roads as well as Germany, a province of interest to Caesar (*Gallic War* 6.11–28) and expressly subjugated by Augustus (*Res Gestae* 26). Included is territory to the east of the Euphrates and Africa as a whole, areas well outside Roman hegemony (Rathmann 2013, 205–206). The copy exists in 11 segments, with the western end missing (Germany might have been rendered on the lost western-most segment). The map reflects a geographical awareness deriving from Eratosthenes in its presentation of physical landscape, the stylization of topographical features (as seen on the Artemidorus map) and the placement of principal settlements (as anticipated by the Artemidorus papyrus: Talbert 2008b; Rathmann 2013). Noted on this remarkable artifact are about 2,700 discrete places and associated distances, extending from Britain and far beyond to the east. Talbert's assessment (2008b) persuades: "There could be no finer articulation of the Tetrarchy's ideals in map form: a seamless, stable, united world—with Rome conspicuously at its center—under Roman sway and readily accessible everywhere overland."

12. "Maps" in Greek and Roman Culture

Cartography was of interest to both scientists and lay people. Many of the endearing stories from ancient mythology are tales of travel and adventure. Heracles, Perseus, and Bellerophon travel to distant locales to slay strange monsters. Odysseus is the renowned Mediterranean swashbuckler. In formal literature, readers can find verbal maps of varying length and detail, overt or subtle, concise or sustained. Throughout the *Ion* (whose eponymous character is a son of the god Apollo), Euripides sketches a map of the world as it was known to contemporary Athens. In the play, we see a map of the physical world, showing the extent of the habitable and peopled globe; a map of the Greek ethnic and political world; and even a cosmological map. All of these maps overlap, intersecting with Athenian hegemony and Apolline favor. Callimachus includes *periploi*

in his Hymns to Artemis and Zeus. Apollonius of Rhodes, in the *Argonautica*, recounts the Homer-inspired adventures of Jason in his quest for the Golden Fleece. Apollonius' mythological aims may have been advanced through the application of contemporary (scientific) geography (Hurst 1998); and, unlike Homer whose geography includes fantastical and legendary places, Apollonius may have interpreted Jason's journey within the parameters of burgeoning contemporary geographical knowledge (Endsjø 1997). Finally, a figurative map appears in Vergil (*Aeneid* 8.671–728), where the expanse of the Roman Empire under Augustus is delineated; emphasized are the symbolic center at Actium and cardinal points, borders, and lands separated by waterways (Nile, Ocean, Rhine and Caspian, Euphrates), returning us to Homer, whose Achilles wielded a shield that likewise replicated politico-cartographic contexts.

13. Conclusion

Maps are important expressions of Greek and Roman culture. Their data were incorporated from political, commercial, and military sources, and Greek cartographical advances came in the wake of increased interactions with other Mediterranean peoples. The shape and array of Greek maps reflect social, cultural, and political prejudices. Descriptive maps were included in diverse sources, from strictly geographical and historical documents to performance literature (comedy and epic), underscoring the general interest in maps as well as the Greek sense of adventure and exploration.

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NOTES

1 With sincere thanks to Duane W. Roller for his comments on an earlier version of this chapter which, as usual, strengthened both the argument and presentation.

CHAPTER 50

Land Transport and Vehicles

Georges Raepsaet

1. Historiography and Epistemological Problems

Transportation constitutes an ongoing human activity. Displacing, moving, dragging, pulling, pushing, lifting, and carrying are full-time needs for both daily life and economic activities. Since the time when hunter-gatherers used rope or poles for dragging game, innumerable forms of traction and portage have been developed; and all forms of energy, both human and animal, were required for driving them. From the Neolithic era, when humans yoked the first animal teams and built the first vehicles, a considerable diversity of draft methods has been put to the service of transport. Here we shall define the technical structures and principal configurations in the Greco-Roman world.

Analyzing land transportation in antiquity is a challenge, however, because direct sources are rare and scattered, and the subject has been much debated. Until the end of the 1970s, scholars of economic history rarely broached the topic, since it was deemed marginal and indicative of the so-called technical underdevelopment in Greco-Roman antiquity. The minimalist concept goes back to the work of a French cavalry major, Lefebvre des Noëttes (1931), who divided the history of transportation and teams in the west into two parts: antiquity, "blocked" by a defective harness that strangled the horse; and the liberating Middle Ages, creator of modernity, marked by the "revolution" of the horse collar. This theory enjoyed immediate success, especially (and first) with Medievalists. The adoption of this simplistic thesis by certain economic historians, in particular Moses Finley (1965), gave rise to an important intellectual trend often called "primitivism," whose fabrication and epistemological mechanisms Kevin Greene (1990, 2000) analyzed with perception.

In the primitivist or minimalist view, the inefficiency of transportation in antiquity was linked to an economic model that was characterized by the absence of trade within the context of a quasi-subsistence economy that produced little surplus. Exchanges were

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limited to rare high-value-added products, and servile labor was of particular importance. According to this theory, the lack of reinvestment precluded technological progress. The allegedly primitive socio-economic structure of antiquity reduced transport solely to that between the rural domain and the neighboring market town, or between the city and its territory, a polygon of limited and largely non-commercial exchange. Even today, this minimalist theory still has its proponents. As recently as 2000, J. G. Landels wrote: "The shortness of this chapter by comparison with the preceding one reflects—crudely but quite accurately—the unimportance of land transportation by comparison with sea transportation in the Classical World" (2000, 170). This goes to show that the epistemological obstacle endures. In fact, ancient transportation is based on the connection of road, fluvial, and maritime networks, and the "simple" nature of the technology does not represent a handicap regarding either linking transport or economic productivity. To fully appreciate the value of this technology of mobility in antiquity, we must contextualize the primary written and artistic sources within the overall framework of pre-industrial production and mechanical systems.

2. Putting Methods and Sources into Perspective

The history of technology cannot be pinpointed in time like battles or institutions, but understanding the technology requires contextualizing it in time and space. Grinding wheat, drawing water from the well, transporting hay or wheat, pressing oil, or tilling the soil constitute activities and knowledge that can be both extremely individualized in their technical styles and micro-cultural environments and, at the same time, fall within spatial and temporal parameters that extend well beyond a particular historical period. Regarding transportation history, there is not a primitive "pre-horse collar" era and a modern "post-" era. At best, there exists a "before" and a "since" the replacement of traditional mechanical transportation technology—human and animal, wind, and hydraulic—with non-renewable fossil and mineral energies that increase the available power while compressing the fuel, a "revolution" of the nineteenth century that was further developed in the twentieth century.

Moreover, varied sources and approaches are informative. The extant texts may be scant, but epigraphy is highly enlightening, whether in accounts of construction jobs (Burford 1960, 1969; Raepsaet 1984) or epitaphs of merchants and transporters (Raepsaet 1987–1988; Raepsaet-Charlier 2007). Papyrus documentation is, likewise, extremely valuable (Leone 1988), as are the Vindolanda tablets (Evers 2011), and the *ostraca* from Mons Claudianus (Bülow-Jacobsen 2009). Archaeology is another fruitful resource: artifacts in context (chariot burials, pieces of harness, etc.), vehicle tracks on the ground, iconography, and the dissemination of commercial products. However, the imagery must be interpreted with care. Geographic distribution further complicates our ability to quantify the extant data.

3. Comparative Ethnology and Ethno-History

Comparative ethnology and ethno-history is indispensable as a structural framework (Raepsaet 2002, e.g., 89–154) in research on ancient technologies, in regards to material, function, epistemology, and theory, in particular with respect to the archaeology of methods, manufacture, and production chains. New advances in the discipline emphasize technological choices, behaviors, and styles as social products and expressions of culture. The study of harnesses, carriages, and yoked teams can reveal as much about

society and culture as does mechanics and technology, and the interaction of these two approaches—social and technological—only enriches our understanding. Even today, economies throughout the world are affected by the structure and functioning of traditional land transportation (Hopfen 1970; *Techniques rurales* 1971). Current research by Paul Starkey and his team on Animal Traction Development at the DFID (Department for International Development) demonstrates this with great acumen (2002). In the point of view defended by ethno-economists, it also appears that a simple "primitive" technique must not necessarily be rejected and replaced by a "modern" Western technique. The cultural and social values linked to tools and technical behaviors should not be considered a priori unfavorable and defective. We seek optimization of traditional knowledge through surplus values/appreciation, and we consider this a factor in the economic progress—and also social and cultural liberation—of the populations under study. Apart from the immense reservoir of comparative documents, conceptual tools and methodological principles are useful. Comparative ethnology can also help in documenting archaeological and technological experimentation, an interesting, sometimes decisive, method when carefully and critically employed.

4. Mechanics of Forces

We understand mechanics as the science of forces and motion. Constituting an interesting and a paradigmatic case study, thus, is transportation technology, which we define as the application of a force to a mass for the purpose of moving it in a given direction by overcoming multiple constraints (Cotterell and Kamminga 1990; Motion and Energy). From antiquity to the nineteenth century, mechanics as applied to agriculture or transportation technology was largely empirical and routine. Nonetheless, we detect efforts at theorization with Archytas of Tarentum, and we see in Archimedes and Vitruvius conscious attempts to synthesize theory and practice (Fleury 1993). However, not until the late eighteenth and early nineteenth centuries did "agricultural mechanics" become a focus in industrial mechanics, with the works of Poncelet, Morin, Coulomb, Lecamus, and Gasparin, who were as interested in the efficacy of the spade as in the draft of vehicles. Their common desire was to understand the action, express it in theory, and heighten productivity. However, even though mechanical sophistication, linked in particular to a fundamental modification of fuel, is a recent phenomenon, the concepts of mechanical progress, choice, and innovation are atemporal, and their applications are sometimes of considerable importance to productivity or economy of effort. This basic mechanics, sometimes more sophisticated than one might imagine (Schürmann 2005), is indeed known in antiquity, and it yielded both interesting achievements and effectiveness.

A few subtle points are important here (cf. Motion and Energy). The movement of any mass involves constraints and obstacles that are more or less difficult to manage. The importance of the coefficients of friction and rolling, the effects of slope, and their combined effects on the required effort show that transportation is a mechanical configuration that must be controlled both in its particular elements and in its overall structure. An identical effort in absolute value may be sufficient on one terrain (or slope) but insufficient on another. The best means of transport often depends on the nature of the surface on which haulage occurs and on the nature of the contact between surface and load. Transporting a load may be easy on a paved Roman roadway, but impossible on loose soil. Similarly, it may be necessary to modify the effect of a slope to accommodate

the bends of a road. To overcome inertia and the effects of rolling friction, it is always necessary to apply a potential force greater than the combined resistances. Between load (resistance) and force, there is an interaction between harnessing, transmission, application, and reaction of the force exerted on the mass to be moved, in this case, the draft harness in harnessed transport (Raepsaet 2002, 19–30).

Given the paucity of extant scientific texts, it is difficult to resolve the question of whether the ancients had theoretical knowledge of the mechanics of forces (Meissner 1999). The question implies other, more general, ones: those of theoretical, applied, practical, and empirical knowledge; their combination; and of the capacity of thinkers to synthesize, theorize, or to apply theory. One of the first to have stressed the existence of a self-aware technical culture in antiquity, Bertrand Gille (1980), collected the research, and he classified successes and failures, principles and methods, concepts and applications. Theoretical technology flourished in Alexandria (Argoud and Guillaumin 1998). Chersiphron, Metagenes, Rhoicos, Theodoros, and Eupalinos were engineers as much as they were architects. These men possessed both practical experience in the field and theoretical knowledge. In the archaeological remains beginning in the seventh or sixth century BCE, we observe the deft application of the mechanics of forces as well as mechanisms for increasing force in building (Greek Public and Religious Architecture). The coherence of the projects and their execution, the accuracy of calculations, the knowledge of materials (including densities), and the mastery of the terrain and its hypsometry go well beyond empiricism. One does not improvise the lifting and hauling of a 10-ton monolith: the risks are too great and the marble too expensive. The necessary knowledge was mastered, recorded, and transmitted (Healey 1999, 42–63, 347–390).

A brief passage from Vitruvius reveals not only the interest that technical literature can bring to bear on the seemingly banal problem of animal traction, but also the desire in antiquity to carry this to the level of mechanical theory. Vitruvius raises the question of balancing loads:

> Following the same principle (symmetry and balance), when their yoke is attached [to the draw pole] by binding straps at the midpoint, the beasts can pull the loads in equal fashion. But when they are of unequal strength, and the stronger one tires the other, the strap is repositioned, lengthening one side of the yoke, thereby easing the weaker animal. (10.3.8)

This is less trivial than it might appear.

5. The Energy Potential of Portage and Traction

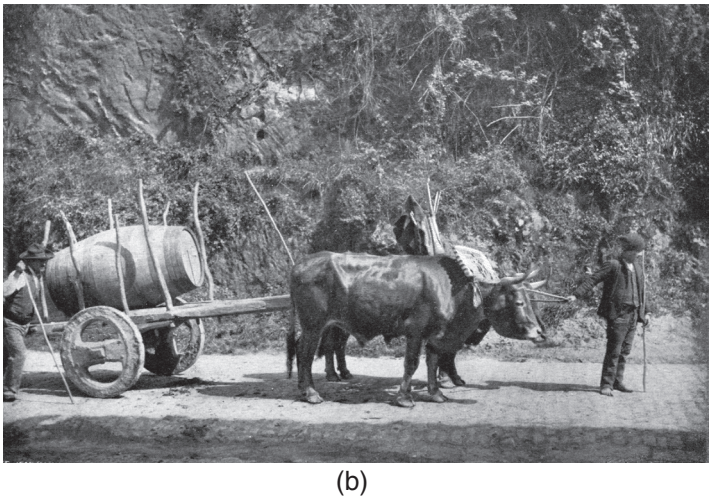
Men and animals are the basic sources of energies that were used in moving loads by road, portage, or harnessed vehicle, as remains the case today in much of the world. Numerous studies focus on the comparative force and power of animals in traditional societies (Hopfen 1970; Raepsaet 2002, 31–64). Generally speaking, one can consider that an animal's tractive force is directly proportional to its weight and that it corresponds to approximately one-tenth of it. The proportion rises to 15% with horses, which, for brief periods, can produce a force of nearly half their weight, or even more. Moreover, zoo technicians have observed that, in general, small animals have a better "output" than large ones, in particular because their angle of traction is lower. They also have greater vigor and endurance, which compensate for their lesser weight. This is true for oxen and small horses (400 kg [about 900 lb], 135–140 cm [about 4.5–4.6′] at the withers, the approximate size of Greco-Roman horses; see Animal Husbandry).

In most traditional societies, from the Neolithic era to the nineteenth century, oxen played a considerable role (Raepsaet 2001, s.v. "Rind"; 2002, 34–44). With the ability to exert 300–400 kg (660–880 lb) of force for six hours, and with a maximal power on the order of 20–25 horse power over 100 m (about 330′) for a vigorous pair, braces of yoked oxen constituted the principal driving force in heavy labor. Yokes are infinitely varied in form, but the principle of traction remains the same. The variables are the weight and size of the ox, and, of course, the number of pairs.

The respective advantages and disadvantages of the horse, ox, mule, and ass were much discussed in the mid-nineteenth century in temperate Europe. In terms of energy, the ass family (asses and mules: Raepsaet 1998–2001; 2002, 44–54) comes immediately after bovines. The mule has advantages in a team, with greater robustness than a light horse, greater docility, and the ability to expend constant effort. Asses and mules accept the yoke, which is less expensive than the collar to purchase and maintain. Although the price of a good-sized mule is almost as high as that of a country horse, the ass is less expensive and quite effective in hilly, dry regions where it sometimes carries more than its own weight for hours on end. Nor is its tractive capacity negligible. In France, barges were still being towed by pairs of asses in the early twentieth century.



(a)



(b)

Figure 50.1 **(a)** Mules of Langres. Museum of Langres (France); **(b)** Oxen cart in Portugal. Photo by Malvaux circa 1910. Private collection (G. Raepsaet).

The horse (Raepsaet 1998–2001; 2002, 35–37) is celebrated for many reasons, few of which are necessarily related to its economic productivity. Beginning in the tenth century CE, the energy potential of the horse was optimized by the shoulder collar. The horse became used increasingly in northern Western Europe, initially in equal shares with bovines, then dominantly in the nineteenth century. The average harnessed power for a light or medium-sized horse is between 40 and 80 kg m/s (about 90 and 175 lb) for work spread out over the course of a day. In plowing, the average effort is 40–50 kg m/s (90–110 lb); on a good roadbed, a light horse (360 kg [400 lb]) harnessed with a 1.5 ton load produces an effort of 45 kg (about 100 lb) m/s, or a force greater than 10% of its weight in moderate effort. For an average African horse, of 400–700 kg (900–1500 lb), Hopfen gives a force of 60–80 kg (about 130–175 lb) of force for a speed of 1m/s (3.3′/s) and a power of 75 kg (165 lb) m/s (corresponding to 1 horse power). There have been studies of the horse in antiquity (Vigneron 1968; Hyland 1990). And research into zootechnics of the draft horse, especially in the nineteenth century, delves in particular into perfecting new breeds of "carriage horses" and heavy draft horses for industry, mines, and ports. This is of little concern to us here because the horse was seldom employed in a utilitarian manner in antiquity or elsewhere outside of modern Western Europe. The horse of mediocre quality is, however, listed in the category of draft animals (Columella 6.27), quite distinct from the "noble horses" (Seneca, *On the Shortness of Life* 19.1).

Draft animals were significant energy sources, utilized since the Neolithic era. Between theoretical potential and pragmatic use, however, there is a considerable gap in which zoological and technological knowledge intervenes, along with economic and social contexts, cultural traditions or the capacities for investment, the state of veterinary medicine, and the treatment to which animals were subjected (Animal Husbandry).

6. Functional Typology of Harnessed Transport

From the Neolithic period up to the present time, harnessed transport with yoke has been universal, and its usage is manifold in all tractive activity: plowing, towing, milling, haulage, and transport. Sources of energy (human, animal, or hydraulic) for moving a load have changed little up to the invention of the steam engine. Yet innovations and adaptations were not precluded. Our approach favors utilitarian and heavy haulage and cart building where we encounter difficulties of traction. For a small, light vehicle, such as a two-horse *biga* with a load of 140 kg (310 lb)—70 kg (155 lb) of weight for one horse—each horse needs to exert a tractive force of 7 kg (15 lb). In the case of a four-horse *quadriga*, the load becomes 35 kg (75 lb) per horse. In both cases, the traction effort required is negligible. A very small horse could provide it with just a simple rope round the neck and a full gallop!

Packsaddle and Portage

From an overarching structural point of view, the packsaddle and portage (Raepsaet 2002, 66–68) are universally prevalent for land transportation for economic purposes, as is yoked traction with two bovines or asses. In poor mountainous regions, portage still remains important. Only human portage is possible on winding or sloping paths. Similarly, in many rural or domestic activities, in ports and on worksites, portage is best adapted to the situation. For example, in equatorial Africa, a man can carry 25 kg (55 lb) on the head over

25 km (15 miles) in one day. In the mountains, Tibetan porters carry up to 100 kg (220 lb) on their backs. A stick or a carrying pole might aid the porter. Portage can also be accomplished by two men using a suspension pole, stretcher, or litter to transport, for example, a kill from a hunt. In antiquity, there were professional porters, *saccarii*, in the ports, and various forms of sacks (*pera*), pouches (*mantica*), or other means of assisting portage, ranging from the simple sack up to the comfortable sedan chair or litter (*lectica*). Portage by animal and, in its developed form, with the packsaddle (Raepsaet 2002, 68–72), was just as fundamental for transporting loads that could be divided.

Over short distances or when carrying loads of low volume or weight, for example, from a small rural estate to the neighboring market town, the ass, mule and, to a lesser degree, the horse, could transport from 100 to 200 kg (220–440 lb) of merchandise, depending on the terrain or climate. (Columella tells us that "the mule is better for the packsaddle:" 6.37)

The miserable life of the packsaddled ass is a literary trope. Variants of the packsaddle include the soft double sack, the two-pouched *mantica* that is balanced on the shoulders

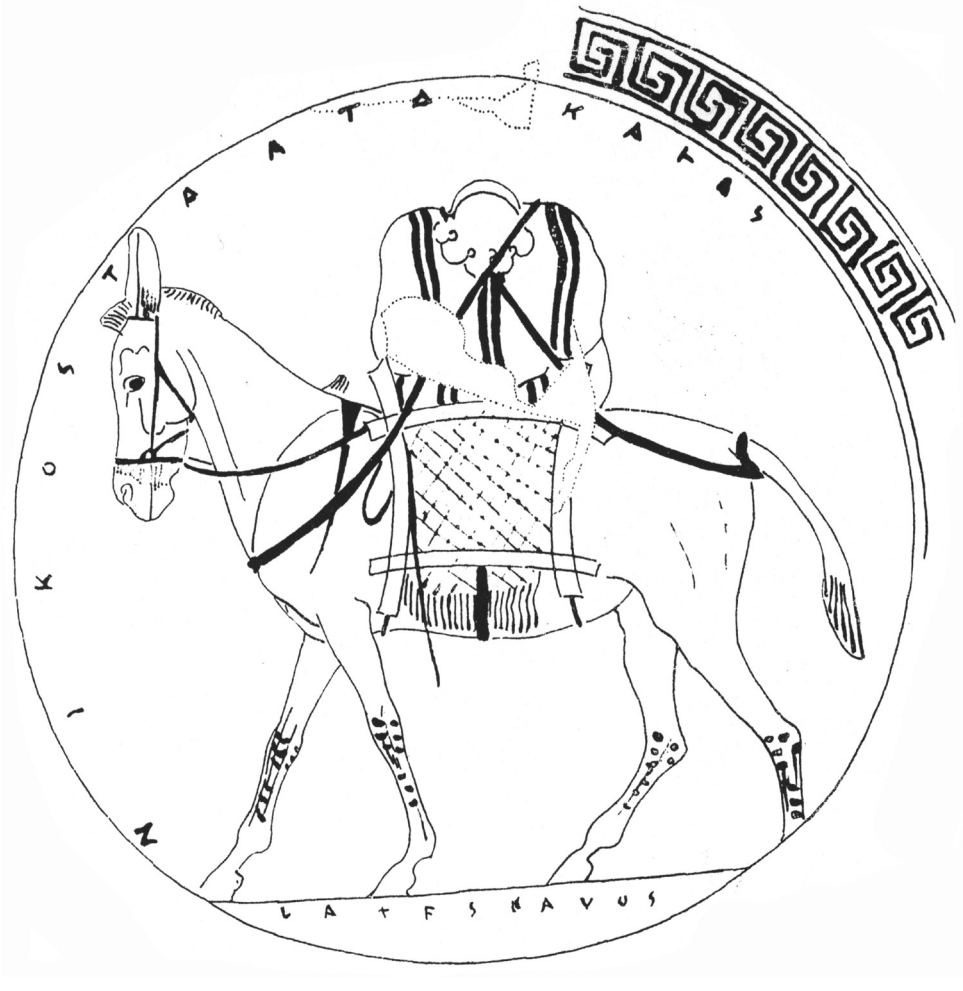


Figure 50.2 Ass with packsaddle in Ancient Greece. Adapted from P. Hartwig Griechische Meisterschalen, Berlin, 1893, plate 63. Cf. Raepsaet 2002, 70, Figure 5.

or back, and complex wooden armatures covered with cloth or equipped with straps (*sagma, stratum*). The packsaddle can even be used for transporting people (*astrabala*?). The packsaddled animal was the official porter of traveling merchants, such as the *utricularii*, a professional association of porters who transported and distributed wineskins and foodstuffs in Gaul by packsaddle, doubtless by muleteer.

Vehicles with Draw Poles, Drawn by Two Horses or Mules

The vehicle with a draw pole, drawn by two horses or mules, is considered the basic team in the Greco-Roman world (Röring 1983; Raepsaet 2002, 72–154). Although highly visible in ancient iconography and well represented in contemporary popular culture (e.g., Charlton Heston's chariot in William Wyler's *Ben-Hur*), it was, economically, the least utilized. As a military, ceremonial, or sports vehicle, the small two-wheeled chariot (*biga*), with a low box, draw pole (*temo*), and double yoke (*jugum*), is well documented in texts and iconography. The draw pole and yoke are joined together. The yoke is then placed on the animal's back and held there by a girth strap or soft trace that rests on the lower front part of the neck (see Homer, *Iliad* 24.268). The interpretation of this tractive system stirred a tremendous debate in the twentieth century. In fact, on the basis of poorly identified and misunderstood iconography, Lefebvre des Noëttes thought that the girth strap strangled the horse, preventing it from breathing, and that the yoke injured the withers, limiting its tractive power to a maximum of 500 kg (1100 lb) for the strongest animals. A new reading of ancient documents, accompanied by extensive experimentation, supports a new interpretation of ancient traction by horses (Spruytte 1977; Raepsaet 2002, 161–168): the yoke, placed on the curve of the back of the working horse or mule, is combined with a girth strap that rests on the shoulder joint, not on the throat. This harness could be described as a "shortened breast harness." The resultant pulling arrangement then becomes mechanically comprehensible. Experimentation shows that loads exceeding a ton on a small four-wheeled wagon pose no problem of traction with two horses, even on difficult terrain. Alongside the wheel horses of the *biga*, exterior horses (*funalis*) can be added to form *trigas* (three horse vehicles) and the *quadrigas* (of which Greek vase painters were so fond). There are also exceptional cases of multiple pairs of horses, with yoke or extended draw beam, but these are of secondary technological interest. The problem of harnessing horses with yoke and breast strap, better understood currently for the Greek and Roman world, is almost identical in the Near East and Egypt, where the rich iconography depicts war and parade chariots (Littauer 1968; Littauer and Crouwel 1979; Crouwel 1992).

Vehicles Drawn by Yoked Bovines, Mules, or Asses

The sole elementary harness system of any real economic significance in transporting merchandise was drawn by yoked bovines or mules (Varro, *On Agriculture* 1.20; 2.8) and asses (Columella. 7.1). Here, too, the team consists of a small vehicle, this "cart-of-all-work" (Lorimer 1903), with two wheels, draw pole and (double) yoke, but the box, often raised on props (*hamaxopodes* in Greek: Raepsaet 1984, 111), can take on multiple forms to adapt to the varied needs of transportation and moving loads.

In this instance, the iconography is limited, but ethnography supplements our understanding, insofar as traction with a yoke for asses or bovines is universal. The low, plunging

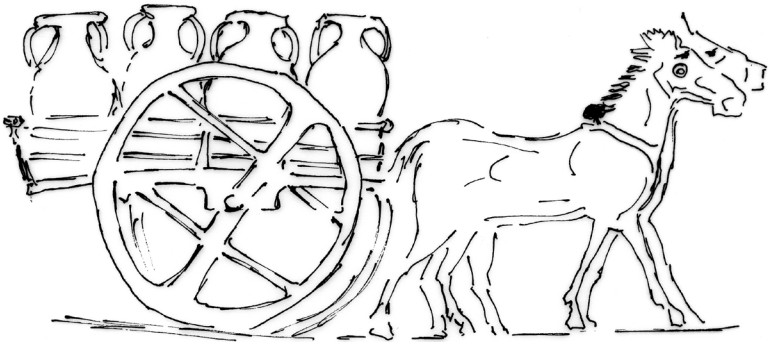


Figure 50.3 Small ancient Greek cart. Adapted from G. Brunns, Kabiren-Heiligtum in Theben, Berlin, 1940, I, plate 11. Cf. Raepsaet 2002, 170, Figures 89, 90.

neck of asses facilitates the positioning of the yoke in front of the withers, and the neck or shoulder strap intervenes to hold the yoke in place. For oxen, there was a perennial debate regarding the advantages of bounding the yoke to the horns or placing it before the withers:

> The yoke is best adapted to the neck. It is the way of harnessing which is the most commonly accepted. But in some countries people bind it to the horns. (Columella 2.2; Palladius 2.3; compare debates of agronomists in the 19th century)

The heavier the load, the greater was the tendency to resort to oxen. Whether in Mount Pentelikon in 450 BCE (Raepsaet 1984) or in Carrara in 1920, transporting architectural monoliths was reserved for oxen hitched in a line or fanned out.



Figure 50.4 Transport at Carrara (Italy). Illustrated postcard (circa 1910–1920). Private collection (G. Raepsaet).

At this weight—blocks of 8–10 tons or even more were not rare—the problem of transportation was concerned more with the construction of the dray and nature of the terrain than with the traction potential, strictly speaking. At Mons Claudianus, the Roman quarry in eastern Egypt, chassis of multiple trains were required for monoliths weighing tens of tons (Bülow-Jacobsen 2009, e.g., 205, #871).

In iconography as in texts, the choice of vehicle seems linked to the means, needs, functions, and circumstances: two-wheeled *hamaxai* were appropriate in the narrow streets of Athens and the vineyards of Corinth (Raepsaet 1988), but four-wheeled *tetrakukloi* were used for traveling to Epidaurus (Burford 1969, 184–190) or taking column shafts or architrave pieces down to Eleusis (Raepsaet 1984). Because of their stability and ease of braking, the four-wheeled vehicle was favored in hilly terrain, but lightness, maneuverability, and rapidity could tip the advantage in favor of the two-wheeled cart. The situation was similar in Rome (Adam 1984, 44–53). In a fresco from Boscoreale, one sees two-wheeled vehicles on a construction site (Adam 1984, 216). But the winegrowers of Langres used a solid four-wheeled cart (Molin –1988).

Vehicles with Shafts and "Single-Headed" Traction

One of the most spectacular innovations in transportation technology during the Roman era was the pair of shafts or "single-headed" harnessing (Raepsaet and Rommelaere 1995; Raepsaet 2002, 242–254). This type of harness, appearing in Northern Italy and Northern Gaul in the first century, allowed for pulling with a single animal. The texts are almost completely silent on this subject, except for the particular case of traction propulsion of the Gallo-Roman harvester (Pliny, *NH* 18.296; Palladius 7.2). The iconography, however, is rich (Molin –1988, 58–60; Raepsaet 1982; Zinn 2001), showing a range of two-wheeled vehicles, for travel or mixed use, drawn by an ass or a horse using a "small yoke" (*jouguet* in French, or "single yoke") placed on the neck. Use seems to have been restricted to the Celtic (including Northern Italy) and Germanic provinces. On the basis of limited iconography, Lefebvre des Noëttes contested the technological value of this innovation for the same reasons put forth earlier: that these harnesses supposedly strangled the throats of harnessed draft animals. Today, the question is resolved following the discovery and publication of a complete single yoke, remarkably preserved with its pieces of harness, found in a second-century Roman well in Pforzheim, Baden-Württemberg (Raepsaet 2002, 247–254). The quality of preservation of these objects enabled an experimental, interdisciplinary research project that has been conducted at the University of Brussels since 2001.

The harness structure with a one-headed yoke or single yoke, described by Pliny the Elder and Palladius in regard to the Gallo-Roman reaper, was also called *vallus* by the Treveri (Raepsaet 2002, 266–267; Greek and Roman Agriculture). Among its other advantages, the harness could be used for both pulling and pushing. The iconography that had caused so much perplexity among archaeologists and scholars of ancient technology (Vigneron 1968, 129–130) can thus be clearly explained. The support combines the one-headed yoke, resting on the nape in front of the withers, and lateral "pebble" disks, wedged closed to the animal and gaining the push of the shoulders. The back and shoulders work effectively together. The lateral "disks," which also prevent the abrasion from the girth strap, are constantly employed in traction; they accompany all the movements



Figure 50.5 Marius the donkey with a single yoke. *Source:* G. Raepsaet in Malagne-Rochefort (Belgium): Raepsaet 2002, 109-10, Figures 39, 40.

of the shoulder and forequarters, without aggravating them, by synergizing their muscular efforts. In sum, this one-headed yoke, combined with swivel joints, represents an interesting and effective compromise between high traction (back, nape) and low traction (shoulders), and it prefigures the medieval horse collar, designed exclusively for the horse.

This noteworthy innovation was based on knowledge of the anatomy of draft animals, the structure and transmission of tractive forces, and the balance of the harness. This harness, reminiscent of the "yoke saddles" of the Near East (Littauer and Crouwel 1979), is well adapted to "single-headed traction," in particular to the ass and mule. Testing this harness with an ass pulling a replica *vallus*, we observe its remarkable efficacy in harvest work, and on slopes and difficult terrain. It must be added that, in this case, traction with shafts works by starting with soft traces which, far from being trivial, constitute a real technological break from the rigid system of ancient traction, hence making it a prototype of the medieval traction with the horse collar.

7. The Diversity of Vehicles

The diversity of vehicles reflects the variety of social contexts, economic needs, and geographical realities in Classical antiquity (Röring 1983; Treue 1986; Fansa and Burmeister 2004).

In Greece and Rome, the vehicle of daily transport was relatively simple. As sources show, wheelwrights were also able to create heavy models mounted on disk wheels. The Roman Empire benefited from Celtic technology (Schönfelder 2002), as indicated in the specialized Latin vocabulary. The rich terminology reveals the increasing functionality and specialization of Roman vehicles, used for short- and long-distance travel and for the public messenger service (Latin words that refer to particular types of vehicles include: *benna* [a Gallic wickerwork carriage], *carpentum* [a two-wheeled carriage,



Figure 50.6 Funeral Monument from Gorsium, near Tac (Hungary). *Source:* G. Raepsaet. From Raepsaet 2002, 230, Figures 126 a-b.

covered for women], *carruca* [a traveling coach], *carrus* [a Gallic wagon], *cisium* [a light two-wheeled vehicle], *covinus* [a british/Belgic war chariot] *currus* [a triumphal chariot], *petoritum* [an open four-wheeled carriage], *pilentum* [a luxury carriage used by women], *plaustrum* [wagon], *sarracum* [wagon/cart], *triga* [a carriage with a three-horse team], etc.). But progress was neither linear nor comprehensive. We observe that, at the same period, in the same region, the pretty vehicle mounted on large, twelve-spoke wheels from the House of Menander in Pompeii coexisted with the rustic cart from the Villa Regina farm in Boscoreale, the latter with solid wheels, a turning axle, and a rudimentary box (Raepsaet 2002, 231).

Although the platform, box, and shaft are a matter of carpentry, wheelwrighting was generally more specialized and localized. Greco-Roman techniques of cart-making, from the primitive solid wheel to the large 12-spoked wheel with a metal rim fastened at only one point, shared a few common characteristics: the wheel disks were always in the same plane and perpendicular to the surface on which it rolled. Offset rims and wheel cambers would not appear until the end of the Middle Ages in the West, and only for the most elaborate vehicles. Construction of the common Greek wheel was rather original: four or six rim segments on a diametrical axis with perpendicular cross-struts ("crossbar wheel:" Raepsaet 1988), whereas the spoked wheel had been known in the east for quite some time, and the Republican Roman world also quickly developed this interesting technology. Another characteristic of ancient wheels is the thickness of the hub and its prominence.

However, the quality of the wheel must not be judged only on its degree of sophistication, its size, or the number of spokes. It is also a question of context and profitability. In the French and Spanish Basque Country and in northern Portugal, attested are vehicles, with two solid disk wheels or with small cutouts, that easily carry loads of more than a ton. The same technique is still used in Anatolia. And we no longer consider it an enigma that a four-wheeled vehicle could be tuned by means of a front axle. From the Hallstatt era, the front-wheel axle unit of the ceremonial chariot could pivot under the box because of a kingpin (Piggott 1983). As for the fixed or turning axle, the two systems coexisted. This is more a matter of quality of workmanship than of chronological evolution.

8. Customs, Contexts and Costs: Reality and Practical Applications in the Transportation of People and Merchandise (Raepsaet 2002)

From rural estates to construction sites, from harbor docks to street markets, land transportation technology was omnipresent and multiform. Technology adapted to the manifold aspects of public and private economy, domestic and commercial, in complementarity with fluvial and maritime transportation. The hitched vehicle was part of the basic agricultural equipment of Hesiod's property in Boeotia (*Works and Days* 426). Trolleys, pulled by long lines of oxen yoked in pairs, conveyed boats over the *diolcos* (the paved portage road) in Corinth circa 600 BCE (Raepsaet 1993), and they transported monumental pieces of architecture weighing several tons as in Didyma, Epidaurus, and Eleusis. Even if one reduces ancient economy to food production and its distribution, transportation technology constituted an ongoing preoccupation to which the Roman agronomists attest: the choice of a property was linked to the necessity of "exporting our crops" (Varro, *On Agriculture* 1.16) and, from there, it was advisable to have access to a "road or river." Aside from the specific cases of racing or ceremonial chariots, transporting people was often done using the same methods and techniques as for merchandise, sometimes at the same time, as iconography shows. In the Imperial Roman world, the sophistication, functionality, specialization, or even the professionalization of transportation and travel would increase (Laurence 1999).

The notable development in transportation technology during the Imperial era is linked to economic and military commercialization, as well as to the official courier service (*cursus publicus*: Kolb 2000). Founded by Augustus, this rapid post, initially on horseback,

became a vast public institution. It was buttressed with an infrastructure of stations and relays on the public road system and its own personnel, but it also relied on requisitions.

In addition to hiring vehicles—with or without coachman—and mounts at city gates, ports, or staging posts, transporters must have played as important a role in the private economy as in public service. They were often grouped together in professional organizations that took on a large share of major trade, especially in the western provinces. Associations of maritime and fluvial transporters (*navicularii, nautae*) were established in the important cities and ports of Gaul and Germany. The *nautae*, "entrepreneurs in fluvial transport," who specialized in a particular basin, river, and tributaries, also had to ensure the land transfer between rivers (*CIL* 13.5489), directly or by subcontracting. They may even have been responsible for picking up merchandise from the artisan or producer. The complexity and technical nature of the organization of long-distance transportation justified the existence of specialized corps, explaining in part, no doubt, that there were fewer known associations of road transporters, aside from the *cisiarii* (*CIL* 11.6215), if we accept them as "transporters" rather than "manufacturers." The *negotiatores* likely owned their own transportation equipment, or they hired the services of owners of teams, in particular, farmers.

9. Roads

We must also mention roads, essential to the issue of transportation (Laurence 1999; see also Urban Infrastructure in the Roman World). The extensive Roman road network, although designed strategically and linked to the needs of a centralized power, nonetheless supported economic transportation. It is, furthermore, not necessary to have a well-built road to circulate merchandise, even with a team. Alongside written sources, archaeological and cartographic studies on the distribution of artifacts show that commercialism, for example, the circulation of *sigillata* wares (Raepsaet 1987–1988), took all routes, from strategic routes to local byways, supplemented, significantly, by rivers. Regarding merchandise, qualitatively and quantitatively, there appears to have been no discrimination between fluvial and land routes, despite the noticeable difference in costs of transportation by road, river, or sea; even the mountains did not dissuade. The Alps were crisscrossed by important roads (like the *Via Claudia Augusta*), equipped, marked out, well-maintained (Walde and Grabherr 2006), and heavily traversed by the Cisalpine commercial network (Raepsaet 2012). One of the traditional arguments of the minimalist theory regarding land transport was its comparatively high cost. In fact, the figures given by the Edict of Diocletian show that, in all cases of travel within the Empire, transportation by road was markedly more expensive than by river and even more than by sea, as corroborated by literary evidence (Cato, *On Agriculture* 22.3). This observation, which appears in the orthodox view as an argument against ancient road transportation, was, in truth, quite common in pre-industrial societies. In eighteenth-century England, the cost ratio of sea versus river versus land transportation is, on average, 1:4.7:22.6. (These figures are close to those of the Roman era, and, it seems, of the modern!) In fact, the ancient commercial system—and, more broadly, pre-industrial if not modern—functioned by integrating the additional cost of transportation into the price of the merchandise, which shows a certain "modernity" of the economic structure and the reality of its commercial interconnection.

10. Conclusion

Ancient land transportation was based on human portage, the packsaddle, the light two-wheeled cart with draw pole and yoke of horses or asses, the heavy team (four wheels or trolley with multiple wheels) drawn by pairs of oxen in line, to which was added the Gallo-Roman innovation of the two-pole vehicle with a single draft animal. The Greek *hamaxa*, a small, light, all-purpose wagon with two wheels in a "cross-bar," was found alongside the heavy *tetrakukloi*, just as in Rome where the small, fast *cisium* with spoked wheels coexisted with the large *carruca*, the precursor of the mail coach. In the Roman Empire, there developed a functional range of service vehicles that integrated interesting Celtic innovations in cartwrighting. The *Pax Romana* ("Roman peace") favored a dynamic of development in which the quality of transportation played an active role.

Generally speaking, in the Greco-Roman world, transportation in all its forms contributed to the economic infrastructure by satisfying needs and effectively harmonizing with the economy. It relied on traditional driving forces (man, animal, water, and wind) that have the inconvenience of low productivity (in comparison with modern energy sources), but the advantage of indefinite renewability. The most common ancient harnessing method was universally linked to the (double) yoke or the single yoke, the customary mode for bovines and asses. It was less well adapted to the horse, whose economic role was marginal. However, with a light load (a ton or even more), the yoke hardly posed a problem of traction, as experiments have shown. Structurally, on the level of available human and animal energies and the principles of draft harnesses, models of Greek and Roman transportation were similar to traditional pre-industrial paradigms. However, efficacy reached an exceptional peak during the Roman Empire, in both private and public use. The technological innovation of the horse collar with soft traces in a few eastern European regions, where it accompanied economic growth beginning in the Middle Ages, has an interesting prototype in antiquity: the Gallo-Roman single yoke combined with lateral disks (one might speak of a true "proto-collar"). Other qualitative leaps regarding the harness and pulling technology include soft traces and whiffletrees. Advances in vehicle technology include the offset rim, wheel camber, suspension on longitudinal straps, and springs. These occasional advances do not effect a quantitative leap before the nineteenth century, which witnessed fundamental ergonomic changes. Somewhat paradoxically, the peak use of traction by horse with horse collar occurred barely a few years before its abrupt fall with the growing use of fossil energies (Lizet 1982).

The value of technology depends as much on economic efficacy as on its own mechanical quality, and it represents a link in the means of production, dormant or active. In Greco-Roman antiquity, real and varied, even innovative, transportation technology conveyed its own rhythms and inflections within the context of pre-industrial societies. However, its quantitative importance in antiquity, and thereby its economic significance, remains difficult to evaluate. Here again, the ancient situation is not unique. With the same technology, an economy can be stagnant or dynamic. In this regard, the Greco-Roman world offers an excellent laboratory of case studies, ranging from closed autarchies on private estates to mass commercialization, rendering, in any case, the minimalist concept obsolete.

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CHAPTER 51

Navigation and the Art of Sailing

Georgia L. Irby[1]

1. Introduction

> Some of the ships were swallowed up, more were cast onto islands fixed farther away. (Tacitus, *Annals* 2.24.1)

From the earliest times, humankind felt the call of the sea, despite its dangers, and men have plowed the waters with any manner of vessel, from plain rafts fitted with simple sails, Huckleberry Finn style, to the mammoth nine-masted, four-decked ships of Zheng He, who traveled the Pacific between China and the shores of East Africa in the early fifteenth century. The earliest evidence of seafaring dates to approximately 50,000 years ago in Australia (Sehul); and remains of tuna bones and obsidian tools may suggest Mesolithic deep sea fishing activity near the Franchthi cave in the Argolid (7500 BCE). Fleets of monumental outrigger canoes cleft the waters of the southern Pacific, making voyages of thousands of miles over the open ocean, perhaps as early as 1000 BCE (Lusby 2009; McGrail 2001, 315; Finney 1976). Polynesian helmsmen were armed with instinct, oral tradition, and elaborate stick charts that showed wind directions, currents, and islands.

Herodotus attests Egypt as an early seafaring nation (2.43, 161, 153). A statue base in Amenhotep III's tomb (circa 1800 BCE) lists Aegean toponyms, likely a record of a voyage wherein the Egyptian fleet circumnavigated Crete and visited the Peloponnese, Cythera, and Troy (Wachsmann 1998, 297). From the third millennium BCE onward, Egyptian ships ventured into the Red Sea, and from there to the eastern coast of central Africa to trade in exotic goods (McGrail 2001, 17).

By the mid-second millennium BCE, the Phoenicians maintained trade routes throughout the Mediterranean. They contracted for trade with Israel (1 Kings 5:8-9, 10:11), Egypt (Herodotus 2.9.2), the Greeks (Herodotus 3.107, 111), and others, especially along the northern coast of Africa (McGrail 2001, 129). Keeping within sight of land

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and sailing only during the day when visibility was clear, the Phoenicians made short-haul commercial voyages. For this reason, Phoenician settlements were established every 25 to 30 nautical miles (29–34.5 miles [46.3–55.5 km]), usually in conjunction with natural harbors (Aubet 1993, 140). Furthermore, the Phoenicians were the first Mediterranean people to explore the waters beyond the Pillars of Hercules (Straits of Gibraltar). The Pharaoh Necho II (circa 600 BCE) sponsored a circumnavigation of Africa, from the Red Sea down its eastern coast, up the western coast, and through the Straits of Gibraltar (Herodotus 2.10; Kahanov 1999; Roller 2006, 23–26). The voyage lasted two-and-a-half years, and the report that the explorers had seen the sun to their right was disbelieved. In the fifth century BCE, the Carthaginian king Hanno led an expedition through the Pillars down the western coast of Africa, but the expedition turned back when supplies ran out.

When sailing on open water, the Phoenicians preferred to anchor in protected coastal areas at night, but they also knew how to maintain course by observing the "Phoenician Star," Polaris, the brightest star in Ursa Minor. Because of their superior seamanship, Phoenicians were prominent in the Persian fleet at Salamis, and Herodotus credits Persian maritime success to the Phoenicians alone (Herodotus 3.19). Both Strabo (1.1.6) and Pliny (*NH* 7.209) admired their superior celestial navigational skills.

By the eighth century BCE, the Greeks came to rival the Phoenicians in maritime exploration and colonization, and their seamanship was no less accomplished. (For the importance of the sea to Greek communities see HYDROLOGY: OCEANS, RIVERS, AND OTHER WATERWAYS; SHIPS AND BOATS.) Though technology advanced, the challenges facing the sailor remain eternal (navigation, steering, and the weather). Storms may rage, or winds may blow unfavorably or not at all. Passengers suffered from seasickness, then as now (cf. Celsus 1.3.11 for treating seasickness). Juvenal, for example, lambasts the mistress whose stomach is steady when she travels with her lover ("she dines with the crew, wanders through the ship, and rejoices to haul rough lines:" 6.100–103) while the proper wife becomes ill at the perilous thought of embarking with her husband.

Offerings to the gods were made upon launching and landing, and a diligent skipper might even maintain an altar onboard. Mid-storm, as Propertius (2.25.25–26) warns those who travel on water, is hardly the appropriate time to fulfill pre-voyage vows, which often included the sacrifice of a bull (sacred to Poseidon), libations, and prayers (cf. Homer, *Odyssey* 15.222–223). Inauspicious signs would delay the launch. In 415 BCE, the Athenians carefully observed the prescribed rites in the hopes of an auspicious naval campaign in Sicily (Thucydides 6.32): a trumpet blast called for silence; customary prayers were then recited; mixing bowls, ashore and on each ship, were tended; and the fleet set sail as the last drops of wine were poured into the sea, while well-wishers ashore raised the paean (cf. Homer, *Odyssey* 2.430–433). Garlands were often tossed from departing ships, and vows for successful journeys were fulfilled with repeated rituals and gifts (Burkert 1985, 266–267). Bad omens included sneezing while going up the gangplank, cawing crows or magpies in the rigging, sighting wreckage on shore, and dreams (dreams of goats, boars, or owls presaged storms or pirate attack: Casson 1994, 155). If the weather turned foul, hair and nail clippings could be tossed overboard to propitiate the gods.

Although handbooks exist in other areas, we have no ancient technical manuals of the art of sailing—such treatises may not have survived or perhaps never existed (Dunsch 2012). Our evidence must be culled from iconographic and textual sources. Limited by scale, artistic convention, and an artist's inexact knowledge of the technical aspects of sailing, iconography rarely shows in any realistic way straightforward representations of

navigational maneuvers (Pitassi 2011, 4–20). Textual sources, composed for a variety of reasons, lack comprehensiveness and impartiality. Such sources, nonetheless, speak to the importance of sailing in the ancient Mediterranean, and they often provide vivid details about sailing and navigation.

2. Officers of the Deck: Kybernētēs, Keleustēs, and Prōratēs

> … Before being a rudder-man, it was necessary to be a rower, then to serve as lookout, and then to examine the winds, and only then to govern (the boat). (Aristophanes, *Knights* 542–544)

In this nautical *cursus honorum*, we have a rational progression of responsibilities and skills: from rower to lookout to helmsman to captain (Plato, *Alcibiades* 1.125c; Ovid, *Metamorphoses* 13.365–367).

The Greek term *kybernētēs* ("steerer") refers either to the helmsman, per se, or to the captain, whose prerogative included taking the steering oar (Odysseus takes the helm when he leaves Aeolus' island: Homer, *Odyssey* 10.32–33; cf. Pindar, *Isthmian* 4.71; Plutarch, *Alcibiades* 35.4, *Nicias* 25.2), and the *kybernētēs* is so called for his ability to lead a crew, rather than to navigate a ship (Plato, *Republic* 1.341c–d). Philostratus (*Life of Apollonius of Tyana* 3.35) describes a merchant ship in service between Egypt and India on which were "many *kybernētai*, subordinate to the oldest and ablest," that is, the captain whose mates took their turns at the helm (cf. Plutarch, *Moralia* 812c; Casson 1994, 316–17). Whoever was at the helm seemed to have command of the deck (e.g., Telephus, below).

Plato defines the helmsman's skill (*kybernētikē technē*) as maintaining "safety while sailing" (*Republic* 346a; cf. *Gorgias* 511c–e, *Laws* 961e). The job requires experience and skill in reading the weather, knowing the winds, and handling the vessel (Homer, *Iliad* 23.316–17; cf. Plutarch, *Table Talk* 1.3). The helmsman must work with the wind to "keep (the ship) straight" (Homer, *Odysseus* 11.10, 12.152), and only the worst storms could disorient the experienced pilot:

> When the middle hold was half-full with the flood, and the masts were already unsteady while the waves splashed over the other side of the stern, when experience offered no help to the white-capped helmsman, he began to strike a deal with the winds. (Juvenal 12.30–34)

Quick action during the onset of a storm was crucial. Reacting as soon as he sensed a storm, the alert skipper "draws tight the slack sails from all directions, so that not any light breeze escapes" (Ovid, *Metamorphoses* 6.231–233). "When a wind swoops down on the sea," after "making all fast, drawing tight the sails," a quick-thinking *kybernētēs* must exercise "his skill, disregarding the tears and entreaties of the sea-sick and fearful passengers" (Plutarch, *Pericles* 33.5). Ovid describes a harrowing storm at sea and the precautions taken to run before the storm:

> The captain shouts: "Lower the yards, already, and close reef the whole sail." He commands, but hostile winds ensnare his orders, nor does the din of the waves allow any voice to be heard. On their own initiative, however, some crewmen hurry to remove the oars, a part protect the hull, a part deny the sails to the winds. This one bails the water into the waves, this one snatches up the spars. (*Metamorphoses* 11.482–487)

This well-trained crew anticipated orders, jumping to stations in the face of emergency.

A good helmsman might even win renown: Pausanias (3.22.10) points out the burial site of Menelaus' helmsman Phrontis (the "thoughtful" son of Onetor, who "surpassed the tribes of man in guiding a ship when storms raged:" *Odyssey* 3.282–383), and Typhus, the Argo's pilot, was a local hero at Tipha (Pausanias 9.32.4). Aeneas' helmsman Palinurus was a master of the art (Vergil, *Aeneid* 3.513–520; cf. *Iliad* 18.483–489; *Odyssey* 5.271–275; Hannah 1993). As the Trojans rested on the shore, Palinurus studied all the winds, grasped the breezes with his ears, marked the all the stars gliding in the silent sky, and saw that all was motionless in the serene sky—conditions were good for sailing. The Trojans then broke camp, tested the watery road (*via*) and "spread the wings" of their sails. Palinurus had earlier found himself so disoriented in the thick of a storm that he was unable to distinguish night and day, and thus he was unable to remember the paths in the midst of the waves (3.201–202). Equally skilled was the Gallic helmsman Telo (perhaps from Gallia Narbonensis), who fought against Caesar (Lucan 3.592–594). Like Palinurus, Telo was skilled at forecasting the weather from observing the sun and moon. "In an agitated sea, keels listened to no hand better than his."

Two other deck officers were essential. "The one who orders," the *keleustēs*, gave the beat to the oarsmen. Oars provided the primary propulsion for ancient ships (Ships and Boats), and men drew lots in pairs for their turns at the oars of a warship (e.g., Propertius 3.21.12). Polybius describes the oarsman's training under the direction of a *keleustēs*:

> They made the men sit on rower's benches on dry land, having the same arrangements as they would on voyages; making the *keleustēs* stand in the middle to teach them all to drive their striving arms back at the same time and then to stoop their thrusting arms forward, they became accustomed to begin and stop their motions at the calls of the *keleustēs*. (1.21.2)

The *keleustēs* could improve or hinder the morale of a crew. An intractable crew could thus more than double "the time to finish the same voyage" (Xenophon, *Economics* 21.3).

A strong voice is essential for the *keleustēs*. In Euripides (*Helen* 1576), the rowers started their strokes as soon as they heard the *keleustēs'* shout. During a violent storm off Patrae in 429 BCE, crew were unable to distinguish one officer from another and thus were unable to follow orders (Thucydides 2.84.3; as also happens in the thick of battle: Thucydides 7.70.6; Appian 5.89). In contrast, during a stealth mission where silence was essential to security, the *keleustēs* called the strokes by "clinking stones together instead of with their voices" (Xenophon, *Hellenica* 5.1.8). To lighten the work, rowing was occasionally accompanied by singing (Longus, *Daphnis and Chloe* 3.21).

The third watch officer was the *prōratēs* ("who watches from the ship's bow"), keeping lookout for shallows, smaller craft, debris, and other hazards (Casson 1995, 300–321), or even swordfish for sport fishing (Polybius 34.3.3). Telephus was ordered to "sit at the helm and command the *prōratēs* to watch the course that the sons of Atreus take to Troy" (Sophocles, *Assembly of the Greeks* 142). As *prōratēs*, Danaus spied his pursuing brother (Aeschylus, *Suppliant Maidens* 716), and Odysseus kept lookout for Scylla (*Odyssey* 12.230). We see this deck triumvirate in action in Figure 51.1: the seated *kybernētēs* mans the steering oar at the stern; amidships an animated *keleustēs* calls the beat, and the *prōratēs* looks to stern (Attic Black Figure Hydria: Paris, Louvre E735: ABV 85,2; Badd^2 23; BAPD 300789; Morrison pl. 11D).



Figure 51.1 Greek Deck Officers. *Source:* DeAgostini Picture Library/Getty Images.

3. Moving the Vessel

In calm weather, when not underway, ships were left at anchor or beached (e.g., Homer, *Iliad* 8.217; *Odyssey* 9.149, 546; Vergil, *Aeneid* 3.135; Ovid, *Metamorphoses* 13.4, *Heroides* 12.15). When violent weather threatened, ships were usually pulled ashore, bows toward the sea (Arrian, *Periplus of the Black Sea* 4.4). Ships would simply be hauled into the sea for launching (Apollonius, *Argonautica* 1.367–390; Ovid, *Metamorphoses* 11.463–466). Stern cables of anchored craft would be cast off before getting underway (Homer, *Odyssey* 2.418). The skipper waited for an opportune time to put out to sea, using coastal winds to his advantage, usually departing at daybreak when land breezes would carry the ship out (Medas 2004, 55–58).

Caesar anchored off Britain (*Gallic War* 4.23.4, 28.3, 29.2–3, 5.9.1). Aeneas' fleet also lay at anchor (Vergil, *Aeneid* 3.277, 6.4), but, when mooring in Caietas Bay, the sterns were beached while the prows were secured with two anchors, one on each side (*Aeneid* 6.900–901; Propertius 2.22.41 asserts that two anchors can better secure a moored ship). Occasionally an anchor would foul, and a swimmer would then dive to release it (Lucan 3.699–700). Sailors secured their vessels with additional anchors when they observed sea urchins clutching stones as ballast to steady themselves a sure sign, mariners believed, of rough seas (Pliny, *NH* 9.100). Anchoring, however, might also leave a fleet susceptible to sabotage. The Greek artist Androbius painted "Scyllus" cutting the anchor ropes of the Persian fleet at Artemisium in 480 BCE (Pliny, *NH* 35.139; the account is not in Herodotus). The Carthaginian general Bomilcar was able to evade Roman notice as he escaped from Syracuse into the sea in 212 BCE during a violent storm that prevented the Romans from lying at anchor in the open water (Livy 25.25.11). Cables and hawsers were sometimes cut to facilitate escaping from the enemy (Livy 28.36.11). Anchors were usually secured by ropes, but Caesar reports that the Veneti used iron chains, instead of cables, to secure their vessels in the rough waters of the English Channel (*Gallic War* 3.13.5).

Propulsion was achieved through a combination of a main square sail and men at oars, often simultaneously (e.g., Arrian, *Periplus* 3.2)—triremes could reach up to 10 km/hour (6 miles [5.4 knots]) at battle speed in calm seas (Casson 1995, 281–296). According to the principle of the lever, rowers amidships exerted the greatest impact on propelling the ship: there was simply more oar (lever) amidships than fore and aft (the greater the distance between force [rower] and fulcrum [thole-pin], the greater the weight that can be moved). It is unclear if our Aristotelian author assumed oars all of the same length or longer oars amidships:

> As the blade presses against the sea, the handle of the oar, which is inside the ship, advances forward, and the ship, being firmly attached to the thole-pin, advances with it in the same direction as the handle of the oar. For where the blade displaces the most water, there necessarily must the ship be propelled the most; and it displaces most water where the handle is farthest from the thole-pin. This is why the rowers who are amidships move the ship most; for it is in the middle of the ship that the length of the oar from the thole-pin inside the ship is greatest. (*Mechanics* 4 [850b10–27])

It is essential, therefore, that the rowers work as a unit, and the *prōratēs'* job is vital in this regard. We see a ship vividly propelled by oarsmen in Lucan (3.525–528): "On one side Caesar's ships are exalted, on the other a fleet with many a Greek oarsman; oar-stricken hulls quivered, and repeated strikes set the lofty ships in motion."

Although oars were preferred (as more dependable especially when the winds failed), the image of a ship under full sail is irresistible. Odysseus' ship leaves Circe's island under "stretched sail" (*Odyssey* 11.11). Ariadne sees the sails which had conveyed the Athenian ship and her absent-minded lover Theseus away from Naxos (Ovid, *Heroides* 10.6). And, despite the damage she took mid-race, running aground on a reef, the *Centaur*, under Sergestus' command, comes into port "with full sails" (Vergil, *Aeneid* 5.281). The poets also describe sailors at their work, hoisting "lucky sails to the mast-head" (Propertius 3.21.11–13; cf. Ovid, *Metamorphoses* 11.474–477).

The ship's wheel was a late-seventeenth-century Dutch invention, improving on the sixteenth-century whip staff that enabled steering ever larger ships. Until then, ships were steered either with a tiller attached directly to the rudder or with steering oars. The tiller is a simple lever that provides torque to turn the rudder. The length of the tiller and force needed to move it are proportional to the size of the boat; thus the force required to control a rudder with a tiller increases with the size of the vessel. Our ancient author also describes the force, applied by the rudder to the sea, which results in steering the ship:

> Why is it that the rudder, being small and at the extreme end of the ship, has such power that vessels of great burden can be moved by a small tiller and the strength of one man only gently exerted? Is it because the rudder is a lever and the steersman works it? The fulcrum then is the point at which the rudder is attached to the ship, and the whole rudder is the lever, and the sea is the weight, and the steersman the moving force. The rudder does not take the sea squarely, as the oar does; for it does not move the ship forward, but diverts it as it moves, taking the sea obliquely. For since, as we saw, the sea is the weight, the rudder pressing in a contrary direction diverts the ship. For the fulcrum turns in a contrary direction to the sea; when the sea turns inward, the fulcrum turns outward, and the ship follows it because it is attached to it. The oar pushing the weight squarely, and being itself thrust in turn by it, impels the ship straight forward; but the rudder, as it has an oblique position, causes an oblique motion one way or the other. (*Mechanics* 5 [850b27–851a37])

Our author also observes that raising the yard increases the speed of a ship under sail: the mast is a lever, the socket to which the yard is attached is the fulcrum, and the boat is the weight to be moved by the lever. Since the same power (wind) moves the same weight (ship) more easily when the fulcrum (mast socket) is further away from that weight, raising the yardarm increases the distance between weight and fulcrum and thus increases the vessel's speed (*Mechanics* 6).

Larger ships were equipped with a brace of steering oars, one at each side of the stern, emerging from outboard oar boxes, sometimes resting in cradles and restrained by straps. The oars were socketed to a tiller bar or made fast directly to the hull (Orphic *Argonautica* 276–277; Casson 1995 224–228; Pitassi 2011, 56–58), leaving a ship vulnerable to sabotage (Vegetius 4.46). On a warship the oars were massive, and they might be operated by "some small little old man … steering massively huge rudders with a slender pole" (Lucian, *Navigium* 6). Figure 51.1 shows the seated *kybernētēs* manipulating the port (left) steering oar. If well-balanced, the steering oars were light to the touch, and the ship was easily steered (Lucian, *Navigium* 5). Like Telephus and the *kybernētēs* of Figure 1, artwork usually depicts the helmsman as seated.

4. Anchorages and Harbors

> On this side and that, Nature has established facing mountains of a rocky cliff and has withdrawn breezes from the sea, so that ships might stand secure on a quivering cable. From there the whole strait lies open, whether sails are carried into your ports, Corcyra, or the leftward (course) is sought—bending Illyrian Epidamnus towards Ionian waters. Here is a refuge for sailors when the Adriatic brings all its strengths to bear, and the Ceraunian mountains have disappeared into the clouds, and when Calabrian Sason is drenched with foamy spray. (Lucan 2.619–627)

It is important to know where is it safe (or even possible) to anchor or moor, and these data are recorded in many sources. Odysseus makes careful note of the harbors where he has moored in Aeaea (Circe's is "fit for ships": Homer, *Odyssey* 10.141), northern Europe (the Laestrygones whose harbor is "renowned": 10.87), and Sicily ("a harbor good for mooring, where there is no need of a cable: neither to throw an anchor stone nor to make fast at the stern": 9.136–139). Vergil replicates Homer's perfect natural harbor when Aeneas, after surviving a storm at sea, finds refuge in a protected lagoon off Libya where "no chains hold tired ships, nor does an anchor bind them with a hooked bite" (*Aeneid* 1.168–169).

Historians and geographical writers systematically record data about harbors, where they are plentiful, and where they are lacking. The anonymous author of *The Periplus of the Erythraean Sea*, a practical merchant-marine guide of the Red Sea (first century CE), sets the tone and purpose in his opening words where he promises to list the harbors and markets along the Erythraean Sea. Xenophon had complained about the lack of harbors near Salmydessus on the western coast of the Euxine (*Anabasis* 7.5.12–13; cf. Strabo 7.6.1; Arrian, *Periplus* 25.1). In the fourth century BCE, pseudo-Scylax (Shipley 2011) duly records "good (or plentiful) harbors" in the Adriatic, and even shipyards in harbors. Syracuse has two harbors (one inside a fort). Josephus describes the "immense fabricated defenses" around Pharos, where the channel is rough and the narrow entrance treacherous, but "perfectly safe" once inside the harbor (*Jewish Wars* 4.614). Pliny praises the many harbors of Italy (*NH* 3.41). Strabo records numerous sites as

having harbors, and others as "harborless" (Ostia is harborless because of siltation from the Tibur). Josephus describes the coast of Egypt as "almost harborless" (*Jewish Wars* 4.614). Pomponius Mela, likewise, distinguishes some places as lacking harbors (1.35: the dangerous, shallow Gulf of Syrtis), and in Gaul, cities are sparse because the harbors there are scant (2.76), but a bay on the Euxine is "full of harbors" (2.2). Arrian also mentions commodious harbors that shelter ships from the south and east winds (*Periplus* 4.2), some suitable only for small vessels (5.1, 13.1, 13.5). An *On Harbors*, cited by Pliny and Strabo, was composed by Timosthenes, a naval commander under Ptolemy II Philadelphus.

Where natural harbors did not exist, they were built, as at Ostia, Caesarea Maritima, Lechaion (at Corinth), and Trapezous on the Black Sea (cf. Arrian, *Periplus* 16.5).

5. Sea Conditions: The Sailing Season, Winds, and Storms

> Wherever the winds and helmsman were calling our course … (Vergil, *Aeneid* 3.269)

Like the Phoenicians before them, the Greeks and Romans preferred not to sail during the stormy winter months, when reduced daylight and persistent dense cloudiness greatly limited visibility. The best conditions for sailing extended generally from late May to mid-September ("after the rising of the Pleiades to the rising of Arcturus:" Vegetius 4.39; cf., Aristotle, *Meteorology* 361b30–33, who observes that sea conditions are usually more treacherous during the changing of seasons). Hesiod, a "lubberly" farmer, restricted sailing to the fifty days following the summer solstice (late June to mid-August: *Works and Days* 663–665; Casson 1995, 270). After mid-September "navigation is doubtful and more exposed to danger," since Arcturus, "a very violent star," heralds fierce equinoctial storms (Vegetius 4.39). The winter months (mid-November to mid-March) were characterized by violent winds and frequent storms (Casson 1995, 270–273). Although Casson has claimed that the seas were "effectively closed" in the winter months, a growing body of evidence suggests that sailing continued into the winter months (no doubt undertaken with greater caution: Beresford 2013).

The rhythm of life in the ancient Mediterranean, including the nautical, often followed the festival calendar. The "Sailing of Isis" (*Navigium Isidis* or *Ploiaphesia*), celebrated on March 5 and observed as the "birthday of sailing" (Vegetius 4.39; Witt 1997, 165–184), opened the sailing season. Apuleius (*Metamorphoses* 11.8–17) vividly describes a colorful and raucous parade of richly bedecked revelers, musicians, performing animals, and priests. The procession culminates on the shore at Cenchreae where an elaborately decorated ship ("an untried vessel"—perhaps a miniature or even a model) is launched as libations of milk and grain are offered to the waves, a first offering of the trading season. The ship is loaded with spices, and its sails proclaim a prayer for prosperous sailing through the new season (*Metamorphoses* 11.16). Isis herself professes her authority over the sailing season: she commands "wholesome ocean breezes," and her cult is inextricably linked with calming stormy winter waves and with the inception of the trading season. Epigraphic evidence attests that *Ploiaphesiae* were celebrated widely at port towns throughout the Mediterranean (e.g., Eretria, Ephesus: Witt 1997, 178) well into late antiquity (John Lydus, *On the Mind* 4.45). The festival was one of many that shaped medieval Carnival galas (ship carriages feature prominently in Italian and Rhineland Carnival parades: Witt 1997, 183), and its nautical

aspects endure in "Blessings of the Fleet" that are still observed as community celebrations in port and fishing towns throughout the world.

A ship under sail is at the mercy of the winds, and thus it is important to understand the winds, their directions, their effects, and to use them to advantage. It is reasonable to assume that records of wind data were maintained to facilitate navigation (Coutant and Eichenlaub 1975, xviii: Cape Sigeum, near Troy, may have been the site of a weather station). During the summer sailing season the prevailing winds in the Mediterranean are northerly (e.g., blowing from the north), thus facilitating southerly travel: that is, from Italy or Greece to Egypt, Africa, Asia Minor, and Syria. Casson (1995, 283: table 1, 284: table 2) shows an average speed of 6 knots for the southerly journey from Ostia to Africa, but 4.3 knots for the northerly trip from Carthage to Syracuse. But these prevailing winds must be considered a substrate for numerous local winds, resulting from ever-varying topography and meandering coastlines.

Aristotle treats the winds in *Meteorology* 2 (359b27–65a12). Most winds, he observes, are northerly or southerly, explained according to the tenets of his physics: as resulting from evaporation of rainfall in the watery eastern and western regions, along the course of the sun's transit (the ecliptic). The trajectory of the ecliptic also accounts for the obliquity of the direction in which the winds blow. Northern (Etesian) winds blow continuously after the summer solstice (originating from the evaporation from the cold moist arctic regions), but there is no corresponding southern wind after the winter solstice (arising from warm, dry places lacking sufficient moisture whose evaporation can sustain a southern breeze), and thus there are more northerly winds than southerly. Furthermore, contrary winds cannot blow simultaneously. Aristotle's student Theophrastus discusses the individuality of both seasonal and local winds in his less speculative *On the Winds* (see Coutant and Eichenlaub 1975).

Twelve prevailing winds were recognized, each originating from a separate point of the compass rose. An ancient wind rose was developed by Aristotle, perfected by Timosthenes (above), adopted by Posidonius and Varro (whose *Naval Books* are unfortunately lost: Vegetius 4.41), and preserved in Vegetius (4.38; cf. Pliny, *NH* 2.117; Seneca, *NQ* 5.17.5; METEOROLOGY).

Cardinal point	Greek name	Latin name
E	Apheliotes	Subsolanus
ENE	Caecias	Euroborus
ESE	Eurus	Vulturnus
S	Notus	Auster
SSE	Leuconotus	Albus Notus
SSW	Libonotus	Corus
W	Zephyrus	Subvespertinus
WSW	Lips	Africus
WNW	Iapyx	Favonius
N	Aparctias	Septentrio
NNW	Thrascias	Circius
NNE	Boreas	Aquilo

Many of the winds are geographically named: Thrascias from Thrace, Olympias from Mt. Olympus, Skiron from Sciron's rocks in Megara, and Kaikias from the river Kaikos in Mysia. Lips originates in Libya (first attested by Herodotus 2.25, as was the Apheliotes: 1.193), and Phoinikias from Phoenicia (SSE: Aristotle, *Meteorology* 363a21–365a13). This seems to suggest a maritime origin of the ancient compass rose based on a central Aegean framework (Davis 2009, 94). However, the names and quarters of these winds were the subject of disagreement, prompting Aulus Gellius to seek clarification (*Attic Nights* 2.22). The names varied, and the quarters of the winds migrated: Euros, originally the east wind, became the SE wind by the fifth century BCE (as reported later by Timosthenes).

Noted in the sources are the winds' effects. Northerly winds steadied and calmed the Black Sea (Arrian, *Periplus* 6.1). Arrian also specifies sailing with the winds (*Periplus* 3.2). Following winds sped the Greek fleet to Trojan shores (Ovid, *Metamorphoses* 12.37), Odysseus' ship to the Sirens' island (Homer, *Odyssey* 12.167), the Argo away from Thrace (Apollonius, *Argonautica* 1.953), and Aeneas' fleet to Crete (Vergil, *Aeneid* 3.130). Winds delayed Protesilaus at Aulis (Ovid, *Heroides* 13.3). Winds ceased to blow when Odysseus passed the Sirens, and his men had to row (*Odyssey* 12.168–169). Likewise the Argonauts must row to Ares' island after the wind had dropped in the night (Apollonius, *Argonautica* 2.1032). And failing winds caused Aeneas to drift to Sicily (Vergil, *Aeneid* 3.568). Pompey's forces nearly overcame Caesar's navy near Dyrrhachium until a rising south wind rescued the Caesarians (*Civil War* 3.26).

Homer and Apollonius frequently specify the wind's direction: Odysseus battled the North Wind as he escaped the Cicones (the violence of the storm ripped his sails, which he immediately stowed to prevent further damage: *Odyssey* 9.67–73). Zeus sent a northerly wind to punish the sons of Phrixus: their sails had been ripped, and their hull split; they floated on the keel of their ship to the safety of Ares island, where the Argonauts eventually found them (Apollonius, *Argonautica* 2.1097–1020; cf. Homer, *Odyssey* 12.420–425). Some winds were notoriously precarious: Horace reviled the Aquilo, Africus, and Notus for delaying Vergil on his return from Greece (*Ode* 1.3.12–14), and Jupiter unleashed the Notus to facilitate a flood (Ovid, *Metamorphoses* 1.262). Arrian specified harbors that protected ships from the Thrascian winds (*Periplus* 4.2, 18.3).

Sudden storms are a perennial threat. Vegetius (4.41) reiterates the signs of impending storms from Vergil (*Georgics* 1.393–463): a ruddy moon, for example, presages rain and squalls. We have already seen how a quick-thinking skipper could avoid storms or save his ship. The Persian fleet was devastated by a sudden storm off Magnesia in 480 BCE: since the beach was so small, the fleet rode at anchor, eight rows deep, the prows pointing out to sea. The sea suddenly began to churn under a clear, windless sky, and a violent east wind ("Hellespontian") dashed some of the ships against the "Ovens of Pelion," others against the stretch of beach (Herodotus 7.188). The Roman fleet heading to Africa in 203 BCE was ravaged by a storm: the fleet had nearly made landfall when the winds failed, shifting to the southwest, damaging and scattering the fleet (Livy 30.24.6–7). Caesar complained about the difficulty of sailing in the stormy Atlantic, but he admired the ships of the Veneti (which he described in detail), well-suited to treacherous sea conditions (*Gallic War* 3.12–13). He also described the sudden storms that damaged his fleet in Britain (4.29, 5.10) and delayed landfall (5.5). Caught in violent southerly winds on the Amisia River (Ems), Germanicus' fleet suffered through hail and fierce squalls from every direction: steering and baling were impossible; the panicked

soldiers were "ignorant of the calamities of the sea"; and animals, packs, and weapons were jettisoned to lighten the hull (Tacitus, *Annals* 2.23; also described by Albovinus Pedo, in a hexameter extract preserved in Seneca the Elder, *Suasoria* 1.15). After enduring a stormy voyage through the Adriatic and Ionian seas, Germanicus saw to repairing his fleet before resuming course to Syria—north winds, incidentally, prevented him from visiting Samothrace (Tacitus, *Annals* 2.53–54). Arrian described waves washing over the sides of his ships in the Black Sea (3.3–4, 6.1). Sailing from Alexandria along the coast to Cyrene in 407 CE, finally, one experienced skipper sought the open sea as a precaution against a looming storm, but his passengers urged him to turn back to the coast (Synesius, *Letter* 5 Martin).

Accounts of storms at sea appear in many genres, and the descriptions are often harrowing. Ovid compares the chariot of the Sun, driven by the inexperienced Phaethon, to an improperly ballasted boat rocked on stormy waves (*Metamorphoses* 2.184–185). The storm that scattered Aeneas' fleet is vivid: squalls were agitated by the combined efforts of the East, South, and Southwest winds; huge waves were churned up from the depths; the sky grew black; and a sheer "mountain of water" towered over the ships (Vergil, *Aeneid* 1.81–123). Lucan paints the picture of a stunning gale so violent that the crew abandoned ship:

> Just as when the frantic South Wind thrusts back the immense sea from Libyan Syrtes and the fractured weight of the yard-arm resounds, the skipper and each sailor leap into the waves from the abandoned ship, and each one makes a shipwreck for himself, before the hull's planks are scattered. (1.498)

Currents and tides (see HYDROLOGY: OCEANS, RIVERS, AND OTHER WATERWAYS) in the Mediterranean are too weak to have any noticeable effect except at the straits (affected by currents) and deep inlets (affected by tides: Epirus, Messina: Casson 1995, 273). Apollonius comments on the swift currents of the Hellespont (*Argonautica* 1.922), and the Po's current was taken into account by Vitellius' engineers when charged with constructing a pontoon bridge (Tacitus, *Histories* 2.34). It is unlikely that the average skipper possessed the conceptual and mathematical tools to consider, in a systematic way, the errors caused by currents (and drift).

6. Navigation

> Zephyr never relaxing the rigging, the seventh night reveals Egyptian shores with her Pharian blazes. (Lucan 9.1004–1005)

Navigation is the art of guiding a craft safely to a particular destination, aided—until recently—with reckoning only by natural or man-made landmarks or by the stars (magnetic compasses are not attested in Europe until the late twelfth century CE, to say nothing of GPS). In its earliest (legendary) form, the art was magical, and Homer (*Odyssey* 8, 557–563) describes the miraculous ships of the Phaeacians that required neither navigator nor even rudder. The Greeks as early as Thales understood the attractive power of the lodestone (Diogenes Laërtius 1.24), and the Minoans may have utilized magnetic direction-finding devices to align important buildings (Downey 2011), but the use of magnetic devices for navigation is unlikely in antiquity (the Vikings [by the thirteenth

century] and Chinese [first century CE] are known to have used magnetic devices for navigation).

Latitude was understood, and it was computed from astronomical observations as early as the late fourth century BCE. Longitude, however, could not be reckoned with any precision until the development of accurate chronometers in the eighteenth century. (Longitude gives positions east or west of some arbitrary prime meridian: for the ancients, this meridian ran through Rhodes). Inability to determine longitude could lengthen a journey or throw a ship well off course. Strabo, for example, gives the distance from Paphos on Cyprus to Alexandria as 3,600 stadia, a distance accurate for a ship heading due south and then west toward the east coast of Egypt, rather than on a direct southwest tack to Alexandria (14.6.3). Mediterranean sailors, however, lacked instruments that could record the distance traveled by a ship on the water, and Menippus attributes discrepancies of distances in geographical authors to variable wind speeds (Marcianus of Heraclea, *Epitome of Menippus's Periplus of the Inner Sea* 5, 1.567–568 Müller). Thus it seems likely that distances were calculated according to an average number of stades sailed during a given day, as Menippus implies, approximately 22 miles per day (Arnaud 2005, 70–87).

Apollonius provides good descriptions of coastlines and landmarks (e.g., *Argonautica* 1.580–608). Seamen also found their bearings by observing animals, especially birds, and for this reason terrestrial birds, which cannot land on water (swallows, doves, or ravens), might be kept aboard in cages to be released for determining where (or if) to make landfall. Land birds would make for the closest shore or return to ship if land was too distant (*Gilgamesh* 11.3.117–130; Genesis 8.6–12; Pliny, *NH* 6.83; Apollonius, *Argonautica* 2.335–339). The behavior of dolphins, seals, cuttlefish, and jellyfish also foretold weather conditions (Theophrastus, *On Weather Signs* 19, 40). The author of *The Periplus of the Erythraean Sea* records the signs of impending storms at Spice Port: turbidity and color changes in the depths (12).

Fires, tended atop towers (lighthouses), such as the Tower of Caepio at Gades, marked the entrances of many ports (Strabo 3.1.9). The most famous is the white-stone tower on Pharos, an island off Alexandria, constructed "for the safety of sailors" according to its inscription (Strabo 17.1.6; Josephus, *Jewish Wars* 4.613; cf. Caesar, *Civil War* 3.112; Lucan 8.184, 433; Statius, *Thebaid* 12.515–516). Strabo also mentions several other towers: at Neoptolemus at the mouth of the Tyros (7.3.16); two at Aulis whose harbor can accommodate fifty ships (9.2.8; the harbor there is actually quite small); pairs of towers at Abydos and Sestos (13.1.22); the Euphrantas Tower on the Syrtis (17.3.20); and the four towers on the Cyrenaian coast above the Plynos harbor (17.3.22). Juvenal mentions the *pharos*-tower marking the breakwaters of the port at Ostia (12.75–82; cf. Suetonius, *Deified Claudius* 20; Cassius Dio 60.113). The Tower of Hercules (rebuilt, possibly, under Trajan in the second century CE at A Coruña) remains intact, and ruins of one of Dover's two ancient towers can still be seen (80′ [24 m] high).

Knowing water depth is essential for maritime activity, and the ancients collected data that facilitated safe passage. Herodotus provides the earliest textual evidence of taking soundings (2.5.2; Casson 1995, 245). Archaeological evidence is much older, predating 2000 BCE: Egyptian boat models from the tomb of Meketra, chancellor to Nebhepetra Mentuhotep II, feature crewmen holding sounding lines in the bows (McGrail 2001, ix; Vinson 1994, 31). Paul's storm-savaged crew also took soundings by heaving a lead line (Acts 27.28). And several varieties of lead line have been recovered (Casson 1995, 246, note 85). This yields critical information especially regarding where it is safe to sail, and these data are constantly changing because the relationship between earth and water is

in a constant state of flux through the process of siltation (Hydrology: Oceans, Rivers, and Other Waterways; Classical Geology and the Mines of the Greeks and Romans). By Polybius's day, Lake Maeotis (the Sea of Azov north of the Black Sea) had silted to such a degree that it was unnavigable without a pilot to steer larger boats through safe, deep channels, away from the shoals (4.40.8). And it was common for river pilots to guide merchant ships through unfamiliar waters. Sources describe waterways as navigable or not: for example, the Nile is navigable in places according to Mela 1.51; Isis' boat is launched on "navigable waters" (Apuleius, *Metamorphoses* 11.5; see also Strabo 1.3.7; Arrian, *Periplus* 7.5, 10.1, 2, and others).

Although the Greeks and Romans preferred to sail by day with good visibility, evidence of night sailing and celestial navigation is not lacking. Palinurus (above) had marked the stars in the sky before embarking, and while sailing back to camp at night, Aeneas explained the course of the stars to his young Arcadian ally Pallas (Vergil, *Aeneid* 10.160–162). This implies a knowledge of celestial navigation. Merchants, traveling the desert by night, were able to navigate by the stars (Strabo 17.1.45), and such knowledge was easily transferred to nautical contexts. Trained maritime navigators could thus sail at night out of sight of land (McGrail 2001, 17). We have already seen that the Phoenicians had learned, early on, to navigate by Polaris. Lucan explicitly cites Cynosura (Ursa Minor) as "a very certain guide" for Pompey's eastern allies as they rallied to his cause (3.218–219).

From the Archaic period onward, the Greeks had knowledge of celestial navigation. Setting off eastward from Ogygia on his makeshift "raft" (fitted with sails and steering oar), as instructed by Calypso, Odysseus carefully observed the Pleiades and Boötes, keeping to his left the Bear (Ursa Minor), who "alone is without a share in Ocean's bath" (i.e. she never sets: *Odyssey* 5.273–277; cf. Ovid, *Metamorphoses* 2.171–173, where the Bear for the first time tries to plunge into the Ocean to escape the heat of the sun in Phaethon's wake). Aristotle, furthermore, casually makes reference to "nautical astronomy" (*nautikē astrologia*: *Posterior Analytics* 78b34–79a6; cf. Manilius 4.279–280).

Pompey learned the art of celestial navigation from his skilled helmsman:

> That star guides the ships, the north pole which is not submerged in the waves. Since this one will always rise to the zenith and Ursa Minor will always rise over the yard-arm, then we face the Bosporus and the Pontus rounding the shores of Scythia. When Boötes descends from the highest yard-arm and Cynosura is borne closer to the sea, the ship makes for Syrian ports. Then follows Canopus, a star content to wander in the southern sky, fearing the North Wind: with that one on your left, proceed past Pharos; the ship will reach Syrtis in mid-ocean. (Lucan 8.174–201)

Eschewing the planets that "glide and slip," the unnamed helmsman relied on the "fixed" circumpolar stars, as did Bacchus, another trained navigator who, like Odysseus, learned to watch the Pleiades and the Hyades (indicators of seasons), Capella (the brightest star in Auriga, abutting the circumpolar constellations), the rainy stars of the Olenian Goat, and the circumpolar Arctic Bears (Ovid, *Metamorphoses* 3.592–596; cf. Aeschylus, *Prometheus Bound* 456–458 where Prometheus, whose gifts to humanity include ships, taught men to read the stars). Vegetius (4.39) confirms the seasonal signs that indicate when it is safe to sail.

7. Maritime Highways and "Charts"

Following Gisinger's 1937 *RE* article on *Periploi*, Casson claims that there is no evidence that the ancients made and used nautical charts in the modern sense (1995, 246; see Arnaud 2005, 46–50). Nor may they have even needed to develop charts since most of the sailing was coastal. Yet preliterate Polynesians created elaborate nautical stick maps accurately depicting wind directions, currents, and islands. Literary contexts suggest that the ancients had a graphic understanding of safe and well-trafficked sailing routes as supported in the archaeological records of shipwrecks and maritime debris. Some routes date as far back as the Bronze Age: for example, Cilicia to the North Syrian coast and the Aegean to Egypt (Wachsmann 1998, 295–299; Sauvage 2012). Most extant ancient maps are, in fact, narrative; and pictorial maps were, if not rare, at least almost always monumental (Greek and Roman Cartography).

A tradition of orally disseminated knowledge is implicit. At *Aeneid* 3.274–275, the cloudy summits of Mount Leucas are dreaded by sailors. The statement is general; the knowledge is common. And Palinurus seems to have remembered sea routes (*Aeneid* 3.202) in waters that he has probably never before navigated.

The epic hero is forewarned of dangers (such as at Cape Pelorus between Sicily and Italy or the Symplegades) and advised on how to avoid them. Circe's instructions to Odysseus are clear: "But sailing quickly past Scylla's lookout, drive close past (her), since it is best to regret (the loss of) six from your ship's crew than all at once" (Homer, *Odyssey* 12.101–110). Vergil's Helenus gives similar advice to Aeneas: keep clear of the breakers on the coast and thus avoid the brace of dangers posed by the monster Scylla and the whirlpool Charybdis, between which runs a narrow path that promises death unless a strict course be kept (*Aeneid* 3.684–686). Apollonius of Rhodes describes the ferocious whirlpool as an endless roar and upsurge (4.923) in his harrowing litany of "ship-smashing horrors at the sea's crossroads" (4.921: μιξοδίῃσιν, a compound of the Greek road for "road").

Nautical charts may have been constructed in monumental contexts (Greek and Roman Cartography). On the pillars in Aeëtes' Cholchian palace, the Argonauts saw tablets on which were "all the roads and paths (πᾶσαι ὁδοὶ καὶ πείρατ') of both sea and land for those who circumnavigate" (Apollonius, *Argonautica* 4.279–281), reflecting, perhaps, monumental charts that might have been displayed in the Hellenistic courts of Apollonius's day (more likely unknown in the Bronze Age Colchis that provided the setting for Jason's adventures).

If not quite a chart, a maritime voyage, at any rate, seems to be rendered on a fresco from the House of the Admiral at Akrotiri in Santorini (circa 1500 BCE; National Archaeological Museum, Athens; see Greek and Roman Cartography). Shown is a fleet departing from one port town (at the left hand side), traversing a body of water, and arriving at another port town (right). Prevailing winds often determined a ship's course, and, given the wind patterns in the eastern Mediterranean, these ships, as the artist has depicted them, could have been on a course past Crete to the Nile (Riis 1970, 163–165).

The narrative accounts discussed above suggest that the ancients had the same understanding of aquatic superhighways that they envisioned for land routes. The ancient conception of sailing channels is graphic; and it is expressed with the same terminology employed for land travel. Strabo cites many roads (6.3.7: Appian Road;

4.6.6: a road so narrow that travelers were affected by vertigo), and roads are rendered on the Peutinger Map. The perception of travel on water was also along organized routes with a commonly known infrastructure that was all but physically visible. Greek and Roman mariners were not traveling as if on some vast, barren wasteland. Or at least they rarely did so. Helenus warned Aeneas that a long "pathless" (*invia*) route separated the Trojans from their final destination in Italy—the journey could be only by sea, and Helenus stressed that the trip would be without a road (*in-via*: 3.383) and thus remarkable—most sea routes were not so. *Via* (path, road) designates sea roads in Vergil (above), and Apollonius employs a rare compound of ὁδός (*hodos*, "road")—μι**ξο**δία—a place where several paths meet. The more commonly used πλόος (*ploos*, "a sailing or voyage by sea") and its compounds come to have the meaning of a sailing route as we see in Apollonius, where the Argonauts must return from Aia by "another sea route" (πλόος ἄλλος: 4.259). Compounds of *πλόος* (ἀναπλόος, διαπλόος, and παραπλόος), meaning "sea route," are commonly employed in Polybius, Strabo, Appian, and others.

8. Conclusion

Travel by water was fraught with danger and not undertaken lightly. But the sea was also the great lifeline of Mediterranean communities. "The sea became as much a bridge between people as it was a natural barrier, viewed with notoriously ambiguous feelings both as a pathway of opportunity and as a sacred domain not to be violated" (Dunsch 2015). Skill and teamwork were essential in conquering this realm. For the purposes of survival, commerce, warfare, expansion, and travel, the peoples of the ancient Mediterranean had perfected the necessary arts of sailing and navigation from their earliest days on the Mediterranean.

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NOTES

1 With sincere thanks to Simon Burris, Paul Johnston, Jake Kirchner, Duane W. Roller, and Eric Speth, whose comments on earlier versions of this chapter have improved both its content and style. All translations are my own, except those of pseudo-Aristotle, *Mechanics* (E. S. Forster in Jonathan Barnes, *The Complete Works of Aristotle*. Princeton: Princeton University Press 1984).

CHAPTER 52

Ships and Boats

Julian Whitewright

1. Introduction

Readers of this volume will be aware of the acknowledged centrality of the sea to human activity in the Mediterranean world. With this in mind, any study of the Greek and Roman world must contain an appreciation of the nature, scale, and capability of the watercraft of the time, provided here in broad terms. We focus more on merchant vessels than military ones for the simple reason that the evidence is more legible for the former than for the latter. No apology is made for this, but key sources relating to naval affairs are provided.

2. Sources

Unlike other topics covered in this volume, no surviving ancient text deals specifically with the technology of ship and boat construction or use. Accordingly, our knowledge of the subject is based primarily upon archaeological evidence, supported by iconographic and textual sources, where appropriate. While the general nature of such sources is probably familiar to most readers, including their various advantages and drawbacks, it is worth briefly outlining them in the specific context of the ships and boats. This allows some of the main archaeological sites and accompanying literature to be highlighted and for some interpretative concerns to be voiced. What follows is therefore concerned specifically and explicitly with evidence available for understanding maritime activity and ships and boats in particular.

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Archaeological Evidence

It is fortunate that for the period under discussion one can draw upon an extensive and well-preserved maritime archaeological record. The majority of the sites are included in Parker's 1992 volume, which over twenty years after publication remains the standard source for shipwreck remains in the Mediterranean. Among this wealth of sites may be found almost every type and size of Mediterranean ship or boat, ranging from the huge, long-distance, wine-carrying merchant ship excavated at Madrague de Giens in the 1970s (Tchernia and Pomey 1978), to diminutive fishing vessels such as Fiumicino 5 (Boetto 2006). As discussed below, because of such discoveries our understanding of the technical aspects of ancient Mediterranean shipbuilding grows, and we are increasingly able to explain instances of sustained technological change (e.g., Pomey, Kahanov, and Rieth 2012). Despite this, it should be noted that there is a bias in the shipwreck evidence to those areas where there has been a longer, stronger tradition of relatively well-funded maritime archaeological investigation, notably the south of France, and, to a lesser extent Italy, Turkey, and Israel.

While the evidence for hull remains is extensive and often well documented, evidence for sailing rigs in situ on shipwrecks is generally quite limited. This can result from the depositional process of a shipwreck, where a vessel's rigging is often broken or cut free and so is detached from the vessel during the sinking process. In addition, the highly organic nature of rigging is generally seen as unsuited to long-term preservation underwater, particularly in warm Mediterranean waters. Evidence from related terrestrial contexts, such as harbor sites, can often be better than on shipwrecks, especially in areas of high organic preservation (e.g., Whitewright 2007).

Our overall view of ancient ships and boats, as provided by archaeological evidence, is therefore heavily centered toward hull remains and the construction of those hull remains. Nevertheless, without an understanding of a vessel's rigging, it is never possible to fully understand a sailing vessel: how it was propelled, how the crew worked while aboard, how the rig and hull interacted. Continuing to close the gap between our comprehension of hull and rigging technology is likely to remain a key challenge for the study of ancient Mediterranean ships and boats in the coming years.

Iconographic Evidence

The iconography of ancient shipping in the Mediterranean is undoubtedly full of valuable information (e.g., Figure 52.1); it is not, however, without clear problems as a source of evidence. Many of the problems and criticisms of employing iconography from other periods and regions hold true for the ancient Mediterranean. Rarely is iconographic evidence unequivocal. Consequently, interpretation can often be difficult, subjective, or indeed both. The nature and, therefore, interpretation of any single representation may be influenced by its overall context. Medium, shape, size, and location of the overall piece can have an important bearing on the shape, detail, and meaning of the representation in question. Vessels can suffer from being wrongly proportioned, stylized, and schematized, all of which can be obvious hindrances to their interpretation and subsequent usefulness as a record of past maritime activity.



Figure 52.1 Carved Roman sarcophagus relief (third century CE) housed in the Ny-Carlsberg Glyptotek, Copenhagen. The relief depicts three sailing vessels at the entrance to a port, possibly Ostia, and is notable for the realism and detail of the subject matter. The central vessel carries a spritsail with the mast stepped far forward in the hull. The sprit is hidden behind the sail but is visible when the relief is viewed from the left. The other two vessels both carry square sails with *artemon* foresails, and the artist has shown their sails in a very different way, with the ruffled sailcloth indicating the path of the vertical brailing lines. The left-hand vessel has a conventional outwardly curved bow. In contrast, the right-hand vessel has a concave bow, forming a cutwater. Both types of hull are commonly depicted and have been attested in the archaeological evidence. *Source*: Julian Whitewright.

The most concise summary of many of these interpretative problems is contained in the semi-ethnographic work of Tzalas (1990) relating to the modern creation of mosaic images of the reconstructed Kyrenia vessel. Meanwhile, the seminal monograph by Lucian Basch (1987) remains still the most comprehensive source of iconographic images and interpretation. Despite obvious and well-documented problems, iconography continues to be a key source of evidence for Greek and Roman Mediterranean ships and boats. Such records are more commonly accessible and have a longer scholarly tradition of study than underwater archaeological remains. The fact also remains that, for many periods, notably Mediterranean prehistory, iconography is still the only widely occurring evidence for watercraft. The period under discussion here is maybe the earliest where extensive archaeological remains complement, confirm, and correct the general interpretations offered via iconographic sources.

Literary Evidence

Although lacking a single identifiable "ancient treatise" on the subject, literary sources for the study of Greek and Roman watercraft are numerous and, as with iconographic resources, they vary in their ease of interpretation, level of ambiguity and, consequently, usefulness. The primary work on ancient Mediterranean watercraft, written largely from the perspective of literary sources, remains that of Lionel Casson (1995). Although Casson does utilize archaeological and iconographic sources, his is a view shaped mainly by the literary material. This is particularly detailed, as might be expected when addressing the Greek and Roman world with its relative wealth of such source material. Other useful commentary, concerned more specifically with the Roman period, comes from George Houston (1987, 1988).

The caveats relating to the application of literary or documentary evidence to the study of ancient maritime technology are broadly similar to those pertaining to the iconographic record. Sources may be subjective in both creation and interpretation, especially where translation is required. When dealing with texts of a broad theme, care should be taken not to assume that authors record everything which they have seen. Only the unique or the unusual may be recorded, with more familiar sights and practices left un-noted. For example, there is a dearth of references to smaller vessels such as fishing boats, presumably because they were considered too commonplace, or low status, to be worthy of comment. Like iconographic depictions, care must be taken to place textual sources within their wider context and to take into account any standard literary conventions or previous sources which an author may have used.

Despite some of the general problems highlighted above, literary sources have the capacity to carry a great deal of information regarding ancient technology. For example authors might describe specific sail-handling practices from which rig types or sailing techniques can be inferred (e.g., pseudo-Aristotle, *Mechanics* 815b7; Achilles Tatius, *Leucippe and Clitophon* 3.1–2). In such scenarios, ancient authors may be taken at face value, unless there is an obvious reason for fabrication. Interpretation becomes more difficult once the content of the texts increases in complexity. If it is accepted that artists misrepresent shipping owing to a lack of knowledge, then there is no reason for writers to be any different. The recording of technology and techniques is probably the most vulnerable in this respect. The use and application of literary sources from the ancient world to inform our study is therefore not as straightforward as is sometimes perceived. However, these problems and considerations do not prohibit the use of such sources; they merely describe the limitations of the evidence.

3. Shipbuilding

An understanding of Mediterranean shipbuilding traditions is obviously central to appreciating the watercraft that underpinned and facilitated maritime connectivity across the ancient world. The main traditions and their key features are outlined below. However, the work of Pomey, Kahanov, and Rieth (2012) offers the best summary of the current situation, with far more detailed discussion of individual sites and practices than is possible here. An in-depth account and interpretation of a number of significant archaeological finds is also offered by Steffy (1994, 23–77), while the principle of ship design in antiquity is explored by Olaberria (2014).

For interpretative reasons, maritime archaeologists have divided shipbuilding traditions into two main types: frame-based building and shell-based building. Pomey, Kahanov, and Rieth (2012, 235–236) provide a succinct discussion of the development of these approaches in the Mediterranean. In simple terms, frame-based building is understood to be a system of construction wherein the vessel's frames play the most important role in its design and construction. Having laid the keel and set up the bow and stern posts, the builder begins erecting the frames (either all of them, or just the major ones) and, in doing so, defines the vessel's shape. The outer planking, forming the watertight shell, is then attached to the pre-erected framing. The frames play the most important role in defining the vessel's shape; because of this, the frames are described as "active" in the frame-based system of building. In contrast, a builder using a shell-based approach begins by first erecting the planking (the watertight shell), once the keel, bow,

and stern post are in place. There are no frames to hold the planking together at this stage, so the planks have to be joined together to make a self-supporting structure, usually achieved by fastening the edges of the planks together. Edge-to-edge plank fastening of some sort is one of the characteristic features of shell-based building systems. The frames may then be added to the shell; but, because they do not dictate the hull's shape, but simply serve as reinforcement, they are described as "passive."

Inevitably, there are variations to these two distinctly defined building processes. Notably, in flat-bottomed vessels, such as river barges, the bottom of the hull (planking and frames) is built first, followed by the sides. Such construction is termed "bottom-based" building. In addition, a method of alternative building, identified in the ancient and late antique Mediterranean, is classified as "mixed-construction." As the name suggests, this technique employs elements of both frame-based and shell-based building at different stages of a vessel's construction. For example, the vessel's lower parts might be shell based with passive frames added after only a few planks are in place. These frames subsequently become active in dictating the shape of the vessel's upper portions, which is therefore frame based. The presence, or absence, of edge-to-edge plank fastening is usually a good indicator of when the builder switches from one method of constructing the vessel to the other.

The ship and boat builders of the Greek and Roman Mediterranean utilized a mixture of all of the approaches just described. Prior to late antiquity, shell-based construction tends to dominate, with planks edge-fastened by mortise-and-tenon joinery, or alternatively by sewing. The latter method is particularly associated with Greek shipbuilding dating to the mid-first millennium BCE. Vessels have also been excavated which use both these fastening methods together. A strong tradition of bottom-based riverine vessels has also been identified from archaeological remains, dating to the Roman period, a spectacular example of which has recently been excavated from Arles, on the river Rhone (see www.arles-rhone3.fr). The first frame-based vessel that has been excavated dates to the late fifth century CE, and vessels built with a variety of mixed-construction approaches occur both before this, and for many centuries afterward.

Shell-First: Mortise-and-Tenon

From the perspective of the archaeological record, the shell-based tradition utilizing mortise-and-tenon joints to fasten the plank edges together is the primary shipbuilding tradition of the Greek and Roman Mediterranean (Figure 52.2). This approach uses relatively thick planks, normally of softwood, such as pine, with a series of mortises cut into the plank edges. Wooden tenons, usually of a hardwood, oak, or olive, are inserted into those cavities and also into corresponding mortises on the adjoining plank when it is fitted in place. Wooden pegs, also of hardwood, are then driven through both plank and tenon to lock the joint in place. Planks are joined to the vessel's keel and posts using the same approach. Planks in shipbuilding are normally not long enough to run a vessel's entire length, and so the planks are joined (scarfed) together at the ends. The resulting length of planks, joined end-to-end, is called a strake. In the Mediterranean mortise-and-tenon building tradition, the plank scarf joints are usually diagonal or S-shaped when seen from outboard with mortise-and-tenon jointing between the ends of the planks. Frames are then fitted inside the planking shell to provide the vessel with additional reinforcement, and these were usually attached with either wooden treenails or with conventional nails, in either case, driven from outboard, through the planking

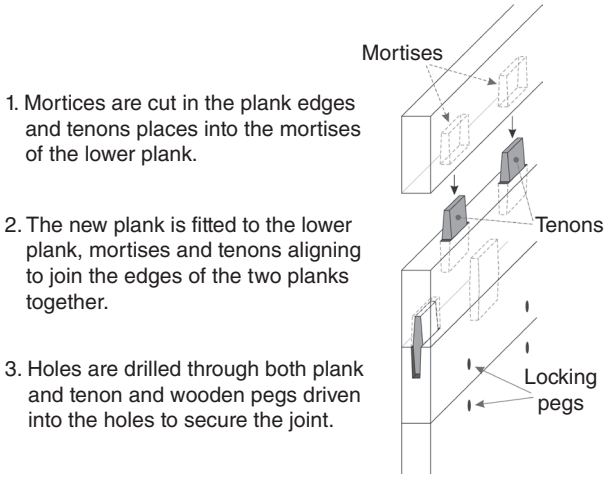


Figure 52.2 The key elements of mortise-and-tenon plank fastening.

and into the frame. An excellent account of the building of such a vessel is provided from an experimental archaeological perspective by Katzev and Katzev (1989).

This method has considerably antiquity beyond the Greek and Roman period. The earliest example of a shell-based, pegged mortise-and-tenon-built vessel comes from the late Bronze Age shipwreck at Uluburun in south-west Turkey (Pulak 1998, 210–213). The archetypal example from the Hellenistic period is that of the small merchant vessel, found off Kyrenia in northern Cyprus, dating to the late fourth century BCE, the construction of which is superbly described by Steffy (1985). Compared to the Uluburun shipwreck, the Kyrenia vessel had a much more developed hull form, characterized by a wine-glass shaped cross section, that was certainly seaworthy, an attribute attested by the performance of various reconstructions of the vessel (e.g., Katzev 1990).

Abundant archaeological evidence from the Roman period allows for the identification of variations in approach within the overall building tradition. One of the largest vessels excavated in the Mediterranean is the first-century BCE vessel from Madrague de Giens off southern France (Tchernia and Pomey 1978), measuring around 40 meters (131′) in length, 9 meters (29.5′) in width and capable of transporting nearly 400 tons of cargo. The vessel had a well-developed keel and a seaworthy hull, characterized by a concave bow, forming a cut-water (e.g., Figure 52.1). Its builder added strength with a double layer of mortise-and-tenon-joined planking, while many of the frame timbers were bolted to the keel. The latter feature contrasts with the Kyrenia vessel, where the frames and keel were not attached, perhaps illustrating the primacy of the planking shell in the mind of the shipbuilder. A contrasting hull form can be seen in the Laurons 2 vessel, dating to the late second century CE (Pomey, Kahanov, and Rieth 2012, 242–243). As well as being much smaller (circa 15 m × 5 m [49′ × 16′]) than the Madrague de Giens ship, the Laurons 2 (Gassend, Liou, and Ximénès 1984) vessel exhibits a much more flat-bottomed hull form and regularly curved bow (e.g., Figure 52.1), perhaps suited to coastal waters and beaching in estuarine conditions, rather than open sea voyages and deeper harbors. An illustration of the longevity of these Mediterranean shell-based approaches is found in the remains of the Dramont E shipwreck

(Santamaria 1995), dating to the mid-fifth century CE. The vessel measured around 16 meters (52.5′) in length with a capacity of about 40 tons and was engaged in trade between Vandal North Africa and southern France at the time of its loss. The ship was built on a completely shell-based system, exhibiting many of the features seen on earlier vessels, including a wine-glass-shaped cross section. As well as giving some indication of the longevity of the shell-based mortise-and-tenon approach, the Dramont E ship also demonstrates the long-distance capability of even relatively small vessels.

The vessels highlighted above are all classified as merchant vessels. Surprisingly little is known about warship construction owing to the absence of a substantial body of archaeological material. The only significant set of vessel remains is a Punic warship off Marsala, Sicily, dating to the third century BCE (Frost 1981). This find, along with other more fragmentary evidence, indicates that warships of the Hellenistic period and later were built using the same shell-based system of mortise-and-tenon edge-joined planking described above. The traditional viewpoint of earlier warships, such as the trireme of fifth-century Athens (e.g., Rankov 2012), is that they were built in the same way. But, given the extent of a sewn shipbuilding tradition in the Mediterranean (below), this is not proven beyond doubt, and Hale (2010, 21–25) has suggested that earlier warships were of sewn construction. Increasing archaeological evidence for warship rams, often recovered from the seafloor beneath naval battle areas, is beginning to shed light on many of the details of the construction techniques specific to warships (e.g., Tusa and Royal 2012; cf. Murray 2012), and this picture is likely to increase in complexity in the future.

The approach to shipbuilding described above is striking in its longevity of use and flexibility of application within the ancient Mediterranean as a whole and the Greek and Roman world in particular. Chronologically, the application of a shell-based, mortise-and-tenon-fastened tradition (when described in general terms) extends from the late Bronze Age through to late antiquity. Therefore, the most archaeologically common approach to conceiving and constructing ships and boats of all shapes, sizes, and function is one with considerable technological continuity across the Mediterranean. It is important that such technological continuity is not confused with technological homogeneity. Clearly, there are technical variations within this overall approach, many of which are now being identified through excavated archaeological remains and which occur on a temporal, spatial, cultural, and functional basis. These may be expressed through the outward shape and size of vessels as well as the details of the internal structures. The mortise-and-tenon-based tradition is central to Mediterranean shipbuilding, but it is important to acknowledge that this was not the only one used in the Greek and Roman world.

Shell-First: Sewn Construction

Sewn construction also utilized a shell-based approach to conceiving and constructing ships or boats. The key feature is in the use of cordage to attach the planks together when constructing the vessel's shell. To achieve this, holes must be made in the face of the plank with corresponding holes in the adjacent plank. Cordage is then passed through the holes and tightened to draw the planks together. If the cordage runs along the planks, passing through multiple holes, it is termed sewing. Meanwhile the practice of passing the cordage through only two adjacent holes (one in each plank) and using multiple individual fastenings is usually termed lashing. As with other shell-based

traditions, frames are inserted to provide additional reinforcement once the hull shape has been formed by the planking shell. Frames can be lashed in place, secured with treenails driven through the planks, or a combination of the two.

It was common in sewn traditions for small dowels to be set into the plank edges as a means of aligning the planks prior to sewing/lashing. Likewise, almost all sewn vessels utilize waterproofing wadding, placed over the plank seam and held in place by sewing/lashing. This can be either on the inside or outside (or both) of the vessel, and it provides sewn vessels with a distinctive appearance in comparison to non-sewn vessels. Further waterproofing and tightening is provided by driving wooden pegs into the sewing/lashing holes in order to seal them.

Two main distributions of sewn vessel can be identified in the archaeological record. The earliest has been termed the "Greek Archaic tradition" because all of the vessels come from that period from sites known to have been contemporary Greek colonies or settlements, with sixth-century BCE examples from Marseilles (Pomey 1998). Other generally contemporary examples have been found off Gela in Sicily, Giglio in Italy (Bound 1985), and Bon Porte in Southern France (Pomey 1981). Some of these vessels are not purely sewn in their construction, but they also utilize mortise-and-tenon fastening in some areas of the hull. Shipwrights obviously possessed an ability to apply and mix together either tradition of building, perhaps depending on local requirements and context.

The second major group of Mediterranean sewn vessels, dating to the Roman period, is situated exclusively within the northern Adriatic, both on the Italian and Croatian coasts (Beltrame 2000). Again, these vessels often employ a mixture of sewn and mortise-and-tenon construction. Perhaps the best-known example is the late-first-century BCE Comacchio shipwreck from Italy (Berti 1990). The chronology of these vessels is less established than the earlier Greek vessels, but it has been suggested that it extends as late as the seventh century CE (Beltrame 2000, 93). While it may be tempting to view the Adriatic sewn vessels as a quaint survival of an earlier, simpler tradition of shipbuilding, in reality it is more helpful to view them as another regional variation in how Mediterranean peoples engaged with and utilized the sea that was so central to their lives.

The relationship between sewn vessels and mortise-and-tenon-built vessels is one that is still quite poorly understood, aside from the basic temporal and spatial distribution of the archaeological finds. In particular, the inter-relationship between the two types of building tradition, clearly present in Greek Archaic vessels, has not been described beyond a simple linear process of logical change in which sewn vessels are gradually supplanted. That in itself ignores the presence of the fully mortise-and-tenon-built Uluburn shipwreck, dating to the late Bronze Age. There is clear scope in this area of Mediterranean shipbuilding for extended, detailed research, identifying not just the nature of technological change but also the factors that were underpinning and driving it. In this regard, it offers an opportunity to visualize and investigate some of the regionality of Mediterranean seafaring and shipbuilding, particularly during the mid-first millennium BCE.

Frame-First and Mixed

Variation in Mediterranean shipbuilding was illustrated above in the context of the mid-first millennium BCE. Around one millennium later, an even more profound and far-reaching change occurred, encompassing the traditions that governed how vessels were built as well as the sailing rigs that propelled them (see below). From the perspective of shipbuilding,

Mediterranean shipwrights began to adopt and develop frame-based traditions for the first time as well as a range of mixed approaches, drawing upon elements of both shell-based and frame-based building. The basic principles of these methods were described above. We can now outline some of the archaeological evidence. Further study should again be guided by the material and interpretation set out by Pomey, Kahanov, and Rieth (2012).

The earliest Mediterranean vessel built in a frame-based tradition is the Dor 2001/1 vessel excavated at Dor/Tantura on the Israeli coast (Mor and Kahanov 2006). Dating to the late fifth century CE, the vessel is shallow-draughted, suited for relatively local coastal trading rather than long-distance open-water navigation. The vessel is totally frame based with no elements of the shell-based mortise-and-tenon tradition that was still widespread. It is unlikely that the Dor 2001/1 vessel was the first frame-based vessel to be built in the region, and so the tradition must be earlier. Exactly how early remains an important question to be answered by the archaeological record.

Another eastern Mediterranean vessel, dating to the fourth century CE, excavated at the site of Yassi Ada (van Doorninck 1976), was built using a demonstrably mixed construction. The lower hull was built on a shell-based system as far as the fifth strake. Thereafter frames began to be added which must have been "active" in their relationship to the remaining planking. Other vessels built in a range of mixed approaches have been excavated from across the Mediterranean throughout the late antique period. One characteristic of the mixed-construction traditions is the reduced use of mortise-and-tenon fastenings to secure the vessel's shell together, with a corresponding increase in the strength provided by the vessel's framing. Overall, there is a long-term trend throughout the Roman Imperial and late antique period of mortises set further apart with tenons looser in their fitting and sometimes left unpegged. This trend, however, does not have a readily discernible pattern; there are both temporal and spatial discrepancies and anomalies throughout the late antique and early Medieval period, leaving much scope for future research.

Summary

Mediterranean shipbuilding in the Greek and Roman world can be broadly summarized as comprising two successive general forms of ship construction: first, the shell-based forms, both sewn and mortise-and-tenon, whose origins lie in the Bronze Age or earlier. The latter method, in particular, comes to predominate by the second half of the first millennium BCE. Second, frame-based forms developed from late antiquity onward. The individual traditions and their respective technical details that can be found within these overarching ways of conceiving and constructing vessels may be considered well documented through archaeological investigation. However, the extent of technological interplay between traditions, either at the macro-level of shell based/frame based, or when focusing on the more specific identifiable traditions (sewn, etc.), is much less clear, for example, the motives behind the use of mortise-and-tenons in the mid-first millennium BCE or frame-, and not shell-, based construction in the mid-first millennium CE. What can be stated with some certainty is that the trajectory of Mediterranean shipbuilding technology during antiquity is not one of simple, linear development; technological change is variable in pace and nature across the Mediterranean for reasons that are not yet well established. Extensive regional variation exists and understanding this, together with an increased appreciation of the broader context of maritime archaeological remains, may offer the most fruitful means of shedding further light on this integral aspect of Mediterranean maritime activity.

4. Mediterranean Sailing Rigs

Extensive, well-preserved, and documented archaeological remains have been fundamental in understanding Mediterranean shipbuilding during antiquity. In contrast, the archaeological evidence for the sailing rigs that propelled such vessels is extremely limited. Rigging components do survive, both underwater and in terrestrial contexts, but not in quantities comparable to the hulls that they were placed upon. The result of this imbalance is a much increased interpretative emphasis on iconographic and textual sources as a means to set out the basic chronologies of when different sailing rigs begin to be used, altered, displaced, and abandoned. While this situation is not ideal for objective interpretation, it is however unavoidable. What follows is simply an attempt to make the reader aware of the breadth of sailing rig form in use in the ancient Mediterranean and to gain an impression of how those rigs were integrated within Mediterranean seafaring practices.

Oared Propulsion

As well as the sail, the use of oar power for propelling vessels in the ancient world requires some brief comment. Iconographic and literary evidence indicates that for much of the Bronze Age, vessels were often propelled by both oars and sails. Such vessels were probably fairly non-specialized, being suited for trading or warfare as required. From the beginning of the first millennium BCE there is more evidence for vessels being developed for specific purposes; oared vessels used purely for warfare and sailing vessels for cargo-carrying purposes. The removal of oarsmen from cargo vessels led to increases in carrying capacity and reductions in the costs associated with maintaining rowing crews. At the same time, a massive reduction in the amount of water that needed to be carried on board to sustain the rowing crew is likely to have greatly reduced the potential range and duration of voyages.

For the remainder of the period covered here, the use of oars was mainly restricted to naval vessels. The reliable, predictable delivery of power and the ability to maneuver at speed ensured that Mediterranean warships continued to be propelled by oar power until the post medieval period. In the ancient world, such ships could be configured to carry several levels of oarsmen, with a single oar per person; alternatively, several rowers could pull on the same oar. The possible combinations, arrangements, and sources of evidence are well described by the sources given above in regard to naval warfare and warship construction. In addition, the contributed volume edited by Gardiner and Morrison (1995) provides an excellent range of material, including useful background context and discussion of shore-side installations.

Square Sails

The square sail is the earliest sailing rig visible in the iconographic evidence, with examples dating to the fourth millennium BCE from Egyptian contexts. Based upon iconographic sources, the square-sail rig undergoes a myriad of changes and developments prior to the late Bronze Age. These lie outside the scope of this work, but it is enough to say that the basic components of the rig had become settled by about 1200 BCE. This was a single sail that was probably quite broad (more rectangular than square), set on a spar (yard) along its top edge (the head), while the bottom of the sail (the foot) remained free ("loose-footed"). In strong wind the sail was furled, or made smaller, by hauling on a series of ropes (brailing lines) that ran up the forward face of the sail and

guided through fairleads (brail rings) sewn to the sail. These lines ran over the yard and returned to the deck toward the vessel's stern, where they could be hauled upon to cause the sail to be folded upward in a manner similar to a Venetian blind. This arrangement (Figure 52.3) resulted in a sail whose shape and size were easily altered to suit the course being sailed upon and the conditions encountered. It also has the potential to leave a

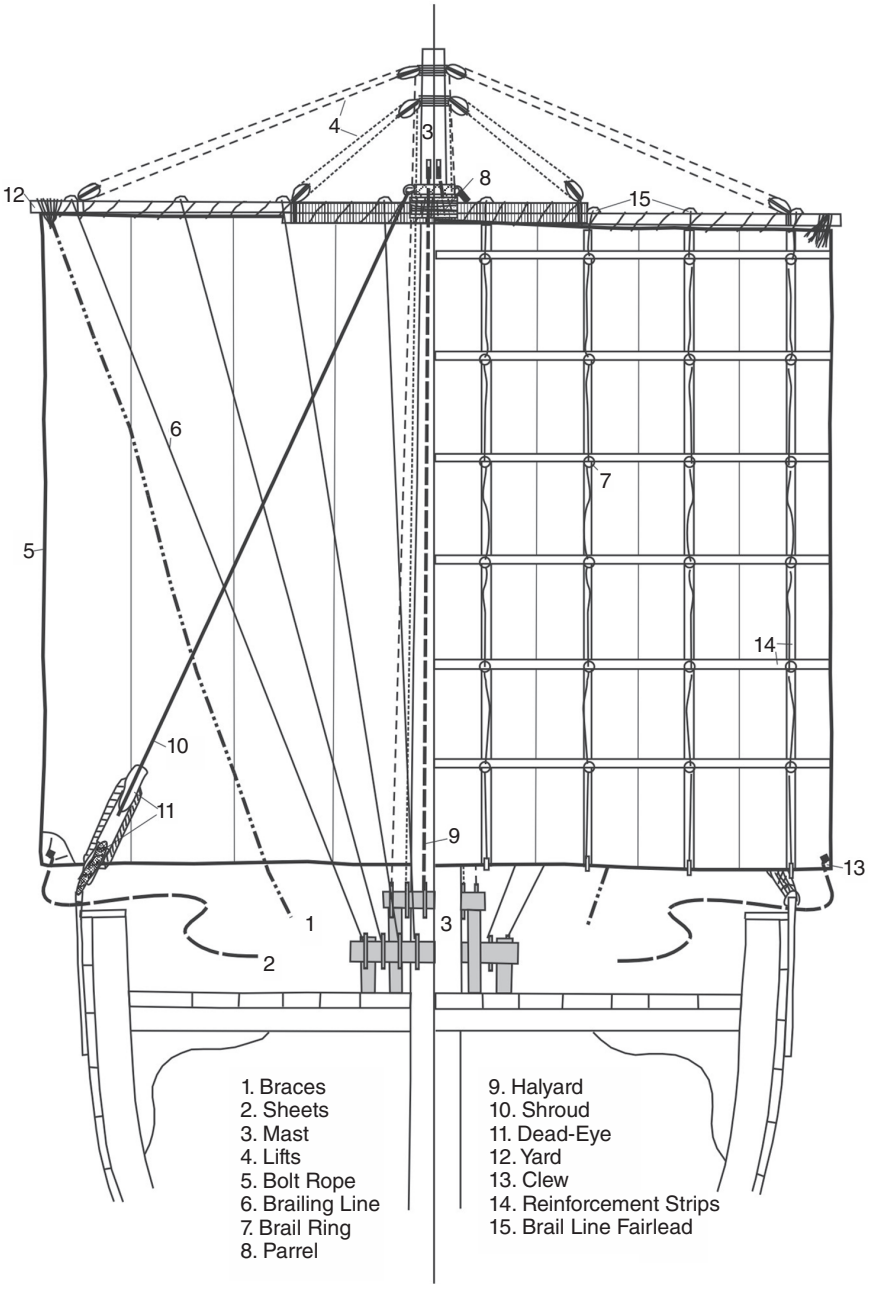


Figure 52.3 The main rigging components and their arrangement, as found on Mediterranean square-sails from the Greek and Roman period.

distinctive archaeological signature in the form of brail rings, a component not utilized on the other types of sailing rig present in the ancient Mediterranean.

The sail just described remained the basic building block of the majority of Mediterranean sailing rigs until late antiquity and was used on vessels as varied as fishing boats, triremes, and grain carriers. This rig underwent a range of technological variation that is visible in the iconographic, literary, and archaeological record (Figure 52.4). Perhaps most notably, in the mid-first millennium BCE a small foresail (the *artemon*) was introduced (e.g., Figure 52.1), probably to improve the maneuverability of vessels when sailing on courses across the wind and at angles of less than 90° to the wind. Further development saw the use of vessels with two equally sized masts as well as vessels carrying a main mast and *artemon*, but also with a third mast (mizzen) at the vessel's stern to further improve maneuverability. Nonetheless, vessels continued to be used that carried only a single square sail, which, according to archaeological evidence, was set around a third of the vessel's length from the bow, in the optimum hydrodynamic location for all courses of sailing (see Palmer 2009).

The rigging components used to create the square-sail rig are relatively distinctive in the archaeological record. Surviving rigging components are often characterized by large numbers of brail rings, made of wood, lead, or animal horn (e.g., Whitewright 2007, 285). Pulley blocks with both disk and cylinder sheaves (pulley wheels) are also common (e.g., Hesnard et al. 1988, 105–126). The mast, yard, and sail were supported by a strong set of ropes (standing rigging), known as shrouds and stays, that were tensioned with wooden blocks called deadeyes, a reasonable number of which have also survived

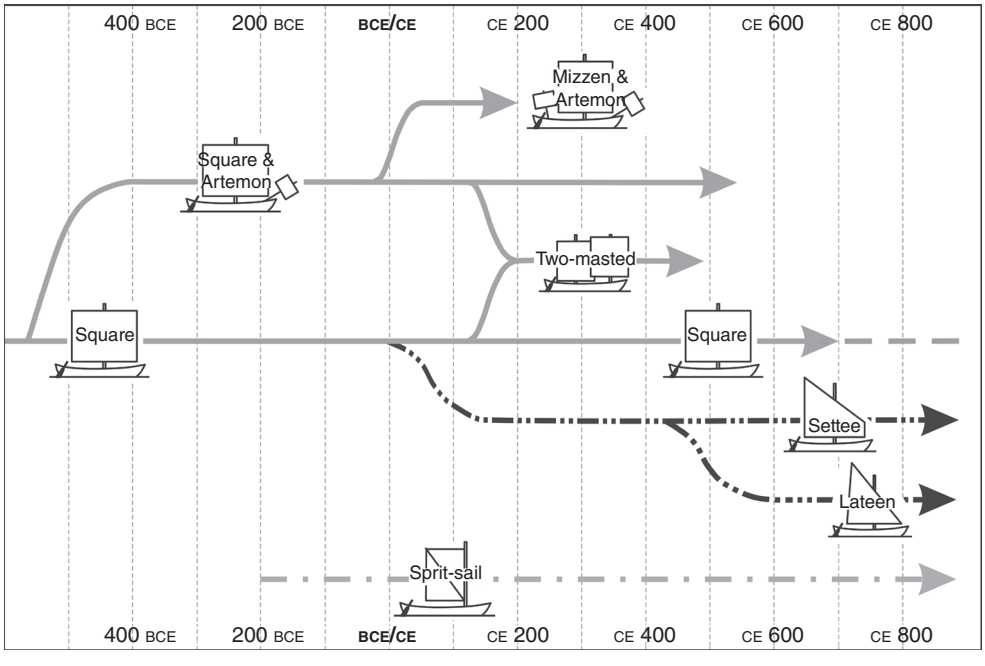


Figure 52.4 The multi-linear nature of sailing rig development in the ancient Mediterranean, based on archaeological, iconographic, and literary sources. Rig families are differentiated by the different line styles.

on a number of shipwrecks (e.g., Ximénès and Moerman 1990). Even from limited evidence, it is possible to hypothesize the presence of regional traditions of rigging, and potentially sailing practice, within the overall rigging tradition of the Mediterranean square sail. Such traditions are still quite indistinct when compared to those visible in the hulls of ships, but they are nevertheless present. A future increase in the documentation and publication of comparative material will bring this picture into sharper focus.

The Mediterranean square-sail rig as used in the Greek and Roman world was a flexible, effective sailing rig. It had the potential to allow vessels to make ground to windward (albeit slowly) in good conditions and probably allowed an average speed over long distances and with a favorable wind of roughly four knots (Whitewright 2011a, 10). With such a rig, a vessel of over 100 tons could probably have been crewed effectively by less than a dozen people and potentially much fewer on shorter voyages. This rigging tradition was used for at least 1700 years in a recognizably distinct, yet continuous form of maritime technology.

Spritsails

The first alternative to the square sail comes in the form of the spritsail, for which there are clear, unambiguous, iconographic depictions from the second century BCE onward (Casson 1956). The spritsail is of a type known as a fore-and-aft rig because of the natural position of the sail lying along the vessel's centerline (the fore-and-aft line). The spritsail is relatively simple to set, from a mast normally located quite a long way forward in the vessel owing to all of the sail being behind the mast when hauled tight. The sail is set from a single diagonal spar (sprit), which gives it a quite distinctive appearance. Other iconographic examples occur from the first to third centuries CE (e.g., Figure 52.1), but it is not until a set of archaeological remains at Yenikapi in Istanbul from the eighth/ninth centuries CE that the rig is visible in the archaeological record.

The appearance of the sprit rig in the Greek and Roman Mediterranean is significant for two reasons. First, the way the spritsail is conceived and used bears no technical resemblance or link to the existing forms of the square sail. It therefore demonstrates technological innovation of Mediterranean mariners in the second century BCE. Second, as far as potential performance is concerned, the spritsail is among the most effective rigs to have been developed and used in European waters, particularly in its performance to windward (Marchaj 1996, 161, figures 144–145). It certainly exceeds the performance potential of contemporary square-sail rigs and later lateen/settee rigs. Traditional academic accounts of Mediterranean sailing consistently state that the introduction of the lateen sail is on the grounds of its superior windward performance when compared to the square sail (see below), and this widely held position should presumably be reasonably extended to the spritsail, given the performance of that rig. Yet, despite clear superiority in windward ability, in comparison to other rigs, the spritsail was not widely adopted, at least on the basis of iconography and in archaeologically attested mast-step locations. The conclusion must therefore be drawn that, contrary to accepted academic tradition, windward performance was not the defining factor in the conception, selection, and use of sailing rigs in the ancient Mediterranean.

The spritsail continues to be something of an enigma in the study of ancient sailing rigs. Rarely visible in the available evidence, it is largely absent from regular academic discussion. Yet it has excellent, well-documented qualities as a sailing rig and remains in

use for a considerable length of time in Mediterranean waters. In this regard, it offers a major challenge to purely functionalist explanations of ancient sailing rig development which indicate that the spritsail should become widely adopted on the grounds of windward performance. That it did not is the best indication that such models are flawed and that other explanations for sailing rig development in the ancient Mediterranean should be sought.

Lateen/Settee Sails

The development and adoption of the lateen/settee sailing rig offers an opportunity to refine how ancient Mediterranean sailing rigs are discussed. The lateen/settee rig is another fore-and-aft rig, carrying a sail set on a diagonally inclined yard that extends forward of the mast. The lateen form is fully triangular, while the settee variant has a short leading edge (luff). Their use in antiquity appears to be basically the same. In contrast to the spritsail, the lateen/settee rig has many practical elements that indicate a probable course of development from the Mediterranean square sail (Whitewright 2011b, 95–98). Unlike the Mediterranean square sail, the lateen/settee rig does not carry any particularly distinctive rigging components (such as brail rings), meaning that it cannot be easily distinguished from the square sail in the archaeological record.

Documentation of the lateen/settee rig, therefore, has to be done on iconographic evidence (Whitewright 2009). The first depiction of a settee rig dates to the second century CE (Casson 1956) although other sources, lacking secure dating, suggest its use in the first millennium BCE (e.g., Basch 1989). These early depictions remain isolated, leading to the conclusion that the lateen/settee rig had not become widely adopted, with a subsequent reflection in the iconographic record. Only from the late fifth century CE onward do depictions of lateen/settee rigs become more common in the eastern Mediterranean. It is of further significance that these depictions, in a variety of contexts and media, all share a common set of well-defined characteristics, as drawn by their respective creators (Whitewright 2009, 100). These characteristics may represent a rig that has become widely adopted, in a settled outward form, to the extent that artists depict it with a standard set of conventions, easily recognizable to the viewer. This idea is given further weight by the continued use of some of these conventions until the twelfth century CE (Whitewright 2009, 101).

The traditional view within maritime academia is that the lateen/settee rig became widely adopted because of the performance advantages that it offered over the Mediterranean square-sail rig, namely, better speed and windward performance (e.g., Casson 1995, 243; Pryor 1994, 67–68; Castro et al. 2008, 348). The example of the spritsail, summarized above, indicates the failure of this model to work effectively in one maritime context from the Roman period. The example of the lateen/settee sail offers another. Analysis of the performance of full-scale vessels, reconstructed historic vessels, and historical sources indicates that the lateen/settee rig offers no performance gain over the square sail in either speed or windward performance (Whitewright 2011a, 10–13). The two rigs are in fact extremely similar. Yet the fact remains that the lateen/settee rig did become widely adopted in the Mediterranean from the late antique period onward, eventually displacing the square sail to the extent that characteristic square-sail rigging components seem to disappear from the archaeological record.

This change in rig type is clearly interesting, even more so when the very long period of use of the square sail is considered against its relatively rapid abandonment. The possible reasons for this change may lie in the wider context of the late antique Mediterranean (Whitewright 2011b, 98–102). The lateen/settee rig does not offer improvements in performance, but it does offer a large reduction in the rigging components required, while *maintaining* the levels of performance of the square sail. Experimental archaeological work at Roskilde, Denmark, has indicated that the creation of a sailing rig in pre-industrial contexts can take almost as many people-hours as the construction of a hull. Moreover, the highly organic nature of sails and rope dictates a relative rapid attrition rate and the need for regular maintenance and replacement of rope and canvas as an ongoing expense. Reducing the overall quantity of cordage and components offers a means to reduce materials and costs, both for building and maintenance. Economic concerns, in the context of the late antique world, appear to offer a likely reason for the adoption of the lateen/settee sail and the abandonment of the long-held Mediterranean square-sail rigging tradition.

Summary

When viewed across the whole of the Greek and Roman Mediterranean, the sailing rigs of the ancient world offer an intriguing picture of long-term technological continuity, interspersed with notable variation and genuine examples of technological innovation and development. For much of the period, the square sail, in all its variant forms, provided the primary propulsion to non-military watercraft, oar power remaining very much the preserve of naval vessels. Only in late antiquity does the lateen/settee rig begin to supplant the square sail as the sailing rig of choice. Although largely invisible archaeologically, this process is increasingly well documented through the iconographic evidence, indicating an intriguingly uniform way in which such rigs are depicted.

As well as the themes of technological continuity, variation, and change summarized above, further comment can be passed on the potential performance of all these sailing rigs. First, Greek and Roman vessels had the ability to make progress to windward in the right conditions, when a suitable hull form was used (e.g., the Kyrenia or Madrague de Giens wrecks). This statement can be extended to all the rigs discussed here, although the spritrig provided the best all-around performance on the basis of modern wind-tunnel testing. This offers a clear indication that windward performance was not the main consideration in deciding upon a particular sailing rig; if so, the spritsail would have been ubiquitous, and it clearly was not. Numerous other factors, such as material cost or required crew size, influenced what type of rig was used, where, and on which vessel type. These choices, along with available rigging component technology, dictated regional traditions and trends in the construction and use of sailing rigs that are likely to become increasingly apparent as archaeological evidence becomes further refined and better understood.

5. Patterns of Technological Change

Most notable is the long-term continuity that can be traced in ancient Mediterranean maritime technology, particularly when the Mediterranean square-sail and shell-based mortise-and-tenon building tradition are viewed together as a way of building, rigging,

and using a ship or boat. Taking into account the variations outlined above, it is arguably a broad approach to seafaring that stretches from the late Bronze Age through to late antiquity. In addition, the shell-based sewn method of building and the use of the sprit rig offer, at different times, alternative methods of both building and rigging a vessel. Although the spritsail does not seem to have been widely adopted, the sewn construction method was clearly a significant Mediterranean building tradition.

A notable alteration to this general picture occurs broadly in the mid-first millennium BCE, and we witness the gradual abandonment of the shell-based sewn building method and the roughly contemporary introduction of the *artemon* foresail. The reasons for the first of these changes are certainly not fully understood and offers considerable potential for future research. The introduction of the *artemon* probably resulted in improvements to the maneuverability of vessels, especially when sailing on upwind courses. While the results of this experimentation and variation are fairly clear, the reasons underlying why it happened when it did have not yet been fully researched and are not clearly understood.

The most far-reaching maritime technological change occurs in late antiquity when long-held building and rigging traditions underwent a fundamental change. The invention and development of frame-first building processes completely altered the manner in which ships were conceived and constructed. While this tradition took several centuries to become widely established, eventually seemingly ubiquitous in the medieval Mediterranean, its origins lie firmly in the late Roman world. Explanations for this technological change are still developing (e.g., Pomey, Kahanov, and Rieth 2012), but motives revolving around economization, the availability of labor, and the efficient use of materials are persuasive. The reasons behind the abandonment of the square sail in favor of the lateen/settee rig may be thought of as economization while maintaining performance (see Whitewright 2011b, 102). The occurrence of such changes to hulls and rigs at broadly the same time and for apparently similar reasons strongly suggests, perhaps unsurprisingly, that changes to hull and rig are interlinked and driven by the same overall trends.

6. Conclusion

An understanding of maritime activity is crucial to our understanding of the Greek and Roman world. It is clear that an appreciation of the construction and rigging of ships and boats gives us an insight into the maritime elements of Greek and Roman society. These societies developed complex watercraft, methodically and carefully built in a shell-based tradition, utilizing either mortise-and-tenon or sewing as a way to join plank edges. These vessels were then rigged with a range of effective, adaptable rigs that allowed efficient travel across the Mediterranean. Numerous variations existed in both building and rigging, within overarching traditions, the temporal and spatial distribution of which is still not fully understood. Finally, the late antique period witnesses wholesale changes to the way that vessels are built and rigged through the development and adoption of frame-based and mixed construction alongside the lateen/settee rig.

Our sources for these vessels are becoming increasingly well documented, especially the archaeological evidence with regard to ship construction. Taken as a whole, they offer a relatively clear view of Greek and Roman Mediterranean shipping practices. This view includes the identification of regional building traditions and a considered assessment of the general performance that such vessels were capable of. Most importantly, documenting and researching this maritime technology has allowed the identification

of periods of significant technological continuity, punctuated by far-reaching technological variation and change. The biggest challenge for future maritime researchers is to further develop our understanding of the relationship between these trends and the societies that were responsible for them. As archaeological data continue to increase the complexity of our understanding, it may be possible, eventually, to explain alterations to Mediterranean societies through their ships and boats, rather than vice versa. Given the centrality of the sea to day-to-day life, this should be the least that we can expect to achieve through our study of the ships and boats of the Greek and Roman world.

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PART IX

Telling Time

CHAPTER 53

Greek Calendars

Laura Gawlinski

1. Introduction

The Greek "calendar" refers to the systematic organization and division of time, both small scale (months and parts of months) and long term (years and year cycles), rather than to a physical object that represents or marks those divisions, as in modern wall or desk calendars. The study of the Greek calendar is complicated by its flexibility and incomplete source material. The way the Greeks reckoned time was of course tied to the various reasons such organization was useful: agriculture, religion, politics, and commerce. Although some of these motives overlapped (e.g., some festivals were tied to the agricultural year or sailing season), different systems could arise even in a single city, and sometimes more complicated management was required in order to keep them working together. For example, at least two calendars were in use at Athens, one ordered by months named for religious festivals, one arranged by the meeting schedule of the political body called the prytany. There is another problem caused by variety: although the Greek world was generally united in its use of a lunar-based structure subjected to occasional modifications to conform to the solar year, it is proper to speak of Greek calendars in the plural, since month names, the starting point of each new year, and the scheduling of modifications were not shared across all Greek cities. In addition to its geographical extent, the Greek calendar is also marked by its long life-span. Little is known about the calendars used before the early fifth century BCE, and, by the Hellenistic period, changes in political structures and alliances, as well as the incorporation of areas that had their own calendars (most notably Egypt and Babylonia), led to transformations and modifications that were primarily regional.

Greek calendars have captured scholarly attention largely for the utilitarian purpose of determining dates for events in antiquity, but their relevance extends beyond that. Calendrical use of astronomical observations and mathematical calculations (both in

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antiquity and in modern attempts to reconstruct them) link them to the realm of science. This is especially apparent in the formation of astronomical calendars, such as the Metonic nineteen-year cycle, and their possible effects on the older, civil calendars. As in other areas of ancient science, Greek calendars must be set into their wider cultural and intellectual milieu. They were part of a larger process of the changing conceptions of time and were a product of political and religious interests.

2. Sources for the Study of the Greek Calendar

Our evidence for Greek calendars is fragmentary. What is presented is technically a restored calendar, derived from often-conflicting scattered references requiring scholarly interpretation and inference. No complete record exists for any city or for any particular time, and few of the sources, if any, are recognizable as anything one would call a calendar today. Greek texts speak of months, days, years, and celestial cycles, but there is no word that corresponds to "calendar." Unlike the Roman calendar, whose dissemination after the reforms of Julius Caesar and Augustus was marked by the erection of tangible calendrical charts (Roman Calendars), most of our information about the Greek management of time comes from indirect sources, some written long after the period for which they claim to be evidence. Inscriptions with dating formulae are key for identifying chronological organization, literary references often reveal what people thought about time, some astronomical treatises include information relevant to the calendar, and devices such as *parapēgmata* record dates alongside other data (Time-Telling Devices). Unsurprisingly, the Athenian evidence is the most plentiful and most studied, but it is also the most complicated, since that city had multiple competing calendars.

Our knowledge of the early form of the calendar is slim. A few Mycenaean lists, organized by month and day, survive among the Linear B tablets, but little can be said about the calendrical system to which they belonged (Hannah 2005, 16–18). For the Archaic period, the poems of Homer and Hesiod, particularly Hesiod's *Works and Days*, demonstrate an awareness of the flow of seasons and the importance of marking them (Greek and Roman Agriculture). Solid evidence for a chronological system imposed upon those natural observations is lacking, however. Both Plutarch (*Life of Solon* 25.3) and Diogenes Laërtius (1.59) associate Solon with the Athenian calendar and lunar adjustments, but whether such regularity was an innovation at that time is impossible to know for certain (Stern 2012, 25; Hannah 2005, 29).

When exactly the Classical form of the calendar came into use is unclear, but it is in the fifth century BCE that our source material increases considerably, owing in part to the abundant epigraphic record. Inscriptions are the foundation for the names and order of months, especially outside Athens (Trümpy 1997; Samuel 1972). Months and days frequently appear within the dating formula, sometimes alongside useful information like the magistracy cycle. The headings of slave manumission records at Delphi have provided a considerable number of clues for aligning the varied calendars of Greek cities (Hannah 2005, 79–82). In Athens, the formulae are especially important for tracing the alternate, prytanic calendar. For example, the heading of *IG* II^3 316 (338/7 BCE) offers both kinds of Athenian dates (lines 1–4; although restorations are necessary, the formula itself is clear): "In the archonship of [Chairon]das, during the [Xth] prytany, held by the [tribe] … [on the X day of] Thargel[ion], on the [X] day of the prytany." One inscription is worth singling out here as the only direct evidence from the fifth century BCE for intercalation, the process of adding a month or days to adjust a calendar.

The so-called Eleusinian First-fruits decree (*IG* I³ 78), published sometime in the 430s BCE, contains an amendment calling for next year's official to insert an additional month (lines 53–54): "[Lampon proposed] that the new archon put in (*emballen*) the month Hekatombaion," (Hannah 2005, 65–68; Cavanaugh 1996, 55–95).

Some inscribed records are organized by date, thus coming closest to what might be termed calendars in a structural sense. These usually involve financial matters. Probably best known are the so-called sacred or sacrificial calendars that list the amount to be paid for which animal to what deity on a specified day, along with other amounts for priestly payments or materials. Figure 53.1 is one of the most complete fragments from the list used by the Athenians in the late fifth century BCE (Lambert 2002). Below the heading indicating which group of sacrifices is listed (those belonging to the "alternate year," *heteron etos*) are several columns. The notations to the left of each column indicate the amount (e.g., ΔΠ, for *deka pente*, means that fifteen drachmas were allotted for the animal listed to the right). At the top of the central column, in larger letters, the month can be read ("of Hekatombaiōn"), followed by the day of the month below (*pemptēi epi deka*, on the fifteenth). Twelve lines below, the list for the next day begins (*hektēi epi deka*, on the sixteenth).



Figure 53.1 Fragment of an Athenian list of sacrifices, Face A, 403/2-400/399 BCE (Agora I 727). *Source:* American School of Classical Studies at Athens: Agora Excavations.

A few passages from the comedies of Aristophanes—an author who notably responds to contemporary trends in natural science—have had a substantial impact on the scholarship of the Greek calendar. In the *Clouds* (1131–1134), Strepsiades, complaining about his debts coming due, counts down the last days of the month backward (fifth, fourth, third, second), ending with the "Old and New Day" (*hena te kai nea*). This pattern is related to the phases of the moon. Elsewhere, the chorus of Clouds reports that the Moon told them she is angry with the Athenians for confusing the organization of the days (606–626). The gods blame her because their activities are no longer synchronized with Athenian festivals (their expectation of sacrificial meals on certain days has been thwarted), and the Clouds say it is better when the days are kept according to the Moon (*kata selēnen*, 626). A similar message may be behind Hermes' observation in the *Peace* that the Sun and Moon have been stealing the days and nibbling at each other's disks (414–415). That something was happening to the Athenian calendar which affected religious observances is clear, and that it concerned the lunar nature of the Athenian calendar is likely, but the details of what lay behind Aristophanes' complaints is open to interpretation. Do these texts show that lunar calendars in general are prone to misalignment with the seasons? Were the officials of Athens tampering with the calendar by adding and subtracting days at will? Or were those officials attempting to make the festival calendar match the prytanic calendar? Some scholars have even read the passage in the *Clouds* as evidence for calendar reform in the fifth century intended to regularize correspondences between the lunar and solar year based on the astronomical calculations of Meton.

Finally, because Greek calendars were based on astronomical patterns, the ancient treatises examining those patterns, their calculations, and the history of advances in that knowledge provide insight into the science behind the calendar. Aratus (*Phaenomena*, third century BCE), Geminus (*Introduction to the Phaenomena*, first century BCE), and Censorinus (*On the Birthday*, third century CE) describe matters such as the length of the month and year, sighting the moon to begin the month, and how and when the calendar would be adjusted by intercalation. These texts also record traditions about early astronomers such as Meton. However, it is not always certain how much of their material is theoretical and to what extent it documents real-world application, especially for early periods of Greek history. Hence, analyzing the conflicts is required.

3. The Calendar and the Sky

The moon, sun, and stars can all be used for reckoning time (Hannah 2009; Hannah 2005, 5–26; Samuel 1972, 1–18). Long-term reckoning (years) and short-term reckoning (days, months) are usually tied to different astronomical movements. Seasons are caused by the tilt of the earth as it makes its elliptical orbit around the sun (Astronomy). During the summer, the earth reaches the point when its northern hemisphere is tilted maximally toward the sun (the summer solstice), while during the winter, that hemisphere is tilted furthest away at the winter solstice. In between are the points called the autumnal and spring equinoxes, when the earth's tilt keeps it axis parallel to the sun's axis. The time it takes for the earth to travel these points and return to its starting position is called the solar or tropical year. This journey lasts 365.24219 days, approximately 365 1/4 days. The solstices and equinoxes are significant points because they allow an observer to calculate how much of the orbit—and therefore of the year—remains. Day

and night result from the earth spinning on its axis so that only part of the earth faces the sun at any given moment. Because the earth is also tilted and orbiting around the sun, the length of daylight changes throughout the year and varies by location. Meanwhile, the moon orbits the earth in about 29.53059 days, approximately 29 1/2 days. Because of the relationships among the movements of the earth, moon, and sun, a cycle of hidden, partial, and full moons is visible to an earth-bound observer. One half of the moon is always illuminated by the sun. When that bright half faces the earth, occurring when the moon, earth, and sun align, a full moon is seen. When the three align but the moon is between the earth and sun, a new moon results wherein none of the moon's lighted half is visible. Between those two points of alignment, a combination of the lit and unlit portion of the moon is seen together, giving the appearance of a partial moon. The moon appears to grow in size as it progresses from new to full (waxing), and then to decrease in size from full back to new (waning). A crescent moon occurs when less than half the moon is visible; more than half is called gibbous. The natural month is created by following this circuit, visible even to the naked eye. This shorter-term cycle is not fully compatible with the longer-term cycle of the sun, however: twelve cycles of the moon are only about 354 days, so a year calculated by lunar months will quickly fall out of alignment with the seasons. In addition, the fact that the solar year and lunar month are not whole numbers means that an absolute, convenient numbering is challenging to maintain. With this often incompatible mix of lunar, solar, and seasonal time, it is no wonder that calendars are fraught with complications.

The Greek calendar was lunar, but because it could be manipulated to better correlate with the solar year, it is often referred to as lunisolar (on this term, see Stern 2012, 6). Its lunar basis is reflected in the names of days, which signify the changing appearance of the moon in its cycle. The month names attested for Athens in the fifth century BCE, listed below, illustrate this pattern, and day names for other cities, where known (Samuel 1972), also display an inclination for terms like new, rising, or waning; in Boeotia the latter is *apiontos*, "going away," rather than the Athenian *phthinontos*, "decaying." By the later fourth century BCE, the Athenian terminology for the count of the last ten days changed to an ordinal number followed by *met' eikadas*, "x after the twentieth."

1. *noumēnia*: new month [day]
2. *deutera histamenou*: the second [day] of the rising
3. *tritē histamenou*: the third [day] of the rising
4. *tetras histamenou*
5. *pemptē histamenou*
6. *hektē histamenou*
7. *hebdomē histamenou*
8. *ogdoē histamenou*
9. *evatē histamenou*
10. *dekatē histamenou*
11. *hendekatē*: the eleventh [day]
12. *dodekatē*: the twelfth [day]
13. *tritē epi deka*: third plus ten [day]
14. *tetras epi deka*: fourth plus ten [day]
15. *pemptē epi deka*

16. *hektē epi deka*
17. *hebdomē epi deka*
18. *ogdoē epi deka*
19. *enatē epi deka*
20. *eikostē*
21. *dekatē hustera*: the latter tenth
22. *enatē phthinontos*: ninth [day] of the waning
23. *ogdoē phthinontos*: eighth [day] of the waning
24. *hebdomē phthinontos*
25. *hektē phthinontos*
26. *pemptē phthinontos*
27. *tetras phthinontos*
28. *tritē phthinontos*
29. *deutera phthinontos*; in a month of 29 days: *hena kai nea*
30. *hena kai nea*: old and new [day]

This ordering of days according to the moon raises several issues. First, the decision was made, at least in Athens, to account for the fact that the moon's circuit around the earth did not take an even number of days by interspersing months with 29 days (hollow months) among months with 30 days (full months). There is no strong evidence for regularizing this pattern as in the modern Julian calendar (taught to children in the traditional rhyme, "Thirty days hath September, April, June, and November …"). Almost every aspect of this process has been subject to debate: scholars have questioned at what point in the month the decision would have been made between full or hollow, how that might have affected the counting of the final days, and which day would be omitted for a hollow month (Stern 2012, 32–46; Hannah 2005; Pritchett 2001; Meritt 1961). A second, related, issue is the means used to determine the first day of the month, *noumēnia* (Hannah 2005, 42–49; Samuel 1972, 14–15). How strictly did the calendar follow the phases of the moon, and what role was played by astronomical observations or calculations? The point of conjunction of the new moon can be calculated, but because it is defined by a complete lack of visibility of the illuminated side of the moon, it is much easier to start a month based on an event that can be observed with the naked eye. Geminus (8.11, 9.7) indicates that the month began when the new moon crescent was sighted, that is, the moment when part of the moon begins to be visible again after the new moon. A number of variables would be involved in setting the month by this observation (Hannah 2005, 48–49). Since the new moon crescent would not be visible before evening, its relationship to the preceding conjunction could vary by several hours, depending especially on the time of year. The location of the observer, both latitude and altitude, is also significant and could result in slight variations across the Greek world. Low visibility because of weather patterns might also affect setting the month. That the beginning of the month was not always tied to formal observation is suggested by references in astronomical treatises. According to Geminus (9.14), the new moon might not be sighted until the third day of the month in some cases (Stern 2012, 26–29). Although the calendar was lunar in its basis, it does not seem that it was always forced into conformity with the moon's astronomical movements, and political decisions were as important, if not more so, in marking the details of the movement of time.

4. Months and Years across Greece

Greece was made up of many city-states (*poleis*) whose governmental structure, festivals, and traditions differed, and those differences were reflected in the calendars created by each. Most cities used a calendar whose organization and month names were related to religious festivals or deities, therefore often referred to as "festival calendars" (Stern 2012, 26–31; Hannah 2005, 42–44; Samuel 1972, 57–58). The term "civil calendar" can also be applied, preferable because it emphasizes the authority of the city in controlling and regulating both the calendar and the religious festivals to which they were tied. These calendars are set by, or at least named according to, civil officials. For Athens, this calendar is termed the archontic calendar after that city's eponymous archon, and that title is often used to distinguish it from the Athenian prytanic calendar.

The month names and their order in Athens are well established, and for many other cities a fair number can also be reconstructed (Trümpy 1997; Samuel 1972). The Athenian months are listed here with their rough correspondence to the Julian months, alongside the Delphic calendar for comparison.

Attic	**Delphic**	**Julian**
Hekatombaiōn	Apellaios	July/August
Metageitniōn	Boukatios	August/September
Boēdromiōn	Boathoös	September/October
Pyanepsiōn	Heraios	October/November
Maimaktēriōn	Daidaphorios	November/December
Poseideōn	Poitropios	December/January
Gamēliōn	Amalios	January/February
Anthestēriōn	Busios	February/March
Elaphēboliōn	Theoxenios	March/April
Mounichiōn	Enduspoitropios	April/May
Thargēliōn	Herakleios	May/June
Skirophoriōn	Ilaios	June/July

Most of these names derive from deities or religious events, but some of the festivals giving the months their names were of great antiquity and had either lessened in status or disappeared by the Classical period. For example, Hekatombaiōn, appearing in the sacrificial list illustrated in Figure 53.1, is the month in which the Panathenaia was held, but the month name is taken from a lower-profile sacrifice to Apollo Hekatombaios on the seventh of the month (Trümpy 1997, 6). The Anthesteria, a Dionysus festival involving the celebration of the new wine, provides an unusual example of correspondence between month name, festival, and agricultural year. At Delphi, whose month names follow a different morphological form, the gods are immediately obvious in Apellaios (Apollo) and Herakleios (Heracles), and both month names attested in other cities as well (Trümpy 1997, 212–213).

In the second century BCE, some cities began to use numerical months. This change is tied to the rise of federations in Greece; because they united several cities together

in alliance, conformity in time reckoning was more useful (Hannah 2005, 28). One example is the Phocian League: the months that eventually replaced the named months are simply ordinal numbers, First through Twelfth:

Protos
Deuteros
Tritos
Tetartos
Pemptos
Hektos
Hebdomas
Ogdoös
Enatos
Dekatos
Hendekatos
Dodekatos

The new year did not begin at the same time in every city. Although it was often tied to astronomical observations like a solstice or equinox, not every city used the same one, and arbitrary points like the birthday of a ruler could be used instead (Samuel 1972, 16–17). In Athens, the new year began in the month Hekatombaion, roughly equivalent to our August/September. It is for this reason that Greek dates are typically rendered in modern scholarship as double years, for example, 480/1 BCE; the Athenian year covers the second half of one Julian year, and the first half of the next. Both Plato (*Laws* 6.767c) and Aristotle (*HA* 543b) connect the opening of the Athenian year to the summer solstice, but just as with the beginning of the month, it is not clear how rigorously this was applied in practice (Stern 2012, 38–39; Samuel 1972, 64). It is obvious which month begins the year for calendars using numerical month names, but where *Protos* (First) fell within the solar year must be determined through synchronization with other calendars. Inscribed records at sites like Delphi that were used by multiple cities often provide calendrical equations when they give the date in multiple formats. For example, slave manumissions from Delphi offer evidence that Delphi started its year at approximately the same time as Athens, but that the Phocian new year began about three months later, set instead by the autumnal equinox (Hannah 2005, 77–81). Of the months listed above, Hekatombaiōn, Apellaios, and *Dekatos* (Tenth) were equivalent.

The process of synchronizing calendars is complicated by the various means of intercalation, the process by which each city's calendar was manipulated to align it with the solar year. Our own calendar continues the process of intercalation: every four years there occurs a leap year, marked by a February of 29 rather than 28 days, except if the year is divisible by 100, a system with its origins in the Julian calendar (ROMAN CALENDARS). In ancient Greece, the process was neither rigid nor consistent from city to city, although over time it did become more regularized (see §6, below). Intercalation usually involved inserting an extra, thirteenth, month, but intercalations of one or more days are also attested. At Athens, there is definite evidence for a month added after Hekatombaiōn (I), Metageitniōn (II), Poseideōn (VI), Gamēliōn (VII), and Anthestēriōn (VIII), with Poseideōn being intercalated more often than the others

(Pritchett 2001, 6–11). Adjusting the lunar, solar, seasonal, and prytanic cycles was not the only purpose for intercalation, and the complaint of the Sun in Aristophanes' *Clouds* has been interpreted as implying that such calendrical adjustments could cause as many problems as they attempted to solve. Other ancient sources offer evidence for political, military, and religious reasons behind some intercalations; changing the calendar could provide a "technicality" that allowed conformity to various rules (Stern 2012, 64–67; Pritchett 2001, 25–30). The historian Thucydides (5.54) records a clever strategy used by the Argives when they attacked Epidaurus in 419 BCE: by counting all the days of their attack as the same day, they stalled the beginning of the next month, Karneios, sacred to the Dorians. Many allies of Epidaurus refused to help because, for them, Karneios had already arrived. This adjustment, which affected only the Argive calendar, took advantage of the calendar's religious ties for a military purpose. Also in the fifth century BCE, the First Fruits Decree, which called for Greeks to send the first fruits of the harvest to the sanctuary of Demeter at Eleusis (see §2, above), records an intercalated Hekatombaiōn; the reason for repeating this first month of the year—early fall—may have resulted from practical considerations, such as dealing with the growing season or the announcement and management of the grain collection (Hannah 2005, 65–68). Political and religious motivations collide in another intercalation recorded for Eleusinian rituals: according to Plutarch (*Life of Demetrius* 26), the Hellenistic Macedonian king Demetrius Poliorcetes requested initiation into both grades of the Mysteries upon his arrival during the month of Mounichiōn. In order to allow Poliorcetes' request, the Athenians renamed the month Anthestēriōn so the required preliminary rituals could be held, and then they renamed it Boēdromiōn for the Mysteries. The Athenians were able to curry favor with the new ruler while still holding the festival at what was, according to the calendar, the customary time. Although this is an extreme example, it shows that the flexibility of the calendar could be taken advantage of in a variety of ways, and that not every modification was intended to improve the reckoning of time.

5. The Athenian Prytany Calendar

The situation in Athens offers further complexity: in addition to the archontic calendar, for much of its history Athens also concurrently used a second calendar, the prytanic or bouleutic calendar, organized according to the cycle of one of the democratic bodies. The Athenian *boulē* (council) was formed by the annual selection of 50 members from each of the ten tribes, for a total of 500 members (on the *boulē*, see Rhodes 1985). Each tribal group took turns serving as the prytany of the *boulē*, its executive board, and the order of rotation was determined by lot. This calendar, then, was divided into ten months whose length conformed to the duration of each rotation. In the fourth-century BCE *Constitution of the Athenians* (erroneously attributed to Aristotle), we hear that the duration followed a regular pattern: the first four prytanies lasted thirty-six days each, and the remaining six lasted thirty-five; this schedule of the year is explained as having a lunar basis: *kata selēnen…eniauton* (43.2). The total number of days (354) does match the number of days in a year of twelve lunar months (§3, above). This prytanic year, then, would also be prone to intercalation, but there is no positive evidence for how the extra days were spread through the ten months. It is unclear, however, whether the *Constitution*'s format is theoretical—prone to variety in practice—and it may not be relevant for the entire history of the prytanic calendar (Rhodes 1985, 225–226).

Almost all of our other evidence for how this calendar functioned comes from the use of prytanic dates in inscriptions. It is subject to restoration, and relatively few years are represented. Evidence from the 420s BCE shows that the length of the prytanic year was 365/6 days, strikingly equivalent to the solar year (Hannah 2005, 44–45). For some time, this calendar was maintained independently of the archontic. When that independent reckoning began has been debated, with the proposed date of separation ranging from the reforms of Cleisthenes in the sixth century BCE down to the middle of the fifth century BCE (Pritchett 2001, 127–183; Rhodes 1985, 224–225). The year 407 BCE is now generally accepted as the end of that independence, based on epigraphic evidence (Hannah 2005, 45). Subsequently, the archontic and prytanic years were coterminous.

This calendar was subject to other kinds of modification because it was based on political divisions. In the Hellenistic and Roman periods, the number of tribes was changed several times as a part of foreign affairs. In 307/6 BCE, two new tribes were added, Antigonas and Demetrias, in honor of Hellenistic kings, and in 124/5 CE the emperor Hadrian's name was given to a tribe. The number fluctuated between twelve and thirteen as tribes were added or even removed. These fluctuations affected the number of prytanies, which in turn affected the number of units in the prytanic year (Rhodes 1985, 226).

6. Meton, Cycles, and the Influence of Astronomical Calendars

The difficulties of lunar and solar cycles, and, in Athens, the introduction of a non-natural basis for the marking of time, resulted in vagaries, inconsistencies, and varieties, especially in the almost haphazard method of intercalations. There is, however, considerable evidence that systems for long-term calculations were developed. Such long-term cyclical planning offers a more balanced way to keep a lunar calendar in check, as opposed to month-by-month or year-by-year intercalation, which, as noted, can be haphazard. For example, our modern calendar makes use of the Julian four-year cycle for intercalation in order to adjust for the buildup of approximately a quarter day each year (i.e., the leap year cycle). One cycle ascribed to the ancient Greeks in later astronomical writings is the *octaetēris*, which spread out intercalations on an eight-year basis (Hannah 2009, 32–35; Samuel 1972, 33–42). Although some of the details are unknown, Geminus (8.25–33) lays out the structure thusly: on the basis of calculations of the difference in days between a solar and lunar year as 11 1/4 days, the Greeks realized that in eight years, the lunar would be behind the solar by an even number of days (i.e., 90). Adding three months of thirty days each into the eight-year cycle would keep the reckoning in line with both astronomical movements, and these intercalary months should be spread out after the third, fifth, and eighth year in the cycle. It was not an entirely accurate solution. Because it was based on an approximate calculation of the lunar month (29 1/2 days), over time the calendar would become significantly misaligned again, though it would take about 144 years before it would move an entire month (Hannah 2009, 33–34). On the basis of information in Censorinus (18.5–6), this cycle went back to the late sixth or early fifth centuries BCE and was applied to the organization of the Pythian Games at Delphi; other evidence suggests that Panhellenic festivals may have indeed taken advantage of the *octaetēris* (Hannah 2005, 35–39). A more general usage, however, is not apparent in civil calendars.

The slight imperfections in calculation found improvement in a nineteen-year cycle (Hannah 2009, 34–42; Lehoux 2007, 88–93; Samuel 1972, 42–46). This cycle is typically called the "Metonic cycle" after a natural scientist of the fifth century BCE who is either associated with it or named as its inventor in the ancient sources; this Meton also appears in Aristophanes' *Birds* (992–1020) as a laughable intellectual (Hannah 2005, 52–53). Geminus describes this nineteen-year cycle as a response to problems with the eight-year one (8.50–58), though he mentions only the astronomers Euctemon, Philippus, and Callipus). A cycle of nineteen years would have seven intercalary months, for a total of 235 months, and the number of days in that period would be 6,940. That number of days could be achieved by taking one day out of 110 of the months, leaving 125 of them full, thirty-day months. They could not alternate evenly because there were fifteen more full months. That the order of full and hollow months was prearranged—after every sixty-three days, a day was removed—sets the Metonic calendar apart from a similar, nineteen-year system created by the Babylonians, which, some have argued, influenced the Greek cycle (Lehoux 2007, 92). Meton's cycle can be connected to his observation of the summer solstice in 432 BCE, which served as the starting point from which the nineteen years were counted (Hannah 2009, 35–36). The sources for this observation and its date are an inscription from Miletus (inv. no. 84; see Lehoux 2007, 479–480), Ptolemy *Almagest* 3.1, and Diodorus Siculus 12.36. From these we learn that it occurred during the year when Apseudes was archon in Athens, on Skirophoriōn 13, and that the Athenian date was equivalent to Phamenoth 21 in the Egyptian calendar. Callipus later refined this cycle, with a new era beginning in 330 BCE, a date used as a marker by Ptolemy in his *Almagest* and also appearing in other astronomical contexts, that is, "in the X year of the Y Callipic cycle" (Lehoux 2007, 93–94). This modified cycle accounted for a small inconsistency in the number of days that would have been noticeable eventually. Because the Metonic year had been calculated as 365 5/19 days, it actually overshoots the solar year by 1/76 day (Geminus 8.57–60). Callipus thus applied a seventy-six year cycle of 27,759 days: for every four nineteen-year cycles, there would be one less day.

Although what the late Hellenistic and Roman period sources say about these increasingly accurate cyclical calculations is fairly clear, what is less clear is whether, to what extent, and when these developments affected the civil calendars in their real-world functioning. The Metonic question can be the most intimidating aspect for a student of the Greek calendar. Depending on the handbook, one reads arguments ranging from a Metonic revolution to complete separation of astronomical and civil calendars. When Diodorus Siculus describes Meton's solstice observance (12.36), he also notes that in his time (first century BCE) most Greeks still used the cycle. It does seem to be true that Greek calendars became more regular in the Hellenistic period, but whether this can be attributed to the use of the nineteen-year cycle is debated (Stern 2012, 52). To test whether the cycle was used requires the use of fragmentary and often heavily restored data; it is easy to restore the missing pieces to "prove" the cycle works, but it is just as tempting to point to the missing pieces to "prove" that it does not.

Some scholars argue that the evidence supports treating calendars like Meton's as theoretical and something more like "pure" science, that is, lacking substantial application to the civil calendars that cities and individuals actually used (Stern 2012, 51–57; Samuel 1972, 52–55). These "astronomical calendars," in this view, were used by astronomers, and they may have included other calculations in addition to the nineteen-year cycle.

The kind of information that astronomers wished to record and calculate was better served by their own more accurate systems than by the civil calendar. It is into this environment that Greek *parapēgmata* may fit as well (Time-Telling Devices). These "extra-calendrical" devices served to mark astronomical and meteorological patterns, but they seem to have had no certain application for civil calendars (Lehoux 2007, 84–86).

On the other hand, some scholars point to increasing evidence in favor of the use of cycles, especially in the Hellenistic period (Hannah 2009, 37). Strict adherence to the Metonic cycle has never been adequately proved for the years immediately following its creation, though perhaps it was attempted inconsistently. It has been argued that it is possible to interpret the complaint about the confused calendar in Aristophanes' *Clouds* as a criticism of that very attempt; changes to calendars in other periods to make them more accurate have not gone smoothly either (Hannah 2009, 40–42). The sequence that has been proposed for the Athenian civil calendar from the late fifth century BCE into the early Hellenistic period sets the seven months with intercalation at years 2, 5, 8, 10, 13, 16, and 18. One piece of evidence that shows the use of the Metonic cycle is the Antikythera Mechanism (Time-Telling Devices), featuring the names of twelve months from a Dorian Greek city, possibly a Corinthian colony (Hannah 2009, 59–62). From the information on the device, a system of intercalation in years 1, 3, 6, 9, 11, 14, and 17 can be deduced. Even accounting for changes to the Athenian intercalation pattern over time, the Antikythera Mechanism shows a different application of the nineteen-year cycle in a place outside Athens. Not everyone is convinced by the evidence on which the Antikythera Mechanism and calculations for other periods are based, and the presence of the civil calendar on the Mechanism might not prove that it was invariably used to fix that city's calendar regularly. However, as more epigraphic evidence becomes available, the case for regularization becomes increasingly strong.

7. The Greek Calendar in Flux

Although Greek calendars remained in essence lunar calendars, they did go through multiple stages and changes. Over time, transformations and modifications occurred. New ways of counting were introduced, advances in astronomy led to newer, more accurate systems, and changes in governmental formations and allegiances created new reasons for conformity. Because the calendar was already marked by a lack of uniformity, changes did not happen everywhere at once.

In the third century BCE, the phrase *kata theon* (according to the gods) or *kata selēnēn* (according to the moon) began to appear in the calendars of several cities across Greece; these phrases became less frequent by the second century, and only a few references appear in the first. That these phrases imply the use of a purely lunar calendar, strictly following the sightings of the moon, is supported by their use in other, non-calendrical contexts, for example, Thucydides 2.28.1, which mentions an eclipse (Stern 2012, 59–62). Determining the relationship between these calendars and others in a single city is tricky. The traditional explanation is that they represented a separate, regulatory calendar based on the moon, and in Athens they would have been used to set the two other calendars in the city (Pritchett 2001, 88–94; Samuel 1972, 57–58). The context of many of these dates, however, suggests that this lunar calendar was intended as a "common calendar," able to provide a better degree of consistency in intercity relations, such as commercial exchanges or treaties (Stern 2012, 61). This situation is not unlike

the introduction of numerically named months in response to the rise of political federations. These are both examples of relatively short-lived adaptations for specific situations that needed common organization; the modifications were not radical, and they built on established qualities like the use of the moon or the separation of the year into twelve months.

The Hellenistic period was marked by increased interaction with other world cultures and the incorporation of new areas of the world into the Greek one. The conquests of Alexander the Great and the subsequent establishment of the Ptolemaic and Seleucid kingdoms presented a new basis for interaction with the Egyptians and Babylonians. The Macedonian civil calendar was introduced into the areas of conquest, at least for official business, but it did not stay completely unchanged (Hannah 2005, 82–83; Samuel 1972, 139–151). The Seleucids came in contact with the Babylonian calendar (Stern 2012, 71–123), which was also a lunar calendar but ran with much greater regularity than the Greek one. The months began either according to evening sightings or predictions of the new moon, and intercalations ran on a nineteen-year cycle—the same length, as noted above, that the later Metonic cycle used. It is perhaps because of these similarities that the Seleucids chose to reckon by the Babylonian calendar. Two vestiges of the Macedonian calendar remained, however: the Macedonian month names were used in Greek documents, and the new year was changed from spring to autumn (Stern 2012, 234–246). The Ptolemies, on the other hand, were met with the strikingly different Egyptian civil calendar, fixed at 365 days with twelve months of thirty days each and five days added at the end of every year (Stern 2012, 125–166). Although this reckoning was convenient because of its regularity, the fact that it did not account for its slight deviation from the solar year meant that, over time, the calendar drifted through the seasons. That the new rulers at least attempted to change it is shown by the Canopus decree, published in Greek alongside Egyptian hieroglyphic and demotic by Ptolemy III Euergetes in 238 BCE. This document established a new festival celebrating Ptolemy and Berenice, but it also set a schedule of adding one extra day every four years to keep that festival synchronized with the seasons. There may have been political motivation behind it, since it would have allowed the Ptolemies greater control over the Egyptian religious year (Stern 2012, 137–142). The command was never brought to fruition, however, though the reach of Ptolemaic rule was responsible for spreading the Egyptian calendar to new areas.

Finally, Greece, including those expansive Hellenistic kingdoms, was eventually introduced to another calendar when it became part of the Roman world (ROMAN CALENDARS). After the Julian reform, the calendar consisted of a 365-day year beginning in Januarius, with a leap year every four years. The number of days in each month differed, but the variation was fixed. In the east, where many cities were using the Egyptian or Babylonian-influenced Seleucid calendar, there was an eventual adoption of the Julian system, if not the Julian calendar wholesale (Stern 2012, 231–234, 274–284; Hannah 2005, 131–147). The Egyptian calendar, for example, finally got its leap year, probably in 26 BCE. Several inscriptions throughout the province of Asia record an edict of the proconsul Paullus Fabius Maximus (probably 8 BCE) that the start of the new year should be changed to the birthday of Augustus, September 23, not an enormous departure for the Macedonian calendar whose new year was already in autumn. The cities decreed, then, that the first month would be named Kaisar, and they set a schedule for the start and lengths of months, the rest of which retained the old names. In mainland

Greece, however, the old lunar system endured for a long time, with evidence that the Athenian calendar did not assimilate to the Julian until the fifth century CE. Although this could speak to a general conservatism, the magisterial control of Greek calendars throughout their history suggests that this was also a politically motivated choice (Stern 2012, 62–64).

8. Conclusion

Although the time reckoning of the Greeks was tied to the movement of astronomical bodies, and Greek scientists had the ability to observe and calculate those movements fairly accurately, Greek calendars were characterized by flexibility. Stern has emphasized that the interpretation of the changes made to those calendars—as always motivated by a desire for accuracy or predictability—says more about modern conceptions of time-keeping than about Greek sensibilities (2012, 63). Even when offered the Roman solar calendar, the Greek world was mostly resistant. That science is intertwined with other cultural and historical processes is wholly exemplified by the study of the Greek calendar. These overlapping spheres are why the eponymous Meton is known to us not only as an astronomer but also as the object of satire on the dramatic stage. Religion, war, economics, agriculture, political structures, social tensions, the shifting balance of power, and interregional communication worked alongside astronomy and mathematics to form the Greek calendars.

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FURTHER READING

Hannah 2005 is an accessible overview of the ancient calendar. Broader material concerning the concept of time is included in Hannah 2009 alongside newer evidence surrounding the Metonic cycle. For a treatment of the Greek calendar in its wider Mediterranean and Near Eastern contexts, see Stern 2012; this work also offers the most complete and up-to-date scholarly references of any of the overviews. The conference proceedings edited by Ben-Dov, Horowitz, and Steele 2012 presents papers on the Greek calendar alongside other lunar calendars. Slightly updated from its earlier 1968 edition, Bickerman 1980 remains a useful handbook of ancient chronology. The calendars of various Greek cities and the evidence for their month names and day counts are outlined by Samuel 1972; more recent information and deeper treatment of the month names is provided by Trümpy 1997. To delve more deeply into the issues of the Athenian calendar and the questions of prytanic and Metonic calculations, see Pritchett 2001 and Meritt 1961; Mikalson 1975 reconstructs the Athenian festival year. An English translation of Geminus with accompanying commentary is available in Evans and Berggren 2006.

CHAPTER 54

Roman Calendars

Robert Hannah

1. Introduction

We live still with the calendar of Julius Caesar, although several adjustments were needed, first soon after its institution in 45 BCE, then several centuries later, and more recently still, in each case as it drifted largely or slightly out of sync with its fundamental timekeeper, the sun. And nowadays even our fundamental timekeeper is no longer the sun, but the caesium atom, which maintains a better rhythm than the sun at the more refined level demanded by modern science. And yet our months remain the same as Caesar's, both in name and in oddly inconsistent length. The religion that underpinned the original was replaced eventually by another, but, even in the more secular world that we live in, the calendar remains. In countries which maintain other calendrical traditions, the Julian calendar is nonetheless acknowledged and runs alongside the others, particularly in the worlds of business and politics. It serves its purpose, which is to provide as good as is reasonably possible in the "real" world a consistent means of coordinating activities across all facets of social life. Yet, curiously, that aspect of the calendar which we most value, its capacity to coordinate across time and space, seems to have been of no value to its inventors. Instead politics and religion were prioritized.

2. The Pre-Julian Calendar

The Ten-Month Calendar

Legend has it that the Roman calendar was originally a ten-month calendar, which began on the first day of the month of March and then ran through the months of April, May, June, Quintilis, Sextilis, September, October, November, and December. All the month

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names in Latin are adjectival in form, agreeing implicitly with "month" (*mensis*). But more than this, the names from Quintilis to December also represent literally the fifth, sixth, seventh, eighth, ninth, and tenth months in a sequence which should begin with March and end with December. Late sources, Macrobius (*Saturnalia* 1.12) and Censorinus (*On the Birthday* 20), talk of a Roman year which was originally of ten months' duration, to which the second king of Rome, Numa, added two new months, January and February, to make it twelve. This may have been reflected in the heading to the calendar, or *fasti*, of M. Fulvius Nobilior, which may be reconstructed from Varro (*On the Latin Language* 6.33–34), Macrobius (*Saturnalia* 1.12.16–18), Censorinus (*On the Birthday* 20.2–4, 22.9–13), and others:

> The consul and censor M. Fulvius Nobilior set up this calendar after the conclusion of the Aetolian War:
>
> Romulus gave names to the ten months, the first and the second he named in honor of his father and his ancestress; after he divided his people into older and younger so that one group would defend the state with their counsel, the other by force of arms, he named the third and fourth months in their honor; the rest of the months were named from their number. Numa gave names to the two months he added from Ianus and the gods of the netherworld respectively. A thirteenth month was intercalated according to a law of the consul Acilius in the year 562. (Rüpke 2006)

These *fasti*, set up some time after Fulvius' Aetolian victory, celebrated in triumph in 187 BCE, were part of the decoration of the temple of Hercules Musarum ("Hercules of the Muses") in Rome (Eumenius 9.7.3; Macrobius, *Saturnalia* 1.12.16).

Tradition held that this ten-month calendar was only 304 days long, and therefore considerably shorter than even a twelve-month lunar year of 354/355 days. Doubts have been expressed over its existence, with it being regarded as a back-formation from later, Imperial times based on the sum of the first ten months of the later Julian calendar, January to October. Yet this ignores the explicit testimony of both Censorinus and Macrobius about the lengths of the months, which do not in their entirety correspond to the Julian months. They assert that this calendar comprised the months from March to December, with four months having 31 days (March, May, Quintilis, and October) and six of 30 days (April, June, Sextilis, September, November, and December). This makes two months, Sextilis and December, each one day less than their later Julian equivalents. So there are prima facie grounds for taking the ten-month calendar seriously. We may speculate that it could have taken the form of an environmentally driven calendar, in which the "missing" months would signify an end to counting until such time as some natural marker signaled that it was necessary to start again. Such markers could be growth in the fields after a lull in agricultural activity, or, if the society is pastoral or even still hunter-gatherer, the seasonal return of birds or animals to the region. Such ecological clues to the passage and marking of time certainly persist in later Roman calendars, which, through to the late antique period, demonstrate the continued dependence of the Roman economy and life on natural cycles. The Antonine-Severan *Fasti porticus* from beneath the Basilica of S. Maria Maggiore in Rome contains frescoes of appropriate seasonal activities accompanying each month. On a much smaller scale, the Calendar of 354 does something similar within the confines of an illustrated book (*codex*) by alluding to the season through its products or even appropriate astronomical



Figure 54.1 Calendar of 354: June. *Source:* Österreichische Nationalbibliothek, Vienna.

associations, such as the summer solstice. Copies made in the Renaissance give an idea of the original appearance (Figure 54.1).

If such a year really existed in practice, it would, of course, have run very quickly out of kilter with the solar, seasonal year of 365¼ days. Macrobius, in fact, informs us:

> … It sometimes happened that the cold weather appeared in the summer months and, conversely, the hot weather in the winter months; when this happened, as many days were allowed to be spent without the name of a month as would bring that time of the year to where the appearance of the sky would be found suitable to the present month. (*Saturnalia* 1.12.39)

Plutarch says much the same thing when he notes that before Caesar's reform of the calendar, "sacrifices and festivals shifted little by little to the seasons opposite to their dates" (*Caesar* 59). Such apparent capacity to absorb what we would regard as huge discrepancies of up to six months between the calendar and the seasons strikes us as intolerable, yet the ancient Egyptian and the modern religious Islamic calendars did and do even more than this, causing the months, along with their attendant sacred festivals, to run through all the seasons of the year over the passage of several solar years. This is noticeably so in the Islamic case, with a cycle of 33 years; but in the Egyptian case, with a cycle of 1,460 of our years, the shift is imperceptibly noticeable in an ordinary human lifetime. The Greek astronomer Geminus (*Introduction to Astronomy* 8.16–19) tells us that this slippage was desired because the Egyptians "want the sacrifices to the gods to occur not at the same moment of the year but to pass through all seasons of the year, and the summer festival to occur in winter and autumn and spring as well." As a result we may posit that the Egyptians wished to sacralize the whole year through the celebration of all the gods' festivals through the year.

The Republican Calendar

A mixture of basic observation and numerological superstition, it seems, governed the structure of the Republican calendar proper, whether or not this was preceded by a ten-month calendar. According to Macrobius (*Saturnalia* 1.13), Numa was credited with making the calendar lunar, by increasing the Roman year first to 354 days and then to 355, and dividing the year into twelve months by adding January and February at the beginning. The length of the year was increased to 354 days to accord with the time "in which twelve circuits of the moon are completed," but then Numa afterward added an extra day "in honor of the odd number." The rule of the odd number extended also to the lengths of the months. Numa so organized these that each, except February, contained an odd number of days—29 for January, April, June, Sextilis, September, November, December, and 31 for March, May, Quintilis and October; February had 28 days.

Despite the truth of the statement that 354 days corresponds to twelve lunations—12 times the average length of a lunar month of 29.5 days is 354 days—it is odd that Numa chose to make his months either 29 or 31 days and in no apparent order. Months of 29 and 30 days in alternation produce a much closer approximation to the passage of the moon through the year, from new moon to new moon, and the Greeks used such a scheme for centuries. The Numan scheme was destined from the start to distance the calendar from the moon's cycle very quickly. Thus the Numan calendar would become "de-naturized" early on in a way that the Greek one would not without human interference. Literary evidence supports this supposition of schematization and de-naturization. Cicero records a solar eclipse on the Nones of June in about the 350th year after the founding of Rome (*Republic* 1.25). This should place the event about 400 BCE. What is important for us here is the notion that an eclipse could take place at a time other than at the actual new moon, which ought to have marked the Kalends, not the Nones. So by about 400 BCE, the Romans would seem to have given up an observational lunar calendar. Historians usually associate the shift with the second Board of Ten (the Decemvirate), who, Macrobius tells us (*Saturnalia* 1.13.21), brought a bill relating to intercalation before the people. This would be about 450 BCE, if such a Board existed, although doubts have been expressed about its historicity.

A visual representation of a Republican calendar is provided by the sole surviving physical example which predates the reforms of Julius Caesar, the *Fasti Antiates Maiores*. (Figure 54.2) This dates to 84–55 BCE, and its preserved fragments cover just over half the year. Originally measuring 1.16 by 2.5 meters (3.8 × 8.2′), it was an imposing physical monument. Similarly impressive originally, and much more learned with its antiquarian annotations, would have been the now fragmentary Imperial *Fasti Praenestini* (Figure 54.3), dedicated in the forum of Praeneste probably between 6 and 9 CE, with some annotations added later, between 10 and 22 CE. We learn from Suetonius (*Grammarians* 17) that these *fasti* were drawn up by the grammarian M. Verrius Flaccus, the freedman teacher of Augustus' grandsons, Gaius and Lucius. A statue of Flaccus was set up in the upper part of the forum, near the hemicycle in which the calendar was displayed.

These two examples represent one of three types of *fasti* now recognized by scholars. As *Fasti Anni*, they chart the days and months of the year, thus representing a cyclical approach to time, as the cycle of the year will be repeated from one year to the next (more or less; see below regarding intercalation). There survive over two dozen such *fasti* in various states of preservation from Republican and (mainly early) Imperial Rome, and almost another two dozen from elsewhere in Italy and Gaul.

Combined with this calendar of days and months from Antium was the other major type of monumental calendar in the Roman world, the *Fasti Consulares*. This lists the consuls and leading magistrates of Rome, and it demonstrates a linear approach to the passage of time from one year to the next, from one point in the list successively and annually to the next. A third type of *fasti* recognized nowadays, the *Fasti Triumphales*, should be set aside here, as they tend to occur separately, whereas the first two types seem to have been regularly combined (six of the thirty-five surviving consular lists are accompanied by calendrical *fasti*), and indeed the triumphal *fasti* do not signal continuous time, but instead commemorate episodic celebrations, with events separated by irregular gaps.

The *fasti* of days and of consuls were generally public documents, insofar as they were displayed in the meeting rooms of priestly colleges, associations, and country towns, but the find spot of the *Fasti Antiates Maiores* (in a building on the site of Nero's later



Figure 54.2 *Fasti Antiates Maiores*, 84–55 BCE. Rome, Museo Nazionale Archeologico, Palazzo Massimo. Photo by author.



Figure 54.3 *Fasti Praenestini*, 6–9 CE. Rome, Museo Nazionale Archeologico, Palazzo Massimo. Photo by author.

villa at Antium, about 57 km [35.4 miles] south of Rome), suggests that this *Fasti* may have been private, as also may have been the much later *Fasti Porticus* of the Antonine-Severan period.

The Antium and Praeneste calendars start on January 1 with a column on the left, which presents a continuously repeated sequence of the eight letters, A to H. The series begins with A on 1 January and runs uninterruptedly to December 29—recall that this is the pre-Julian calendar, with months of 29 and 31 days; the intercalary month, with 27 days, is attached after December (the length of each month is signaled explicitly at the bottom of each column). By December 29, the eight-letter alphabetic sequence has reached C.

These letters are called the nundinal letters. This "cycle of nine," the *nundinae*, is an eight-day week but counted as nine because of Roman inclusive reckoning. The name *nundinae* came to mean "market day," because the Romans held their markets in

different towns on successive day of the cycle. Precisely how the system worked, however, remains a mystery. A number of nundinal cycles survive from different localities, and the fact that some share the same town names has led to attempts to correlate the separate cycles. Some of these inscriptions also provide the seven-day (or hebdomadal) week: Saturn, Sun, Moon, Mars, Mercury, Jupiter, and Venus, named after the planets—an innovation introduced under Augustus, as we may judge from Tibullus' (Augustan-era) reference to "Saturn's holy day" (1.3.18; our Saturday), and from the week's presence on the fragmentary *Fasti Sabini* (after 19 BCE), *Fasti Nolani* (early Imperial), and the Augustan *Fasti Foronovani*. (See Figure 54.4 for an illustration of Sunday from the Calendar of 354.) But because the towns, which these market-day lists share, turn up in a different order in the seven-day week, it seems that nundinal cycles did not necessarily correspond from one town to another.



Figure 54.4 Calendar of 354: Sunday. *Source:* Österreichische Nationalbibliothek, Vienna.

Undoubtedly lunar elements survive in the subdivisions of the pre-Julian Roman months. Each month was divided into three parts: at the Kalends (*kalendae*) on day 1; then the Nones (*nonae*) at day 5 (in the shorter months) or 7 (in the 31-day months); and the Ides (*idus*) on day 13 (in the shorter months) or 15 (in the longer). Rüpke has suggested that a fourth dividing point may be found at the end of the month, almost matching in its position the Nones at the beginning of the month. The vestiges of this last marker, he argues, are to be found in the calendars at the point of the "double festival" of the *Tubilustrium* on 23 March/May and the day marked QRCF (*Quando Rex Comitiavit Fas*—"when the 'king' goes into the Assembly, it is lawful") on 24 March/May. Overall, then, we would be facing four "weeks" in the month, which match lunar periods: from new moon to first quarter (Kalends to Nones), from first quarter to full (Nones to Ides—*idus* may stem from a Greek word for the full moon: Macrobius, *Saturnalia* 1.15.14–17), from full to last quarter (Ides to *Tubilustrium*/QRCF), and last quarter to new (*Tubilustrium*/QRCF to Kalends). In addition, these four lunar "orientation days," as Rüpke calls them, initially correspond reasonably well to a market-day cycle, but any relationship that may have begun between this "orientation-day" cycle and the *nundinae* disappeared as the calendar's relationship to a lunar cycle dissolved over time.

This sense of a lunar basis to the structure is realized for us by Varro, writing just about the time of the Julian calendar reform in the mid-first century BCE. He explains the term *kalendae* as deriving from the fact that the Nones of a month are called (*calantur*) on the Kalends. He provides us with the formula spoken by the priest who did the calling: *kalō Iuno Covella* ("I call, O Juno Covella"), repeated five times if the Nones were to fall on the fifth day of the month, and seven times for Nones on the seventh (*On the Latin Language* 6.27). Macrobius (*Saturnalia* 1.15.9–11) explicitly derives the word *kalendae* from the Greek verb *kalō* ("I call"), on the basis of the same story. He describes the event in more detail, which demonstrates the foundation of the term in practical, observational astronomy: originally a minor priestly official was delegated the task of watching for the first sign of the new moon and then reporting its appearance to the high priest. A sacrifice would then be offered, and another priest would summon the people and announce the number of days that remained between the Kalends and the Nones, "and in fact he would proclaim the fifth day with the word *kalō* spoken five times, and the seventh day with the word repeated seven times." The first of the days thus "called" was named *kalendae* after *kalō*.

The name *idus* may also stem from a Greek word for the full moon, as Macrobius reports among other derivations (*Saturnalia* 1.15.14–17). The fixing of the Nones at "nine" days before the Ides suggests that, while the division of the month at this point may well reflect a lunar basis (at first quarter), the Romans must already have moved away from a strictly observational calendar, since the time between the first quarter and the full moon is not so fixed in reality. It is also important to note here that the people invested with the authority to deal with the calendar were the *pontifices*, a college of priests. Religion, however politicized it may at times have been, was a fundamental part of the calendar's raison d'être.

Intercalation in the Republic

With a year of only 355 days, the Republican calendar would have rapidly slipped out of synchrony with the seasonal, solar year of 365¼ days. That the Romans, unlike the Egyptians but like the Greeks, felt a need to bring calendar and solar time back

into correspondence is demonstrated by their use of an intercalary cycle, in which the "missing" days between calendar and season were regularly and systematically restored—or, in other words, a temporal brake was applied to the lunar calendar, which otherwise would run ahead of the solar year.

Macrobius (*Saturnalia* 1.13.9–10) describes how the Romans attempted to introduce an intercalary cycle similar to the Greek eight-year cycle (Greek Calendars). The version of this story as told by Solinus (1.42) has these 90 days (expressed in terms of the 11¼ days' difference between the solar and lunar years multiplied by 8) added by the Greeks at the *end* of the eight lunar years, whereas we know from other sources that they were inserted a month at a time in different years, in various formulations of the *octaetēris*. The Romans, on the other hand, are supposed to have added the requisite 90 days through *four* intercalations, alternately of 22 and 23 days, every two years. Such an awkward length for an intercalary month is further evidence that the Romans had foregone observational correspondence between their calendar and the moon.

Over a period of eight years, then, the Roman system covers 2,930 days [(355 × 8) + 90], instead of 2,922 days [(354 × 8) + 90, or (365¼ × 8)], and produces an average year of 366¼ days, which is a close approximation to the solar year of 365¼ days. This might suggest that the Romans abandoned the lunar calendar in favor of an attempt to follow the solar year, but in eight years the Roman system overshoots eight solar years by eight days, so any semblance of correspondence with the sun is soon lost, even more so than in the Egyptian system. Macrobius (*Saturnalia* 1.13.12–13) informs us that this error was corrected by intercalating not 90 but 66 days every third octennium, that is, 24 days less than expected, on the basis that the 24 extra days generated by the Roman system over three eight-year cycles could thus be suppressed. It is doubted whether this refinement of biennial intercalation was ever utilized for any great period of time, if at all—Macrobius is our only source—and instead it is then assumed that the Romans practiced intercalation on a haphazard basis.

The intercalation itself was inserted in an unusual fashion, which the mural *fasti* from Antium were incapable of demonstrating. In that version, the intercalary month is simply tacked on at the end of the year, after December. But in reality it was always added in February. Both Varro and Macrobius state that, rather than coming at the end of the month, the 22 or 23 intercalary days were placed after the 23rd day of February. The remaining five days of this month were then tacked onto the end of the intercalary month (called *mensis intercalaris*, but also nicknamed "Mercedinus" or "Mercedonius," according to Plutarch, *Numa* 18.3, *Caesar* 59.2), thus bringing it effectively to 27 or 28 days' length. Censorinus puts the intercalation "in February between the Terminalia and the Regifugium," that is, between two religious festivals, the former falling normally on the 23rd, the latter on the 24th (*On the Birthday* 20.6). Varro calls the day of the Terminalia the last day of the year (*On the Latin Language* 6.13). He was writing at the end of the Republic in the mid-first century BCE and so reflects a situation with which he would have been familiar, unlike Macrobius or Censorinus, who wrote a considerable time after the Julian reform, and who therefore may have been trying to explain something which they had difficulty understanding.

At one point, Livy tells of the beginning of an intercalary year being "on the third day after the Terminalia" (43.11.13), which, by Roman inclusive reckoning, translates to February 25. But at another point, he has the beginning of another intercalary year falling "on the day after the Terminalia," February 24 (Livy 45.44.3). The resolution to this apparent inconsistency may be that the intercalary month was always of 27 days'

length, but that it might begin on either February 24 or 25, thus effectively giving the intercalary year an extra 22 or 23 days, respectively.

Cicero lists negligence as one of the causes for haphazard intercalation in the past (*On Laws* 2.29). Yet he himself, while stationed overseas, hoped his friends in Rome might persuade the officials to omit the intercalation so that he could return to Rome as soon as possible and not be delayed by the extra month (Cicero, *To Atticus* 5.9.2, 5.13.3, 5.21.14, 6.1.12; *To his Friends* 8.6.5). This accords with accusations in other authors that the priests were improper and corrupt in performing duties on behalf of business and political friends, who, because of hopes of personal gain, were motivated to shorten or lengthen the year (Suetonius, *Deified Julius* 40; Censorinus, *On the Birthday* 20.7; Solinus 1.43; Ammianus Marcellinus 26.1.12).

Over the last two centuries BCE, something went seriously wrong in the calendar, leaving it badly out of synchrony with the seasons; yet at other times it seems to be reasonably in harmony. Between the 190s and 160s BCE, the misalignment between calendar and sun was as large as four months at the start and as small as 2½ at the end. A reduction on this scale over this number of years indicates that there must have been intercalation in more than just alternate years, and therefore sometimes in successive years. Then, for the period between about 150 and the 60s BCE, reasonable synchronization between the calendar and seasons seems to exist. Nevertheless, however close the correspondences between season and calendar may have been in these years, a significant drift away from alignment occurred through the 50s, to the point that it would take the insertion of 90 days in 46 BCE to bring everything more or less back in order.

3. The Julian Calendar

In 46 BCE, Julius Caesar ordered a wholesale revision of the calendar to the point of dismissing the quasi-lunar calendar of the Republic and adopting a purely solar one. The new calendar had an average year of 365¼ days, with the quarter-day absorbed into an extra single whole day added every fourth year.

After describing the corrupt practices of the *pontifices* with regard to intercalation down to Caesar's time, Censorinus describes the changeover:

> Things had deviated so much that Gaius Caesar, as *pontifex maximus*, in his third consulship and that of M. Aemilius Lepidus, in order to correct the past mistake, inserted between the months of November and December two intercalary months of 67 days, since he had already intercalated 23 days in the month of February, and made that a year of 445 days, at the same time taking care that the mistake would not be repeated in future; for with the intercalary month done away with, he shaped the civil year to the course of the sun. And so to the 355 days he added 10, which he distributed through the seven months which had 29 days as follows: two days were added to January, Sextilis, and December, and one to the others; and he placed these days at the ends of the months, evidently so that the religious ceremonies of each month might not be moved from their place. Therefore now, although there are 31 days in seven months, nevertheless four are distinguished by this feature of the original tradition, that they have the Nones on the seventh day, while the other three remaining ones have them on the fifth.
>
> Moreover, to take account of the quarter of a day, which in fact would appear to complete the year, he ordered that after a period of four years had been completed, a single day, which is now called the bissextile, should be intercalated after the Terminalia, where a month formerly

> used to be. From this year, thus regulated by Julius Caesar, the rest down to our lifetime are called Julian, and they start in the fourth consulship of Caesar. (*On the Birthday* 20)

Macrobius tells the same tale at even greater length (*Saturnalia* 1.14.6–12). This solar year of 365¼ days had been discovered earlier, but if it had ever been put into use, it was only in the metropolis of Alexandria, and then only for a few years. In 330 BCE, the Greek astronomer Callippus proposed a method of achieving a year of this length by combining four Metonic cycles of 19 years each into a period of 76 years, from which one day was to be dropped (Geminus, *Introduction to Astronomy* 8.59–60; see also ASTRONOMY; GREEK CALENDARS). This gave a total of 27,759 days over 76 years, and therefore an average year of 365¼ days. Only astronomers, however, appear to have used this cycle. Then in 238 BCE, Ptolemy III Euergetes decreed the addition of an extra day every fourth year into the Egyptian calendar of 365 days, to create an average year of 365¼ days and thus correct the drift of the Egyptian year from the solar year, but even this royal decree was largely ignored. In his own calendar reform, Caesar had the services of Egyptian astronomers, whose expertise he called on while in Alexandria helping return Cleopatra to the throne (Appian, *Civil Wars* 2.21; Cassius Dio 43.26). Indeed, the story of Caesar's calendar is so tangled in the narrative of his dalliance with Cleopatra, that it becomes difficult to distinguish his reasons. On the technical front, the astronomer Sosigenes, "skilled in this knowledge" (Pliny, *NH* 18.211), is credited with orchestrating the new calendar. We know little else about this individual—he is associated with the correction of the Julian leap-day cycle later (Pliny, *NH* 18.212)—but it is safe to assume that he was a Greek (as his name suggests) living in Alexandria, where Caesar and Cleopatra were based. By linking the calendar once again with astronomy, by shifting the focus to the sun after the calendar had lost its initial bond with the moon, Caesar effectively re-naturalized it after centuries of increasing de-naturization.

4. Intercalation in the Julian Calendar

Caesar added 90 days to the year which we call 46 BCE, making it a very long one of 445 days. This was achieved by the massive insertion of not only the normal intercalary month after February (of the 23-day variety on this occasion), but also of two further intercalary months, of 22 and 23 days, between November and December. This extraordinary year was called "the final year of confusion" (Macrobius, *Saturnalia* 1.14.3). From January 1, 45 BCE, a normal year of 365 days was instituted, with months of the same length as they currently are in our Western calendar.

From this stage on, an extra day was meant to be inserted every fourth year after the day called "the sixth before the Kalends of March" (*ante diem VI kalendas Martias*), that is, 24 February. This had been the regular point of insertion for the intercalary month under the Republic, and now it became the date at which the intercalary day was to be added. The new day was called *ante diem bis sextum kalendas Martias* ("the sixth doubled before the Kalends of March"), and so the year in which it occurred was called *annus bissextus* ("the year with the sixth doubled"); hence the English term "bissextile" (and cognate words in Romance languages) for a "leap" year.

Caesar's assassination in 44 BCE may have affected the correct implementation of instructions for intercalating the leap day, although Pliny's report suggests that an error in theory rather than practice fundamentally caused the difficulty. As several authors inform

us, the priests initially inserted the extra day by mistake every three years. This continued for 36 years, by which time twelve leap days had been added instead of the requisite nine. Inserting a leap day has the effect of slowing a calendar down. In this case, by the time the mistake was recognized after 36 years, the calendar was running three days behind the solar year. Such a discrepancy is small, however, so it must have been discovered by astronomers with precision instruments. Politicians, priests, or others might have been able simply to use their eyes to see what date was being signaled by the shadow cast along an inlaid meridian line by the large Egyptian obelisk set up by Augustus on the Campus Martius in Rome in 10/9 BCE. But its date there was expressed in terms of degrees within the zodiacal signs, so again it spoke to astronomers, or at best to the highly educated.

The change of name of the month Sextilis to August in 8 BCE probably provides a point by which the leap-year error had been recognized. Macrobius (*Saturnalia* 1.12.35) records the decree of the senate authorizing the change of name. Cassius Dio (55.6.6) and Censorinus (*On the Birthday* 22.16) provide the date in the equivalent of 8 BCE, while Suetonius (*Deified Augustus* 31.2) reports it along with the leap-year reform.

Order was eventually restored by Augustus, who decreed that there should be no further intercalation for twelve years. This procedure, while slow, nevertheless avoided the social problems that were encountered when the Julian calendar had to be realigned with the sun from 1572 onward, when several days were peremptorily cut from one year to forcibly bring the calendar back into line. So sudden a procedure raised issues on many levels in society—in particular, in the areas of economic and religious life, with, for instance, missed festivals and shortened rents. On the latest model proposed by Bennett, the last false leap year was 8 BCE, the following twelve years (by inclusive Roman reckoning) had no leap days, and the proper four-yearly leap-day cycle began with a leap day in 4 CE, to be followed by the next one in 8 CE (2003, 221–240; 2004, 165–168; cf. Stern 2012, 215, 266–267). Augustus also ordered that the proper arrangement of the calendar be engraved on a bronze tablet, so that it could be maintained forever (Pliny, *NH* 18.211; Suetonius, *Deified Augustus* 31; Solinus 1. 46–47; Macrobius, *Saturnalia* 1.14.13–15).

The suggestion by Bennett (2003, 221–240) that the leap-day error may have been a function of the vicissitudes of the life of M. Aemilius Lepidus, the *pontifex maximus* from 44 BCE to 13 or 12 BCE, is attractive but problematic. According to this hypothesis, while Lepidus may have known when the leap day was meant to be inserted, his enforced removal from public life from the mid-30s BCE may have led to his priestly colleagues, uninitiated in the proper rule, slipping in the leap day incorrectly. It is impossible now to know whether one man alone would have been left in control of such vital information. Common bureaucratic sense would suggest not. It may be simpler to accept that the astronomical theory underpinning the leap-year rule was wrong and took some time to correct, as Pliny indicates (*NH* 18.211–212).

5. Festivals in the New Calendar

Seven months were affected by the changes wrought by Julius Caesar: January, Sextilis, and December with two extra days; and April, June, September, and November with one extra day. February had no additional days, which may seem a lost opportunity, since it left the month shorter than any other, but, Macrobius tells us, this was "so as to avoid change to the religious ceremony for the gods of the underworld" (*Saturnalia* 1.14.7). March, May, Quintilis, and October gained no extra days either, so that 31

days remained the limit on the length of a month. While these four months also retained their Nones on the seventh day, the three new 31-day months (January, Sextilis, and December) preserved their Nones on the original fifth day

> because Caesar wanted to insert those days which he added neither before the Nones nor before the Ides, for fear that he might ruin, by an unprecedented two-day postponement of the Nones or Ides, a religious ceremony which was on an appointed date. But neither did he want to insert soon after the Ides, for fear that the declaration of all the holidays might be dishonored, but when the holidays of each month had been completed, he made a place for the foreign days. (*Saturnalia* 1.14.8–9)

It would be difficult to find a Western secular parallel for the religious sensibility which runs through this passage. It is impossible to know what source Macrobius based his report on, but the Romans took these matters seriously, being prepared to adapt practical life to suit the religious. So here Caesar is reported to have delayed the insertion of the extra days in the affected months until all the religious festivals of a given month had run their course. A major aim of the process of insertion was to ensure that the festivals kept their relative positions in each month, and so the new days were added at different points near the end of each of the seven months (Macrobius, *Saturnalia* 1.14.9–11).

What the Romans were at pains to do was to maintain the position of any given festival relative to the Nones or Ides of the month in which it fell. So after the reform any festival held on a day up to the Ides of a month retained its traditional date, expressed in terms of so many days before the Nones or Ides. This encompassed a majority of the festivals in the Republican era. But those festivals celebrated after the Ides were dated according to the number of days which lay between them and the following month's Kalends. These festivals thus remained the same number of days from the Ides (and hence from the start of the month), but their distance from the next Kalends increased and therefore the expression of their dates changed. A festival formerly held on December 21 remained eight days from the Ides on the 13th (or nine by Roman inclusive reckoning). But, since the day fell after the Ides and its notation used to read *ante diem X kalendas Ianuarias* ("the tenth day before the Kalends of January"), this now changed to *ante diem XII kalendas Ianuarias* ("the 12th day before the Kalends of January"), because the month now had 31 days instead of 29.

We should not lose sight of this aspect of the calendar reform. We have seen already that three groups of people in Roman society had a prime interest in the reform: politicians, priests, and astronomers. The last group worked not in a scientific cocoon divorced from the "real world," but at the service of the first two. The first two groups, on the other hand, overlapped, as priesthoods were often steps on or up the social and political ladders, the chief priesthood of the *pontifex maximus* being an obvious case in point. It was while he was *pontifex maximus* that Caesar promulgated his calendar reform, as our ancient sources indicate, although it was also while he was *dictator*. Certainly religion (as the Romans understood the idea) and politics were intertwined in a way that is difficult for many nowadays to grasp. The process of intercalation and indeed of telling the principal hours of the day under the Republic had been in the hands of religious officials. Certainly they were open to corruption and incompetence, as the sources tell us, but this does not mean we should downplay the religious aspect in favor of the political. Religion, in some form or another, imbued every strand of social life in antiquity.

A decree dated to 8 or 5 BCE demonstrates well the closely intertwined nature of politics and religion in the Greco-Roman world within the realm of calendar reform. Passed

on the motion of the Roman proconsul Paullus Fabius Maximus by a number of the Greek cities in the Roman province of Asia, its purpose was formally to adopt Augustus' birthday as New Year's Day, the first day of the year:

> It was decreed by the Greeks in the province of Asia, …
>
> … whereas the birthday of the god was the beginning of the good tidings for the world through him, and [the cities of] Asia decreed in Smyrna … that there was to be a crown to gain for the one devising the greatest honors for the god; and whereas Paullus Fabius Maximus, proconsul of the province sent for its safety by that god's right hand and purpose, benefited the province with countless benefits … and devised for the honor of Augustus the thing until now unknown by the Greeks, namely, that the time for life begins from his birth;
>
> therefore, with Good Fortune and under the power of Safety, it has been decreed by the Greeks in the province of Asia that the New Year shall begin in all the cities on the ninth from the Kalends of October, which is the birthday of Augustus;
>
> and, so that the day always corresponds in every city, that the Greek day also is named with the Roman day;
>
> that the first month, Kaisar, as was also previously decreed, be reckoned as beginning with the ninth from the Kalends of October, the birthday of Caesar …
>
> The months shall be reckoned thus: Kaisar 31 days; Apellaios 30 days; Audnaios 31 days; Peritios 31 days; Dystros 28; Xandikos 31; Artemision 30; Daisios 31; Panemos 30; Loos 31; Gorpiaios 31; Hyperberetaios 30; altogether 365 days.
>
> And in the year, because of the intercalation, Xandikos will be reckoned as 32 days.
>
> So that from now the months and the days may correspond, the month of Peritios which is now current will be reckoned until its 14th day; and on the ninth from the Kalends of February we shall celebrate the first day of the month Dystros, and for each month the ninth from the Kalends will be the beginning of its first day; and the intercalary day will always be that of the intercalary Kalends of the month Xandikos, with two years coming in between …
>
> (*OGIS* 458.II.30–77)

Flattery, no doubt, played a part in the promotion of this calendar change, and Fabius was duly rewarded locally with the award of a wreath and public proclamation at the games. The impact of the decree on local calendars seems to have been minimal, since some of the Greek lunisolar calendars in the region began anyway after the autumn equinox, with which Augustus' birthday coincided almost to the day (e.g., Priene, and possibly Ephesus and Magnesia-on-the-Meander). Nonetheless, it would be foolish to disregard as sycophancy the language of divinization and deliverance directed toward Augustus ("the birthday of the god was the beginning of the good tidings for the world through him," "that the time for life begins from his birth"). In the eastern Mediterranean, from the time of Alexander the Great, whole eras, let alone annual calendars, had begun from a date marked by the "rescue" from one rule by that of its conqueror. The Seleucid era and the era of Tyre are obvious instances at the regional and local levels. Fabius was astute in latching on to this tendency within the *Realpolitik* of this part of the Hellenized world, especially as it could not have been done within Rome itself at that time. But to seek a division between "sacred" and "secular" in the reform of the calendar would be mistaken.

The month names of the Asian Greek calendar in the decree, apart from the first, are those of the Macedonian calendar, which spread throughout the East in the wake of Alexander the Great's conquests. The first Macedonian month, Dios, reflective of the chief Greek god, Zeus, has been replaced by Kaisar (sometimes Kaisarios), in its turn

reflective of the new god, Augustus (not a status he could claim in Rome while he lived). The months then follow in the normal Macedonian order, but from this point onward they are given fixed lengths which allow the year to correspond with the Roman Julian year of 365 days, rather than having lengths based on the moon and adding up to 354 days. Furthermore, the system operates in such a way that each month starts on the ninth day, by Roman reckoning, before the Kalends of the following month. The new Greek calendar then runs alongside the Roman as follows:

Greek month	**days**	**Julian date of first day of month**
Kaisar	31 days	23 September
Apellaios	30	24 October
Audnaios	31	23 November
Peritios	31	24 December
Dystros	28	24 January
Xandikos	31	21 February
Artemision	30	24 March
Daisios	31	23 April
Panemos	30	24 May
Loos	31	23 June
Gorpiaios	31	24 July (formerly Quintilis)
Hyperberetaios	30	24 August (formerly Sextilis)
TOTAL:	365 days	

The leap day required by the Julian calendar is, by decree, created by doubling the first day of Xandikos. Since Xandikos began on February 21 in the new Greco-Roman scheme, doubling it meant that the Greek leap day would correspond closely, although not exactly, with the Roman leap day of February 24.

One further point of interest is that the new calendar did not start operating on its New Year's Day of September 23 and in the month Kaisar, nor did it delay until then. It started instead with the month following the passing of the decree, Dystros, in late January. Other new calendars, such as the Gregorian calendar, have begun likewise in midstream, thus minimizing to one year the confusion that any such transfer inevitably causes.

The Egyptian calendar was also made to adopt a leap-year system probably from 22 BCE (as the year when the first leap year was observed). This alteration was effected so that the Egyptian calendar, like the calendars of its Greek neighbors, would correspond with the Roman Julian calendar. From the start, the Egyptian calendar adopted the ideal Julian calendar's four-year leap-day rule. The extra day was inserted as a sixth epagomenal day before 1 Thoth.

The adoption of the Julian calendar across the rest of the Roman Empire is a story in itself, too large to relate here, telling of both localized variety and occasional confusion in the process of diffusion. Of great interest will be renewed research on one of the major forms of evidence for the Julian calendar in the eastern part of the Empire: the *hemerologia*, or lists of the calendars of various cities or regions. These were tabulated in such a way as to show their month-by-month correspondence through the year (Figure 54.5). These fundamental documents were last studied a century ago by Kubitschek, and the time is ripe for a re-examination of these tables in light of more recent discoveries and research.

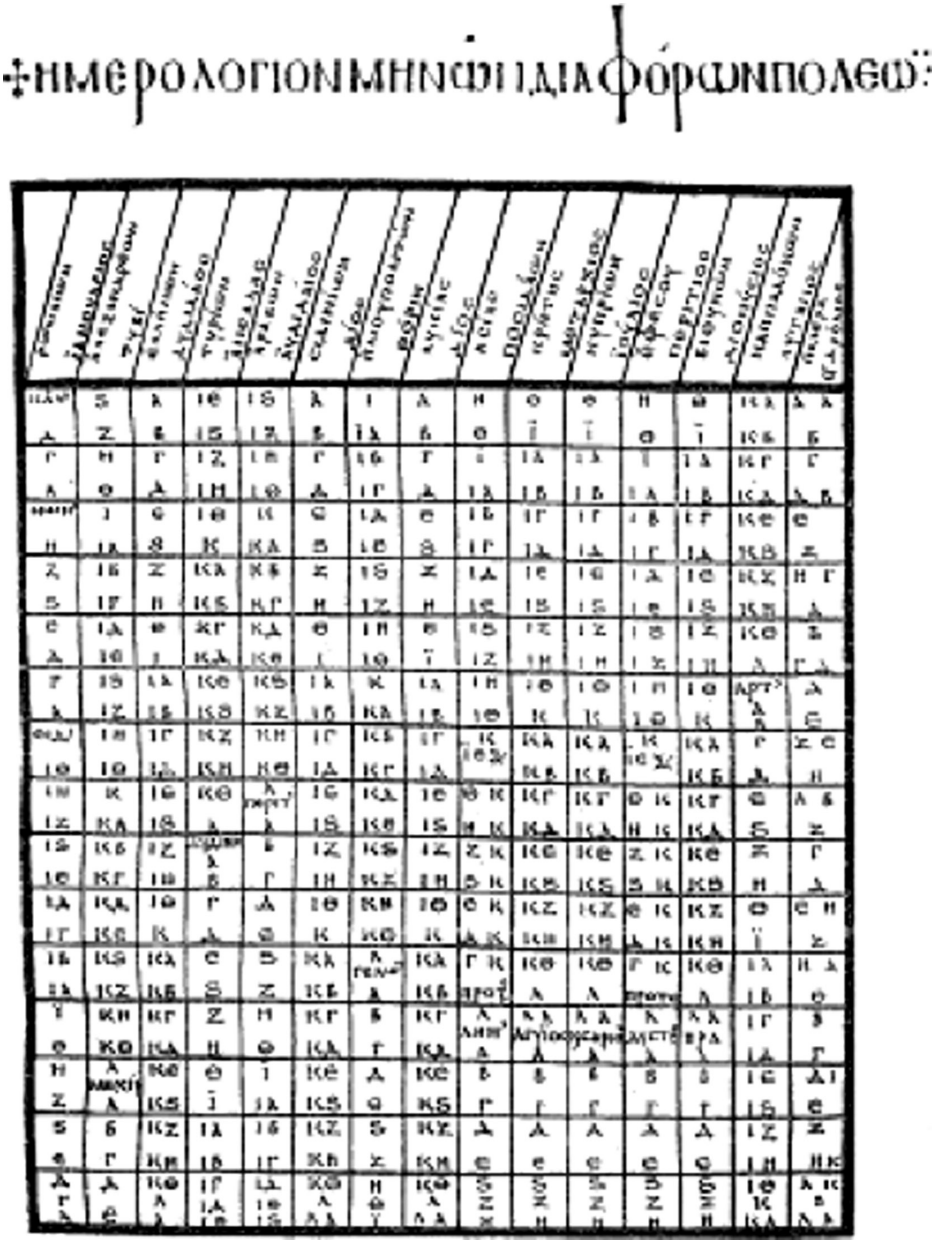


Figure 54.5 Hemerologion: January. Florence, Med. XXVIII 26. Adapted from Kubitschek 1915.

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CHAPTER 55

Time-Telling Devices

Robert Hannah

1. Sundials

The Gnōmōn

Diogenes Laërtius mentions the introduction to Greece of the *gnōmōn*, a shadow-casting projection of some kind. He associates it with the philosopher Anaximander, who lived in Miletus in the first half of the sixth century BCE:

> He also was the first to discover the *gnōmōn*, and he set it on the shadow-catchers (*epi tōn skiothērōn*) in Lakedaimon, as Favorinus recounts in his *Miscellaneous History*, showing the solstices and the equinoxes; he also made *hōroscopeia*. (2.1)

Much later still, the Byzantine encyclopedia, the *Suda* (s.v. "Anaximandros"), also attributes to Anaximander the introduction of the *gnōmōn*, as well as the discovery of the equinox, solstices, and *hōrologeia*. As early as the sixth century BCE, a *gnōmōn* was a simple, shadow-casting stick placed vertically in the ground, as we may infer from both later usage of the word, and from the story that, by the late fifth century BCE, the astronomer Oenopides adopted the term to refer to a perpendicular line as being "like a *gnōmōn*" when drawn to another straight line from an external point (Proclus, *Commentaries on the First Book of Euclid's Elements*, p. 283, 7–10).

A basic *gnōmōn* of this form provided most readily a measure of the noon shadow lengths. But the fact that Diogenes says that Anaximander placed his instrument "on the shadow-catchers in Lakedaimon [Sparta]" suggests that a broader space in front of the *gnōmōn* captured its shadows, thus indicating time through the year and day, at least in Sparta. The "shadow-catcher" (*skiothēras*) is itself specifically identified by Vitruvius

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as a type of a sundial, comprising an upright *gnōmōn* set up on a flat surface (1.6.6). So perhaps Anaximander set a pole in the ground and thereby created a formal, permanent *gnōmōn* of fixed height and location—a kind of early "town clock."

We are not told that this *gnōmōn* displayed anything except the times of the solstices and equinoxes. Assuming that Anaximander's *gnōmōn* was a noontime shadow-casting instrument, one could then observe the midday shadow cast by it on these four occasions, which could already be known from observation. The solstices would then represent the ends of the shadow line running north–south along the local meridian, and the equinoxes would be at a point between them. This gives a simple meridian line, and such an instrument was to have a long history. An advanced form of such a line has been found on Chios, between circa 150 and 50 BCE (Schaldach 2011). It is a small, flat north–south, noontime line, in this case set vertically not horizontally, with the summer and winter solstices marked at the extremities, this time together with the divisions between solar "months" denoted by the twelve zodiacal signs. It therefore provided a measure of the passage of time from one solar month to the next. The *gnōmōn* itself appears to have been 12.4 cm (4.8″) in length. The change in shadow length from midday March 24 (the time of the spring equinox and of the entry of the sun into the zodiacal sign of Aries at the time of the instrument's construction) to midday April 24 (the time of its entry into Taurus) was 8.9 cm (3.5″), a perceptible movement. Unfortunately, at the latitude of Chios (38°22′N), the shadow measured by this *gnōmōn* changed too little to help in distinguishing one *day* from the next. Between midday March 23 and midday March 24, for example, the difference in shadow length was just 2.3 mm (0.09″). A gigantic form of such a line would be much more useful, and may be imagined from the remains of an inlaid bronze meridian line in the Campus Martius in Rome, datable through its dedicatory inscription to 10/9 BCE and mentioned by Pliny (*NH* 36.64). This used as its *gnōmōn* an obelisk over 30 m (98.5′) tall brought from Egypt by Augustus, who had it set up to commemorate his takeover of Egypt in 30 BCE and the correction of the Julian calendar (Roman Calendars).

Quite what Anaximander's *hōroscopeia* and *hōrologeia* were, and whether they were related to the *gnōmōn*, is hard to tell now. It is possible, given later usage, that they refer not to sundials but water clocks, or even both. The names imply instruments which permitted observation of the *hōrai*, a term that can refer to the "seasons" of the year as well as to the "hours" of the day. In the late fifth century BCE, Herodotus seems not to have a word for "hour." The use of *hōra* to express "hour" first appears in the Hippocratic medical texts of the first half of the fourth century BCE. In the later fourth century BCE, the Cynic philosopher, Diogenes of Sinope, is reported to have been shown a *hōroscopeion* and then commented on how useful it would be in preventing one from being late for dinner (6.104), which suggests a recognition of the "hours." By the third century BCE, Callimachus was certainly using *hōra* to refer to a single hour (fragment 550 Pfeiffer). But this meaning is unlikely for Anaximander's time. Instead his *hōroscopeia* would have measured only the seasons, so they would seem closely related to his *gnōmōn*, which marked the solstices and equinoxes. Therefore, while Anaximander's *gnōmōn* may have cast noon-time shadows and showed when the solstices and equinoxes occurred, perhaps his *hōroscopeia* comprised markers on the shadow-receiving surface for the appropriate season which encompassed each tropical point, which, by ancient understanding, marked the midpoints of their seasons. Later evidence certainly

indicates that the term *hōroscopeion* was applied to shadow-casting sundials. Geminus (2.35, 16.13) and Strabo (2.5.4) imply as much, and a conical sundial from Pergamon is explicitly called a "*hōroscopion*" by its inscription.

A brief passage in Herodotus credits the Babylonians as the specific source of the *gnōmōn* for the Greeks: "For the Greeks learned the *polos*, and the *gnōmōn*, and the twelve parts of the day from the Babylonians" (2.109.3). All three mechanisms mentioned by Herodotus appear to do with time-telling via the sun. As we have already seen, the *gnōmōn* is probably a shadow-casting stick. The twelve-part division of the day looks to be an early reference to the hour but lacking its own terminology.

Polos occurs in the late-fifth-century drama of Euripides (*Orestes* 1685, *Chrysippus* fragment 839.11 Nauck), where it refers to the celestial vault, while in the contemporary comedy of Aristophanes' *Gerytades* (fragment 163) it is equated with a sundial (*hōrologion*), and in his *Daitaleis* (Achilles Tatius, *Introduction to the Phenomena of Aratus* 28.34) it refers to the *hēliotropion*, which ought to be a sun-tracking instrument. Altogether, the *polos*, *gnōmōn,* and twelve-part division of the day assisted in telling the time both through the year and day, providing the basis for both calendars and clocks.

If a *gnōmōn* marked only the solstices and equinoxes, then it marked only the times of the significant changes in daylight in the seasonal year: when daytime is longest, when it is shortest, and when it equals nighttime. The *gnōmōn*'s focus is therefore purely calendrical, and, as a calendrical device, it is very basic. What about the sundial's development as a clock, to mark out time during the day? By the second half of the fourth century, we have evidence provided by the oldest surviving Greek stone sundial, an equatorial plane dial from the Amphiareion at Oropos in Attica, that the twelve equinoctial hours were recognized, and this in a setting of social (possibly dramaturgical), not scientific, interest. The dial is so sophisticated as to imply the identification of this type of hour at an earlier stage. It certainly looks likely that sundial technology and the division of the day into hours could have infiltrated Greek society, at least its "scientific" community, by Herodotus' time.

Dividing the Day

In antiquity, the hours were a function of dividing daylight or nighttime into twelve sections, but there were two means of doing so. The type of hour that we currently employ, and the one which the Oropos sundial used, is of equal length regardless of the season. This derives from the length of the hour specifically at the equinoxes, when daytime and nighttime are practically equal. An equinoctial hour may be defined as one-twelfth of the daytime or nighttime at the equinoxes, or as one-twenty-fourth of the time from one sunrise to the next at any time of the year.

But another method, much more conventional in antiquity, produced "seasonal" hours. Because the length of daylight and nighttime in temperate latitudes like Greece varies according to the seasons, dividing the day or night into twelve equal parts produces daylight hours which are necessarily longer in summer than in winter, while the nighttime hours are shorter in summer and longer in winter. These hours are called "seasonal." A seasonal hour would stretch, in our modern terms, from about three-quarters of an hour in Athens or Rome in midwinter (47 minutes in Athens, 45 minutes in Rome) to about an hour and a quarter in mid-summer (1 hour 14 minutes in Athens, 1 hour 15 minutes in Rome).

But at the popular level it is not "hours" that we find marking time in the day so much as "feet." A passage from Aristophanes' *Ecclesiazousae*, produced perhaps in 391 BCE, demonstrates the system. The citizen Blepyrus is wondering, in the new, communal world decreed by the women of Athens:

Blepyrus: … But who will work the land?
Praxagora: The slaves. Your only concern will be to get perfumed and go to dinner, when the *stoicheion* is ten feet. (*Ecclesiazousai*, 651–652)

The time for a meal is here reckoned from the length of a *stoicheion*. The actual process of stepping out to measure the shadow gives us the derivation for the term *stoicheion*: from *steichō*, "I walk," in Greek. Fixed shadow lengths throughout the year, such as this ten "feet" time, would lead to a variable time for the same meal, and a variable mealtime may well have suited people's biological clocks, since the length of the day itself varied throughout the year. Meals would literally have been movable feasts. There is evidence of seasonally varying shadows in Greek shadow tables, the earliest dating to circa 200 BCE, another to Roman times, while still others are Byzantine from the 12th to 16th century CE. The tables fall into two main categories: those which organize seasonal shadow lengths according to the zodiacal months, and those which group them by calendar month. These means of organization suggest that the tables are originally of Hellenistic date at the earliest, since the zodiacal month is an invention after circa 300 BCE, and since the calendar months—Julian or Alexandrian—are later still (see Roman Calendars).

One of the Byzantine examples gives a good indication of the type of entries, with a table of each zodiacal month's hours in feet. Here they are arranged in pairs of months which bear the same shadow lengths, for example,

When the Sun is in Sagittarius and in Capricorn			
hour 1	feet 28	hour 2	feet 18
hour 3	feet 14	hour 4	feet 11
hour 5	feet 9	hour 6	feet 8
hour 7	feet 9	hour 8	feet 11
hour 9	feet 14	hour 10	feet 18
hour 11	feet 28	hour 12	feet 0

When the Sun is in Scorpio and in Aquarius			
hour 1	feet 27	hour 2	feet 17
hour 3	feet 13	hour 4	feet 10
hour 5	feet 8	hour 6	feet 7
hour 7	feet 8	hour 8	feet 10
hour 9	feet 13	hour 10	feet 17
hour 11	feet 27	hour 12	feet 0

The variation of foot-length, and therefore hour-length, from one zodiacal month to another indicates that these hours are seasonal, not equinoctial. Other tables in the calendar-month mode, however, use equinoctial hours.

But to return to sundials, these are typically pilloried by satirists as slave-driving instruments which force people to eat only at fixed times. Aulus Gellius (second century CE) quotes from the Roman comic playwright Plautus, three hundred years earlier:

> The gods damn that man who first discovered the hours, and—yes—who first set up a sundial here, who's smashed the day into bits for poor me! You know, when I was a boy, my stomach was the only sundial, by far the best and truest compared to all of these. It used to warn me to eat, wherever—except when there was nothing. But now what there is, isn't eaten unless the sun says so. In fact town's so stuffed with sundials that most people crawl along, shriveled up with hunger. (3.3.5)

The moment it was decided that a fixed hour should serve for mealtimes, or for any other activity, a tension was created between people's physical or social needs and mechanical demands. The story of how the Greeks and Romans learned to measure time is a history of the gradual distancing of people from nature, of their "de-naturization." The process of de-naturization seems complete by the sixth century CE, when Cassiodorus points out to the barbarian Gundobad, king of the Burgundians, that the ability of humans to reckon time through sundials marks them out from the animals, which are ruled by hunger (*Letters* 1.46.2).

Types of Sundials

By the second/first centuries BCE the Chian meridian line (above) is just one of a number of more or less complex types available to the Greeks and Romans. Vitruvius lists fourteen types, along with their supposed inventors, the earliest being Eudoxus (9.8.1). The principal kinds surviving in the archaeological record are spherical, cylindrical, conical, and plane. Other types are known, including eventually small, portable ones, which were functional over much of the Roman Empire—a remarkable feat, considering the dials were latitude sensitive.

The spherical type of sundial was the most labor intensive and difficult to construct, as it entailed carving out, initially a hemisphere, but usually a quarter sphere of stone. It was, however, theoretically the simplest to mark out, because it captured the celestial dome inversely on a matching concave surface. Its *gnōmōn* hung out over the hollow partial sphere. It is generally assumed that Vitruvius refers to this spherical type when writing about the *scaphē* or *hēmisphaerium* (9.8.1) —the latter name particularly recommends the identification.

An imposing example, now in Selçuk in Turkey, is said to be from Aphrodisias (Figure 55.1). The dedicatory inscription on the dial's base provides, through reference to the Roman Emperor Caracalla and his mother Julia Domna, the general date of CE 198–217. The dial alone is 58 cm (23″) in height and 1.18 m (46.5″) in width; with the preserved base, the ensemble stands about 93 cm (36.5″) high. (Its present *gnōmōn* is a modern restoration, and the sundial has been set to face the wrong direction.) Typically, such sundials present two lines marking out the extreme limits of the lines tracked by the shadow of the *gnōmōn*. These are the shadows of the winter and summer



Figure 55.1 Selçuk, Archaeological Museum, inv. no. 375: Spherical sundial from Aphrodisias. Photo by author.

solstices. An intermediate line, which serves for both equinoxes, is often marked out in between. Other lines may be added for other days in the year, sometimes for the change of months, sometimes for particular festivals. On the Selçuk dial, we find two clearly cut lines near the outer edges, while traces of possibly a third line can be made out closer to the *gnōmōn*. The outermost line usually represents the time of the summer solstice, the innermost that of the winter solstice, and the intermediate line the equinoxes. But these lines do not correspond exactly with where they should be by calculation. A lack of care about the precise positions of these lines is not unusual.

On the Selçuk sundial, eleven hour lines have been marked, crisscrossing with the solstitial and equinoctial lines. In the spaces between the hour lines are the twelve seasonal hours of the day, numbered in the Greek fashion: A B Γ Δ E S Z H Θ I IA IB. Since the lengths of hours vary according to the season, the hours on the dial face increase in width the closer they are to summer at the bottom of the dial face, and decrease as they approach winter at the top. If we imagine the sundial facing directly into the sun to the south, with observers looking north into the dial and the sun at their back, the sun would then rise in the east on their right, casting the first hour's shadow from the *gnōmōn* to their left (A). The sun will cross the sky behind them from right to left, passing south at midday (the line between S and Z). It will finally set in the west on their left, casting the twelfth hour's (IB) shadow to their right.

The conical type of sundial is a variation on the spherical, representing a simpler, partial hollowing out of the stone block. The type is well illustrated by an elaborate example from Pergamon in Turkey (Figure 55.2). The formal similarity to the spherical type is clear. Here the dial has been provided with an artistic support in the form of the thematically relevant figure of Atlas, the Titan condemned perpetually to uphold the heavens.



Figure 55.2 Bergama, Archaeological Museum: Conical sundial supported by Atlas, from Pergamon. Photo by author.

In the surviving archaeological record, the conical competes with the spherical as the most popular type. The earliest surviving conical dial is from Heraclea ad Latmum in Turkey, dating probably to the end of the third century BCE. This might be close to the period of the type's invention, if there is value in Vitruvius' attribution of the *arachnē* type of sundial to Apollonius, presumably the mathematician of circa 200 BCE, who wrote on conic sections. This work on the theory of conic sections suggests that Apollonius may have had something to do with the exploration of sundials, given that one of the main types is conic, and that from them he may have derived the theorems for conics (see further, MATHEMATICS). It is likely that the conical was much easier to construct in stone than the spherical, because its generating line was straight, not curved, while its theoretical underpinning was kept to a minimum—and indeed obviously simplified or even not understood by many of the makers, to judge by their inaccuracies.

The plane type of sundial, which occurs usually in horizontal or vertical forms but also uniquely in the slanted, equatorial form at Oropos, dated to the second half of the fourth century BCE, is the easiest to construct but technically the most difficult to mark out. The difficulty arises from the projection of the hemispherical dome of the sky on to a completely flat surface. A shadow, which tracks the movement of the sun through the year, is cast by a *gnōmōn*, which is usually stuck perpendicularly into the flat surface of the sundial (but at an angle in the Oropos specimen, because of the initial slant of the dial face). The vertical plane dials on the eight sides of the Tower of the Winds in Athens, built by Andronicus from Cyrrha in Macedonia, are now dated to the second century BCE (Figure 55.3). They are therefore among the earliest surviving examples of the vertical plane type, but their complexity and accuracy suggest an older ancestry.



Figure 55.3 Athens, next to the Roman Agora: Plane sundial on the Tower of the Winds, southeast side. Photo by author.

The proliferation of sundials in a wide variety of geometrical forms from the late Classical period onward is indicative of an increasing abstraction in the way time was measured and perceived. Whether from patterns on the ground based on the human shadow, or from mirror images of the celestial dome designed to recapture the apparent movement of the sun across the sky, the development of Greek and Roman sundials followed a route which distanced their users further and further from the natural means of time measurement. The de-naturization which we witnessed in the skits of Greek and Roman satirists is matched in the very forms of the instruments used to mark the passage of time. It becomes increasingly harder to see the natural or the human in the end products. Yet, as Cassiodorus indicates (*Letters* 1.46.2), this distancing from nature comes to be seen as a mark of civilization, something that distinguishes humans from animals. Sundials carry an extraordinary evolutionary responsibility.

The degree of abstraction which was quickly achieved by Greek dialers is well illustrated in the contrast between the two broadly contemporary sundials found at Ai Khanoum, the Greek city established at the extreme east of the Hellenistic world in Afghanistan. These were certainly in use in the mid-second century BCE, in the last phase

of the city before its destruction, but they may have been manufactured earlier, in the third century. The spherical sundial is inscribed with a network of lines indicating the twelve hours of the day and the twelve solar, zodiacal sign boundaries (three of which do double service for the solstitial and equinoctial lines). The concave form of the dial still recalls the apparent domical form of the sky above, while the inscribed lines track the observable path of the sun through the day and the year via the shadow of the *gnōmōn*. Nature is not very distant from the mind of the dial maker here.

With the cylindrical sundial from the same site, on the other hand, we encounter a form unique so far in the literary and archaeological records, and clearly a considerable conceptual distance from the natural world. This sundial consists of a block of marble, taller than it is wide, out of the center of which a cylindrical hole has been carved. The inner surface of this hole has been graduated with two sets of straight lines, a set emanating from each of the broad faces of the slab and radiating toward the interior of the hole. The stone is of unequal length on its front and back faces, and beveled at its base, so that it did not stand upright, but was set at an angle. Measured from the vertical, that angle is 37°4′, which is practically the latitude of Ai Khanum (37°10′). With the slab's longer face set toward the north and its shorter to the south, the angular fix causes the stone to be parallel to the celestial equator. This means that the sun would have shone into the southern aperture of the cylindrical hole from the autumn equinox, through the winter solstice, and on to the spring equinox, and then into the northern interior of the hole from the spring equinox, through the summer solstice, and on to the autumn equinox. Because it is set parallel to the celestial equator, the stone would have borne no shadow at all on the days of the two equinoxes themselves. The lines inscribed within the hole then told the time of day in hours, but the season of the year only with regard to the solstices and equinoxes, which marked the inner and outer extremities of the interior lines, respectively. In that sense, it was a less precise calendar than its spherical cousin, even though it was a more complex form of dial.

Portable Sundials

Even among miniature portable sundials, there is complexity. Some of these dials are simply very small versions in limestone of the stone spherical or conical types. Even on one of the smallest and earliest of such miniatures, an ivory conical dial only 2.8 cm (1″) in height dating probably to the first century BCE, the accuracy of the hour lines is remarkable: it was made for a latitude of 33°, which corresponds reasonably well with the latitude of its provenance, Tanis in Egypt at 31°. It was found in the private house of perhaps an official who worked at the nearby temple of Amun. Fixed in place, the dial appears to have been used by a temple official to keep him on time in his duties. Not all portable dials were intended to be taken far.

Dating slightly later to the first century CE is a portable sundial from Herculaneum. Known as the "Ham Dial" because its distorted bronze plate looks just like a small leg of ham, it consists of a spike on one side, which threw a shadow on to a series of criss-crossing lines on the plate, from which one could read the hour of the day. Another early portable dial, also dating to the first century CE, is a tiny Roman cylinder type made of bone and bronze, from near Este in northern Italy. Other portable bronze dials are circular in shape, and some come with extra plates to suit different latitudes. One small dial of perhaps mid-third century CE date consists of just two plates and a *gnōmōn* and

yet permits the reading of the time of day anywhere between latitudes 30° and 60° N; thirty locations are specifically listed.

These dials foreshadow the astrolabe, a portable timepiece characteristic of the Middle Ages. None survives from antiquity, but the instrument was probably a late Greek invention. Via a system of stereographic projection, the celestial hemisphere was represented in two-dimensional form. Ptolemy describes this method of representation in his *Planisphere*, and it may have been known to Hipparchus in the second century BCE. The earliest surviving description of the astrolabe, Philoponus' *On the Use and Construction of the Astrolabe* (sixth century CE), depends on an earlier one by Theon (fourth century CE).

2. Timers

It remains characteristic of ancient time technology that stone sundials were, by and large, not used to tell daily calendar time. Even the largest, the conical specimens from above the Theater of Dionysus in Athens and from the sanctuary of Apollo at Claros in Turkey, which present meridian lines of 480 mm (19″) and 397 mm (15.5″) in length, respectively, and so would have the capacity to demarcate small periods of time, still notify the observer only of the solstices and equinoxes within the year; there is no interest in displaying the zodiacal months, let alone the days within them. As for time within the day, the smallest diurnal unit on surviving sundials is the half hour, and that is very rare: neither of the two large dials just mentioned bothers to display it. This fraction of the hour is inscribed on only a couple of surviving Greek sundials, suggesting such refinements in time really were of little interest either in private or public contexts. It first appears in surviving literature in a fourth-century BCE comedy by Menander, to judge from a stray surviving fragment (fragment 1015). In his instructions for making sundials in the third century CE, Cetius Faventinus remarked that almost everyone is "in too much of a hurry to ask more than what hour it is" (29.2). Calculations derived from some sundials, which were carried a considerable distance from one latitude to another and yet still used, have suggested that people would tolerate a quarter of a seasonal hour's inaccuracy in the telling of local time. If this is so, then ancient expectations of accuracy and punctuality differ markedly from those in modern, industrialized societies, notwithstanding Seneca's complaint that sundials were notoriously inaccurate: the hour of the emperor Claudius' death could not be clearly identified, he says, because "it is easier to find agreement among philosophers than among sundials," and so he opts for somewhere "between the sixth and seventh hours" (*Apocolocyntosis* 2).

Even in scientific contexts, inadequate means of measuring small amounts of time leave Hero of Alexandria with only a sundial to calculate the rate of flow of water, by letting water flow into a large basin for an hour (*Dioptra* 4). For more rapid movement, there was simply no mechanism for Hero to measure the speed of revolution of his newly invented steam machine. Yet occasion did demand the *measurement* of much smaller units of time within a day, and this need drove the development of other forms of timekeeping technology.

Various devices were used to measure small pockets of time. For example, Pliny (*NH* 33.96–97) mentions how men in a deep Spanish silver mine bailed out the water in shifts measured by lamps. The ordinary, ubiquitous, clay oil lamp lent itself admirably to this function, since it could burn for a determinable period of time, depending on the capacity of the bowl, material of the wick, size of the flame, and type of oil. Most

of these variables feature in the instructions for the use of lamps in magical rituals, such as conjuring up and holding on to gods or spirits for their favors, preserved in Greek papyri from Egypt.

Such a mechanism provided the facility to measure the passage of time within the day or night. In that sense, it achieved the same effect as a sundial, but overcame the problems that arose from lack of sunlight owing to inclement weather or nighttime. But unlike a sundial, lamps fail to tell the time: they cannot in themselves indicate either the time of day as such-and-such an hour, or the period of the year one happens to be in. They are simply timers.

As timers, these devices provided an even measure of whatever division of the day was desired. Each unit of measure was the same as the preceding and the following one. This is an interesting point, insofar as with sundials we became used to the idea of seasonally variable units of time (hours). In contrast, from the Hellenistic period onward, astronomers regularly used equinoctial hours in their calculations. Yet only one sundial, the early plane dial from Oropos, currently demonstrates the facility to measure equal, or equinoctial, hours regardless of the season. So the Greeks and Romans were plainly capable of thinking in quite different terms when it came to measuring small blocks of time within the day. The puzzle is why they chose not to standardize their time divisions on sundials into equal segments in public, non-scientific contexts. If the equinoctial hour was utilized in sundial technology so early on at rural Oropos, why did it not become the hour type of choice through the Hellenistic and Roman periods in the city centers?

It may be that the geometrical and astronomical knowledge required to construct the Oropos sundial was more than most manufacturers could assimilate—and this one seems to betray signs of hesitation on one face of the dial. Equatorial plane dials are not at all common in the surviving corpus. The equatorial cylindrical dial discovered in Ai Khanum is unique, and even it did not use equal hours. The answer to the question of the relative popularity of unequal hours must lie to a large degree in the relative popularity of the spherical and conical types of sundial in Classical antiquity. These present dial faces which more or less mirror the perceived celestial dome, a characteristic which may have given the forms their preferred status among makers and users. If one wanted to subdivide daytime on these types of dials through the day, the very geometry that underlies the forms of the dial faces demands, in practical terms, subdivisions which create unequal hours from one day to the next.

3. Water Clocks

One other major form of timer existed in antiquity: the water clock. Initially it too, like the lamp, did not derive its units of measure from mimicry of the motions of the celestial bodies, yet even it was drawn eventually into matching its measures with the heavens.

In Greece, what is nowadays called a water clock was originally not a clock or calendar at all, but just another timer, which measured the set times for certain activities by the fall or rise in water level in a container. The name given to the instrument was *clepsydra* ("water thief"), a term apparently borrowed from a device which worked like a large, bulbous pipette (e.g., Aristotle, *On the Heavens* 294b14–30; pseudo-Aristotle, *Problems* 914b). The same name, interestingly, was applied also to a stream which ran, mostly underground, from the north slope of the Acropolis in Athens and probably fed one of the most famous water clocks of antiquity, the Tower of the Winds.

One imagines the pipette form of *clepsydra* to be quite small. It is essentially an inflow device. It could also be used as an outflow type, if the mouth was bunged once the vessel was full or partly full of water and it was then lifted from the container of water and the bung removed. But other types of outflow timing devices existed, of quite different form from the "pipette" variety, and some of them very large indeed. The name *clepsydra* was simultaneously applied to these different types of containers, which were used at least from the fifth century BCE so as to time non-scientific activities, notably speeches in the law courts. Indeed, the *clepsydra* became synonymous with the courts, as Aristophanes' plays show (*Acharnians* 694; *Wasps* 93). But more than this, by the mid-fourth century BCE, the orator Demosthenes could use the word "water" (*hydōr*) as a synonym for "time" itself. He talks of the period allotted for his speech in the law court as being his "water" (*Against Polycles* 2; *On the Crown* 139; *On the False Embassy* 57).

Different measures were used for different speeches. Ten *choes*, for example, were made available for cases involving more than 5,000 *drachmai* in monetary value and seven *choes* for those under that amount (pseudo-Aristotle, *Constitution of the Athenians* 67). An example of a judicial *clepsydra* has been excavated in the Agora in Athens, dating to circa 400 BCE (Figure 55.4). A bucket-like vase with a piped hole near the base for the outflow and marked on the outside with the Greek letter *chi* twice (XX, i.e., two *choes*), it was found by experiment to hold 6.4 liters (1.7 gallons) or the equivalent of just six minutes' worth of water, a refinement of time unattainable by sundial. The *clepsydra* was treated much like a modern stopwatch. Demosthenes requests of the court official, "Stop the water!", when the taking of depositions interrupts his speech (*Against Euboulides* 21; *Against Conon* 36; *Against Stephanus* 1.8). Dramatic plays too were apparently timed before Aristotle's time by the *clepsydra*, in this case a container presumably on a larger scale (*Poetics* 1451a7–9).

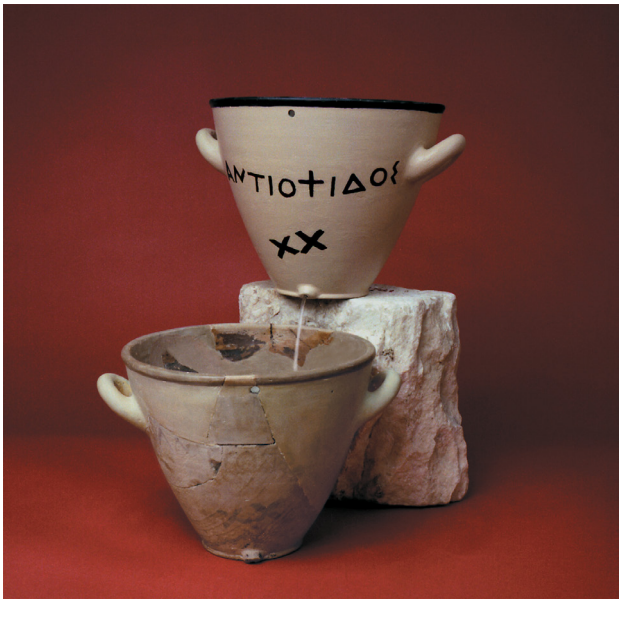


Figure 55.4 Athens, Agora Museum LCT-149: *clepsydra*. *Source:* American School of Classical Studies at Athens: Agora Excavations.

The aversion to being controlled by a time machine which we have already encountered with sundials is found also with the water clock: Plato has Socrates express his belief that, in contrast to the freedom to expound at length and will enjoyed by philosophers, the pressing needs of the law court, including the flow of water from the *clepsydra*, enslave lawyers (*Theaetetus* 172c–e). But the *clepsydra* also assured equality through standardization, a fundamental characteristic of democracy.

The standardization of time through the *clepsydra* extended also to the whole of the legal day in Athens, in those cases that demanded more time. This so-called "measured day" was made to correspond, regardless of the time of year, to the length of the shortest days of the year, those of the Athenian month *Poseideōn* in midwinter (pseudo-Aristotle, *Constitution of the Athenians* 67.4; Harpocration, s.v. *hēmera diamemetrēmenē*), or about 9½ hours in our terms. This was then subdivided into a certain quantity of water—the fourth-century orator Aeschines talks of one such day being equated with "eleven amphoras"—with thirds being given to the prosecution, the defense, and the judgment. Once again, it is interesting to note how time is restricted, presumably in the interests of equality: access to the same amount of time for court cases throughout the year was ensured by correspondence with the shortest day of the year, guaranteeing that cases tried in other seasons would still occupy only the daylight hours. The equinoctial and solstitial days, for instance, would have been too long in winter.

Despite Socrates' avowed dislike of the tyranny of the water clock, Athenaeus (*Deipnosophists* 4.174) tells of Plato himself making a *nukterinon hōrologion*, a nighttime clock, which was "like a very large *clepsydra*," but what sort of *clepsydra* was intended is impossible to recover, and so, therefore, are the device's workings. *Hydrologion* is another term applied to outflow water clocks, and we find it used in scientific circles, for instance, in an experiment to deduce the size of the sun relative to its full circuit of the sky over a day and night:

> For when it [the sun] is measured with *hydrologia*, it is discovered to be $^{1}/_{750^{th}}$ part of its own circle. For if, let us say, a *cyathus* flows in the time the sun rises fully from the horizon, the water let to flow out in the whole day and night is discovered to be 750 *kuathoi*. Such an approach is said to have been invented first by the Egyptians. (Cleomedes, *The Heavens* 2.1.184–191)

The calculations provided by water clocks continued in use in scientific, political, legal, and military contexts. In Rome, Scipio Nasica was credited with introducing the first water clock, in 158 BCE, just a few years after the first accurate sundial was set up in the Forum (Pliny, *NH* 7.214). The *clepsydra* divided the hours of the day and night equally, Pliny records, and it can therefore be classed, along with its nearby sundial, as a clock, allowing the time to be told through the day.

Yet the earlier function of the *clepsydra* as a timer was not lost on the Romans. We see this clearly in the Roman law courts, where a speech for the prosecution or defense was timed against the water clock. In the latter part of the first century CE, Pliny the Younger, a lawyer himself, relates that in one very important court case, "I spoke for almost five hours, since to the twelve water clocks of the largest size that I received, four were added" (*Letter* 2.11.14). From this description we can calculate the rate of outflow: with sixteen very large water clocks providing almost five hours' speaking time, one water clock was worth almost twenty minutes.

In a different context, another lawyer, this time in Dalmatia, even had the time of his death noted on his tombstone, down to the very hour:

> Sacred to the spirits of the dead, Q(uintus) Publicius Aemilianus, lawyer, by nationality African, lived 47 years, 9 months, 7 days, in the fifth hour of the night.
>
> *CIL* 3.2127A (*ILS* 7774)

The time must have been taken from a water clock.

Julius Caesar, in a mixture of scientific curiosity and military need, measured the length of the nights in Britain "by water," presumably with *clepsydrae* (*Gallic War* 5.13.4), and the popular tables of the lengths of day or night in terms of hours on the longest day reported by, for instance, Geminus (6.7–8), Strabo (2.5.38–42), Pliny (*NH* 2.186), and Cleomedes (2.1.438–451) may still reflect the results of this older technology. Cleomedes' system for calculating the monthly increase in daylight from the shortest day to the longest (1.4.18–29), while smacking of an arithmetical schema, is nonetheless reasonably accurate. One wonders therefore to what extent it was based on empirical data derived from measurements taken by water clock.

Clepsydrae of some kind were also used to measure out the length of night watches in the military world. But there a measure based on subdivisions of a standardized, winter day, such as Athens had instituted in its legal "day," could not work for the longer days of the campaigning season, so attempts were made to ensure that watches, and hence responsibilities, were equalized by adjusting the volume of water that the clocks held through coating the inner surface of the *clepsydra* with varying layers of wax (Aeneas Tacticus 22.24–25).

Two *clepsydrae*, from the Athenian Agora and the Amphiareion at Oropos, are very large outflow water clocks with a capacity of about 1,000 liters (about 260 gallons). They are sufficiently close in form as to suggest that the same person may have designed both. The Oropos example is the better preserved, and calculation of its outflow suggests that both specimens would take about 17 hours to empty, long enough to operate uninterruptedly over the whole of a summer's day of under 15 hours. At Oropos, the clock may have been used to time rituals or performances at the nearby theater.

The Athenian *clepsydra*, however, shows signs of being redesigned from an outflow to an inflow type over the period of its use down to the first half of the second century BCE. In its first version, as with its counterpart at Oropos, the clock was filled at the start of the day, and then allowed to empty gradually through the day or more limited period if desired. A gauge of some kind was presumably fitted to enable people to see how much water had passed, and therefore how long a period of time had elapsed or remained for whatever activity was being measured. This outflow was regulated only by the narrowness of the outlet pipe at the bottom of the tank. Unfortunately, this pipe did not survive the later renovation at Athens, and its hole was filled in; but the equivalent at Oropos has survived, comprising a bronze cylinder, 9 cm (3.5″) in diameter, terminating in a hemisphere, punctured by a hole of only 2.6 mm (0.1″) diameter. Water would therefore exit the tank at a slow rate through so narrow an outlet. But if the tank had vertical walls, then, as it emptied, the pressure would decrease, and the rate of exit for the water would decrease. Any gauge against which the outflow was to be measured ought to take this rate of change into account, in the interests of equity, with unequal calibrations for the periods of time being measured, but it is not clear that this was possible. The Egyptian

solution, on a much smaller scale, was to slope the walls of the conical, bucket-like container, so that the pressure could be equalized as far as possible; a limestone *clepsydra* from Karnak, dated to about 1400 BCE, has slopes set at 70° to the horizontal, and it achieved a nearly uniform rate of emission. At Oropos, the upper part of the walls of the tank were sloped outward, and then the rest of the tank was made vertical to produce roughly equivalent rates of emission through the day.

An alternative method was to provide a constant source of water and to insert an overflow pipe near the top of the *clepsydra*, so that the level of the water and its pressure remained constant. This became the basis of the inflow type of water clock. A version of this method was introduced for the Athenian water clock in its later renovation. Two reservoir tanks were added above the main tank (one for supply, the other perhaps for overflow), an overflow pipe was apparently added on the outside of the tank (but does not survive), and the first outlet pipe at the bottom of the tank was filled in and replaced with another larger drain hole of 16 mm (0.6″) diameter, which allowed a much more rapid exit of water in less than 40 minutes. With the outlet now so open as to make it useless for an outflow water clock, the tank must have been transformed into an inflow type, by which the time was measured not by falling water in the main tank but instead by the rising water level in it.

A float, whether in the outflow tank or in the inflow, could be connected via gear wheels, and it could even automate figures to some means of displaying the passage of time, as water entered or exited the tank. This time display could be a simple cylinder marked with a scale of hour lines. The difficulties presented by the need to represent the uneven seasonal hours persisted. Yet, however retarding to further mechanical development these hours may seem, Greek ingenuity found ways to overcome them. Vitruvius describes sophisticated examples of such water clocks devised by Ctesibius in the third century BCE (9.8.4–15). Later in the same century, Archimedes devised further refinements, which improved the engineering and, hence, accuracy (HYDROSTATICS AND PNEUMATICS IN ANTIQUITY).

An alternative approach to calibrating time against the seasonal hours was to tie the passage of time explicitly to the stars. This development returns us to measuring time via the motions of the celestial bodies, but in a mechanism that began life completely divorced from the heavens. It demonstrates the strength of the attraction for the ancients toward keeping time in line with the *cosmos*. The end result is the anaphoric clock, which told the time via an automated representation of the sequential risings of the stars represented by images of the zodiac or through stereographic projections of the celestial sphere. Vitruvius is our principal source for the description of this form of *clepsydra* (9.8.8–15).

Physical remains of such complex machinery are rare. Fragments have been found of the star-plate of two or three such water clocks, dating perhaps to the second century CE: one from Salzburg, monumental in scale at a diameter of over one meter (3.3′); another much smaller one from Grand in Lorraine; while a third might be represented by a small bronze garment found recently at Vindolanda on Hadrian's Wall in Britain. Inside the Tower of the Winds in Athens (Figure 55.3), built in the second century BCE by Andronicus from Cyrrha in Macedonia, there are traces on the floor of channels for piping water from a reservoir set at the back of the building. On the basis of Vitruvius' description of such water clocks, Stuart and Revett (*The Antiquities of Athens* 1762, 1.15–16) innovatively interpreted this piping as servicing a water clock. They

pointed out how a suitable natural water source existed in the appropriately named stream Clepsydra, which ran from the north slope of the Acropolis, above the Tower, and then underground to resurface kilometers away at the coast near Phaleron (visitors to the Acropolis slopes can still walk down an alley named after this stream). Judging from its mention by both Varro (*On Agriculture* 3.5.17) and Vitruvius (1.6.4–7), the 13 m (42.5′)-high octagonal Tower was well known in antiquity. It was a tour de force of timekeeping instruments, incorporating not only a water clock inside but also nine sundials on its exterior walls and the reservoir annex. The influential reconstruction by Noble and Price (1968) of the interior water clock, which partially reflects Vitruvius' description of an anaphoric clock, is now disputed, and we await a new reconstruction.

One final instrument deserves special mention, as it combines in a space no bigger than a modern shoebox a great variety of means of marking time. This is the so-called Antikythera Mechanism, dating to the second century BCE, broadly contemporary with the Tower of the Winds. Found by chance in 1901 by Greek sponge divers, its fragmentary, mangled remains have revealed under x-rays and more recently CT scanning that the Mechanism managed to correlate, in an ingenious system of about thirty geared wheels, the motions of the sun and the moon via the 19-year Metonic Cycle, and probably of the five planets known to antiquity in epicyclic motion through the zodiac (ASTRONOMY). The instrument could also be used to compute eclipses, and it had a dial to signal the two- and four-yearly games festivals at Olympia, Isthmia, Dodona, and Delphi. A *parapēgma*, or star calendar, also coordinated with dials giving the zodiacal year, the Egyptian calendar, and even a civil calendar. This extraordinary tour de force of engineering (it is thought that it would take a single person a year working full-time with ancient techniques to make it) will probably still provide more surprises, as the CT scans are not yet fully analyzed. Its purpose remains a puzzle, but it is tempting to take it as a prestige item for a wealthy patron who was used to living in the Doric Greek-speaking world, perhaps in the sphere of influence of Corinth, famous for bronze-working.

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PART X

Synthesis and Response

CHAPTER 56

The Crossroads of Hellenistic and Sanskrit Science

Tejas S. Aralere

Ἀνθρώποισι πᾶσι μέτεστι γινώσκειν ἑωυτοὺς καὶ σωφρονεῖν.
All men have a share in self-knowledge and sound thinking. Heraclitus (*TEGP* 30)

1. Introduction

Unlike Westerners, the people living in the Indian subcontinent felt little compulsion to conquer lands beyond their own borders. This may have been due to the deep connection of Vedic rituals with the physical geography of India itself, as described in the Manusmṛti, a text of Vedic laws dated to 500 BCE: Brahmins are told to stay in the land of the Āryas and to learn all practices from the Brahmins born in that land (2.17–25; Olivelle 1998, 24–25). These verses show that the proper place for a Brahmin to perform Vedic rites is in India alone. For the Greeks, the allure of the East always existed, as did the desire to conquer the land beyond the Indus River, but this dream was never fully realized. The Northwestern Hindu Kush mountain range was a formidable barrier between India and the west, and just on the other side was Takṣaśilā or Taxila. Though the history of Taxila may go farther back to its interactions with the Persians, its documented history begins with Alexander's arrival. This town served as the major university center for Indians, Greeks, Persians, and Chinese until the fourth century CE, when it fell with the rise of the Gupta Empire (Banerjee 1981, 42).

Although Darius I's Royal Road (500 BCE) extended to the Hindu Kush mountains and Indian soldiers served in the Persian army (Herodotus 7.65), there is no proof of the exchange of information between these two great civilizations. Herodotus provides the first Western record of the Indian people, showing that India was in contact with the west, primarily through trade but with little interest in conquering neighboring lands.

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The trade history of India with the Phoenicians dates back to 975 BCE with Hiram, the king of Tyre, sending ships to the Red Sea to obtain "ivory, apes, and peacocks" which originated in India (Rawlinson 1975, 425). Herodotus also provides the first (and somewhat fantastical) ethnography of Indic peoples. Ethnography and historiography were possibly both created from repeated interactions between the Greeks and Persian invaders (Skinner 2012, 4), which in turn led to the creation of the Hellenic self-identity and the "othering" of the Persians and all foreigners as "barbarians," the complexity of whose cultures was measured against a Greek standard (Skinner 2012, 5, 16).

The history of India's scientific interaction with the west falls into two periods, divided by Alexander's campaigns. And this division guides our discussion, which focuses first on philosophical parallels (in early physics and mathematics), and then on encounter, exchange, and synthesis, especially in astronomy.

2. Pre-Hellenistic Scientific Developments

The Sanskrit word Veda (from the PIE Vid: "to know" or "see") refers to the knowledge that was revealed to ancient *ṛṣis*, or seers. These seers are credited with composing in Sanskrit the Ṛgveda (RV), Yajur Veda, Sāma Veda, and the Atharva Veda (listed chronologically in order of their composition). These Vedas were sacred chants that provided information for performing various sacrifices, which were considered crucial for maintaining cosmic order. The actual date of the Ṛgveda's composition is uncertain but estimated to be around 1200 BCE (Brereton and Jamison 2014, 5). The Vedas, and later religious texts, were transmitted orally, from the first generation of Brahmin priests to their children, for approximately 1,600 years before being committed to palm leaf manuscripts in the Gupta Empire in 400 CE. The "unwritten" aspect of Vedic society, noted in Strabo (15.1.66), struck the Greeks as odd, but it was crucial because of the importance of Śruti (heard knowledge) over Smṛti (remembered texts).

As early as 800 BCE, there was widespread skepticism regarding the ritual-based system of Vedic sacrificial rites. Scholars questioned the true purpose of these sacrificial rites, and this eventually led to setting the Upaniṣadic texts that in turn systematically questioned the Vedas and laid the groundwork for Indic science. We note the importance of the oral tradition in Indian philosophy. Vedic sacrifice was not merely physical. The fire sacrifice (*yajña*) was a physical rite that carried with it a sense of internalizing the external actions by means of the words that were chanted. This is further explored in the Upaniṣads, where speech, by which the words of the Vedas are chanted, is equated with the sacrificial fire, and the words themselves become the physical offerings that are burned by the fire (Bṛhadāraṇyaka Upaniṣad [BU] 3.1.3). Though the Vedas originally lacked a written form, the use of tonal techniques—such as fluctuations in pitch and setting the verses to a metrical system—allowed the entire Vedic corpus to be transmitted unchanged to the present day. This applied to post-Vedic teachings written in the sūtra (aphorism) format as well. The memorization of these verses was accompanied with the aid of a guru's (teacher) thorough explanation. This system of education continued with the use of the sūtras for various subjects including mathematics, astronomy, and medicine.

By the 700s BCE, the Indians had a complex system of physics stemming from Upaniṣadic thought, and different renunciative traditions were in development. Upaniṣadic discourse had elucidated the nature of Brahman (the Absolute) and how it was the source of all material reality. The goal of every practitioner of Brahmanical and non-Brahmanical (Buddhist and Jaina) religion was *mokṣa* (liberation) from Saṃsāra

(the cycle of rebirth). The BU, the first written Upaniṣadic text, discusses the nature of Brahman using a methodical system of inquiry in which various kings or sages attempt to comprehend the true nature of Brahman. The debates between Yājñavalkya, various sages, and King Janaka in BU 3.1.1–4.2.4 elucidate the nature of Brahman. The systematic *neti-neti* (neither-nor) method of rejecting specific qualities is used to show that Brahman is the essence of all matter in the debate between Yājñavalkya and the female sage Gārgī (BU 3.8.8). This idea of an all-pervading entity is paralleled in Greek thought by Anaximander, whose *Nous* (Boundless) has no source, and yet it serves as the source of everything (*TEGP* 16).

During Alexander's visit to India in 327 BCE, Indian philosophy, both Brahmanical and non-Brahmanical, was in full bloom. The Vedas had given rise to the Upaniṣads and then the formation of the six *Āstika* (orthodox) *darśanas* (philosophical schools), which accepted the authority of Vedic scripture. The three major *Nāstika* (unorthodox) philosophical schools—the Buddhist, Jain, and Cārvāka—refuted Vedic teachings. Strabo tells us they were quite hostile toward Brahmanical traditions, calling them boastful (ἀλαζόνας) and devoid of knowledge (ἀνοήτους) (15.1.70). Of the six *Āstika darśanas*, the two credited as the foundations of Indic science are the Sāṃkhya (enumerating) and the Vaiśeṣika (atomist). An alternate theory suggests that this occurred in the opposite direction and that atomism originated with the Buddhists and that the Brahmins created the Vaiśeṣika *darśana* to counter Buddhism's claims of non-reality of the physical world (Bronkhorst 2011, 189). While both of the Vaiśeṣika and Sāṃkhya schools fell out of favor owing to the dominance of later Brahmanical, theistic traditions, complete texts, and commentaries for both are extant.

We must first discuss one of the most important naturalist schools of philosophy in India, the Vaiśeṣika *darśana*, which proposed an atomic theory. Their name derives from the Sanskrit *viśeṣa* (particularity) noting the principle of demarcation or differentiation. An alternative derivation could be from *antyaviśeṣa* (ultimate particularity) referring to all generic matter. This concept of demarcation then allows differentiation between all matter into specific sub-categories (Halbfaß 1992, 272). The sub-categories consisted of the nine *dravyas* (substance), or elemental types: earth, water, fire, air, aether, time, space, soul, and mind (*manas*). Each *dravya* has specific physical properties (*guṇa*) that apply to it (Gupta 2012, 158). For example, fire (*tejas*) has the fundamental quality of *fireness*, but it also has the physical properties of touch, form, number, extension, separateness, connection, separation, distantness, nearness, and fluidity. Its color is bright white, and it has a hot touch. Vaiśeṣika understanding of the manifest forms of single element aggregates was informed by the Vedic/Upaniṣadic manifestations of that element (see Frauwallner 1973, 2.145 for a full listing of all properties and forms of fire and the other *dravyas*). Their teachings are preserved in the Vaiśeṣika Sūtra (VS), attributed to the Sage Kaṇāda, who was reputedly active before Gautama Buddha (sixth century BCE) (Gupta 2012, 156).

In Greece, atomism grew from Empedocles' proposal of a universe of four different elements—water, fire, air, and earth—that combined and separated to manifest themselves in different materials without being destroyed or created (*TEGP* 28–29; see MATTER). Leucippus and his student Democritus further inquired into the specific mechanisms of elemental combination, resulting in atomism. The initial categorization of the four elements by Empedocles was an important step in assuming that these elements were all made of some substance that had inherently similar properties, but it failed to explain how substances other than the elements came to exist on a very small scale.

The atomists offered precise explanations of the properties of atoms and mechanics of combinations. The Vaiśeṣikas present explanations of atomic combination which are dependent on combination owing to inherent qualities instead of surface geometries as proposed by the Greeks. Every atom in the Vaiśeṣika doctrine is spherical (*parimaṇḍalaḥ*) and identical in size, differing only by the quality inhering within it (Frauwallner 1973, 55–56). In parallel with Democritus (*TEGP* 24), the Vaiśeṣikas propose that atoms with similar inherent qualities are drawn to one another. Atoms of some elements, like fire, possess internal vibratory action (VS 1.1.13). Democritus also made reference to motion by vibration (the only kind of motion that exists: *TEGP* 35). Furthermore, Kaṇāda (VS 1.5; 4.1.1) echoes Democritus' claim that no physical matter can arise from nothing, and that existent matter cannot give rise to new matter: thus all "new" matter must necessarily be a rearrangement of previously existing atoms (*TEGP* 28).

The original cause of atomic combination is given by Epicurus as *Swerve*, a chance off-course movement of an atom falling through the void and colliding with another atom. Similarly, the Vaiśeṣikas attribute initial atomic interaction to an unseen force, *Adṛṣṭam* (VS 5.2.13). With these mechanical rules, neither explanation requires a theistic element in their physics, and yet the Vaiśeṣika *darśana* is accepted as orthodox. It recognizes the authority of the Vedas. Śaṇkara Miśra, a fifteenth-century commentator, criticizes the Vaiśeṣikas for their lack of a conscious initial cause. It was originally an atheistic physical system like Greek atomism (Bronkhorst 1996, 282). The Vaiśeṣikas retained their status as an orthodox school of philosophy because their goal was aligned with the other Āstika *darśanas*: to attain *mokṣa*.

The two systems, however, differ in their initial definition of the individual atom. While Leucippus and Democritus claim that the atom was indivisible, Epicurus clarifies that the atom is made of parts, but that the atom was considered indivisible because it was immune to change (Simplicius, *On Aristotle's Physics* 925.10–17). The Vaiśeṣika maintained from the beginning that atoms were the smallest indivisible unit of matter based on the supposition that a limit for the division of matter exists. This view of atomic singularity was later opposed with the claim that it was impossible for a part-less atom to form compound structures, but the Vaiśeṣikas did not change their theory (Frauwallner 1973, 54). Despite these parallels in metaphysics, the differences in the fundamental structure of the atom—and the fact that atomic theories pre-date Alexander's campaign—leave us with no proof that one system influenced the other.

3. Mathematics

The origin of Indian mathematics can be traced to the Brāhmaṇa texts, canonical writings elaborating on proper ritual procedures, and to the Vedānta, "end of the Veda" scriptures, that elucidated the true meaning of the Vedic hymns, usually applying to only a single religious sect. The decimal integer counting system existed since the earliest times of Vedic civilization, and this is attested with the use of numbers in powers of ten in the Ṛgveda:

> You, lovely-faced one, are lord over all; you are the counter(part) to thousands, hundreds, tens. (RV 2.1.8)

This sort of enumeration in hymns of praise is found in many verses of the Ṛgveda (see also RV 2.18.5–6, 3.9.9), describing both the deity invoked in the verse, but also abstract entities.

The Śatapathabrāhmaṇa (SB) explains the symbolism of the fire sacrifice in Vedic religion and serves as evidence for Indian understanding of the concepts of integers and fractions. It gives a celestial numerical determination of the length of the month and the year by delineating the thought process of the Vedic creator deity Prajāpati when he determined the length of the calendrical year and the phases of the moon (SB 10.4.2). In SB 10.4.1.12, Prajāpati is said to be none other than Agni (the Vedic fire god) himself, and then in SB 10.2.1.16, Agni is said to be the calendrical year. Later, in SB 10.4.2.27, Prajāpati (a different manifestation of Agni) creates an altar consisting of 360 enclosing bricks and 360 special formula stones, and he also creates living and non-living things, as well as the gods and men. Upon completing this creation, Prajāpati fears, since he is empty, that death will take him. Since he cannot destroy his creation, he devises a method of reintegrating these 720 days and nights into his body. As the ultimate body, he must contain all manifest matter in himself (cf. "Ecology" in the Ancient Mediterranean). Because he is the calendrical year, he divides his body into fifteen units of the waxing and waning moons.

Plofker (2009) explains that each of the divisions omitted by Prajāpati (factors of 7, 11, 17, 19, 12, 22, 23) are those that would have produced fractional quantities of bricks; thus the Indians understood fractions. Prajāpati finally accepts 720 bricks (representing the days and nights in a year) which he divides 24-fold, creating 24 divisions of 30 bricks. This factor results exclusively in integers. He proposes 15 alternative combinations before arriving at his final choice of a 24-fold division, representing the 15 phases of the waxing and the waning moon (SB 10.4.2.17; Kak 1993; Plofker 2009). In this way, Prajāpati maintains his position as the ultimate being.

The importance of certain numbers occurs throughout this text, showing the significance of numerical thought in Vedic ritual. The SB says the number 100 invigorates Prajāpati because he has

> the life of hundred years, a hundred powers, a hundred energies. Only by a hundred he invigorates him, and not by less than a hundred: wherefore no *soma*-sacrifice should have *dakṣiṇas* (gifts to the priest) of less than a hundred … (SB 4.3)

The use of enumeration in sacrificial rules occurs throughout the Śatapathabrāhmaṇa. In SB 3.6.4.16–27, religiously significant numbers are used in cutting a stake for an animal sacrifice. In these verses, the sacrificer fells a tree to create the stake for fettering the sacrificial animal, and then he is instructed to cut it in lengths of either 5, 6, 8, 9, 11, 12, 13, 15, or 17 cubits. These can be grouped based on significance as follows:

1. *Metrical/poetical:* 8 (the number of syllables in Gāyatrī hymn and sides to the stake used in the Vājapeya Soma Yajña representing the four cardinal and four inter-cardinal directions); 11 (the number of syllables in Triṣṭubh meter); 15 (15-versed chant is a thunderbolt).
2. *Calendrical:* 5 and 6 (number of seasons in a year); 12 and 13 (number of months in a year).
3. *Mathematical:* 9 is considered significant because it has a square root.
4. *Religious:* 5 (five-fold sacrificial rite and five-fold victim); 17 (specifically for the Vājapeya sacrifice).

The discussion of the number of bricks in the sacrificial altar brings us to another much-debated text, the Śulba Sūtra of Baudhāyana. This text, in the sūtra format, gives methods of constructing numerous types of fire altars, but one is of particular mathematical interest: the methodology for constructing the square altar. *Śulba*, literally "rope," refers to the rope tied to a stake that was moved in accordance with specific directions in the Śulba Sūtra (SS) to create various geometrical shapes, such as circles, squares, trapezoids, and triangles, but also to construct more complex shapes such as a bird, a chariot wheel (with and without spokes), a square and circular trough, and a tortoise. The original source for the geometric shapes is unknown, but each shape was used for a specific purpose; for example, the trough shape for gaining food, and the isosceles triangle for annihilating enemies (Sen and Bag 1983, 8–9). The first version of this text (written by Baudhāyana and Mānava between 800 and 500 BCE) was, as is common with post-Vedic texts, modified by two later mathematicians, Āpastambha and Kātyāyana (Plofker 2009). Standard units of measurement existed, and the text describes the creation of right angles in squares, and from that, the production of triangles, trapezia, rhombi, and circles.

Due to their sūtra format, the mathematical calculations and geometric diagrams are not explicitly produced, so these texts do not contain anything resembling a Greek mathematical proof. However, because of the methods employed to produce the various geometric shapes, Plofker (2009) states that "it is explicitly recognized that the square on the diagonal of a given square contains twice the original area; and more generally that the squares on the width and the length of any rectangle add up to the square on its diagonal (the so-called Pythagorean theorem)." Thus the Indians comprehended the mathematical theory behind their own methods.

Sarasvati Amma (1979) provides additional examples of the right triangle in Vedic altars, all pre-Śulba Sūtra, found in the Kṛṣṇa Yajurveda, which contains the Taittirīya Saṃhitā (TS). She also observes that the measurements given for the *Mahāvedi* (altar) suggest that it must be constructed with squares made of triangles with the side lengths 15, 36, and 39 (Sarasvati Amma 1979, 6). Besides giving the measurements of the rational right triangle in the Baudhāyana Śulba Sūtra, she provides the numbers for the irrational right triangle (1,1, $\sqrt{2}$) and the approximate right triangles that appear in the text: 36, 90, 97; 40, 40, 56; 5, 6, $7\frac{5}{6}$; 4, 4, $5\frac{2}{3}$ (Chennakesavan 1976, 17–18).

Further, suggesting that the origin of the right triangle calculation lay in observations made in the construction of squares, Chennakesavan cites the following verses from the Āpastambha Śulba Sūtra:

> The diagonal cord of a rectangle makes both (the squares) that the vertical side and the horizontal side make separately.
>
> The diagonal cord of a square makes double the area. (SS 1.4)

Reputedly introduced to the Greeks by Anaximander, who learned it from the Babylonians (Herodotus 2.109; TIME-TELLING DEVICES), the *gnōmōn*, "marker" or "pointer," originally referred to an upright stick that cast shadows on a plane, allowing the measurement of time. This term, later used to indicate a reference line that allowed the formation of a right angle, eventually resulted in the carpenter's square (Heath 1921, 78). This original use of the *gnōmōn* is seen in the Śulba Sūtra for determining east and west for the orientation of the altar.

The directions in which sacrifices were made, the priests faced, and the *yajamāna* (sacrificer) sat, were all of utmost importance (Kak 1993, 120; Olivelle 1998, 17–18). Different fires were lit at different locations in the sacrificial area, and different Vedic priests faced different directions during the performance of the sacrifice. The calculation of the east–west line must have been known prior to the writing of the Śulba Sūtras, but the early method of calculation is unknown. The east–west line was determined using a *gnōmōn*, as described in detail in the Kātyāyana Śulba Sūtra (third century BCE). A stake was fixed in the ground and a circle drawn. The two points on the circle—where the shadow of the stick fell in the morning and then in the evening—were marked, thus creating the east–west line (Sarasvati Amma 1979, 22).

Lloyd (1990, 101) debates whether this text technically shows that the Indians were capable of performing such calculations. Although not denying that Indians were doing the math and getting results, Lloyd questions the purpose of their calculations. Indians did not record exact results for calculating lengths of lines and arcs; their calculations were merely approximations. This presents an unanswerable question. Sarasvati Amma (1979, 22) addresses this lack of proof in Indian mathematics by stating that the proof of understanding lay in the construction of these altars and that Greek-style proofs were most likely transmitted orally from teacher to student. They had no place in the sūtras because the texts were meant to be transmitted to the student by the teacher. Plofker (2009) agrees. Indian thought centered on practicalities almost always traceable to an original reason rooted in some need arising from the Vedic rituals, and their mathematical calculations are no different.

4. Alexander in India

Let us now consider direct interactions between Greek and Indian thinkers, which began to occur in 327 BCE with Alexander the Great's invasion of India. We lack records of any exchange of scientific information, such as star charts or medicinal handbooks, but Greek sources attest collaboration in metaphysics between Greek thinkers and Gymnosophists ("naked philosophers"). The Greeks believed that there was something to be learned from these Brachmanes (Brahmins) and Gymnosophists. Greek thinkers inquired into the Brahmin belief system, and conversations between Alexander, the philosophers accompanying him, and Indian philosophers were recorded in detail.

Alexander's meeting with the Gymnosophists changed his perception of the world and deeply influenced the three philosophers traveling with him: Pyrrho (360–270 BCE), Anaxarchus (340 BCE: Diogenes Laërtius 11.58), and Onesicritus (330 BCE: Diogenes Laërtius 6.84). Alexander sent Onesicritus, the commander of his fleet, to meet with curious ascetics living in the forests of northwestern India, described in detail by Strabo (15.1.63). Megasthenes, who wrote an *Indica* excerpted by Strabo (15.1.58–60), describes seven different castes in India, dividing the first group of philosophers into two groups, the Brahmins (Brachmanes) and the Śramaṇas (Garmanes) who were non-Brahmin ascetics. The Brahmins were more involved in society because of their adherence to dogmas (Vedic laws), like those given in the Dharma Śāstra. But they also pursued a "frugal life," sleeping on either straw or animal skins (*aparigraha*: refrainment from coveting), practicing celibacy (*brahmacārya*: the Yogic vow of celibacy), and vegetarianism (*ahiṃsā*: nonviolence), three of Patañjali's five Yogic abstentions (*yamas*) (Bryant 2009).

Strabo explains the purpose of this asceticism as a preparation of the body for death, since, according to Brahmanic philosophy, death "is birth into the true life," and the life we live is one of unhappiness. This aligns with Yogic philosophies which employ these austere measures to render the body a suitable vessel to unite with Brahman. Further, Strabo records that the Brahmins believe that nothing that happens to mankind is good or bad. They accept a fate in which they are merely performing dharmic duties as described in the Manusmṛti. Pyrrho was greatly influenced by his encounter with the Brahmins. Upon returning to Greece, he adopted a simple lifestyle, renouncing all material objects and accepting that nothing of this world was real, recalling the illusory world described by the Upaniṣads. Pyrrho claimed that "no single thing is in itself any more this than that," showing his belief in a single epistemological source for the physical world, echoing the monistic Upaniṣadic Brahman (Diogenes Laërtius 9.61).

Pyrrho's detached disposition earned him great respect. His ability to remain calm aboard ship in the stormy sea and not to flinch during surgery showed his control over his senses, a highly respected trait (Hankinson 1995, 67). It is difficult to prove that Pyrrho's Skeptic teachings arose exclusively owing to meeting the Gymnosophists, but it is clear that the lifestyle he adopted upon returning to Greece—enduring harsh physical conditions such as heat and pain—was strongly influenced by the Gymnosophists, who were engaging in these same ascetic practices (Bett 2000, 169–170).

Although these interactions with the Gymnosophists may have influenced Pyrrho, precursors to this philosophy were already present in Greece (Banerjee 1981, 95). In contrast, Flintoff (1980, 92) argues that Pyrrho's quadrilemma—quoted by Eusebius, *Evangelical Preparation* 14.18.3–4, and identical to the Buddhist method of the Catuṣkoṭi)—is a novel introduction to Greek philosophy:

> We must not say about any one thing (1) that it is or (2) that it is not or (3) that it is and is not or (4) that it neither is nor is not.

This view is refuted by Seldeslachts (2007, 133–134), who argues that the Catuṣkoṭi is an Indian (not specifically Buddhist) skeptical tool, and that both Pyrrho and the Buddhists can trace this back to Indian philosophy. This argument nonetheless supports an Indian origin for Pyrrho's philosophy, but it does not prove an Indian origin for all Greek skepticism.

The discussion regarding the shift in significance of Vedic rites was in full swing in 327 BCE when Alexander came to India. And the renunciative traditions and asceticism he witnessed was a result of this re-examination of Vedic ritual thought. The concept of liberation (allowing the *ātman* to be released from the body after death) was widespread owing to the focus in the Upaniṣads. One such method of inquiry into the process of liberation was the Sāṃkhya method, grouped under the category of the *ānvīkṣikī* traditions which enumerate aspects of a subject based on its content through logical reasoning. This is seen more as a scientific method of inquiry than a philosophical school because this technique is used to delineate topics in various fields of study, for example, grammar, medicine, and cosmology (Larson and Bhattacharya 1987, 4).

This methodology of inquiry and categorization (Sāṃkhya) in its earliest form served as one means of spiritual inquiry that led to divine knowledge, which in turn led to liberation from the cycle of rebirth. Liberation required attainment of three types of knowledge: *vidyā*, *jñāna*, and *viveka* (Larson and Bhattacharya 1987, 5). Sāṃkhya itself

was a method of reasoning that did not include the harsh ascetical practices or breathing techniques employed in yoga. It consisted only of a method of inquiry. But this early form of Sāṃkhya, labeled as Proto-Sāṃkhya (800 BCE–100 CE) by Larson, was interacting with other philosophical traditions in its day and was probably one of the philosophical doctrines that influenced the Buddha (Larson and Bhattacharya 1987, 6).

Sāṃkhya philosophy is crucial for other schools of Indic philosophy because it was the first to describe the dualist system of Consciousness and Material Reality (*Puruṣa* and *Prakṛti*). *Puruṣa* is pure consciousness, all pervading and contentless. It can only manifest creation when mixed with *Prakṛti*. The concept of an all-pervading, contentless, pure consciousness—represented by the *Puruṣa* in Sāṃkhya—is found in the earliest Upaniṣads and serves as the foundation for the shift in Vedic traditions from purely ritualistic to more spiritual. This pure consciousness, the *ātman* in Upaniṣadic works, refers to the metaphysical "self" (Larson and Bhattacharya 1987, 74). The goal, upon accepting the Sāṃkhya methodology, is to realize that the manifest world is existent only due to the mixing of the *Prakṛti* with *Puruṣa*. Once a person realizes that *Puruṣa* does not need *Prakṛti* to exist, that is, that the individual soul is the same as *Puruṣa*, *mokṣa* is attained.

The other key realization in Sāṃkhya is that all life is suffering (*duḥkha*—later a central aspect of Buddhist thought), and this is what one escapes through the process of realizing the true nature of self-consciousness.

Sāṃkhya philosophy deeply influenced Yogic metaphysics. This concept of an all-pervading consciousness (*Puruṣa*) or soul (*ātman*) was at the core of the Brahmin lifestyle. The renunciate ascetics whom Onesicritus encountered were living a yogic lifestyle, as implied by the various postures that they were holding. Organized ascetic orders have existed in India since the sixth century BCE, and they have propounded a codified system of asceticism. Onesicritus understood that Brahmins and Śramaṇa ascetics were different groups of thinkers. From his account, we understand that "the Brachmanes are somewhat more distinguished, for they are in more agreement as to their beliefs," showing that while there was a clear unity among the Brahmins, who belonged to one of the Āstika *darśanas*, the Śramaṇa ascetics did not accept Vedic authority, but instead they opposed the fancy and expensive ritualized Brahmanical system of worship (Gupta 2012, 62). Megasthenes' description shows the deep divide between the two traditions, even from an outsider's perspective. Onesicritus' discussion with Calanus demonstrates the admiration of the Greeks for the Indian ascetic orders and their simple lifestyle. Onesicritus and Calanus discussed a variety of topics in natural philosophy, including prognostics, rains, droughts, and diseases (Strabo 15.1.65). The Indians had extensive knowledge of natural matters, but sadly the Greeks did not document this knowledge.

As the Seleucid ambassador to Sandrokottos' (Ćandragupta Maurya) court (321–297 BCE), Megasthenes worked with translators to understand more fully the culture with which he was interacting. How well the translators themselves were able to convey purely Indic thoughts in a Greek context has been questioned (Dahlquist 1962, 27; Stoneman 1995). Megasthenes accurately described the contemporary philosophical dichotomy on the Indian subcontinent. Of all the fantastical accounts of the Indian land and its peoples, Strabo's descriptions of Brahmins are most likely direct quotes of Megasthenes' *Indica*, giving them more credence than later descriptions, which redefine the Brachmanes based on their geographical location (Majumdar 1960, 275).

Strabo refers to the system of five physical elements: fire, water, air, earth, and the unique "element of which the heavens and the heavenly bodies are composed"

(15.1.59). This fifth element is not explicitly named by Strabo, but we assume that it refers to *Ākāśa*, or aether, enumerated as an element by both the Sāṃkhya and Vaiśeṣika *darśanas* (VS 1.1.5). In VS 7.1.22, we are told that Ākāśa is infinitely large and is the material of the soul (*ātman*). Aristotle proposes a similar fifth element, aether, which he says Anaxagoras misinterpreted as fire (*On the Heavens* 270b24–26). He explains how this fifth substance is not subject to the same physical alterations as the original four elemental types owing to the nature of its motion. The eternal and unalterable qualities make it divine (*On the Heavens* 269b17–270b25). Unfortunately, in these records of early interactions, there are few references to medical knowledge. Strabo cites the Indians' ability to cure snakebites (15.1.45), and Megasthenes describes one subgroup of the Garmanes who serve as physicians and use cereals, ointments, and poultices to cure various diseases (Strabo 15.1.60)—their medicine is highly regarded.

Finally, the Pramnae are said to have been greatly skilled in medicine, but descriptions do not clarify their Sanskrit name. Majumdar suggests that Pramnae might be a Hellenized term for Prāmāṇika, referring to a specific methodology in Indian and Buddhist philosophy but nowhere precisely explicated. The Pramāṇa is defined as the means of obtaining valid knowledge, or *pramā*. Gupta lists the various roles Pramāṇa plays in both Nāstika and Āstika schools of philosophy and says that *Pramā* refer to both the means of which understanding arises and the means of justifying the acquired knowledge as accurate (2012, 13–14). Since adoption of the Prāmāṇika method is noted in nearly every philosophical school, both *Āstika* and *Nāstika*, Megasthenes could be referring to Buddhists, Jains, or a specific group of Hindu philosophers. Megasthenes tells us that one subgroup of these ascetics, especially skilled in medical practices, carried small satchels filled with roots and drugs, with which they only "pretended" to cure people (Strabo 15.1.70). However his description of the Pramnae ridiculing the Brachmanes, whom Megasthenes (or Strabo) clearly holds in higher regard, suggests strongly that these Pramnae are another group of Śramaṇa ascetics (Leslie 1976, 25–26). However, the two different ascetic traditions of Pramnae are cited in the Gautama Dharmaśāstras: city-dwelling and forest-dwelling. Olivelle offers the following distinctions: the *renouncers* were city-dwelling ascetics who lived in the forests, but were allowed social interaction with the towns in which they begged for food; the *anchorites* were completely settled in the forest and were not allowed any social interaction. This second group of ascetics, called Hylobii by Strabo, were required to sustain themselves on roots and fruits and to wear clothing made from tree-bark (Olivelle 2003, 272; Strabo 15.1.60).

5. Yavana Jātaka

Alexander's campaigns in the East resulted in the establishment of numerous, highly unstable Indo-Greek kingdoms in Western India. Yavana, a form of *Yauna* (the Achaemenid word for Ionian) was the primary term that Indians used when referring to the Greeks (Thapar 2013, 159–160). Most Brahmanical references to the Yavanas are negative, usually indicating Yavana kings who prefer Buddhists over Brahmins. Despite this animosity, the Brahmins did not reject Hellenistic astronomical knowledge (Thapar 2013, 206). Most of these Indo-Greek kingdoms were formed in Northwestern India, stretching into modern-day Gujarat, where we find a crucial text called the Yavana Jātaka (YJ) or "Greek Horoscopy" that brings the west and east together for the first time in Sanskritic scripture.

The origin of Indian astronomy can be traced to Vedic scriptures, specifically the Brāhmaṇas. In SB 4.3 (§3, above), we see the use of the lunar cycle as part of the determination of the length of the year. Vedic mythology explained this lunar cycle through the belief that the performance of the *Soma Yajña* ritual filled the waxing moon (*soma* juice collected in the moon which then waned when the gods drank from it like a cup). The *Soma Yajña* consisted of the pressing of the *Soma* plant thrice in one day to collect its juice. According to Olivelle (1998, 19), this was followed by a goat sacrifice; then this juice was mixed with milk, offered into the sacrificial fire, and consumed by the priests. Since *Soma* juice filled the moon, the performance of this sacrifice was crucial for maintaining cosmic order.

Indians were also observant of solar, lunar, and planetary motion. The star at the ecliptic was named Varuṇa, and the Indians observed 12 full moons in this ecliptic. The length of the year is given as 12 months (RV 1.25), and the location of Varuṇa is given as the point at which the paths of the ecliptic and the Milky Way intersect, near the constellations *Canis Major* and *Canis Minor* (Holay 1990, 4). The Indian sage Lagadha (1150 BCE) composed *Vedāṅga Jyotiṣa*, the first work exclusively on astronomy (Sarma 1984, 13), which included astrology, calendrics, and astronomy (Plofker 2009, 61). This was the first text to elaborate the 27 asterisms, the *nakṣatras*, which were calculated based on Jupiter's path (Sarma 1984, 7). The full circular path of the moon's movement was divided into 27 asterisms on the basis of the length of the circle that the moon traveled each day of the month. This system resulted in one or two *nakṣatras* in excess of the full circle, reconciled by the alternation of 29 and 30 *nakṣatras* per month. An extra *nakṣatra*, Abhijit, was included initially, but later removed by Lagadha to make a mathematically perfect division of 13.33 degrees per *nakṣatra*, instead of the 12.857 degrees arising from the 28 *nakṣatras* (Holay 1990, 17).

The 27 *nakṣatras* are listed in the *Aitareya Brāhmaṇa*. These stars were then mapped onto the body of the *Puruṣa* charted across the sky (note that this *Puruṣa* differs from the cosmic *Puruṣa* in RV 10.90). Yavaneśvara, the original author of the Yavana Jātaka, maps the twelve zodiacal signs of the Greeks onto this Nakṣatra Puruṣa, demonstrating a synthesis of the two sciences instead of a complete rejection of Indic astronomy. In the sixth century BCE, Varāhamira, the most renowned Indian astrologer, divided Jyotiṣa into three branches:

1. gaṇita/tantra (mathematical astronomy)
2. saṃhitā (natural astrology/divination)
3. horā/jātaka (horoscopy/genethliacal astrology)

The majority of the Yavana Jātaka belongs to the last branch, but the last chapter is primarily mathematical astronomy. Composed in 269/270 CE, the original text was Yavaneśvara's prose translation of an unspecified Greek astronomical text in 149/150 CE. The extant prose version was versified by Sphujidhvaja, an astronomer for King Rudrasena II (Pingree 1978, 1.4). Of the 4,000 verses that Sphujidhvaja claims to have translated, only 2,270 exist. While Pingree proposes that the name Yavaneśvara refers to the writer's high social status in the *kṣatrap* court, Mak (2013, 16) suggests that the name is probably a general attribution, not a specific reference to a real person. If Yavaneśvara was historical, he was most likely a subject of Rudradāman, who ruled in Gujarat (Thapar 2013, 68). The original text is lost, but most of it was captured in Sphujidhvaja's versification.

According to Pingree, YJ 79.60–61 implies that the treatise is a translation of an Alexandrian Greek text into Sanskrit. Yet recent research suggests that YJ was likely a completely new text that resulted from the assimilation of Indian and Greek thought (Mak 2013, 13). Mak raises additional questions regarding Pingree's translation and interpretation of the text. A new copy of the text, version Q, found by Yano in the Nepalese-German Manuscript Cataloguing Project (NGMCP), dating to the eighteenth century, is a more complete version, containing verse numbers (omitted in the first manuscript) and three verses missing from the original manuscript N (Mak 2013, 4).

The YJ serves as an interpretative guide for the Indian trying to understand Greek astronomical science. Though these two cultures had been in contact for centuries, the YJ is the first instance of a Sanskrit collaboration with a Greek text. Neither the name of the original Greek text nor the name of the Greek astronomer is given. It is thus impossible to compare the new text with the original. Pingree hypothesized the original Greek text to be Alexandrian, dating it to approximately 149–150 CE. However, Mak dates it between the fourth and sixth centuries CE, owing to its reference to the ostracized Kāpālika Śaiva tantric cult, the latter of which arose after the fifth century CE (Mak 2014).

Pingree (1978, 2.191) interprets Sphujidhvaja's assertion of translating a text written in Yavaneśvara's own language (*svabhāṣā-*) as a Sanskritized trace of the first author's (Greek) origin. Mak understands the use of the term "*bhāṣā*" in Sanskritic literature to be commonly defined as "jargon." The newer version of the text also states that the original author was inspired by the god Viṣṇu, highly unlikely if the text were originally Greek (Mak 2013, 12). The text also contains numerous references to the elements associated with specific Indic planetary deities and references to Āyurveda (Vedic herbal medicine), which do not appear in Greek texts, further supporting the hypothesis that the YJ was a novel synthesis of Greek and Indic cultures. Numerous Greek astronomical terms were Sanskritized by Sphujidhvaja to make it accessible to its Hindu audience: Hora, Decan (YJ 3), Nychthemeron (YJ 79.7), *meṣūrana* (*mesouranma*: YJ 1.45), and *jāmitra* (*diametros*: YJ 1.49) (Pingree 1963, 226).

Of these terms, the Decan and the Hora are the two key concepts that were introduced to Indian astrology. A total of 36 Decans are given, with three assigned to each zodiacal sign. These Decans refer to 36 constellations, documented since 2100 BCE. Sphujidhvaja describes two Horae belonging to each of the twelve zodiacal signs. The concept of 24 Horae can be traced to Egypt (Pingree 1963, 227).

The Yavana Jātaka gives a zodiacal melothesia, mapping the twelve Greek zodiac signs on different parts of Prajāpati's body. An indigenous Hindu melothesia was scattered in the Ṛgveda's *Puruṣa Sūkta* (RV 10.90), where the cosmic Puruṣa spans the universe. This is followed by the description of Prajāpati, who embodied the year, spanning the heavens with certain constellations located at points of his body (SB 6.1.2.19). BU 2.2.4 provides another instance of early Indic melothesian thought (Kak 1993, 24).

Pingree provides the following table to show the locations of each of the twelve zodiac signs on the astral Prajāpati (Pingree 1978, 2.199):

Aries: head
Taurus: mouth and neck
Gemini: shoulder and arms
Cancer: chest

Leo: heart
Virgo: belly
Libra: navel, hips, and bladder
Scorpio: penis and anus
Sagittarius: thighs
Capricorn: knees
Aquarius: shins
Pisces: feet

Mak (2013, 8) notes miscalculations by Pingree:

1. The number of tithis (civil days) in a yuga is corrected from 60,265 to 61,230.
2. This text is not the first instance of *bindu* (zero), nor is it the first reference to a decimal system—not disproving an Indian origin for zero, but confirming that this text is not the source.
3. Bhūtasaṃkhyā, the system of representing numbers with symbolic words, is not used in this text, and Pingree's use of "*śara*" as the number five in the final chapter of the text is incorrect.

A novel astronomical cycle of 165 years, which occurs neither in Greek nor Indian astronomical texts, is also introduced in the YJ, further supporting its novelty (Mak 2013, 9). The Yavana Jātaka does not attempt to replace the pre-existent Indian system of astronomy given by Lagadha, but it rather incorporates the Greek zodiacal system and suggests that, although the Greeks favored Buddhists over the Brahmins, the Brahmins found Hellenistic science valuable. While the cross-pollination of Indian and Greek mathematical ideas remains unresolved, there is little debate that Alexandrian astronomy influenced Indian astronomy, playing a crucial role in the development of Indian scientific astronomy. In time, as more manuscripts of this text are found, the lacunae will hopefully be filled, allowing more accurate contextual information to be drawn about the source of this fascinating Indo-Greek work.

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FURTHER READING

On the Śulba Sūtra, Sen and Bag (1983) provide a complete translation and detailed commentary with diagrams of altars. Plofker (2009) gives a comprehensive treatment of Indian mathematics from its Vedic origins to the modern period. Pingree (1978) provides a complete translation of the Yavana Jātaka, but Mak (2013, 2014) should be read for the more recent discoveries and major revisions of the original translation of its 79th chapter. Finally, while Sinha (1911) provides a complete Sanskrit text and translation of the Vaiśeṣika Sūtra, Frauwallner (1973) and Halbfaß (1992) give thorough explanations of Vaiśeṣika philosophy and ontology which are crucial for understanding these teachings.

CHAPTER 57

Roman Responses to Greek Science and Scholarship as a Cultural and Political Phenomenon

Thorsten Fögen

1. Introduction

The Romans were deeply influenced by Greek culture and learning, particularly apparent in areas such as science and scholarship. Roman works on agriculture, geography, architecture, mechanics, medicine and pharmacology, astronomy, musicology, mathematics, military affairs, philosophy, grammar, linguistics, rhetoric and literary criticism drew a great deal of inspiration from Greek predecessors and often referred to their sources quite explicitly. This has repeatedly induced modern scholars to question the value of Roman science and scholarship. In the nineteenth century, it was common in analyzing Roman technical texts to concentrate on the question of their originality and on the reconstruction of their Greek sources. With their alleged preference for the practical, the Romans were frequently blamed for their lack of interest in theoretical issues and empirical approaches. Roman technical authors were regarded as uncritical dilettanti who to a large extent compiled their texts from superior Greek treatises (e.g., Beaujeu 1957; Africa 1968, 68). Representative is the following statement from Stahl (1962, 71–72):

> Even the most intellectually curious Romans, like Lucretius, Cicero, Seneca, and Pliny, were satisfied to obtain their knowledge of Greek science from manuals and made no original contributions. Latin handbook science was outdated from the beginning, since it was a synthesis of Greek investigations and theories that were a century, or even two or three centuries, old by the time they had been introduced at Rome. And because of most Latin compilers' lack of aptitude for theoretical studies, handbook traditions of Greek science suffered further deterioration each time they passed through the hands of a new compiler.

To some degree, such a view can be explained by the long-lasting impact of nineteenth- and early twentieth-century scholarship, which often had a tendency to look down upon

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Roman technical writers, especially in the area of the exact sciences. In certain instances, this went together with an outright contempt for the Romans as a whole. To single out just one case, Hoppe (1911, 362–363) claims that the Romans did not understand mathematics, but further, because of the cruelty and terror with which they dominated the Mediterranean world, they made any further development of this discipline impossible, even among the Greeks. This is taken as evidence of the fact that the Romans lacked any scientific spirit and restricted themselves to the basic needs of social life. They are described as barbarians who destroyed the indigenous cultural heritage ("die heimische Kultur") wherever they came (Hoppe 1911, 351). It is obvious that such an approach is based upon the idea of decline: while earlier representatives of Greek mathematics—especially those living in the third century BCE—are celebrated as heroes, the discipline in its later stages (i.e., from the late Republican period onward) is said to suffer from stagnation or even mummification. Outstanding scholars such as Aristarchus, Hero, and Hipparchus are succeeded by compilers and commentators (Hoppe 1911, 435):

> … die selbständige Forschung wird unterdrückt durch den Fußtritt der Römerwelt. Langsam sinkt die Fahne nieder. Menelaos, Ptolemaios, Pappos suchen den Prozeß aufzuhalten, aber vergebens. Die Produktion sinkt, und nach kurzer Zeit fehlt sogar die Kraft der Konzeption. Man kommentiert, weil man sich wissenschaftlich beschäftigen will, aber die inhaltsreichen Arbeiten jener Heroen entschwinden mehr und mehr dem Verständnis der Gelehrten. Die Dekadenz schreitet voran, und das einst so stolze griechische Volk hat mit der politischen Selbständigkeit auch die Selbständigkeit der Forschung verloren.

This passage demonstrates that Hoppe employs rather bold rhetorical strategies to convince the reader of the validity of his position and that he bases his argument upon questionable ethnic stereotypes related to a presumed Roman cultural mentality. It goes without saying that the ideological implications of such an outlook, especially in the context of widespread Hellenophilia (in particular in Germany of the nineteenth century), had negative consequences not only for the perception of Roman science and scholarship, but also for Roman literature and culture as a whole, which were seen as epigonal and therefore less worthy of study than the Greek models.

Such negative assessments, which have been challenged only relatively recently (e.g., Lehoux 2012, with further references), were also suggested by the ways in which the Romans viewed themselves as opposed to the Greeks (especially Petrochilos 1974; Wardman 1976; Kaimio 1979; Fögen 2000). When Horace says in his *Epistles* that "conquered Greece conquered the savage victor and brought the arts into rustic Latium" (2.1.156–157), he acknowledges that Roman civilization is essentially Greek, although Rome now rules over the Greeks—or, to follow the original text even more closely, that the Romans were without culture (*ferum*) before they gained political power over their hitherto leading neighbor. Although it was in particular early Rome that was commonly associated with agriculture, the self-perception of the Romans as a people of farmers had a lasting effect in later centuries as well, as can also be gleaned from the lines that follow the above quotation from Horace who refers to the "traces of the countryside" (*Epistle* 2.1.160) which could still be identified in his own days. In the same poem, he also points out that Roman engagement with Greek literature was a comparatively late phenomenon, datable after the Punic Wars (2.1.161–163; cf. Porcius Licinus, *Fragment* 1 Morel/Büchner/Blänsdorf).

The antithesis between Greek cultural refinement and Roman political power is also expressed in another famous passage. In the sixth book of Vergil's *Aeneid*, Aeneas obtains the following recommendation from his father Anchises:

> Others will hammer out images of breathing bronze, no doubt, and draw living faces from marble. Others will plead cases more persuasively and describe the movements of the sky with a compass and predict stellar risings. You, Roman, remember to rule over peoples with power (these will be your arts), impose a custom of peace, spare the vanquished, and battle down the proud. (6.847–853)

The first four lines comprise examples of disciplines in which non-Romans may predominate, for example, sculpture, rhetoric, and astronomy. This is then contrasted with the subsequent three lines, commencing with the emphatic pronoun *tu* ("you," as opposed to *alii* ["others"] in 6.847): the Roman task is to govern mankind with their power, circumscribed as a specific set of skills (*artes*). Ruling other people in a clearly defined way is thus accentuated as a distinctively Roman trait, and the implication seems to be that Roman society can do without the sophistication of various fields in which the Greeks have excelled.

On the whole, the Roman attitude toward the Greeks, as well as their culture and learning, is ambivalent, characterized by admiration as well as reservations, and sometimes even rejection. Here we provide an overview of a representative sample of Roman responses to Greek science and scholarship, and an analysis of their cultural as well as political ramifications. Our survey begins with Cicero. Next we move on to Vitruvius, Columella, and Pliny the Elder, three important technical writers from the early Empire, which Beaujeu (1957, 6) has called the richest period of scientific publication in Roman history. Furthermore, we consider a few Roman reactions to non-Greek science, represented here by the Carthaginian Mago and the Pontic king Mithridates. The conclusion draws some attention to the fact that from the early Empire onward it becomes increasingly difficult to distinguish between "Greek" and "Roman" scholarship; it also focuses briefly on encyclopedism as a distinctively Roman form of technical literature.

2. Cicero

With regard to Greek culture and learning, the Roman sense of inferiority toward the Greeks seems to have been fairly widespread among intellectuals of the late Republican period. This is at least what Cicero frequently seems to suggest. Since Cicero is eager to portray himself as a pioneer in a variety of disciplines, in particular philosophy and rhetoric, it is a view that he does not share—neither concerning Greek science and scholarship as such nor regarding the adequacy of the Latin language as the medium of Roman technical texts (for secondary literature, Fögen 2000, 90).

Cicero expounds his opinion at greater length in the introduction to his *Tusculan Disputations* (*Tusc.*). The Romans found out everything more wisely than the Greeks did, or improved the things they got from them (*Tusc.* 1.1). Moreover, in areas such as morality, family, household, public affairs, and warfare, Cicero regards the Romans as superior to the Greeks because of their adherence to traditional "Roman" virtues. In his view, it would be difficult to compete with the Romans, who by nature possess excellent characteristics such as seriousness (*gravitas*), steadfastness (*constantia*), loftiness of spirit

(*magnitudo animi*), integrity (*probitas*), and trustworthiness (*fides*); these are elements which are impossible to replace with any learning (*Tusc.* 1.2). Cicero admits that, for a long time, the Greeks had surpassed the Romans with their scholarship and literary pursuits, in particular in the area of poetry, although even in that area one could find talented Roman writers who could easily compete with Greek poets (*Tusc.* 1.3). However, he believes that the picture has changed: the historically motivated inequality between Romans and Greeks has diminished (*Tusc.* 1.3–5; cf. 4.5), as is evident from the example of rhetoric (see Fögen 2016). There are nonetheless areas in which the Romans still have certain deficits, namely, in mathematics and philosophy. While mathematics enjoyed the greatest esteem among the Greeks, the Romans tended to limit this science to its usefulness for measuring and calculating. As for philosophy, Cicero purports that it has lain neglected until his own time, and he thus intends to fully establish it in Rome through his own writings (*Tusc.* 1.5).

Many of his contemporaries will have reacted to this project of presenting philosophical ideas in Latin with a great deal of skepticism, as can be gathered from a number of passages in works such as his *Academics* or *On the Ends of Good and Evil* (*De fin.*). Cicero vigorously opposes the common view that Greek philosophy can only be understood in the original language. Writing philosophical works in Latin offers the advantage of enriching Greek thought with one's own ideas and comments. Ultimately this may lead to an independent literary product that can claim a sufficient degree of stylistic elegance as well as intellectual sophistication (*De fin.* 1.6–8). The addition of an enhanced rhetorical quality to philosophical texts is something that Cicero regards as one of his major achievements, which distinguishes him from those who previously endeavored to write philosophy in Latin. He also refuses to accept the prevalent stereotype of the poverty of Latin (*patrii sermonis egestas*), which supposedly prevents writers from expressing complex ideas in their mother tongue; for Cicero, Latin offers a plethora of linguistic means, in particular with regard to its vocabulary, and is even a richer and more expressive language than Greek (*De fin.* 1.10 and 3.5; *On the Nature of the Gods* 1.8). It is thus not surprising that he devotes a great deal of attention to lexical and terminological issues, often in the context of discussions about the appropriate Latinization of Greek terms (Fögen 2000, 79–117; 2011, 455–457). He is convinced that he was the first to have created a philosophical terminology in Latin (*De fin.* 3.5), and it is in fact hard to overestimate the contribution that he has made to philosophy written in Latin, but also to many other areas of learning, in particular rhetoric.

However, one must not forget that Cicero has a much more ambitious agenda than mere self-advertisement. He understands the writing of philosophy in Latin as a service to the Roman people, in particular as a valuable contribution to the education of younger Romans (e.g., *Tusc.* 1.5; *De fin.* 1.10; *On Duties* 1.1). Moreover, the transmission of knowledge entails a significant political value, as the entire society will profit from elements of learning that are available in written form (especially *On Duties* 1.155–156). Cicero argues that it enhances the status of a political entity when philosophical treatises are not written in a foreign language. For the Romans, the existence of philosophical texts in Latin is proof of their high moral and cultural level (*On the Nature of the Gods* 1.7). One could interpret Cicero's programmatic statement that one day Greek libraries may be replaced with Latin ones (*Tusc.* 2.6; *On Divination* 2.5; cf. *Orator* 22) as an exaggeration, but on the other hand it is understandable that it was important to the Romans to create a literature in their mother tongue, as it had a high symbolic value,

representing a certain degree of cultural independence. At the same time, it cannot be ignored that Cicero had a great deal of respect for Greek culture and learning, as evident from a variety of his works including private writings such as his correspondence with Atticus, which is interspersed with Greek elements. He was fully aware that the emancipation from Greece could not be accomplished overnight, and one may go so far as to say that he would have been extremely reluctant to do without the cultural and literary achievements of the much admired neighbor. That his attitude toward the Greeks is not always fully consistent is partly due to the fact that his statements occur in different literary contexts; public speeches, technical treatises, and private letters may have rather divergent tendencies and objectives, and they are composed for different audiences (Trouard 1942).

3. Vitruvius

Vitruvius' *De Architectura* ("On Architecture"), published after 31 BCE (Fögen 2009, 107–110), is the only comprehensive treatise on architecture that is extant from antiquity. It is an important source for the reconstruction of Greco-Roman theoretical thinking about architectural forms, styles, and aesthetics, and has therefore been used by Classicists, and in particular by archaeologists, as a treasure trove of information.

In Vitruvius' view, the knowledge with which an architect of his time should be acquainted has become very wide-ranging. As he describes immediately after the preface to Book 1, addressed to the emperor Augustus, an architect's knowledge ought to combine practical experience, that is, technical skills, and intellectual activity, which must, however, be intricately interwoven if architecture is to be practiced successfully. It is precisely this postulate of a reciprocity of theory and practice which makes knowledge of different skills desirable. Vitruvius' extensive educational program for the architect comprises the following fields: dexterity in writing enables him to set down his knowledge and thus make it accessible to others. The ability to draw allows him to make sketches of the buildings he envisions. Familiarity with the principles of geometry, optics, and arithmetic contributes to similar purposes; the latter also serves to calculate the dimensions of a project, and in addition to provide a reliable estimation of the costs (1.1.4; resumed in 10 preface). Moreover, Vitruvius recommends an acquaintance with historical events, which helps to explain the use of certain decorative elements and motifs (1.1.5–6). Philosophical education is vital in two respects: on the one hand, with its focus on ethical issues, it endows the architect with the right way of thinking (*ethos*), characterized primarily by honesty and modesty. On the other hand, it imparts a command of natural philosophy, which is indispensable for architecture (1.1.7). Even instruction in music is advantageous, as Vitruvius explains at greater length (1.1.8–9): an understanding of harmonic theory facilitates the construction of theater buildings, in which actors' voices need to be audible from every vantage point (5.3–5.7), and of water organs and similar instruments (10.8). Further, catapults and siege machines will not work properly unless their stringing is sufficiently well balanced by the determination of the correct tone relations (10.12). Also useful for the architect are three other disciplines: medicine (including climatology), astronomy, and law. The first two provide the basis for choosing appropriate sites for building projects (1.1.10); as Vitruvius repeatedly accentuates, the health of a town's citizens must be the most important criterion for an architect (especially 1.4, 1.6, 6.1, 8.6.10–11). Legal expertise is useful for avoiding lawsuits or

any other juridical quarrels. It also guarantees that the architect abides by building regulations and that clients and contractors draft written agreements (1.1.10).

Vitruvius is aware of the comprehensive nature of the educational program that he outlines for the architect, and he makes the requirement of knowledge in specific areas plausible by referring to their interdependence. Intriguing in this context is his comparison of "encyclopedic education" (e.g., Kühnert 1961) with a body that consists of different parts which necessitate and supplement each other. In his view, architecture is a complex discipline with many prerequisites which one cannot practice in a serious way if one has not acquired the necessary expertise (1.1.11–12). In particular his remarks on the requirement of philosophical expertise indicate that he conceives of the ideal architect in a way that is analogous to the model of the perfect rhetorician postulated by Cicero (Schulte 1935, especially 80–91; Romano 1987, 59–80). As Vitruvius does in the case of architecture, Cicero strives to present rhetoric as a subject that should not be reduced to mere practical experience but instead as a discipline that requires intricate familiarity with a variety of branches of knowledge (especially *On the Orator* 1.72–73, 3.126–127, 3.132–136). Just as the orator can only be truly competent in his profession if he really knows what he is talking about, so does the architect need to have a comprehensive expertise which transcends the narrow boundaries of his own discipline. In particular the ethical component plays a decisive role here: Cicero's ideal of the rhetorician as a "good man skilled at speaking," which originates from the Elder Cato, has been adopted by Vitruvius for his exemplary architect, who ought to be a morally impeccable figure (with regard to rhetoric, e.g., Cicero, *On Invention* 1.1–5; *On the Orator* 1.68–69, 1.165–171; *On Laws* 1.62–63). By subscribing to this concept, Vitruvius attempts to enhance the status of architecture in Roman society and build up a solid reputation for its practitioners.

One of the consequences of Vitruvius' approach is that the comprehensive training of architects can no longer be summarized in a short account. What is required instead is a full-scale treatment of the discipline, and this is precisely what Vitruvius offers with his *De Architectura*, which he calls "a new manual." However, he also points out that he could not have achieved any progress in his discipline without relying upon earlier experts and their writings (7 preface 10–11), whom he lists with a great deal of respect (7 preface 11–18). From this catalog, it becomes apparent that the majority of his predecessors are Greek authors who have predominantly written on rather specific topics. Conceding that there is a limited number of Roman experts in the area of architecture, he mentions Fuficius, who produced a work in one volume; Varro, who dedicated one book of his *Disciplinae* to architecture; and Publius Septimius, who wrote no more than two books. Although the Romans had a rather impressive know-how in this field, as can be seen from architects such as Cossutius or C. Mucius, they rarely made their knowledge accessible in writing. Hence, Vitruvius is the first to have produced a comprehensive treatise on architecture in Latin.

Yet, while he portrays his work as a ground-breaking enterprise, he chooses a fair approach to his sources. He repeatedly praises individual Greek predecessors as well as Greek science as a whole. In the third book of *De Architectura*, he admires the acumen and skillfulness of Hermogenes, whose account of the symmetries of temple districts he finds immensely useful (3.3.8–9; cf. 4.3). In his discussion of the position of the sun in space, he pays tribute to Euripides for his astronomical knowledge, manifest in the lost tragedy *Phaethon* (9.1.13–14). Vitruvius also extols the Greek method of wall

construction, which aimed at a higher degree of durability than the Roman technique (2.8.5–8). When it comes to the scientific pursuits of the Greeks, Vitruvius is particularly enthusiastic about their findings on stars, summarized at 9.6: the introduction of calendars is owed to their meticulous observation of heavenly bodies and weather conditions. However, he does not limit his accolades to the Greeks, but he also praises the Chaldaeans, among whom Berossus (fourth/third century BCE), who established a school in Cos, is singled out. What deserves special commendation in his view is the openness with which these scientists share their insights with others—a fact from which later generations still profit greatly (9.6.3).

Vitruvius thus attributes a considerable significance to non-Roman and in particular Greek sources for the development of architecture as a discipline. This converges with his intention to present himself to his readers as a respectful authority who refrains from massive polemics. Roman sources conspicuously do not play any major role throughout *De Architectura*, which suggests that before Vitruvius there were only a few short overviews on architecture in Latin. The same impression is conveyed by the later treatise *De Diversis Fabricis Architectonicae* ("Concerning Diverse Architectural Constructions") by M. Cetius Faventinus, an epitome of Vitruvius' work presumably from the third century CE. Faventinus speaks of "other authors" than Vitruvius, but does not provide any names (1, p. 40 Plommer). If the works of these other writers had been of an extent or quality comparable to *De Architectura*, Cetius Faventinus would likely have been much more explicit about them.

One of the most intriguing aspects of Vitruvius' work is its political dimension. Any reader will notice that he addresses Augustus throughout his treatise. Given the emperor's ambitious building program, which *De Architectura* seems to buttress, this is perhaps no surprise (cf. Roman Monumental and Public Architecture). As can be gathered from Suetonius' biography of Augustus, the emperor intended to turn Rome into an admirable center of the Roman Empire which would satisfy the highest aesthetic demands as well as the strictest criteria of safety (see especially *Deified Augustus* 28.3). He also cared very much about public hygiene so as to guarantee the safety and health of the citizens (*Deified Augustus* 30.1; on aspects of public hygiene, Vitruvius, 1.4, 1.6, 6.1, 8.6.10–11). It is important to note that Augustus not only undertook numerous building projects, but that he also successfully encouraged leading citizens of Rome to support his plans actively (*Deified Augustus* 29.4–5; cf. Velleius Paterculus 2.89.4). In his autobiographical *Res Gestae* (19–21) Augustus described his accomplishments in this sector, in particular with regard to temples. The fact that he dedicated no fewer than three paragraphs of his rather short catalog of deeds and merits to the architectural restoration and extension of Rome signals the importance which he attached to this topic. Given such vigorous building activities in the city of Rome and elsewhere, it was consequent that an expert composed a treatise which outlines a similar agenda and thus supplies an orientation for the transformation of the Empire into a well-ordered space, a *cosmos*. Admittedly we do not know to what extent Vitruvius' work was actually used in the Augustan period. However, his work can be regarded as a theoretical and practical framework which seeks to contribute to the cultural development of Rome. As Cicero did for philosophy and rhetoric, Vitruvius filled a gap within technical literature written in Latin.

In light of Vitruvius' *cosmos* idea, one also needs to interpret his praise of Italy, which he articulates at 6.1. Similar to what Aristotle does in his *Politics* with regard to Greece

(1327b20–1328a16, especially 1327b29–33), Vitruvius defines Italy as a climatically favored zone situated between the less privileged northern and southern areas. It is differences of weather and climate which are responsible for distinctive physical and psychological characteristics of the peoples who live in those regions (6.1.3–11; also 1.4.3–8). Among people from the north, moisture and cold generate bigger physiques and deeper voices as well as a fair complexion, reddish hair, and fullness of blood (6.1.3). Fullness of blood, in turn, results in courage and belligerence but also proneness to fever (6.1.4, also 6.1.10). Further traits of people from the north are their sluggish minds (6.1.9) and lack of slyness (6.1.10). In contrast, the southerners' bodies are drained of their moisture by the sun (6.1.3), which makes them smaller and gives them a darker complexion, curly hair, and thin blood (6.1.4). Thinness of blood creates fear of fights (6.1.4, 6.1.10) but also resistance to heat and fever (6.1.4). Southern people tend to have thin and high-pitched voices (6.1.6–7), acute minds, and a certain resourcefulness (6.1.9). This description of the two extremes is followed by a definition of the qualities of the Italian people (6.1.10–11). Its geographical position makes Italy the center of the world and, with its temperate climate, secures a well-balanced medium between the extremes for the bodily as well as mental constitution of its people. In the further course of his argument, Vitruvius invokes these features of the Italian people to justify Rome's power over the world, said to be based upon divine will. Vitruvius' praise of Italy, developed from a rather wholesale comparison of the north and south, thus amounts to an explanation of Rome's pre-eminence, which forms a core element of Augustan ideology, as evident from other texts of the same period (e.g., Vergil, *Aeneid* 6.847–853; discussed above). This kind of panegyric is not uncommon in ancient technical literature; *laudes Italiae* can also be found in Varro's *On Agriculture* (1.2.3–7) and Pliny the Elder's *Natural History* (3.39–42, 36.101, 37.201–202), to give just two examples (for a synopsis, Bauck 1919). It shows that ancient technical texts do not shy away from intertwining scientific exposition with political or ideological issues. In this respect, Roman technical writers are no different from Greek ones.

In his *De Architectura*, Vitruvius does not only intend to impart knowledge in a comprehensive as well as systematic fashion, but also an ethical consciousness that guides the architect in his professional pursuits. Furthermore, like Cicero, he presents his scholarly accomplishments as an active form of service to the Roman Empire and thus as an engagement for the public's benefit. How seriously he takes his agenda is underscored by his pronounced disinterest in material gain; his reward will be a "good reputation" (*bona fama*) which will arise from his efforts as an author (6 preface 5). *De Architectura* is not least an appeal to those who are involved in building projects to adopt high standards for themselves and expect these from others as well in the interest of Roman society. Vitruvius' self-presentation in his treatise suggests his belief that he is the one who may function as a model for others to imitate, both in scholarly and moral respects (Fögen 2009, 106–151).

4. Columella

Columella's *De Re Rustica* ("On Farming" [*Rust.*]), written in the first century CE, is the most substantial ancient treatise on agriculture and thus surpasses Cato's *De Agricultura* ("On Agriculture") and Varro's *De Re Rustica*. Little is known about its author, who was born in Gades, located in the Hispanic province Baetica; maybe he was

a military tribune from the equestrian order (Fögen 2009, 153–158). His knowledge of farming is impressive and clearly based upon personal experience as a landowner. Columella also composed a lost work on astronomy (11.1.31), a discipline with which a farmer ought to be well acquainted, as it is relevant to his daily tasks (1 preface 22, 1 preface 32, 1.1.4).

As Vitruvius does for architecture, Columella defines agriculture as a fundamental and complex field which has a high value for Roman society and thus deserves to be revitalized and systematized. Columella presents it as a key discipline connected with numerous other branches of learning. Knowledge in these areas can only be acquired through rigorous instruction, and it presupposes intellectual aptitude (1 preface 21–28). For a subject such as agriculture, the Roman tradition (*mos maiorum*), represented by illustrious as well as knowledgeable predecessors (*exempla*), plays a particularly important role. Through his references to the importance of farming in previous generations and through his emphasis on its complexity, Columella intends to enhance the prestige of his discipline—an objective that needs to be seen as a reaction to rather widespread negative attitudes toward agriculture (e.g., Sallust, *Catiline* 4.1; Cicero, *De fin.* 1.3, 3.4). It is thus logical that he cannot accept a purely oral transmission of knowledge, as envisaged in Xenophon's *Economics*, undeniably one of Columella's sources. Agriculture is so intricate and multifaceted that a more differentiated approach in the form of a comprehensive handbook is necessary, and this is exactly what he provides with his *De Re Rustica*.

For the composition of such a handbook, Columella is indebted to previous writers (for secondary literature on his sources, Fögen 2009, 171 note 60). Although their approaches may be at variance with contemporary practices, they merit careful study since they often contain valuable information which has not lost its validity (*On Agriculture* 1.1.6). Such a position reveals that Columella is eager to show a sufficient amount of respect toward his predecessors. At the same time, he encourages landowners to develop a critical mind enabling them to question the accuracy of the elements of knowledge found in earlier manuals. Columella stylizes himself as an expert able to explain to his readers which elements of the traditional agricultural lore are still relevant. However obliged he may be to earlier authors, he underlines that he has established new standards and thus has contributed a great deal to the advancement of agriculture in Rome (Fögen 2009, 152–200).

In the first chapter of Book 1, Columella catalogs his predecessors (1.1.7–14): a long list of Greek experts, reminiscent of a passage in Varro's earlier treatise *De Re Rustica* (1.1.8–9), is organized according to their origin and spearheaded by the poet Hesiod. It is followed by a slightly shorter record of Roman writers, beginning with the Elder Cato, "who first taught agriculture to speak in Latin" (1.1.12), and ending with contemporaries such as Celsus, Iulius Atticus, and Iulius Graecinus (1.1.14). This ordering of writers implies a linear development which leads to Columella himself as the culmination. In addition to Greek and Roman sources, there is the Carthaginian specialist Mago, whose treatise was translated into Latin (1.1.13; cf. Varro, *On Agriculture* 1.1.10; for a brief discussion, see §6 below).

Unlike other Roman technical writers such as Pliny the Elder, Columella does not indulge in harsh polemics against the Greeks (Fögen 2009, 176–178). This becomes particularly apparent through a comparison with Varro, who repeatedly interprets the Romans' use of Greek words as a sign of exaggerated Hellenophilia that he subjects to ridicule (Varro, *On Agriculture* 2 preface 1–2, 3.3.7, 3.10.1). While one may be

tempted to classify such passages as instances of typical Varronian humor and of his interest in linguistic issues, it cannot be denied that they express a certain degree of moral criticism, directed toward the Romans' withdrawal from the countryside and their preference for urban life, associated with idleness and extravagance, ultimately leading to a loss of identity.

Despite the rather extensive list of predecessors, Columella does not explicitly refer to them often. To give just one example, Theophrastus, included in the list of authorities (1.1.7), is mentioned nowhere else in the entire treatise. By contrast, Varro, who also lists Theophrastus in his catalog of experts (*On Agriculture* 1.1.8), specifically mentions him five times as his source (*On Agriculture* 1.7.6, 1.7.7, 1.37.5, 1.40.1, 1.40.3) and even reflects on the limited usefulness of his botanical writings for farmers (*On Agriculture* 1.5.1). However, when Columella does specify his Greek sources, he is full of praise, as in the case of Aristotle (7.3.12) and Epicharmus of Syracuse (7.3.6).

5. Pliny the Elder

With his *Natural History* in 37 books, Pliny the Elder produced a massive work which represents the most extensive Latin treatise on the natural sciences and related disciplines (especially Beagon 1992; Naas 2002; Fögen 2009, 201–264; also Fögen 2007 and 2013, with further references). In his preface, Pliny asserts that he has utilized about 20,000 excerpts from about 100 selected authors. In the table of contents, which follows the preface, he lists more than 450 writers (146 Roman and 327 "external"). From his rhetoric, it is obvious that Pliny is eager to emphasize his considerable scholarly achievement, which for him consists of the reduction of the complexity of the material that he has digested and its resulting usefulness for the reader. Throughout his work, he evaluates various sources, in particular Greek authorities. His critical assessment frequently results in approval or even admiration, but also in personal attacks on writers whom he deems badly informed and unreliable. In what follows, examples of Pliny's evaluation of predecessors are chosen from his zoology (*NH* 8–11) and his history of medicine (*NH* 29).

As Pliny reveals, his zoology relies to a large extent on Aristotle, whom he calls an outstanding expert in any area of learning (especially *NH* 8.43–44). At the same time, he wants his own books on animals to be understood as a supplement to Aristotle's zoology: what the Greek scholar did not take into account is discussed in the *Naturalis Historia*, Pliny declares. This rather bold claim is substantiated through a reference to the political context in which the two scholars are to be located: as Aristotle did for Alexander the Great, Pliny also writes his work for powerful rulers, namely Titus and Vespasian. This analogy enhances the self-portrayal of Pliny as the Roman Aristotle. But since he also claims to cover material that cannot be found in Aristotle, he even goes so far as to say that he transcends his Greek model. Modern scholars have repeatedly doubted the validity of such a self-perception and attributed a clear superiority to Aristotle because of the more scientific character of his works (e.g., Naas 2002, 401–403). Yet, while there is little reason to contradict such an opinion, one cannot ignore the heuristic value of Pliny's statement, as it provides clear evidence of a Roman writer's self-confidence.

In other sections of his zoology, Pliny openly censures sources for their implausible stories. Good examples are reports on werewolves, as they can be found in the Greek writer Euanthes (*NH* 8.80–82), or accounts about bird-like creatures given by Dinon, Democritus, and Homer, which Pliny assigns to the realm of the fable (*NH* 10.138).

Book 29 of the *Naturalis Historia* is devoted to medical remedies made from animals. Its introduction serves to underscore the innovative character of Pliny's account (*NH* 29.1). Given the existence of other medical works in Latin that predate Pliny, in particular Celsus' *De Medicina* ("On Medicine"), one may be inclined to interpret such a pronouncement as an authorial strategy of self-advertisement. These opening remarks are followed by an overview of the development of medicine as a discipline which represents an invaluable testimony within the history of ancient science. For Pliny, no other field is as prone to changes (*NH* 29.2, 29.11). Soon after Hippocrates, whose achievements he applauds (especially *NH* 26.10; Byl 1994), medicine is said to have turned into a field of endeavor which attracted doctors with a penchant for material gain (*NH* 29.3–5; similarly 29.7–9, 16–17, 20–22). Pliny also criticizes those experts who have transformed medicine into a public show which focuses on their self-presentation and neglects the patient; for them, medical innovations do not aim at the healing of the sick but are instead intended to generate financial success (*NH* 29.9, 11; cf. 26.11–20). Pliny rejects unnecessarily complicated recipes for drugs and pleads for simple and affordable remedies based upon readily available natural ingredients (*NH* 29.24–25; cf. 24.4–5). He advocates Cato the Elder as a paragon of an honest and unpretentious, but nonetheless efficient approach to medicine. Cato's traditional *Hausvätermedizin* ("house-father medicine") is based upon personal experience; with its plain and straightforward character, it is constructed by Pliny as diametrically opposed to Greek medicine, heavily spurned by Cato (*NH* 29.14; also Plutarch, *Cato the Elder* 23.3–5). Pliny emphasizes that, like earlier Roman authors, he by no means condemns medicine as such, but instead its abuse, for which Greek doctors in particular are to blame (*NH* 29.15–16). By subscribing to Cato's approach, which is centered around the well-being of the family, ensured by a conscientious and knowledgeable *pater familias*, he emerges as a writer who seriously cares for his readers and has no interest in financial gain. One cannot fail to notice the eagerness with which Pliny distances himself from what he calls the Greeks' "self-promoting art" (*NH* 29.20: *ambitiosa ars*).

How tendentious Pliny the Elder's history of medicine is can be gathered from a comparison with the preface to Celsus' *De Medicina* (see especially Mudry 1982; further references in Fögen 2009, 246–248), which comprises precise information on the development of medicine as well as individual schools and their doctrines. Celsus' outline is not only much more extensive and detailed, but it also lacks any strong polemics, although this does not mean that his attitude toward his precursors is uncritical. While he also states that medicine has undergone numerous changes, he does not take this to be a sign of its disreputable character (especially preface 8 and 11). Whenever he disagrees with certain positions, he gives a reason (e.g., preface 58–61, 74–75). Moreover, it is one of his principles to elucidate the doctrines of individual medical schools before he evaluates them (preface 12). He has a great deal of respect for the achievements of Greek doctors (preface 2; cf. preface 11) and does not limit himself to the propagation of the traditional Catonian *Hausvätermedizin*. This may be explained by the fact that his work is more specialized than Pliny's books on medicine and offers a much broader spectrum of topics. It is reasonable to assume that Celsus wanted to address a more narrowly defined, open-minded readership that had a greater familiarity with medicine. In a compendium written for such an audience, there is no real need to disparage Greek science and thus rehearse conservative views that were rife among the majority of Romans.

6. Responses to Non-Greek Science

Although Roman science and scholarship were for the most part influenced by the Greeks, the achievements of other cultural spheres were not ignored. An entire discipline such as land surveying is said to have Etruscan origins, as indicated by authors such as Frontinus (*On Land Surveying* p. 8.23–29 Campbell) and Hyginus (*On Establishing Boundaries* p. 134.7–14 Campbell), although it is difficult to determine the actual impact of Etruscan science on the Roman *agrimensores* (Fögen 2014, 226–227, with further references). In certain areas, individual non-Greeks were praised for their impressive expertise, such as the Carthaginian Mago for agriculture and the Pontic king Mithridates for herbal pharmacology.

The Carthaginian Mago

Several ancient sources mention the Carthaginian Mago and his 28 books on agriculture, written in Punic. According to Varro, he surpassed all Greek agricultural experts in reputation (*On Agriculture* 1.1.10); for Columella, he is the father of husbandry (1.1.13). What is interesting about Mago's work is the fact that Cassius Dionysius of Utica reworked it into a Greek version comprising 20 books, incorporating supplementary material from agricultural treatises of Greek origin (Varro, *On Agriculture* 1.1.10). The extent of the changes made by Dionysius vis-à-vis the original cannot be measured, since neither Mago's Punic treatise nor Dionysius' Greek version have survived. Diophanes of Bithynia later reduced the size of Dionysius' twenty-volume epitome to six books.

According to Columella (1.1.13) and Pliny (*NH* 18.22), there existed an official Latin translation of Mago's Punic text commissioned by Senatorial decree after the Roman victory over Carthage in 146 BCE. The passage in Pliny indicates that the consulted translators were especially conversant in Punic, most of all a certain Decimus Silanus, who perhaps led the group of translators (for the most recent treatment of Mago, Santini 2000; cf. Martin 1971, 37–52). One can only speculate over the reasons for commissioning this Latin translation. In any case, Mago's treatise appears to have been of central importance for the Romans. It must have been deemed innovative in comparison to Cato's *De Agricultura*, for otherwise the highest seat of government would not have underwritten such an enterprise. Nevertheless it remains an isolated case in Rome of transforming non-Greek literature from the pen of a "barbarian" into Latin. Knowledge was imported mostly from Greece.

The Pontic King Mithridates

At the beginning of Book 25 of his *Naturalis Historia*, Pliny the Elder offers an outline of the history of herbal medicine in Greece and Rome. In a synopsis of those authors who have significantly contributed to advances in herbal pharmacology (*NH* 25.4–15), Roman specialists are listed before Greek writers. The list of experts begins with Marcus Porcius Cato, who is said to have dealt with herbal pharmacology only briefly, although he remained the only one to do so among the Romans for a long time. Next comes Pompeius Lenaeus (first century BCE), freedman of Pompey the Great and educated as

a grammarian, and later on, in the Augustan period, Gaius Valgius Rufus. According to Pliny, serious interest in herbal pharmacology among the Romans was not discernible until Pompeius' defeat of the Pontic king Mithridates (66 BCE), who had engaged in major research in this area.

In three full paragraphs (*NH* 25.5–7), Pliny acknowledges Mithridates' intellectual capacity and scholarly accomplishments, also evidenced by his astounding mastery of foreign languages (*NH* 25.6; similarly 7.88). Given that his pharmacological research resulted in such significant findings, it seems almost irrelevant for Pliny that Mithridates was one of Rome's former arch-enemies (*NH* 25.5). The political victory of the Romans over Mithridates interests Pliny only insofar as it enabled Pompeius' freedman Pompeius Lenaeus to translate the Pontic king's notes into Latin (*NH* 25.7). It is thus the *scholarly* profit which the Romans derived from this conquest that matters most to Pliny.

7. Conclusion

As we have tried to demonstrate, Roman responses to Greek science and scholarship were rather heterogeneous: they range from respectful acknowledgment and adaptation of Greek models to rejection and even prohibition. It is even possible to discern cases where one writer does not always exhibit a coherent attitude toward the Greeks. In particular from the late Republic onward, the demand for cultural self-sufficiency, combined with strategies to replace Greek learning with genuinely Roman achievements in science and scholarship, becomes noticeable. Stereotypes concerning the Greeks regarding their purported loquacity, cunning, mendacity, inconsistency, vanity, or softness are perpetuated even in serious scholarly and technical writings and serve as arguments to denigrate the reputation of certain Greek experts. While such negative portrayals still prevail in the early Empire (e.g., Juvenal, *Satire* 3), the picture changes with emperors such as Trajan (reigned CE 98–117), Hadrian (CE 117–138), and Marcus Aurelius (CE 161–180), who fervently promoted Greek intellectuals (Fögen 2000, 183 and 218–219, with further references). From the first until the third century CE, Greek culture and learning enjoyed a high level of prestige. In this period, a considerable number of Greek scholars were active in the Roman world; the medical doctor and philosopher Galen is a particularly good example. Furthermore, many Roman authors preferred to write their works in Greek despite the fact that by this time Latin had developed into a full-fledged standard language with an appropriate array of technical terms for all kinds of disciplines.

For modern studies on ancient technical literature of the Roman world, it is impossible to treat Greek and Latin authors separately. Especially from the first century CE onward, a separation of "Greek" and "Roman" becomes problematic. In this respect, future investigations will need to overcome disciplinary boundaries. Such a methodological shift will perhaps also contribute to a more thorough analysis of the Roman influence on Greek technical and scientific writers.

If there is one distinctively Roman form of technical literature, it is encyclopedias (see Scientific Encyclopedias). The idea of an all-round education is evident certainly as early as the fifth century BCE (Plato, *Hippias Maior* 285d, 368b–d; Cicero, *On the Orator* 3.127), and the works of polymaths such as Aristotle cover an impressive array of disciplines, but they were not conceived of as comprehensive handbooks, constituting a unified whole. Hence, genuine encyclopedias are a specifically Roman phenomenon, represented by authors such as Cato the Elder, Varro, Celsus, Pliny the Elder, and later

on by Martianus Capella, Cassiodorus, and Isidore of Seville (for a useful summary, see Grimal 1965; see also König and Woolf 2013). What is more, from a Roman point of view, it is often the combination of such men's impressive learning and versatility on the one hand and their political activity and moral impeccability on the other that leads to their brilliant reputation (e.g., Quintilian, *Instruction in Rhetoric* 12.11.23 on Cato; Pliny the Younger, *Letters* 3.5 and 6.16 on Pliny the Elder; also Fögen 2009, 262–264). This demonstrates once again that respect for traditional norms and values (*mos maiorum*; see Wallace-Hadrill 2008, 213–258) was regarded as a crucial criterion for the standing of scholars in Roman society. At the same time, this does not mean that the vast majority of Roman technical writers transmitted elements of knowledge which they viewed as obsolete; there is ample evidence that many of them actively endorsed scientific progress (Fögen 2009, index, s.v. "Erkenntnisfortschritt"), although in several cases, this may have been no more than a rhetorical gesture. On the whole, scientific culture in the Roman world was less static and less epigonal than some modern scholars have tended to believe.

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FURTHER READING

With a particular focus on the period of the early Empire (first century CE), Fögen 2009 examines not only the lexical, morphological, syntactical, and pragmatic characteristics of Greek and Roman technical writing, but also various forms of self-presentation of the authors of these texts and their specific rhetorical strategies. It takes into account the social, political, and ethical aspects of ancient scholarship, and pays attention to the relationship between Greek and Roman technical authors.

The Latinization of Greek terms and related problems is discussed by Fögen 2000 and 2009 (especially 67–105); see also De Meo 2005 and several of the contributions in Fögen 2005. Langslow 2000 analyzes the influence of Greek on the development of medical Latin.

On Cicero and Greek scholarship, one may consult Trouard 1942 and Fögen 2000, the latter of whom also has sections on Lucretius, Quintilian, and Aulus Gellius. Earlier enquiries into Roman attitudes toward the Greeks are offered by Petrochilos 1974, Wardman 1976, and Kaimio 1979, to which one may add Balsdon 1979, who also investigates Roman views on peoples other than the Greeks. Relying on literary and archaeological evidence, Wallace-Hadrill 2008 considers the cultural transformations in the process of the redefinition of Roman identity in the late Republic and early Empire.

Lehoux 2012 attempts to rehabilitate the status of Roman science between 100 BCE and CE 200, but, with its limited contextualization, is more suited to readers sufficiently familiar with the history of ancient and modern science.

CHAPTER 58

Scientific Encyclopedias

Katerina Oikonomopoulou[1]

1. Introduction: Defining the Term "Scientific Encyclopedia"

Greco-Roman antiquity bequeathed to us a wide variety of scientific or pseudo-scientific writings, which aspired to a comprehensive exposition of a particular area of knowledge or expertise. Key examples include Greek and Latin technical treatises and handbooks, such as Vitruvius' *On Architecture*, Celsus' *On Medicine*, Ptolemy's *Almagest*; and, in later antiquity, numerous Greek and Latin medical epitomes and compendia, such as Oribasius' *Medical Collections*, the *Medical Books* by Aëtius of Amida, and Paul of Aegina's medical epitome (van der 2010; for other types of Latin encyclopedic writing in later antiquity: Formisano 2013). In addition, we possess two large-scale works that offered a synthetic overview of scientific knowledge, in differing areas that either presume a certain affinity (methodological or conceptual) between discrete fields of scientific investigation, or which lay claim to a sort of command of science that transcends the bounds of specialism. These are the pseudo-Aristotelian *Problems*, 38 books of predominantly medical-naturalist causal enquiries, and Pliny the Elder's *Natural History*, whose 37 books cover fields as diverse as astronomy, geography, and living as well as inanimate beings, although its thematic range is by no means confined to science. The eight books of Celsus' *On Medicine* were themselves originally part of a much more extensive work that collected knowledge on different fields of human knowledge and practice (apart from medicine, also agriculture, the military art, rhetoric, philosophy, and law).

All these writings may be characterized as "scientific encyclopedias," on the understanding that "encyclopedia" be employed to do justice to their scope and aim as informative repositories of scientific knowledge. It is, however, important to keep in mind how they differ from their modern counterparts (Yeo 2001). First, ancient "encyclopedias" tend to vary in terms of their level of systematization, ranging from the use of logical

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principles of exposition to looser, associative schemes for organizing content. Notably, alphabetical methods of arrangement, common in works of such kind today, are only sparsely employed. Second, they cannot always be neatly designated as technical or specialist, since they sometimes adopt tropes (such as poetic quotation, literary allusion, and non-scientific digressions) that point to the possibility of a wider outreach. Both these features partly reflect the fact that what we call "ancient science" was neither a fully organized system of interconnected disciplines nor an ivory-tower practice, distinct from other facets of society. Further, the encyclopedia was never a full-fledged genre of writing in the ancient world for reasons that probably had to do with the absence of an encyclopedic movement comparable to that of early modernity. Thus, we cannot safely presume the existence of a distinct concept for the "encyclopedia" even in the case of ancient authors such as Pliny the Elder, who explicitly link their writings to Greek *enkyklios paideia* ("ordinary/general education:" *NH* preface14; see Naas 2002, 16–34; Doody 2009; §2 below). Nevertheless, the proliferation of textual forms that, one way or another, attempted to collect and systematize scientific knowledge suggests that such writings did have a significant role in the transmission and dissemination of scientific enquiry across and beyond scientific communities. As a result, in recent years interest in such writings has received a boost, with scholarly interest concentrating on their formal features, the techniques they employ to adapt their source material, the authorial strategies they adopt to communicate knowledge, and, last but not least, the socio-cultural conditions of their production and dissemination. In light of these considerations, our discussion will focus on key themes, structural patterns, and methods employed by antiquity's scientific encyclopedias, with a view to conveying an understanding of their respective aims and intellectual mindset. Further, it will seek to promote comprehension of important socio-cultural factors of the production and dissemination of such texts, by situating them in three intellectual contexts: the activity of Aristotle and his successors in the Peripatetic school, the tradition of Roman encyclopedism, and Greco-Roman Imperial culture. Finally, it will seek to assess the contribution of these texts to the transmission of ancient science.

2. Encyclopedism and Science under the Peripatetic School

Aristotle and his successors in the Peripatetic school lay the foundations for the writing of scientific encyclopedias in the ancient world, as part of their broader endeavor to systematize the study of different fields of knowledge. Peripatetic compilatory writings of encyclopedic scope are distinctive in that they were products of collaborative research likely conducted over several centuries. Such was their corpus of city *Constitutions*, which amassed a wealth of historical-antiquarian information on customs, laws, and political institutions of various Greek communities (Gigon #143), and, on the scientific side, their 38-book collection of *Physical Problems* (pseudo-Aristotelian *Problemata*). The *Problems* possibly derived from a now lost collection of *Physical Problems* written by Aristotle himself. It probably acquired its present form through a process of continuous input well into the late Hellenistic period, or even into the second century CE. The *Constitutions* and *Physical Problems*, both vast projects, amply illustrate the key role played by the Peripatetic school as an institutional structure and context enabling the coordinated accumulation of knowledge over generations of philosophers and scientists. The composition of both works must also have been facilitated by the rise of a book culture

in ancient Greece from the fourth century BCE onward, enabling unprecedented access to a wide variety of textual sources through the medium of private book collections or libraries. This, in turn, inspired the composition of encyclopedic writings, which sought to offer synthetic overviews of available knowledge (Jacob 2013, 66–76; Pinto 2013).

Let us now turn our focus to the *Physical Problems*. Each of its books is essentially a collection of a variable number of discrete why …?-type enquiries that investigate the causes of different physical and physiological phenomena. Their topics are overwhelmingly concerned with medicine and human physiology (books 1–11, and 31–38), phenomena that lie at the juncture between physiology and physics (such as sympathy in book 7, and voice/sound in book 11), as well as with naturalist topics such as odor (good or bad), climate, plants, waters and the sea, nourishment, and the air and winds (books 12–14, 17, 20–26, respectively). But the collection also takes into account subjects such as mathematics and mechanics (books 15–16), the love of letters (book 18), music and harmonics (book 19), and ethics and psychology (books 27–30).

We can gauge some of the scientific aims that underpinned the *Physical Problems*' wide-ranging accumulation of scientific knowledge by considering its structure. It is thus notable that the medical-biological subject matter was placed at the head and conclusion of the collection (books 1–11, 31–38, respectively), in a way that suggests ring composition. Well attested in other types of ancient Greek philosophical writing (Flashar 1962, 330, particularly regarding the placement of medical books), this ordering scheme probably does not obey aesthetic criteria alone, but is connected with aspects of method. Most likely at stake is the achievement of an integrated method of investigation for medicine and natural philosophy, an issue that Aristotle himself twice raises in the *Short Treatises on Nature*, where he observes the overlap of medicine and philosophy (see *On Sense and Sensible Objects* 436a20–b2; *On Respiration* 480b28–31; Mayhew 2013 on a possible dependence of *Problems* 1 on Aristotle's lost works on medicine). Indeed, the approach to medicine of the opening ten books appears closer to the interests of a naturalist than a physician—yet there is no doubt that their authors had solid, first-hand knowledge of therapeutic practices. Thus, book 1 is concerned with how changes in the environment (seasons, geographical location, or waters) can affect health and disease, and with the power of certain nutritive or healing substances to effect certain types of change within the body (on the relationship to the Hippocratic Corpus [especially *Airs, Waters, Places*]: Jouanna 1996; Ulacco 2011). The explanations are generally sought in material factors, such as the interaction between elements (the hot, cold, wet, and dry) within the body (in turn influenced by how the same elements interact in the external environment), the role of the body's humors (phlegm and bile are mentioned), and certain key physiological processes (concoction, colliquation, heating up or cooling down). A similar materialist framework underpins the explanations concerning the causes of specific physiological conditions in books 2–9, and is also apparent in book 10, whose comparative investigations of humans and animals heavily draw on Aristotle's biological writings, but modify their explanations to suppress teleological reasoning. Book 11, finally, blends physiological and naturalist subject matter on the voice and sound, thus serving as a fitting preamble to the ensuing naturalist topics. When medical topics recur at the very end, this time examining the human body according to its anatomical parts (beginning with the eyes), the answers presume an understanding of the physical properties and behavior of inanimate substances (such as water and oil, *Problems* 32.10), in accordance with what is discussed in earlier problems (e.g., 24.1).

A second motive behind the composition of the *Physical Problems* lay in the critical re-examination of scientific tradition, and its adaptation to new intellectual aims. This relied on a process of reading and excerpting from a wide range of scientific texts for the purpose of formulating problems that sought to build on existing causal explanations, or to correct or offer alternatives to them. Principal sources were Aristotle's treatises on animals, Theophrastus' medical opuscula (especially *On Sweat* and *On Fatigue*: Fortenbaugh, Sharples, and Sollenberger 2003) and physical writings, and medical literature such as the so-called Hippocratic Corpus. Contact with such a broad range of source material offers opportunities for productive encounters between different intellectual traditions. This is most visible in books such as 4 and 14 (on sex and climate, respectively), whose problems draw on Hippocratic sources (namely, *On Generation*; *Airs, Waters, Places*; and *On Regimen*) as well as on Aristotle's biological corpus (Flashar 1962; Mayhew 2011, *ad loc.*). A similar inclusivity is displayed by individual problems, often utilizing in their answers different theories and approaches, toward explaining a given phenomenon in the most ingenious manner possible.

Finally, the *Physical Problems*' exhaustiveness, paired with its tendency to replicate material, may be associated with a normative aim. Specifically, both features can be interpreted as demonstrations of an exploratory method of research and writing, whereby one can freely take up lines of enquiry, develop them in different directions, and, in certain cases, return to them, in order to refine their answers or address them again from a fresh perspective. This explains why the problems contained within its books are, with very few exceptions, not ordered in a logical fashion, but succeed one another in a loose or associative style, with most replications of material concentrated toward the ends of books. We can gain a more concrete sense of this feature if we consider three partially overlapping problems from book 23, whose topic is salt water and the sea:

> Why does a wave not break in the deep seas, but it does in the small and shallow ones? Is it because when a small amount of liquid is being carried it is more divided by the wind than a large amount? (23.1, 931a35–38)
>
> Why do waves settle more slowly in the greater seas than in shallow ones? Is it because everything settles more slowly when it is coming out of a lot of motion than out of little? And the tide is higher in the greater seas than in the shallow ones. Therefore the fact that what is greater subsides more slowly is not absurd. (23.17, 933b5–10)
>
> Why doesn't a wave break in the deep seas, but it does in the small ones? Is it because when a small amount of water is being carried it is more divided by the air than a great amount? For this reason it is broken up, since it strikes more. And in the deep water what is set in motion is great (in quantity), whereas in shallow water it is small. (23.24, 934a25–29)

All three problems are introduced as why…?- type questions (see Louis 1991, xx–xxiii), and, in all three, the enquiry is formulated as a paradox, or by referring to a contradiction. This not only serves to convey the narrator's sense of wonder at the remarkable nature of the phenomenon in question, it also suggests that the enquiry results from first-hand knowledge, itself stemming from familiarity with the seas. The enquiries are posed in such a way as to call for a blend of logical inference and empirical observation. This is not to say that intellectual rigor is absent, however. For one thing, the authors sought to formulate original enquiries, as evident from the overall content of book 23: although we can trace the pedigree of all 41 problems back to works such as Aristotle's

Meteorology (book 2), or Theophrastus' partially extant *On Water*, their overlap with either work appears minimal (also noted by Flashar 1962, 649). Waves, for example, are only mentioned by Aristotle in passing, in the context of the role played by the winds in forming earthquakes and tidal waves (*Meteorology* 368a27–31). *Problems* 23.1 and 23.24, too, explain the waves' breaking as concomitant of their being divided by the wind, but, for 23.17, the sea's intensity of motion seems to be the key factor that determines whether waves will settle slowly or not. This suggests the scientists who contributed to the *Physical Problems* made a genuine effort to offer creative solutions to their enquiries: even though we certainly detect variations in the extent of originality exhibited across different problems or books (in turn probably reflecting differences of approach or intellectual maturity of the authors), it is indeed rare to find a blind adherence to tradition, or an uncritical assimilation of the views of other scientists and philosophers.

Further, the answers to all three problems are formulated as interrogative propositions ("Is it because…?"), rather than as definitive assertions; and their authors are for the most part reticent, offering only sparse statements of personal opinion, or evaluations of others' opinions (Oikonomopoulou 2013a). This format successfully lures the reader into the problem-solving process, inviting reflection on the proposed solutions, and either adoption, rejection, or improvement. This, in turn, may well have been what ensured that the *Physical Problems* reached its current proportions as a text, its different readers contributing new problems according to an open-ended process of scientific investigation, which relied on revision as much as on fresh insight. A comparison of the answers to problems 23.1 and 23.24 provides a good hint to the sorts of intellectual principles that might have governed this process: the latter problem aims at a more informative account, by expanding the former's solution, and by also integrating insights from the solution of problem 23.17. Its own answer is not necessarily more successful—in fact, the comment about the wave that "strikes more" is quite confusing, while its concluding point, presumably aiming to spell out the fact that the quantity of water is greater in the deep seas than in the shallows, is trivial at best. It does clearly underscore, however, the role a broad scientific *paideia* would have played in the problem-solving process, stimulating new approaches, and encouraging the provision of well-informed, and, hence, authoritative answers.

3. The Tradition of Latin Encyclopedism

The second keynote tradition for the history of ancient scientific encyclopedias is that of "Latin encyclopedism," primarily identified with the writing of systematic treatises of specialist subject matter during the late Republican and early Imperial period (on cultural ideology: Diederich 2007). These are principally the writings on agriculture composed by Varro and Columella (see Reitz 2013; both works are entitled *De Re Rustica* and inspired by Cato the Elder's rather disjointed handbook on agriculture, *On Agriculture*). Varro is also credited with two large-scale encyclopedic compilations: *Disciplines* (reportedly an overview of all the disciplines useful to a free man) and *Hebdomades vel de Imaginibus* (*Weeks or On Images*: a collection of portraits of important Greek and Roman men, each accompanied by an epigram and short biography: Cardauns 2001, 77–81). We also have Vitruvius' *On Architecture* and Celsus' *On Medicine*, which does not conceive of its subject matter as a science (as we do, or as the pseudo-Aristotelian

Problems) but as one the five arts (together with agriculture, rhetoric, philosophy, and military art) that the encyclopedia sought to represent (for the position of the medical books in the larger plan of Celsus' encyclopedia: Serbat 1995, xi–xiv; for medicine in the broader context of Roman encyclopedism: Stok 1993).

All these works attempt to codify and make accessible practical experience and theoretical insight gleaned from wide reading in a methodical format (Fuhrmann 1960, 69–98, 157–159, 162–181; Scarborough 1993, especially 29–32). A passage concerned with the consumption of drinks offers a good illustration of how such an aim affects the style in which scientific (and, in particular, medical) knowledge is communicated:

> Of drinks now those that are made from grain, and similarly milk, honeyed wine, grape syrup, raisin wine, sweet or strong wine, wine that is still must or of great age, are of the most potent nature. But vinegar and wine, that is a few years old and is either harsh or dense, are of an intermediate substance; and for this reason nothing of the latter kind should be given to the weak. Water is the least nourishing of all; and the most nutritious is the potion from grain, to the extent that the grain itself is more nutritious… (Celsus 2.18.11)

The passage belongs to the part of *On Medicine* dedicated to dietetics, one of the three divisions of medicine (dietetics, pharmacology, and surgery) according to which Celsus undertakes to structure his exposition (preface 9; Mudry 1982; Deuse 1993). Its immediate context is a discussion of nourishing substances, at the conclusion of an extensive account of various healing practices (2.9–18). Our passage describes various liquid potions, including water, in terms of heaviness or lightness, potency or strength. In contrast to the pseudo-Aristotelian *Problems*, the aim here is not to launch a theoretical enquiry open to different interpretations, but to prescribe a reliable therapeutic regime.[2] Accordingly, the properties in question are not listed from the point of view of a naturalist, but rather of a physician who seeks to classify substances according to their suitability to the constitution and needs of a sick patient (on the medical background and likely sources, see Serbat 1995, 176–177. Celsus' classificatory intent becomes more apparent in subsequent lists of substances and foodstuffs according to their healing properties [2.19–33]). This point of view also affects the style of presentation, in which impersonal factual statements are predominant (von Staden 1994; on impersonality as a feature of Latin technical texts in general, see Hine 2009; 2011).

Cato, Varro, and Vitruvius are more explicit still about their treatises' practical orientation. Thus, Cato stresses the economic advantage and social standing that farmkeeping brings to a Roman (*On Agriculture*, preface), while Varro underlines that the advice he seeks to offer on land cultivation is meant to augment a farm's productivity (*On Agriculture* 1.1.2). Vitruvius, finally, dedicates his treatise to Augustus, expressing the desire that it will offer information useful for his public building program (*On Architecture* 1–3 preface). At the same time, however, the statements also underline the fact that all three works in question, more than being narrowly "technical" literature, were underpinned by key socio-political concerns of Roman elites—namely, land possession as a marker of social status and moral excellence, the construction of buildings as displays of Imperial power, and the practice of a healthy lifestyle as a prerequisite for the successful fulfillment of public duties. Looking back to the earlier passage from Celsus

(2.18.11–12), we see that his dietetical prescriptions do not constitute ivory-tower science, but are meant to have a direct social impact, insofar as their intended beneficiaries are elite Romans seeking advice on how to lead a healthy life.

The close bond between encyclopedism and the structures and ideologies of Roman power is most vividly apparent in Pliny the Elder's monumental *Natural History*. The work is rightly regarded as the intellectual forefather of modern encyclopedism, on account of its broad scope, relatively clear-cut organization, and the fact that it furnishes an extensive table of contents, which leaves no doubt as to its aim to function as a reference work (Conte 1994, 67–104; Doody 2001; Naas 2002, 171–224; Murphy 2004, 29–48). Scientific knowledge holds a prominent role in Pliny's encyclopedia, as evident from its overall selection and distribution of topics: astronomy and meteorology (*NH* 2), geography (*NH* 3–6), anthropology (*NH* 7), animals (land animals, marine, birds, and finally insects, in *NH* 8–11), plants (beginning with the exotic ones, in *NH* 12, and progressing to useful plants for agriculture and civilization, in *NH* 13–22), and inanimate beings, including a long excursus on pharmacological substances (*NH* 23–34). It is quite clear that Pliny had access to and excerpted from a wide range of Greek and Roman scientific authors (on sources: Naas 2002, 137–170; on science in the *NH*: Paparazzo 2011). Pliny's vast accumulation of scientific knowledge is primarily motivated by an attempt to provide a holistic examination of the natural world, in all its different facets. This vision, as Mary Beagon notes (1992, 13), distinguishes Pliny from other Roman encyclopedists, who, as we have seen, sought rather to compartmentalize knowledge according to a division into different arts (Naas 2002, 16–68; Doody 2009, 3). The unity of Pliny's ambitious scope and a vastly heterogeneous conglomeration of knowledge is guaranteed by Pliny's anthropocentrism, expressed through the idea of a provident nature (benign to the human race), as well as through an emphasis on human achievements, and the way humans have tamed nature to better serve human needs (Beagon 1992; 36–91; on nature in Pliny, Doody 2013). This is paired with a triumphalism about the vast geographical outreach and authority of the Roman Imperial state (Citroni Marchetti 1991, 15–80; 2011, 31–55, 72–99; Naas 2002, 69–105; Murphy 2004, especially 5–24; Laehn 2013, 57–90). Accordingly, both the selection and ordering of subject matter and the style of presentation for scientific knowledge are underpinned by these core Plinian convictions. In order to gain a clearer sense of the text's economy and style, let us consider two chapters from the second book, both on tides:

> But all the tides cover and lay bare greater spaces in the ocean than in the rest of the sea, whether because it is more violent when moved in its entirety than when in part, or because the open greatness feels the force of the star more effectively when this proceeds freely, whereas narrow spaces hold off this force. This is the reason why neither lakes nor rivers are moved in a similar manner (Pytheas of Massalia states that north of Britain the tides rise 120′ [36.5 m]). Besides the more inland seas are enclosed by land as if by a harbor; yet in some places a wider expanse succumbs to the power, since for instance there are several examples of people who have made the crossing from Italy to Utica in two days in a calm sea and with no wind in the sails when a strong tide was raging. But these motions are observed more around the shores than in the deep sea, since in the body too the extremities feel the pulse of the veins, that is, of the breath, more. But in most estuaries owing to the different risings of the stars in each district the tides occur irregularly, varying in time though not in procedure, as for instance in the Syrtis. (2. 217–218)

This section belongs to a unit of chapters toward the end of the second book, which treat the seas and waters (*NH* 2.212–235). Tides play a prominent role in the account, occupying over ten chapters (*NH* 2.212–223). In the section quoted here, Pliny is especially focused on differences in the magnitude of tides, depending on whether they occur in the ocean or over narrower, more enclosed, expanses of water. It is easy enough to detect an overlap with pseudo-Aristotelian *Problems* 3.17. The influence of the tradition to which the latter work belongs may, in addition, be evinced from Pliny's concern with providing causes for the phenomenon in its different manifestations: the ocean, we learn, is more furious when moved in its entirety than in part; moreover, open expanses feel more strongly the force of the moon (responsible for tides [*NH* 2.212], together with the sun), while narrow spaces, by contrast, contain that force; finally, inland seas are naturally enclosed, while the open seas are subject to the tides' full sway. But Pliny's account, in comparison to that of the *Problems*, is much more vividly colored with geographical detail (mentioning Britain, the sail from Italy to Utica, and the Syrtis). This imbues it with exoticism and conveys a sense of the Roman Empire's broad geographical bounds. Moreover, the reference to the tremendous height of the tidal waves in Britain, attributed to Pytheas (see Hydrology: Oceans, Rivers, and Other Waterways), showcases Pliny's predilection for the remarkable, as well as his tendency to prop up the credence of the miraculous facts that he lists by providing numerical estimates of their sizes, quantities or proportions, as well as by citing authorities for them. As in the case of Celsus, expressions of personal opinion or experience are sparse, with the factual style prevailing (Citroni Marchetti 2011, 100–124). Pliny's perspective may nevertheless be surfacing more clearly in his analogy between the land and the human body. This anticipates the detailed treatment of the human animal in *NH* 7 (Beagon 2005) and the zoological books that follow (*NH* 8–11), and it provides a good hint of Pliny's anthropocentric perspective in the *NH* as a whole.

4. Greco-Roman Imperial Culture

The writing of scientific encyclopedias intensified during the later centuries of the Roman Empire. This is directly related to key intellectual phenomena of the Imperial Greco-Roman world. For starters, the development of a reading culture (Johnson 2010), boosted by an active bookselling trade, as well as by the wide access to libraries across the Roman Empire, ensured that Imperial Greco-Roman scientists had ample opportunity to consult the works of their predecessors (Johnson 2013; Zadorojnyi 2013). At the same time, philosophy and science instruction became increasingly standardized in terms of the subjects and order of presentation (Hadot 1984; on medical teaching in antiquity: Horstmannshoff 2010). On the one hand this fact entailed an increased demand for exegetical writings (seeking to explicate the content of earlier writings; e.g., Galen on Hippocratic texts, or Alexander of Aphrodisias on Aristotle), and for works that sought to offer a comprehensive overview of different scientific domains on the other. As result, this period was replete with comprehensive handbooks, epitomes, compendia, and anthologies, all of which, nevertheless, may be considered as representing different varieties of encyclopedic writing. Thus, the scientific treatises that Ptolemy produced in the second century CE can be characterized as encyclopedic by virtue of the fact that they aim to offer a systematic exposition of all available knowledge on astronomy and astrology (*Almagest* and *Tetrabiblos*, respectively), geography (*Geography*), harmonics,

and optics. Similarly, late antique medical compendia such as Oribasius' *Medical Compilations* (fourth century CE, only partially extant), Aëtius of Amida's *Medical Books* (early sixth century CE), and Paul of Aegina's medical *Pragmateia* (as he himself calls his work, seventh century CE) may also be regarded as encyclopedias, since they seek to cover all areas of medicine in a comprehensive fashion.

Despite essentially different formats and aims, all these works have in common certain key structural features, suggesting that certain technologies for organizing information through text became more or less standardized in the later centuries of the Roman Empire. The first of these is the table of contents (or index), listing each book's chapter headings in numerical sequence (König and Whitmarsh 2007, 34–35). The fact that, in all cases, each book is preceded by its own table of contents means that these tables were considered intrinsic to reading the treatises, and they were intended as practical tools for locating subject matter within each book. The enumeration of each chapter heading further consolidates the impression that these are carefully structured works, aiming to furnish ease of reference. By contrast, the usefulness of Pliny the Elder's summary table of contents (*NH* 1) is questionable, not least because this does not always faithfully describe the content of each book (Doody 2001; Murphy 2004, 30–33, 214–215). It may rather be regarded as an advertisement of content of the different books, or perhaps as a synoptic taste of the work's vast scale, designed to impress, rather than to serve as an actual practical aid.

Second, all works include prefaces which are explicit about the method of exposition and authorial goals. Thus, the preface to Ptolemy's *Almagest*, dedicated to an otherwise unknown Syrus, is methodological in character, aiming to defend the philosophical value of studying astronomy. At the preface's conclusion, Ptolemy declares his goals:

> … we shall try to present as briefly as possible those theorems that we believe have come to light until now, and in such a way so that those who have already made some advance on the subject can follow, [namely, by] explaining for the sake of the treatise's completeness all matters useful to the theory of heavenly things, the exposition of which we will pursue according to their proper order. And so as not to make the treatise too long we shall only go through what has been ascertained by the ancients, investigating anew, to the extent that is possible, what has either not been fully explained or not explained in a manner that is adequately serviceable. (1.1)

Ptolemy presents himself in a dual role: compiler of pre-existing knowledge, and original thinker who critically builds on or improves the achievements of his scientific predecessors. His preface stresses the need to achieve an orderly exposition of his subject matter, and indeed the preface is followed by a chapter specifically dedicated to explicating the order in which the *Almagest* will pursue its astronomical exposition (Pedersen 2011, 32–33; Feke 2009, 17–67; for a translation of the preface: Toomer 1984). Finally, the preface underscores the need to keep the requirement of informative completeness in check, by sticking to criteria of conciseness and brevity (Pedersen 2011, 29–32). There are several parallels with the prefaces of Oribasius and Paul of Aegina, both of whom also emphasized their texts' intended function as informative and reliable shortcuts to knowledge (excerpted from earlier medical writers, most prominently Galen), as well as on the method according to which they seek to achieve the orderly exposition of the material they have excerpted (van der Eijk 2010, 525–536). No

general preface survives for Aëtius of Amida's medical compendium). The medical compendia differ from Ptolemy, however, in that their prefaces are the only places where we find such clear statements of authorial intent: in the main body of each work the style is, for the most part, factual, lacking more detailed declarations of method or rationale (van der Eijk 2010, 525–536). By contrast, Ptolemy's authorial persona has a steady presence throughout the *Almagest*, actively assisting the reader in navigating its contents.

How exactly do these scientific encyclopedias achieve the orderly exposition of their material? In Oribasius' *Medical Compilations*, the material is grouped together by theme, following different divisions of medicine, namely, dietetics (books 1–15, including pharmacology in books 11–15), anatomy (books 24–25), diseases and other pathological conditions (books 43–47), and surgery (books 48–50). Aëtius proceeds from inanimate substances (drugs, minerals, the earth, and animals, books 1–2) to diagnostic and therapeutic practices (books 3–5), with the last three books (6–8) concentrating on specific ailments affecting the body's different parts, beginning with the head. Paul of Aegina, finally, begins with dietetics (book 1), proceeds to an account of different diseases or pathological conditions (books 2–5), and concludes with surgery and pharmacology (books 6 and 7, respectively). These variations in organization are not just a matter of subjective preference, but they possibly also reflect differing assessments of the relationship that different parts of medicine hold to one other (or differing perceptions of what part of medicine is more general, or accessible, as opposed to more specialist), and the best terms in which the reader can access them. In addition to these overarching organizational schemes, these three medical authors utilize an alphabetical arrangement when listing therapeutic substances by name. Similarly, Ptolemy's treatises include tables of computations, catalogs, and figures which illustrate the content. Further, the content of each work is subdivided into chapters (each preceded by its own heading), sometimes so concise that they resemble entries in a lexicon. Their brevity is, however, fundamental to the aim of rendering knowledge accessible, since it offers easily memorable units of specialist information. This would have been particularly handy in the case of lengthy encyclopedic compilations such as Oribasius', the complete version of which numbered a total of 70 (or 72) books (on the cultural importance of itemizing knowledge in this way: König and Whitmarsh 2007, 35–39).

There is no doubt that the scientific encyclopedias in question are highly specialized, as their technical language and level of detail suggests. A passage from Oribasius' *Medical Compilations* book 24 makes this clear:

> If you expose the brain in a suitable manner you will see the dura mater looking much thicker along the middle of its length, and going down like this up to a point, especially in the part where there is the middle suture of the brain. And in the same way under the lambdoid suture you will see the dura mater doubling itself and at the same time coming down up to a certain point to the brain. And the veins that come up through it will also be visible to you, one on each side, along the sides of the lambdoid suture.

However, that is not to say that they did not aim at a broader audience. For one thing, Oribasius (1 preface) stresses that he composed his medical compendium because he was instructed to do by the emperor Julian, when they were both in Gaul. Whether truthful

or not, this claim serves to yoke Oribasius' project to Imperial authority, as well as to invest it with a relevance and value beyond the specialist domain. Further, it is conceivable that at least some aspects of the knowledge contained in such works had a broader socio-cultural role. Works such as Plutarch's *Table Talk*, Aulus Gellius' *Attic Nights*, and Athenaeus' *Learned Banqueters* (all second century CE) stage social encounters at symposia and other settings (libraries, gymnasia, or the villas of wealthy intellectuals) in which knowledge of scientific subjects—medicine, optics, astronomy, and music—is not confined to professionals: members of a wider, highly educated Greco-Roman elite used it to disarm the arguments of ignorant individuals in intellectual debates, and to enhance their own status among their peers, by citing the opinions of scientific authorities on key subjects, such as dietetics. This background allows us to surmise that later Imperial scientific encyclopedias may well have catered to a broader spectrum of readers than was perhaps first believed.

5. Conclusion: The Role of Scientific Encyclopedias in the Transmission of Greco-Roman Science

The obscurity and neglect surrounding ancient scientific encyclopedias today do little justice to their historical and cultural significance. In fact, most of the texts that we have discussed here enjoyed a rich afterlife, which provides perhaps the most eloquent testimony to the vital contribution that they made to the transmission of ancient science. In the centuries following their composition, ancient scientific encyclopedias were approached as valuable repositories of knowledge that could be extracted and re-used in new contexts. Further, they inspired the writing of new scientific texts, which sought to make their own contribution to a long-standing tradition of scientific investigation. Last but not least, they were instrumental to the reception of Greco-Roman science by the Arabs, as well as to its "re-discovery" during the Renaissance.

The fascinating *Nachleben* of ancient scientific encyclopedias is too convoluted to chart here in detail, but a brief discussion of some pivotal points regarding their reception should suffice to shed useful light on how they promoted the theory and practice of scientific investigation throughout and beyond the ancient world. Thus, we know that from the first century CE onward, different versions of the pseudo-Aristotelian collection of *Physical Problems* (partially overlapping with the version that has been transmitted to us) must have circulated widely in philosophical, or philosophically minded, circles (Louis 1991–1994, xi–xviii, Oikonomopoulou 2011; 2013b). This inspired the composition of new bodies of scientific problems, by authors such as Plutarch who wrote a collection of *Natural Questions* (Meeusen 2013). From later antiquity as well we have two extensive collections of medical-naturalist problems, namely, the *Medical Puzzles and Natural Problems* by pseudo-Alexander of Aphrodisias, and the anonymous collection of *Supplementary Problems*, both relying on the pseudo-Aristotelian *Problems*, but also adding their own insights (Ideler 1841; Kapetanaki, and Sharples 2006). In a similar process, the medical sections of Pliny's *NH* were excerpted during the fourth century CE, toward forming a self-standing medical compilation, the so-called *Medicina Plinii* ("Medicine of Pliny:" Doody 2010, 135–152); and, during the same period, the grammarian Gaius Iulius Solinus, widely excerpted from different parts of the *NH* to compile his own *Polyhistor* (Dover 2013).

During the Middle Ages, encyclopedic works of medical-naturalist content such as the pseudo-Aristotelian *Problems*, the *Medical Puzzles and Natural Problems* of pseudo-Alexander of Aphrodisias, and Oribasius' *Medical Compilations* continued to be popular, and this popularity was boosted by the existence of Latin translations and commentaries, which rendered their contents widely accessible (*Physical Problems*: de Leemans and Goyens 2006; Oribasius: Morland 1932). Further, the encyclopedic cultures of the Middle Ages and Renaissance looked back to these works as models to build on, but also to supersede (Cadden 2006; Ventura 2004, 2006; Doody 2010, 75–91). Finally, the Arabic reception of ancient scientific encyclopedias constitutes another fascinating chapter in their transmission history, opening a window into the role they played in communicating Greco-Roman science to an altogether different cultural context (Translation and Transmission of Ancient Scientific Texts). Once again, translations of the works into Arabic were seminal in this process. To give but one example, the medical compendia of Oribasius and Paul of Aegina were instrumental in the transmission of Greek pharmacological knowledge to the eastern world, through Arabic and Syriac translations. Further, Oribasius' Arabic translations served as an important medium for the transmission of Galenic medicine among the Arabs (Oribasius: Ullmann 1970, 83–84; Paul of Aegina: Pormann 2004).

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FURTHER READING

On the pseudo-Aristotelian *Physical Problems*, Flashar 1962, Louis 1991–1994, Mayhew 2011, and Mayhew and Mirhady 2011 offer solid starting points for study. B. Centrone (ed. 2011. *Studi sui "Problemata physica" aristotelici*. Naples: Bibliopolis) offers analyses of specific aspects or books. A comprehensive volume of essays is currently under preparation by R. Mayhew. On Pliny the Elder's *Natural History*, Citroni Marchetti (1991, 2011), Beagon 1995, Naas 2002, Doody (2001, 2009, 2010, 2013), and Murphy 2004 are indispensable. By contrast, the medical encyclopedias of later antiquity remain very understudied. van der Eijk 2010 offers a wide-ranging overview of key aspects of their contents. New editions and translations are currently under preparation, in the context of the "Episteme in Bewegung" research project in Berlin (http://www.sfb-episteme.de/teilprojekte/sagen/A03/).

NOTES

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2 Cf., e.g., pseudo-Aristotle *Problems* 3.1, 6, 12; 21 *passim*. That is not to say that *On Medicine* lacks a theoretical backdrop—on the contrary, it closely engages with the wider medical tradition and theoretical debates on medicine: Mudry 1993; Manetti and Roselli 1994; Mazzini 1994.

CHAPTER 59

Translation and Transmission of Ancient Scientific Texts

Sonja Brentjes

1. Introduction

This chapter treats four themes:

1) the cultures involved in translating Greek scientific texts into other languages;
2) problems facing translators and their solutions;
3) institutions involved in the processes of translation and transmission; and
4) narratives that accompanied these activities.

We make no claim that our examples are representative of an entire culture of translation and transmission. They serve instead to individualize and illustrate generalizing descriptions. Owing to the necessarily aggregate nature of our information, the term "scientific texts" stands for a broad range of themes and disciplines, while specific examples are drawn mainly from mathematical and astronomical texts.

Greco-Roman science was multifaceted and multicultural, and the processes of translation and transmission were complex. Natural philosophers, astronomers, physicians, and alchemists in antiquity were geographically diverse (hailing from the Mediterranean, Anatolia, Armenia, Mesopotamia, and Iran), as well as multicultural and multilingual (Aramaic, Middle Persian, Armenian, Coptic, Punic, Greek, and Latin) (Goulet and Rudolph 2011, i–xxxvii). The very formation and survival of the sciences in the Middle East and Byzantium depended substantially on the participation of non-Greek native speakers, especially regarding Neoplatonism and Hippocratic and Galenic medicine.

It is less clear where, when, and by whom alchemy and other so-called occult sciences were taught and translated. The numerous Syriac and Arabic texts of undeniably Greek background testify to lively circles in Egypt, Palestine, Syria, and Iraq at different times (Mertens 2006). The combination of Syriac alchemical treatises with medical texts

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suggests a closer relationship between the two fields in Syriac monasteries (Martelli 2010). New research shows that foundations of ancient Greek alchemy and its Syriac, Arabic, and Latin successors depended on ancient Babylonian practices (Martelli and Rumor 2013; Greco-Egyptian and Byzantine Alchemy). Likewise, Greek astronomy and astrology incorporated Near Eastern knowledge (Britton and Jones 2000; Jones 2003). Moreover, astrological and astronomical work recorded in Greek was conducted in temples of Roman Egypt (Jones 1998, 2001, 2006–2008; Astronomy; Astrology). Other studies indicate knowledge of Babylonian astrology among Jewish communities of Roman Palestine (Leicht 2006). Hence, translating and transmitting ancient sciences involved an arborescent net of translation from and into ancient Near Eastern languages, Greek, Latin, Syriac, Punic, Sanskrit, Middle Persian, Arabic, Armenian, Coptic, Hebrew, Old Slavonic, Old Georgian, and Gə'əz (an Ethiopian language), New Persian, Ottoman Turkish, and Chinese.

Cultural interest in the legacy of Greek science varied in quantity, quality, and disciplinary breadth. Before 1500, the largest number of translations was undertaken from Greek into Arabic. But Greek scientific texts were also translated into Syriac, Middle Persian, Armenian, and Sanskrit. Arabic texts (and translations of Greek texts) in turn were rendered into Armenian, Latin, Hebrew, and New Persian. Syriac and Middle Persian texts (and translations) appeared in Arabic, while treatises in New Persian, at least partly engaging with theories, methods, or data from ancient Greek texts, can be found in summaries or other forms of translation in Armenian, Georgian, or Chinese and perhaps Tibetan. Hebrew and Latin treatises were reciprocally translated. As a corpus, the works of Aristotle and his commentators and detractors—among them Alexander of Aphrodisias (circa 205 CE), Simplicius (*fl.* 530–538 CE), and John Philoponus (490–570)—were translated into Arabic, Hebrew, and Latin before 1500. But individual treatises were not as widely disseminated across languages (except for introductory texts on logic). While some Aristotelian texts as well as commentaries by Alexander of Aphrodisias and John Philoponus also are found in Syriac translation, numerous other Aristotelian texts were never translated into Syriac. Whether or not bilingual Syriac monks read Aristotelian natural philosophy, ethics, or psychology in Greek merits further investigation.

After its initial rejection, Aristotelian logic became the basis for interpreting Christian and then Muslim scripture and belief. Thus, we find Aristotelian texts studied in monasteries, madrasas, and universities in many languages throughout North Africa, Europe, the Middle East, central Asia, and India. One of the most important schools of eastern Syria, where parts of Aristotle's *Organon* apparently were taught, was the so-called School of Nisibis, east of the Euphrates in the Sasanian Empire (224–651 CE) (Becker 2008). These logical texts, probably translated by western Syriac monks (late fifth to sixth centuries) in the Byzantine Empire, served as exegetical tools. Across different languages and times, they were shared among a variety of clerics and laymen: Greek, Syriac, Armenian, Georgian, Latin, and perhaps also Slavonic. In Islamicate societies, they formed a part of legal education and the basis of the epistemology of natural philosophy and astronomy.

The translation of these Aristotelian texts into Syriac, Armenian, and Arabic highlights three important socio-cultural elements that defined opportunities and set boundaries from late antiquity to the early ninth century. 1) Teachers and students were mobile, linking Alexandria with Athens (until the early sixth century), Antioch, Edessa (until 489), Nisibis (after 489), Cappadocia, Constantinople, and other places,

such as the monastery at Qenneshre on the upper Euphrates. 2) From the fourth century onward these educational networks reflected deep changes in the political and legal administration of the Roman Empire, which encouraged bilingual and multilingual skills as well as multiple cultural identities. These networks influenced Greek philosophy, science and literature, Roman law, and Syriac, Armenian, and—to a lesser degree—Arabic religious and literary education (Watts 2004a; 2006; Bradbury 2004, 3) Also affecting the trajectory of transmission were shifts in religious systems (Christianity, Islam), the recognition of new religious doctrines and their practitioners as tools and agents of governance, and the conflicts (internal and external) that these shifts caused or responded to.

Thus, the processes of translation and transmission were rich, multifaceted, and contradictory. The same applies to the contexts, content, and participants who in turn approached ancient texts with different interests, goals, and tools.

2. Translators and Modes of Translating

Translations were often anonymous. Several medical texts (of Hippocrates, Rufus of Ephesus [*fl.* 70–100 CE], Oribasius [*fl.* 350–400 CE], and Alexander of Tralles [*fl.* circa 550–605 CE]), for example, were translated into Latin in the sixth century at Ravenna, where Galenic medicine was pre-eminent—Galenic physicians, often known by name, were unlikely to have translated non-Galenic texts. It is possible that translators and physicians belonged to different schools in Ravenna or even different communities (Mazzini and Palmieri 1991).

Latin translators of Arabic treatises on astrology, magic, divination, alchemy, and similar subjects were usually anonymous. Furthermore, we rarely know why texts were chosen for translation or how those texts were obtained. Since late antiquity, such studies were marginalized and even feared by many Christian clerics as part of competing systems of belief and practice. During the twelfth and thirteenth centuries, when many of these anonymous translations seem to have been made, perceptions of the "occult" sciences were in conflict. Some clerics and chroniclers condemned them, while others debated which aspects were acceptable within a Christian framework and which needed to be suppressed (Hegedus 2007; Page 2013). Within this intellectually contested context, there even arose tales of the negative impact of studying such texts. For example, William of Malmesbury (circa 1095/96–1143) recounts how Gerbert of Aurillac—the future archbishop of Reims who would become Pope Sylvester II (999–1003)—learned about the astrolabe and Indo-Arabic numerals in the northern Iberian Peninsula. After studying the mathematical sciences, Gerbert was gradually seduced into engaging with divination and astral magic, which finally led him to live with a female demon, construct a mechanical head which could answer yes-no questions, and sign a contract with the devil (Watkins 2007).

Not all translations, however, were anonymous. More than ten translators (twelfth to thirteenth centuries) who worked on the Iberian Peninsula or north of the Pyrenees signed their Latin translations of Arabic treatises on astrology, magic, divination, and alchemy. Plato of Tivoli (circa 1100–1150) came to Barcelona, where he translated several texts from Arabic: Ptolemy's *Tetrabiblos*, Abū ʿAlī al-Khayyāṭ's (circa 770–835) book on nativities, a book on divination, further astrological texts, and the astronomical and mathematical treatises of Theodosius of Bithynia (200–50 BCE), Muḥammad b.

Jābir al-Battānī (died 929), and Ibn al-Ṣaffār (died 1035). In addition, Plato of Tivoli translated from Hebrew a geometrical text penned by his colleague Abraham bar Ḥiyya Savasorda (circa 1065–1140), and the two men may even have collaborated on casting horoscopes (Sela 2005, 2–4). John of Seville (circa 1100–1150) and Hugo of Santalla (circa 1100–1150) translated Arabic texts on astrology and divination. While John's provenance is unclear (he is linked to Seville and the Portuguese court), Hugo worked under the patronage of Michael, bishop of Tarazona (Burnett and Pingree 1997). Hermann of Carinthia (circa 1100–1150), perhaps a Slav from the northern Balkans, who considered astrology the "queen of the sciences," translated from Arabic numerous astrological, astronomical, and mathematical texts by Euclid, Theodosius, Ptolemy, and Abū Maʿshar (787–886). He also wrote his own texts on astrology, natural philosophy, and metaphysics. In collaboration with a local Christian in Toledo, Gerard of Cremona (circa 1114–1184) translated Arabic texts of Greek and Arabic astronomy, geometry, medicine, philosophy, astrology, and alchemy. Working in Sicily and perhaps also in the Latin Crusader States, Adelard of Bath (circa 1080–after 1150) translated several works into Latin: one of Abū Maʿshar's astrological texts; Thābit b. Qurra's (died 901) treatise on how to manufacture talismans; and the pseudo-Ptolemaic astrological *Centiloquium*. He, or someone of his circle, even compared newly available Arabic astrological knowledge with methods taught by the Roman astrologer Julius Firmicus Maternus (circa 334–357 CE; Burnett 2005, 5).

The first Abbasid caliphs (circa 750–800) actively promoted astrology and possibly alchemy (a horoscope had been cast to ensure that construction of the new Imperial capital began on an auspicious day in 762). While scattered remarks on translators, patrons, or collaborators can be found in copies of ninth-century works (from 750–800, only fragments are extant), in the tenth century we see comprehensive surveys on translations from Greek, Syriac and possibly other Aramaic dialects, Middle Persian, and Sanskrit into Arabic. The most informative, the *Catalogue* of Ibn al-Nadīm (died 995 or 998), has a chapter (7) on translations of philosophical, mathematical, medical, and technical texts. Ibn al-Nadīm provides three somewhat irregular lists of fifty-seven names of men of diverse origin and religious affiliation who translated philosophical treatises into Arabic from Greek, Syriac, Middle Persian, Sanskrit, and Nabataean (an Aramaic dialect) (Dodge 1970, 586–590). Although we cannot confirm all fifty-seven names, most were historical and are independently attested. Thus, the number of men who made their living by translating scientific, medical, or technical texts into Arabic was much higher (perhaps by a factor of ten) than in any preceding campaign of translation into Latin, Syriac, or Armenian.

Similarly, the number of ancient authors and texts translated into Arabic is remarkably higher than those translated into other languages. Ibn al-Nadīm lists forty-six ancient Greek, Babylonian, and Indian authors whose works were translated. Of these, the most reliably identifiable are Greek (Dodge 1970, 634–645). Not until the sixteenth century do we find again such widespread interest in and translation of ancient scientific works into multiple languages (when such activities enjoyed greater geographical and political diversity—Arabic translation initiatives [circa 775–925] were mostly conducted in Baghdad). Chapter 7 of Ibn al-Nadīm's *Catalogue* enumerates translations of texts by many Greek mathematicians, including Euclid, Archimedes, Hero, and Ptolemy. This information derives from book lists, doxographies, historical chronicles, and from Ibn al-Nadīm's autopsy of manuscripts. Furthermore, Ibn al-Nadīm lists titles of texts, by Euclid for instance,

that are otherwise unknown in Greek sources (Dodge 1970, 636). In other cases, Arabic titles represent either Greek or Arabic texts falsely attributed to famous authors.

Most translators into Arabic were Christians or early converts to Islam. Their patrons were caliphs, courtiers, and physicians. Christian translators hired by Muslim patrons clearly dominate Ibn al-Nadīm's list (about two-thirds were Syriac- or Greek-speaking Christians of different denominations). Other translators were Sabian polytheists from northern Iraq and southeastern Anatolia. The Sabian Thābit b. Qurra, for example, translated texts by Archimedes and Nicomachus of Gerasa (100–150 CE) from Greek into Arabic. He also corrected several existing Arabic translations. The former Zoroastrian ʿUmar b. Farrukhān (*fl.* 750–800) translated Middle Persian astrological texts. Al-Ḥajjāj b. Yūsuf b. Maṭar (*fl.* 750–830) was possibly the only Muslim Arab among Ibn al-Nadīm's translators, who—in cooperation with the Christian Sergius, son of Elias—translated Euclid's *Elements* and Ptolemy's *Almagest* for two Abbasid caliphs or their viziers.

Translators were proficient in at least Greek and Arabic: Qusṭā b. Lūqā (died circa 922) from Baalbek translated Diophantus' *Arithmetic* and Hero's *Mechanics* for Caliph al-Muʿtaṣim's son Aḥmad. Others were competent in Syriac and Arabic. Ḥabīb b. Bihrīz (*fl.* 750–850), the metropolitan bishop of the Church of the East in Mosul, translated Nicomachus of Gerasa's *Introduction to Arithmetic*. This translation was used by Yaʿqūb b. Isḥāq al-Kindī (died circa 870). A third group spoke, read, and wrote Arabic, Syriac, and Greek (a language learned at home in medical families, as part of monastery education, or from travel to Constantinople for improving language skills). Timothy (died 823) from Hazza in northern Mesopotamia, who came to Baghdad by 780, was an astrologer and military advisor to Caliph al-Maḥdī (ruled 775–785) and patriarch of the Church of the East from 780 to 823. Timothy's classmate at a monastic school in Bashosh (where they had studied Aristotelian logic in Syriac and Greek), Abū Nūḥ al-Anbarī (eighth century) was secretary of the Muslim governor of Mosul. Ḥunayn b. Isḥāq was the most prolific translator of Hippocrates, Galen, and Aristotle (mostly into Syriac). His son Isḥāq b. Ḥunayn (died 911) translated Aristotle's *Physics*, Ptolemy's *Almagest*, and Euclid's *Elements* into Arabic. Translators, whose families had dwelled in the Sasanian Empire, most likely also understood at least some spoken Middle Persian, which remained the language of administration until the early eighth century. All in all, translations of Greek scientific texts into Arabic exceed those of all other cultures until 1500. Similarly, new scientific contributions based on the content of these translations attained a recognizably higher theoretical level in geometry, planetary theory, and mechanics in Baghdad than in any other contemporary culture. The survival of ancient Greek philosophy, medicine, and science owes much to the scholarly achievements in the Abbasid caliphate.

Despite differences in approaches to ancient Greek scientific treatises over a vast geographic and cultural area, translators largely shared a set of problems, methods, and values regarding translation and its goals. Translations into various languages oscillated between what Brock (1991, 143) has called "reader-" and "text-" oriented translating. Reader-oriented translating focuses on the target language, and the translator often makes modest to substantial modifications. Particularly vulnerable were passages concerned with religious concepts and beliefs not shared in the translator's culture. In addition, unfamiliar concepts, terms, and methods might be reproduced in a manner that made sense to the translator but that deviated from the source text.

In text-oriented translation, attention is focused on the source language, with an aim to produce a "faithful," literal translation, at the expense of the grammatical and

idiomatic conventions of the target language. Heiberg (1884), for instance, rejected Arabic versions for his critical edition of Euclid's *Elements*, because he considered them "unfaithful." Text-oriented translations were, likewise, often considered "barbaric," to the distress of some translators. Ḥunayn b. Isḥāq, for example, who was commissioned to translate Galen into Syriac or Arabic, first consulted the older translations by Sergius of Resh'ayna (died 536), Ammonius' student in Alexandria, and Job of Edessa (*fl.* 817–832), who had translated for leading Syriac physicians in Baghdad. Ḥunayn reports that his hopes for employing the work of both translators were often frustrated by their "bad" quality (Brock 1991). Perhaps most famously, Gerard of Cremona, translating "blindly word for word" (Kunitzsch 1974; Burnett 2001), invested many years in finding better manuscripts of Ptolemy's *Almagest* and correcting his own mistakes. Two versions of his work circulated among readers, offering passages with improved translations and occasionally less Arabicized Latin formulations against earlier, more convoluted, faulty expressions (Kunitzsch 1974). These contradictions, exacerbated by the modifications and interferences of later copyists, induced the humanists to reject Arabo-Latin translations in favor of those made directly from Greek (Kunitzsch 1990, 19; The Reception of Greco-Roman Science in the Renaissance: Assimilation(s), Transformation(s), rejection, hybridization). The Portuguese physician and merchant Garcia da Orta (died 1568), for instance, impugned Gerard as an incompetent translator, "not a good Arabic scholar," whose medical and pharmaceutical names would have been better rendered as given by "the Arabs," since "they were the inventors of this medicine." Gerard clearly did not know the drugs he was describing (Markham 1912, 41, 102, 113; cf. 409, 412, 457). Da Orta likewise attacked the humanists for unfairly and pretentiously accusing Arabic physicians of "barbarism" on the basis of their translations into Latin, "while the faults are their own" (Markham 1912, 13, 113; see Kunitzsch 1990, 10 for an evaluation of the humanist accusations).

Difficulties faced by translators were tackled in various ways. For instance, to explain unfamiliar terms unobtrusively, the translator might employ hendiadys, by rendering one Greek word with two words in the target language to capture its nuances. For example, the Armenian translator of the *Physiologus* translates *dia chrēstologias* ("through fair-speaking") as "with sweetness and blessing," and *phulaxsei* ("he will guard") as "guards sitting" (Muradyan 2005, 64–65). Likewise, periphrasis, that is, the use of more words in the translation than in the original, intends to clarify elliptical or opaque statements in the source language. In the Armenian translation of Philo, the Greek *therapeutai … kai therapeutrides* ("men and women of the sect of therapeuts") is rendered *bowžič'k 'əst erkowc' azgac' ` əst arowin ew əst iģin* ("healers according to two kinds, according to male and female") (Muradyan 2011, 53).

For difficult and unknown words, translators had to question native speakers or consult dictionaries (not widely available). Both methods yielded mistakes. Individual translators may have misunderstood/misheard and hence misidentified some words, or they might not have grasped the specialized meaning of some terms. In his translation of Muḥammad b. Mūsā al-Khwārazmī's (*fl.* 800–850 CE) astronomical handbook *Sindhind*, for instance, Adelard of Bath used *manqūṣ* ("diminished") instead of the recorded word *mankūs* ("reversed") (Burnett 1985, 166–167), a transposition easily explained if we assume that Adelard did not read the text but rather listened to a recitation. The Arabic letters of these two words are easily differentiated when written, but can be mistaken when heard.

Words that remained inaccessible, despite the translator's best efforts, were simply transliterated: personal names, names of disciplines or titles (geometry, astronomy, *Categories*), or terms whose technical meaning could not be deciphered. For example, we have *elalem* for *al-ʿalam* ("signpost," "banner," identified with the *ǧnōmōn*), and *al manxor* for *al-manshūr* (the "outstretched," signifying a prism) in Arabo-Latin translations. We see transliterated Greek words in Greco-Latin translations: *eteromekes* ("oblong"), *ritus* and *alogos* ("expressible" and "non-expressible," signifying commensurability or incommensurability between lines and surfaces [*Elements* 10, definitions 3–4]; *ritus* is a Latinized transliteration of *rhētos*, if we pronounce *eta* as *iota*) (Busard 1968, 31; 1977, 161; 1983, 76–77, 79, 151; 1987, 14). But translators also tried to recognize the Greek original terms in Arabic transliterations, sometimes succeeding in re-transliterating the word correctly (Kunitzsch 1990, 156–157).

Particularly challenging were foreign names of people, stars, plants, animals, diseases, stones, or gods. Arabic translations often transformed polytheistic gods into the singular God, following a practice also found among earlier Syriac translators. Common are corrupt transliterations of Greek personal names, animate and inanimate objects, and concepts, which scholars cannot always identify. For example, in Abū l-ʿAbbās al-Nayrīzī's (died after 922) commentary on Euclid's *Elements*, the names Aghānīs and Ḥarūmīdis stem from a collection of extracts of Greek commentaries by Hero of Alexandria, Proclus (died 485), and Simplicius (Arnzen 2002). Similarly, translators into Latin rarely managed to identify correctly the names of Greek or Arabic authors found in Arabic texts (Lorch 2008, 35; Kunitzsch 1974, 160; Schoonheim 2000, 186): for example, Mithilem for Maslama of Madrid (died 1007/8); Herundes for Ḥarūmīdis, Inkimis for Anaksimānis/Ankasimānis = Anaximenēs (sixth century BCE), or Abrachis for Hipparchus.

Differences between spoken and Classical Arabic compounded the challenges for Latin translators, yielding new designations like "wolf" (*lupus*) for the Greek constellation *to thērion* (wild animal), slightly modified in Arabic to "predator" (*al-sabuʿ*) (Kunitzsch 1990, 161). Other problems arose from abbreviations, lack of punctuation, use of majuscules, lack of diacritical marks, or different forms for numerals, all of which easily lead to error in interpreting Greek, Syriac, Arabic, Latin, or Hebrew (e.g., in Greek, εἰμί [I am], εἶμι [I go]). The irregular manner of adding or omitting vowels and diacritical signs for identifying consonants in Arabic texts, for instance, often vexed Latin translators. Names of stars or (parts of) constellations were sometimes mutated significantly by such scribal features: for example, confusion of two short vowels "u" and "a" in the shift from "pit" (*ḥuqq*) to "truth" (*ḥaqq*); the omission of a dot above an "h", yielding "ass" (*ḥimār*) for "veil" (*khimār*); or the misreading of "f" for "t" in the replacement of "shoulder blade" (*al-katif* = *spatula*) by "palm" (*al-kaff* = *palma* or, in one case, *planta*) (Kunitzsch 1990, 65, 69–70, 83–84, 107; see Kunitzsch 1974). Hugo de Santalla vividly described his challenges with handwritten Arabic texts:

> Often the translator gasps under the strain of the difficulties. He sees some strange word which resists being translated correctly because of either the variety of diacritical marks on the letters, or the lack of marks—often, too, because of the incompatible differences of the languages in all of which the significance of the roots is different. Then he simply guesses what the word means, lest he may seem to have left out a word, or to be more stupid than he already is. (Burnett 1985, 168)

Translators also testified to their efforts to learn foreign words and expressions. In manuscript 529 of Euclid's *Elements* (Bruges, thirteenth century), a scholiast made marginal notes to explicate some phrases: for example, *aulefeaulen* (which to a German ear sounds undeniably funny) renders *awwalun fa-awwalun* ("each time the first available"). Burnett speculates that this might be a trace of collaboration between Iberian natives (Arabicized Christians [Mozarabs] or Jews) and those men, mostly clerics, who had come from abroad to search for Arabic scientific texts (1985, 167). A similar kind of collaboration occurred three to four centuries earlier in Baghdad, when Christians, Sabians, and newly converted Muslims translated for Christian and Muslim clients and patrons.

Later readers occasionally tried to overcome translation and scribal errors. One of the Latin manuscripts of Gerard of Cremona's translation of Ptolemy's *Almagest* (Vat. Lat. 2057, thirteenth century) contains repeated, though not always accurate, annotations by someone who had compared the Latin text with a Greek copy (Kunitzsch 1990, 17).

Translators also had to tackle grammar, and they employed many methods to express grammatical forms that differed between source and target language or did not exist at all in the target language. Syriac and Arabic, for instance, have no neuter gender (Greek and Latin have three grammatical genders: masculine, feminine, and neuter). Arabic and Hebrew have three numbers (singular [one], dual [two], and plural [three or more]). Homeric Greek also has a dual, rare in Classical and later Greek. Syriac, originally possessing a dual, lost it before our texts were translated. The available types of tenses and other verbal forms also differ significantly between the individual languages. The fact that Greek prepositions can serve as verb prefixes (not possible in Syriac or Arabic) posed additional problems.

Some translators, however, were bilingual or multilingual and fluent in multiple literary cultures. For such men it was easier to navigate between languages, literatures, themes, and meanings. This was particularly the case for translations from Greek into Syriac and from Arabic into Hebrew, New Persian, or Ottoman Turkish. In such environments, the preservation of words and expressions from the source language in the target language signified cultural appreciation or dominance rather than translation difficulties. Although many Arabic translations or commentaries on translations of ancient scientific works were also translated into Hebrew, New Persian, and Ottoman Turkish—for example, Euclid's *Elements*, Archimedes' *On the Measurement of the Circle*, and Ptolemy's *Almagest*—the focus had shifted and was now defined by scientific literature newly produced in Arabic.

3. Multivalent Texts

Multivalent texts, exemplified by the *Physiologus*, *Geoponica*, and Euclid's *Elements* and *Optics*, have been shaped by a series of authors who have contributed new thoughts, methods, and images.

Let us first consider the *Physiologus*, which presented elementary knowledge mainly about animals as an allegory for Christian values and beliefs (see also Zoology). Translations and transformations of the *Physiologus* are known in Syriac, Arabic, Latin, Armenian, Old Georgian, Old Slavonic (Bulgarian), Gə'əz, Coptic, and in lavishly illustrated bestiaries in Icelandic, Old and Middle High German, Anglo-Saxon, Old French, Waldensic, Spanish, and other vernaculars. Its socio-cultural contexts were monasteries,

ecclesiastic schools, courts, royal bedrooms, medical schools, libraries, and, in all likelihood, the homes of better-off families. Hence, we find the *Physiologus* in verse and prose, richly illustrated or hastily penned, as individual folios or mural paintings, gifts to kings and queens, khans and sultans.

The Greek text of the *Physiologus* was repeatedly complemented by material from other sources. For instance, the Syriac translation includes thirty-four items attributed to Basil of Caesarea's (329/30–379) *Hexaemeron* (*Commentaries on the Six Days of Creation*) but omits the last four of the Greek text (Curley 2009, xxvii). The text of the richly illuminated *Aberdeen Bestiary* (circa 1200; MS Aberdeen University 24, provenance unknown) extends to themes not found in the Greek *Physiologus*: for example, the explication of Greek terms and religious themes. In 1542, the manuscript was part of Henry VIII's (ruled 1509–1547) newly established library. But already in the twelfth century, the Plantagenets showed great interest in this kind of literature. Philippe de Thaon (or Thaün; circa 1100–1150) translated a Latin versified *Physiologus* into Old French, dedicating it to Adela, wife of Henry I. Eleanor of Aquitaine, wife of Henry II, received a second copy. Several Plantagenet princes decorated their bedchambers with images from the *Physiologus*. The *Aberdeen Bestiary* may have been used to teach illiterate lay Augustinians and Cistercians who found the images an aid in grasping and memorizing the content.

The *Physiologus* also underwent two partial Arabic translations. In a newly composed text, several entries of the *Physiologus* were combined with medical information from Hippocrates and Galen, a pseudo-Aristotelian book on animals (perhaps Timothy of Gaza's [490–510 CE] lost *On Animals*), and new thoughts by the physician Ibn Bakhtishūʿ (died 1085), a Syriac speaker from a famous medical dynasty. In his own work on the usefulness of animals, Bakhtishūʿ omitted all passages of Christian relevance. An unknown scholar composed the *Use of Animals*, casting the *Physiologus* as a dialogue between Bakhtishūʿ and Aristotle, thus strengthening the text's medical and philosophical aspects (Contadini 2012, 39–49, 50–51). Like the bestiaries for Anglo-Norman queens, the *Use of Animals* was produced for a ruler and, accordingly, richly illustrated. Thus the *Physiologus* remained a living text as scholars, poets, clerics, and other users actively engaged in rewriting, restructuring, reinterpreting, and modifying its content and messages.

Similarly redacted was the *Geoponica* (Greek and Roman Agriculture), the most widely read Byzantine encyclopedia of the tenth century and one of several encyclopedias created on the basis of ancient knowledge during the reign of Constantine VII (ruled 913–959). More than fifty Byzantine manuscripts of the *Geoponica* are extant, produced from the tenth to sixteenth centuries. Printed in Basel in 1539, it continued to be cited in other works until the nineteenth century. Deriving from a (badly damaged) version of Cassianus Bassus Scholasticus' (sixth century?) *Eclogues on Agriculture*, which included a verbatim copy of the fourth-century CE *Collection of Agricultural Practices* (by Vindanius Anatolius from Beirut), the *Geoponica* is a compilation incorporating "Constantinian" material: for example, a chapter on the right season for growing vegetables in Constantinople and mythologies of local plants (Rodgers 2002, 161–163).

The transmission of these texts is still not fully understood, since several translations remain unedited. Anatolius' work was translated, partially or fully, into Latin (fifth century), Syriac (sixth–seventh centuries), and Arabic (eighth to early ninth centuries) (Rodgers 2002, 163; Guignard 2009, 246–248). Bassus' text was translated into

Middle Persian and from there into Arabic (Nallino 1922). The claim found in an Arabic manuscript (MS Leiden Or. 414, dated 813 hirja [=1435 CE]) that Sergius, son of Elias, had translated Bassus' *Eclogues* from Greek into Arabic in 827 in Baghdad is contested, despite the fact that Sergius is known as a translator of ancient Greek scientific texts (Guignard 2009, 251–254). Also disputed is the Armenian translation of an Arabic version of a Greek agricultural text. Guignard (2009, 246; 2012) believes that the Armenian translation renders a version of Anatolius' work, while Scardino (2009, 147) claims that it was made from an Arabic paraphrase of the contested translation of Bassus' Greek text into Arabic by Sergius, son of Elias.

Translations met with various fates according to culture, time, and location. In the western Asian Islamicate territories, for instance, relatively few new agricultural texts were written. In contrast, numerous Arabic treatises integrated ancient agricultural knowledge in al-Andalus (tenth to fourteenth centuries) and Yemen under the Rasulid dynasty (1229–1454). Exceeding the goals of the tenth-century Byzantine encyclopedist, these texts consolidated dozens of books by writers from antiquity and different regions of the Islamicate world. Including observations about local and imported crops, fruits, trees, and flowers, these works were compiled by physicians, courtiers, and agriculturalists with interests in education, the treatment of human diseases, experimentation with plants, and the improvement of agricultural yields. For them, the transmission of ancient texts was both literary and practical (Varisco 1989; García and Carabaza 2009). The *Collection on Agriculture* by Ibn al-Wafīd (died 1074/5), an Andalusian physician, was, moreover, translated into the vernacular languages of Christians on the Iberian Peninsula (Castilian, Catalan) (see http://www.filaha.org/introduction.html).

Transmitted differently was Euclid's *Elements,* the most important text for elementary geometry, number theory, and the theory of proportions. The *Elements* were taught at schools and royal courts in Islamicate, Catholic, and later also Protestant contexts, but also elsewhere in Greek, Arabic, New Persian, Latin, Hebrew, numerous European vernaculars, and perhaps Chinese. Ottoman Turkish versions were translated from Arabic as well as English. This text was given as a marriage present for a princess in India (possibly in the sixteenth century), and in 1607 as a diplomatic gift of Carmelite missionaries to the Safavid shah in Iran. In the same year, the Jesuit Matteo Ricci (died 1610) and the recent convert to Christianity (in 1603) Xu Guangqi (1562–1633) translated the first six books into Chinese. The Chinese translator, an official of the Ming dynasty, believed that scientific works from the "West" (including the *Elements*) could complement Confucianism and restore to virtue the people corrupted by Buddhism and Daoism (Engelfriet 1998, 294).

Short Syriac and Armenian fragments of the *Elements* reflect the particular interests of individuals. A Syriac fragment ultimately goes back to the work of al-Ḥajjāj b. Yūsuf b. Maṭar (*fl.* 786–833). A brief Armenian fragment, ascribed to Gregorios Magistros (990–1059), a well-known Armenian political figure and scholar, also seems to contain traces of an Arabic ancestor—it was probably not translated directly from Greek (Leroy 1936; Zuckerman 1995).

As a late antique and Islamic school text, the *Elements* were considered essential for comprehending Ptolemy's *Almagest* and gaining the necessary theoretical and practical tools to practice geometry, number theory, philosophy, and astronomy/astrology. Euclid's *Elements* guided the research of Arabic scholars, who discussed its structure, definitions, and theorems. Emulating its methods for solving problems or proving

assertions, these scholars applied Euclid's approach in geometry, number theory, algebra, and astronomy. Highlighting the enormous cultural importance attached to the *Elements* in Islamicate scholarly circles, many new editions and commentaries were written in Arabic and, to a lesser degree, in New Persian. Over time, the text lost its scholarly prominence. Teachers, however, sometimes took a more lively and innovative approach to mathematical education—crafting wax models of geometrical objects with which to visualize Euclidean theorems and proofs (Brentjes 2008a, 2014).

4. Institutions

Infrastructure and the institutional framework, within which intellectual activities occurred, strongly affected initiatives to translate, teach, study, or work with ancient scientific texts, images, or instruments. At the schools of Alexandria, there existed a close relationship between Aristotelian logic and Ptolemaic astronomy, especially noted in the works of the Neoplatonist philosopher Ammonius (*fl.* 470–517 CE) and his colleagues. The medical instruction in Alexandria also incorporated substantial parts of Aristotle's *Organon* (Hugonnard-Roche 2004, 2007; Calzolari 2007). Syriac, Byzantine, and Armenian clerics were interested in the zodiac, tables for calculating syzygies, eclipses, and the calendar (in particular the date of Easter). Syriac and Byzantine authors relied mostly on Theon of Alexandria's (360–385 CE) commentaries on the *Almagest* and Ptolemy's *Handy Tables* (Tihon 2009; Claude-Villey 2012, 27). Occasionally, they referred to Ptolemy's *Almagest*, but they also confused the names of authors and their works (Claude-Villey 2012, 26–27, 38, 40). Studies of planetary models are not found in extant Syriac and Armenian sources before the influence of Arabic research. In Byzantium, systematic study of the *Almagest* in the thirteenth century was a response both to the destruction of the Byzantine Empire by the Latin crusaders in 1204 and also to the growing availability of Arabic and New Persian astronomical handbooks and texts on astronomical theory (Tihon 2009; Nicolaidis 2011). In Armenia, astronomical knowledge was gained from reading Aratus of Soli (*fl.* 290–240 BCE) and Basil of Caesarea's *Hexaemeron*. Aratus' treatise was translated into Latin (by Cicero and Augustus' nephew Germanicus) and Armenian, while Basil's book could be read in Latin, Syriac, Armenian, Coptic, Arabic, Georgian, and Old Slavonic (Zuckerman 1995; Arevshatyan 2009; Thomson 2012). The low degree of astronomical expertise among clerics of the eastern churches is exemplified by the predominantly textual use of sources, prevalent in clerical schools. They lacked interest in observations, despite repeated controversies regarding the date of Easter (Tihon 2009; Sanjian 1966).

The curricula established at Neoplatonic schools in Athens and Alexandria in the fifth and sixth centuries—and power struggles there—profoundly shaped the translation activities of Syriac and Armenian Christians. The emergence of multilingual and multicultural identities among Syriac-speaking elites during the fourth century was a response to changes in political, military, and cultural policies first in Rome, then in Constantinople (Brock 1994; Bradbury 2004; Watts 2004a). As a result, numerous men from prominent families began to study at schools in Syria, Anatolia, Alexandria, Athens, or Beirut under the tutelage of scholars of Greco-Roman rhetoric, philosophy, medicine, or law. Over time, local village schools were founded, as were schools for religious education attached to monasteries. Various Christological struggles and the ensuing competition

for adherents bolstered the formation of curricula specifically tied to differences in doctrine, liturgy, and other ecclesiastic issues. Translating, re-translating, editing, commenting, and teaching parts of the ancient sciences in some of these monasteries was integral to social and ideological struggles among elite clerics (Tannous 2013). In the seventh and eighth centuries, the Syrian Orthodox monastery of Qenneshre on the Euphrates was the main center of work with ancient scientific (and other) texts.

Similarly, political and military conflicts between the Byzantine and Sasanian Empires induced Armenian elites in the late fourth century to abandon multilingual (Greek, Syriac, or Middle Persian) administration, education, and liturgy. The Armenian monk Mesrop Mashtots (362–440) created an Armenian alphabet derived from Greek, possibly with the help of Syriac monks from Edessa and Samosata. Patronized by the court and the head of the Armenian Apostolic Church, Mashtots—together with his students—translated (primarily) religious literature from Greek and Syriac into Armenian during the first half of the fifth century. On the basis of these efforts, further translations were undertaken in the fifth and sixth centuries by mostly unknown men of "the Hellenizing school" (Tērean 1982; Thomson 1995). Likewise, with dynastic support, the Armenian Apostolic Church moved to replace Byzantine schools with ecclesiastic education conducted in Armenian (Hairapetian 1995). Translating in Armenia (circa 400–600 CE) was, thus, a highly political endeavor within a religious framework. Teaching about nature, the heavens, and numbers remained a low priority among Armenian clerics—as well as Syriac, Coptic, Byzantine, and Slavonic—for centuries (Zuckerman 1995; Tihon 2009; Richter 2009).

An important institutional form of safeguarding, questioning, and even transforming ancient texts in content and context was the production of commentaries, a practice begun in the second century CE (Mansfeld 1994, 1998). Syriac commentaries, primarily on Aristotle's *Organon* and composed under the influence of training at Alexandria, were produced more or less continuously from the late fifth/early sixth century into the mid-tenth century, and then again in the thirteenth (Brock 1993). Armenian commentaries, much rarer and less studied (Pontani 2011, 129), focus primarily on Aristotelian logic, the pseudo-Aristotelian *On the World*, and translations of Philo (circa 20 BCE–50 CE). Commentaries in Arabic, New Persian, Ottoman Turkish, Hebrew, and Latin, on the other hand, are plentiful, representing different teaching and learning cultures.

More significant are the processes of professionalization and standardization. Before 1500, no professional specialization as translator existed. But some men spent much of their lives translating scientific texts in addition to their other occupations as doctors, monks, courtiers, deacons, or teachers. Among these men were John of Seville, Gerard of Cremona, and Michael Scot (died circa 1232) first in Toledo and then at the court of Frederick II (ruled 1220–1250) in Sicily. Ḥunayn b. Isḥāq and Thābit b. Qurra translated, edited, wrote, and trained a younger generation of translators and scholars in medicine, philosophy, and the mathematical sciences. Ḥunayn's son Isḥāq b. Ḥunayn and nephew Ḥubaysh became well-known translators in their own right. Thābit trained young Christians and Jews.

Under the Abbasid caliphate, the court sponsored many translations of scientific works. The first generations of Abbasid rulers and administrators created a complex, expressive narrative of identity and allegiance, revolution, piety, familial obligation, and knowledge (El-Hibri 1999). Gutas argues that the ideological, relational, and institutional conditions of the Abbasid upheaval and their manner of seizing, defending, and negotiating power in the 740s and 750s set the framework for these activities of

translation (1998, 28–104). In the eighth century, translation efforts focused on Middle Persian astrological texts (mainly) and Sanskrit astrological and medical treatises. In the later eighth century, attention began to shift to Syriac and Greek texts on logic, rhetoric, argumentation, and ethics. In the ninth century, many philosophical, medical, and scientific works were translated from Greek into either Syriac and then Arabic, or directly into Arabic. Gutas (1998) argues that this shift in cultural and disciplinary interests followed from a philhellenic, anti-Byzantine policy designed by Caliph al-Ma'mūn and his advisors in the 820s. Gutas' analysis, focusing almost exclusively on events in Baghdad and the entourage of the Abbasid caliphs, takes translation activities as components of a single, long-term process. Rejecting Gutas, Saliba denies the importance of the Iranian element in the Abbasid rebellion and its reinvention of Sasanian ideology and institutions (2007, 39–49, 65). He downplays earlier parallel translations of Middle Persian, Syriac, and Sanskrit treatises. Suggesting an institutional change (the early eighth century administrative move from Greek or Middle Persian to Arabic), Saliba accepts anecdotes (from later ninth and tenth-century writers) of professional competition between Greek and Iranian scribes who lost their jobs to Arab native speakers (2007, 49–64). These displaced scribes allegedly regained employment by studying and translating advanced mathematical and astronomical works (Saliba 2007, 58–62). As documented in extant translations, the only local, professionalized groups indisputably involved in translating ancient sciences from Greek, Syriac, Middle Persian, and Sanskrit were Syriac and Arabic physicians and Iranian astrologers of different religious beliefs. Where the Iranian astrologers had lived, learned, and practiced during the previous century of Muslim rule is unknown. Most first- or second-generation converts from Zoroastrianism had migrated to Basra or Baghdad from Khorasan, that is, the Iranian east, and they may have received their training at the fringes of the caliphate.

Courts, house teachers, and the economic, infrastructural, and cultural opportunities to travel widely constituted the main institutional elements for the spread, preservation, and intensive use of the ancient sciences in the Abbasid caliphate and its Islamicate competitors in central Asia, Afghanistan, northern India, Iran, eastern Anatolia, Egypt, Yemen, North Africa, Sicily, and al-Andalus. Many newly emerging local dynasties patronized scholars of ancient sciences: the Samanids in central Asia, Aghlabids in North Africa and Sicily, Fatimids in Egypt and Sicily, and Umayyads in al-Andalus (Brentjes 2008b). Therefore, the ninth to thirteenth centuries are often called "the Golden Age" of sciences in Islamicate societies. Later, these sciences, nonetheless, were not abandoned or marginalized by religious forces. After 1200, courts also patronized scholars studying philosophical questions, observing eclipses, calculating prayer tables, or solving geometrical, algebraic, and arithmetic problems (Brentjes 2008c). What had changed was that a new kind of institution (the madrasa), formed by a religious community in the East, became an instrument in the political, religious, and social struggles in Iran and Afghanistan under the new Turkish dynasty of the Great Seljuqs (1045–1256). In its Seljuq form, the madrasa first delivered higher education in Islamic (Shafi'ī) law. Within a century or two, this new institution spread throughout Iran and Iraq to Anatolia, Syria, and Egypt, and then, in the following centuries, into North Africa, the Iberian Peninsula, India, central Asia, and Sub-Saharan Africa. The disciplinary scope also grew considerably. Since the late twelfth century, the ancient sciences and their Arabic (and later New Persian and Ottoman Turkish) successors gained entrance and found stability in madrasas (and mosques). This also meant that Aristotle, Euclid, Archimedes,

Ptolemy, and others were taught and studied in Arabic translation in various cities and, at times, even in little towns, villages, or fortresses.

Similarly, institutions of higher education secured the continuation of the evolving ancient scientific traditions among Jewish, Catholic, and Orthodox scholars in Byzantium, kingdoms in Europe, or cities of North Africa and the Middle East, although with their own special trajectories.

5. Narrating the Translation and Transformation of the Ancient Sciences

Many narratives recount the transmission or revival of ancient science. For example, we hear (apocryphally?) that Ammonius brokered a "deal" with the patriarch of Alexandria, Peter III Mongus (477, 482–489), that allegedly "saved" the school and protected ancient sciences and philosophy against further Christian attack. Three hundred and fifty years later, two conflicting Byzantine stories emerged. One regards the transfer of technological (and other) knowledge from Abbasid Baghdad to the Byzantine court; the other highlights the superiority of a mathematician at Constantinople over those at the Abbasid court in Baghdad. Physicians, philosophers, and courtiers of the Abbasid and later dynasties told stories about both the transfer of medical and philosophical education from Alexandria to Baghdad and the origin of the so-called translation movement.

Latin translations of Arabic astrological, philosophical, and other twelfth-century treatises in the northern Iberian Peninsula contain narratives of cooperation between the translator as student and a local expert as teacher of the ancient sciences. Here we can merely highlight the importance of such narratives in periods when translations were undertaken, networks of patrons, scholars, and readers emerged, or institutions were created or reformed.

The transmission and loss of ancient scientific knowledge across the Mediterranean was integral to conflicts between and within different philosophical and medical schools as well as between adherents of non-Christian religions and various Christian denominations. Best known, perhaps, is the legend of Theon's daughter Hypatia, an accomplished philosopher in her own right, murdered by Christians circa 415. Others include Horapollo (late fifth century), Heraiscus (late fifth century), Ammonius, and the Neoplatonist Damascius of Athens (died after 538 CE) (Szabat 2012).

Conflicts surrounding Proclus (died 485 CE) and his successors Marinus of Neapolis, Isidore of Alexandria (died circa 520 CE), and Hegias of Athens destabilized the school in Athens, where wealthy Christians increasingly tried to curb religious rituals advocated by Proclus and Hegias and the study of philosophy, astronomy, and mathematics. Proclus, for example, succeeded in marginalizing his classmate, Domninus of Larissa (died 480 CE), the Jewish philosopher and mathematician from Syria, whose works are mostly lost (excepting the *Introduction into Arithmetic*: Watts 2006, 112–113). Watts considers these internal controversies and resultant tensions an important context for Justinian's edict of 529 whereby the school's outreach and financial stability was severely curtailed (2006, 115–136).

Justinian's edict accused philosophers of misleading rather than educating students in philosophy, astronomy, and other divinatory arts. Damascius, Simplicius, and their colleagues are said to have left for the Sasanian Empire, seeking refuge from Khus-

row (ruled 531–579) renowned for his interest in philosophy (Watts 2006, 5–7, 422). Damascius and his companions left Athens in 531 after two new Imperial laws mandated the loss of their houses, personal property, and financial support (Watts 2004b). In 532, in a peace treaty with Justinian, Khusrow stipulated the philosophers' return without further harassment (Watts 2006, 6). An epigram from Emesa, attributed to Damascius, suggests that the now elderly philosopher, who no longer considered Athens his home, returned to Syria, the country of his birth.

It is unknown where Simplicius and others worked on their Platonic and Aristotelian commentaries after 532 (Watts 2005, 2006). And it is disputed whether this riddle is connected with the transfer of philosophy from Alexandria to Baghdad. According to tenth- and thirteenth-century Arabic sources who talk of a limited Syriac engagement with Aristotle's *Organon*, the hubs of transfer were Antioch in northern Syria, famous for its Christian communities, and Harran in northern Mesopotamia, where polytheistic communities continued to thrive well into the Abbasid period (Meyerhof 1930; Tardieu 1990). Considering Syriac monasteries in northern Iraq as the most likely venue for such transmission, historians of Syriac intellectual history emphasize the variegated character of Syriac Aristotelianism, pointing to Syriac translations of *Posterior Analytics*, for instance by Athanasius of Balad (634–686) (Watt 2010; Griffith 2008, 106–108).

Currently, four versions of this transmission narrative are known in Arabic. Focusing on the transmission of philosophy are versions by al-Fārābī (transmitted in a thirteenth-century history of physicians) and the traveler, historian, and geographer ʿAlī b. al-Ḥusayn al-Masʿūdī (died 956). Pertaining to the transmission of medicine are renditions by the physicians Ibn Riḍwān (died 1068) and Ibn Jumāyʿ (died 1198). Two intermediary stations (Antioch and Harran) are cited for philosophy, and Harran alone figures in the transfer of medical knowledge. A closer look at these accounts suggests that the transfer stories were not the invention of Muslim physicians and philosophers, but originated partly in an ancient milieu (Gutas 1999, 169).

Two strands form the likely ancient nucleus of these four stories: 1) the role of rulers in the flourishing or decline of philosophy or medicine; 2) a later crisis of teaching, in philosophy and medicine, and the curricula resulting from that crisis. The remainder contains essentially the story of transmission, also combining two cores: the trajectory of the move and its circumstances; and the fate of these domains of knowledge in Baghdad.

Since the 1930s, historians of medicine and philosophy have studied this narrative of transmission, teasing out the historical from the fictitious (Meyerhof 1930, 1933; Strohmaier 1987; Stroumsa 1991; Lameer 1997; Gutas 1998, 1999; Daiber 2012). They substantially disagree in their evaluations. Lameer (1997) attributes the transmission from Alexandria to Baghdad via Antioch and Harran to the Church of the East and the Sabian community, but he overlooks the participation of other Syriac and Greek Christian communities as well as the involvement of Muslim patrons and researchers.

Daiber sees in these stories both the importance of Alexandria for the translation and transmission of Greek science into Syriac and Arabic, and the intermediary role of Harran for the transmission of Hermetic, alchemical, astrological, and Neoplatonic treatises (2012, 50–51). Rejecting the role of Antioch, he claims, without proof, the existence of translators of Greek scientific works in Harran, of whom only one is known: the Chalcedonian patriarch Theodore Abū Qurra (died circa 830) translator of the Pseudo-Aristotelian *Virtues and Vices* (Griffith 2008, 107). Daiber proposes instead that the move from Antioch to Harran reflects the transfer of the Umayyad seat from Damascus

to Harran by the last Umayyad caliph Marwān II (ruled 744–750) (Daiber 2012, 49). Stroumsa accuses al-Fārābī of anti-Christian bias (1991, 281). Gutas, on the contrary, interprets the narrative's anti-Christian tone as anti-Byzantine (1999, 175–177). The anti-Christian language in the transmission narrative stems from the prominent role of al-Ma'mūn's anti-Byzantine rhetoric and military activities of the later 820s (Gutas 1998, 95–94; 1999, 177). No scholar, however, has yet analyzed the transmission narrative as narrative, disentangling its layers, plots, and rhetorical strategies, investigating the strata provided by each transmitter/storyteller, and tracing the elements of the Arabic versions in Greek or Syriac sources.

Patriarch until the end of the second iconoclastic period (837–843), John the Grammarian (died before 867) served as ambassador to Caliph al-Ma'mūn for his student, the emperor Theophilus (ruled 829–842). John was apparently impressed with the Abbasid court's splendor, technology, and scientific knowledge (partly anchored in the translation activities undertaken in Baghdad since 762). On his return to Constantinople, John participated in constructing various automata for a Bithynian palace, newly restored on the Abbasid model (Nicolaidis 2011, 55–56).

While this Byzantine narrative bespeaks the superiority of Abbasid technology, the other is more complex. The second tale describes the adventures of a hero in search of lost philosophical and mathematical knowledge. Looting monastery libraries far away in the Mediterranean, the traveler returns some of the ancient sciences to the Byzantine elites. In its second part, the account emphasizes Byzantine intellectual leadership and the hero's preference for Constantinople over Baghdad. In the end our "scientific saint" receives Imperial honors through a letter of invitation to the Abbasid court. Hence, the hero's intellectual preeminence can only be validated through the Abbasid court and the caliph's desire for scholars trained in Euclid's *Elements*.

The hero of this second story is John the Grammarian's aristocratic cousin Leo the Mathematician (790–869). Leo lamented that the capital had few teachers of the *trivium* and none of the *quadrivium*. In his search for teachers (and manuscripts), Leo came upon only one badly educated instructor at Andros, whose monasteries, however, held a treasure trove of manuscripts. Leo ransacked the monasteries and restored the ancient sciences to Byzantium. This tale of the restoration of the secular sciences accords with a basic structure of Byzantine hagiography (Nicolaidis 2011, 57). The second part recalls Leo's invitation to the court of Caliph al-Ma'mūn. As a prisoner of war and slave at the Abbasid court, one of Leo's students allegedly applied Euclid's proofs to a problem in land surveying, showing himself more skilled than the caliph's surveyors. The caliph released the student with a letter of invitation to his teacher Leo. Leo showed the letter to Theophilus, who finally rewarded the man's talents with a commission to offer public courses in the ancient sciences in Constantinople (Nicolaidis 2011, 57). Not wishing to reveal the glory of Byzantine Greeks to the enemy, Leo "patriotically" refused the caliph's invitation (Nicolaidis 2011, 57). The narrative is fanciful self-aggrandizement conceived for a Byzantine audience. Knowledge of the ancient philosophy and mathematical sciences at al-Ma'mūn's court in Baghdad was, however, extensive in the 820s, and three of al-Ma'mūn's courtiers produced sophisticated annotated editions of the *Elements*. Moreover, Euclidean theoretical geometry was not applied in manuals on surveying. Early Abbasid historical literature preserves pieces of al-Ma'mūn's anti-Byzantine propaganda. It often features condescending anecdotes toward illiterate, ill-educated Byzantines, but it contains no trace of Byzantine envoys or prisoners of war skilled in mathematics.

Although it is important to search for historically sound features in such narratives, their significance consists in the valorization of actors and their activities. The appreciation or rejection of actors and activities illuminates attitudes toward the ancient sciences, their practitioners, and patrons as well as competing camps (where they existed). Such attitudes stimulated or obstructed scientific research and teaching (in whole or part) and could inspire students and teachers to explore new directions in interpreting old knowledge. Such transmission narratives continue to inform our own beliefs about the value of ancient knowledge.

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CHAPTER 60

The Reception of Greco-Roman Science in the Renaissance: Assimilation(s), Transformation(s), Rejection, Hybridization*

Roberto Lo Presti

1. Introduction*

This chapter provides an overview of one of the most complex, controversial, multifaceted, and deeply investigated phenomena concerning the reception of the Greco-Roman intellectual legacy in the Western world. This aspect nevertheless remains underestimated in many respects. Our topic is twofold:

(1) the early modern reception of Greco-Roman science; and
(2) Greco-Roman epistemological debates on how to define "science."

We will investigate early modern arguments regarding how to distinguish "speculative" science from, for example, applied technical knowledge, as well as how to order, classify, and hierarchize different "scientific" forms of knowledge according to a number of criteria (logical, methodological, ontological, discursive, and didactic/pedagogic). These two trajectories—the "factual" and the "epistemological"—cannot be separated and therefore must be considered conjointly for at least two reasons. First of all, Greco-Roman "scientists" (natural philosophers) characteristically developed epistemological discourses on methods of inquiry and proof in parallel with, and in support and justification of, the scientific discourse in the strictest sense. This is especially pertinent for medicine, since many Hippocratic authors and, later, Galen wrote extensively on the

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methodological and logical foundations of the medical *technē* (craft, skill). But this is also relevant for Aristotle, whose logic as expounded in the *Categories* and whose theory of proof and demonstration as expounded in the *Posterior Analytics* provide a solid and necessary basis for the investigation of the natural and biological world. Second, the link between scientific practice and epistemological inquiry into the premises, conditions of validity, and internal organization of the "scientific" enterprise is also a peculiar trait of this intellectual movement, which accompanied, characterized, and influenced the rediscovery of Greco-Roman science in the early modern age.

The breadth, richness, and complexity of the topic render impossible any degree of comprehensiveness in the short space of a companion chapter. We shall, therefore, offer insight into perhaps one of the most distinctive, problematic, and simultaneously fertile aspects of this reception, that is the manner in which Greco-Roman science and epistemological debate on the very nature and boundaries of the notion of "science" were received, handled, understood, transmitted, taught and (re-)thought, criticized, (re-) used, or rejected in the intellectual milieu of Italian universities and the *Academie* in the period ranging from 1500 and 1650, with a special focus on three disciplines: medicine, physics (still understood in the Aristotelian sense of "physiology" [*physiologia*]) or "natural philosophy" (*philosophia naturalis*), and mechanics.

Anyone interested in the history of science and history of the reception of Classical antiquity must deal with two key problems. The first problem concerns defining that science, or those sciences, of which we want to make the history, for "science" is a complex, theory-laden, and historically determined notion. Not only is *our* notion of science very different from the ancient notions of *epistemē* and *scientia*, but also this modern notion of science usually follows a process of distance from and the emphatic rejection of the ancient scientific model. This very process, which historians of science usually refer to as the "scientific revolution," culminates around the middle of the seventeenth century with Galilean and Cartesian paradigms and in what has been defined as the "mechanization of the world picture" (Dijksterhuis 1961). This process has been long represented as a most dramatic "paradigm shift" (Kuhn 1962), resulting in a sharp and even violent break with an earlier conception of the world substituted with an entirely new alternative worldview (Butterfield 1959; Koyré 1939, 1957, 1961, 1966).

In more recent times, however, an historiographical approach has been more sensible to the permanence and persistence of the past and more inclined to give a full account of the gradual progression of the intellectual processes even within the stream of major paradigmatic transformations. This approach has put forth persuasive arguments in support of a "continual" account of the formation of "modern science" intended both as a notion and as an organized and highly formalized system of practices (Cunningham and Williams 1993; Osler 2000; Lindberg and Westman 1990; Jacob 2010). It has been shown that the early stages, and even the premises of the scientific revolution, are traceable to the beginning of the sixteenth century. At this time, as a consequence of the fall of Constantinople, many Greek manuscripts arrived in the West (especially in Venice, Padua, Rome, Naples, Bologna, Pisa, and Pavia). A number of Greek scientific, philosophical, and technical texts thus became available for the first time in their original languages (e.g., most mathematical texts were known in the Middle Ages only through compendia and translations from Arabic versions into Latin) or were first translated from Greek into Latin (e.g., the pseudo-Aristotelian *Mechanical Questions*, first printed in Latin in 1517). These treatises were the subject of rigorous philological editions and commentaries, and (re)printings.

On the one hand, this phenomenon gave rise to an impressive "humanistic" revival of, interest in, and a new and deeper understanding of Greco-Roman science and technology, especially of the Hellenistic period. This humanistic revival was characterized by a strong experimentalist and anti-dogmatic attitude (Russo 1996) and by a clear emphasis on disciplines like mathematics, mechanics, hydraulics, and anatomy. In this respect, it was not by chance that medical representations of the body, such as those of the Hellenistic doctors Herophilus and Erasistratus, were often regarded as the first attempt to produce a mechanistic account of human anatomy and physiology (von Staden 1997). On the other hand, the reappraisal of the most "progressive" aspects of ancient Greco-Roman science was coupled with a growing interest in collecting, assessing, classifying, and systematizing observations, facts, and experiences. Both these phenomena also explain why, from the very beginning of the sixteenth century, issues concerning the logic and methodology of (scientific) discovery started to stimulate lively debate. Now, with regard to both these tendencies—the humanistic rediscovery of Greco-Roman science and a new emphasis on "facts" and "observations" as the fundamental material (*materia prima*) of the scientific enterprise—Italy played a predominant role; for Humanism as a method of inquiry into the Greco-Roman world and, more broadly speaking, as a cultural movement was first and foremost an Italian phenomenon (Kristeller 1979, 21–32, 85–105). It was also in Italy that the new empirical vein started forming and orienting the epistemological debate on the logic of proof and demonstration, a debate that finally culminated in the elaboration of the experimental method. This trend occurred not only in universities like those at Padua, Pisa, and Bologna, where the theoretical study of natural philosophy was propaedeutic and subordinate to that of medicine, a "practical" discipline, but also at other institutions like the *Academie*.

The secondary problem concerns the very nature of that cultural process that we define as "reception of Classical antiquity." For we tend to consider this centuries-long process—an ongoing intellectual enterprise in the Medieval and early modern Western world—as merely, or primarily, an acquisitive one: a process firmly based on the respect, and even veneration, of ancient authorities and consisting in the preservation, transmission, elucidation, and explanation of given texts and knowledge rather than in the exploration of new paths of enquiry and in the development of original knowledge. Of course, this picture is partial, and I would say even patently wrong; for, at every stage of this process, reception, assimilation, and transmission have been synonymous with the transformation, adaptation, and in some cases even of radical rethinking of and distancing from the contents of the ancient sources.

This combination of the "acquisitive" and the "transformative/critical" aspects is more manifest in some contexts and in some periods than others. From the early sixteenth century to the middle of the seventeenth century, however, it becomes striking, especially if we consider the developments of Aristotelianism. Until its emphatic rejection by Galileo, Descartes, and the followers of the new experimental method and the mechanistic conception of the (natural) world, Aristotle's system of thought provided both the predominant worldview and also the logical, methodological, and epistemological framework for every kind of investigation that was to be labeled "scientific." For in the preceding century and a half that prepared for the definitive dismissal of the Aristotelian worldview and his scientific methodology, Aristotle's works on natural philosophy (especially his physical, zoological, and psycho-physiological treatises: *Physics*, *On Animals,* and *Short Treatises on Nature*), together with Greek, Byzantine, and

Arab commentaries on those works, were received with great interest. There appeared an unprecedented number of commentaries, which in many cases took into account new discoveries and theories, especially in anatomy and physiology, and tried to align them with the elucidation, interpretation, and defense of Aristotelian doctrines. Italian universities also played a role of unparalleled importance, as testified by the fact that the number of commentaries written in Italy or by Italian commentators on the above-mentioned Aristotelian works between 1500 and 1650 is far higher than the number of commentaries written in the rest of Europe in the same period. It is also to be noticed that, especially in Italy—and in particular at the universities of Padua, Bologna, and Pisa—the reception of Aristotelian doctrines as well as of specific texts belonging to the Aristotelian Corpus was in some cases the premise for the development of new theories. For example, the circulation of blood was discovered by William Harvey, whose debt to Aristotelianism has been widely investigated by Pagel (1967), French (1994), and Cunningham (2006), among others. There occurred, furthermore, highly progressive debates on the nature, scope, and methodology of disciplines. The sixteenth- and seventeenth-century debate, for example, between Tartaglia, Benedetti, Guido Ubaldo, and Galilei on whether mechanics was an "art" or a "science" was largely prompted by the reception of the pseudo-Aristotelian *Mechanical Questions* (see §5 below).

A final general point concerns the structure of the *curricula* of the arts faculties in the Italian universities, that is, of those institutions where this reception mainly occurred in our period, for arts faculties did not develop in the same way in Italy as they did in Paris or at the German universities. The liberal arts subjects in Italy were principally directed toward preparation for medical or legal studies. For the most part, the arts degree was not considered an end in itself or a first step toward a degree in theology (as in Paris), but instead the arts degree was deemed as propaedeutic to a degree in medicine, which represented the culmination of the university education (Schmitt 1975). Medical education, as organized in the Italian universities, was divided into a two-tier curriculum: a biennium, during which students were taught logic (on the basis of Aristotle's *Posterior Analytics*) and natural philosophy (on the basis of Aristotle's *Physics, GC, On the Soul, Short Treatises on Nature*); and a triennium, dedicated to the study of theoretical and practical medicine through reading Hippocrates, Galen, and the Arab physicians Avicenna and Rhazes. This peculiarity of the Italian university system is essential in fully understanding why the reception of Greco-Roman science as a whole and of every single "scientific" discipline developed in some directions rather than in others and why some disciplines fared better than others.

2. The Reception of Greek Logic and Epistemology in Early Modern Debates on Method

In 1637, René Descartes published his *Discourse de la méthode* ("Discourse on the Method"), considered by many as the beginning of a new era in philosophy and epistemology. In fact, vivid debates on scientific methodology and the logic of discovery and proof already characterized the sixteenth-century intellectual milieu. Their theoretical richness was such that, as suggested by intellectual historians like Cassirer (1906) and Randall (1961), they "foreshadowed the great expansion of scientific research in the next century" (Gilbert 1960, XIII). These debates are relevant to an account of the

reception of Greco-Roman science in the early modern age because they relied entirely on discussing, commenting on, and eventually developing the ideas of ancient authorities. These authorities were mainly four: Plato, Aristotle, Galen, and the Greek and Arab commentators on Aristotle.

Plato was seen as the father of the "dialectical method," and more precisely of four kinds of dialectical methods: analytical, definitive, divisive, and apodictic. These could be extracted from his dialogues; and their characteristics, fields of application, and conditions of validity were still discussed in the sixteenth and early seventeenth centuries.

A second source, by far the most important, of early modern debates on scientific methodology was Aristotle, especially his *Physics* and *Posterior Analytics*, both part of the standard biennium curriculum at all Italian faculties of medicine and consequently the object of a great number of commentaries. This represents a kind of paradox, since neither the *Physics* nor even the *Posterior Analytics* are treatises on what we would call the scientific method. The latter is a treatise on the logic of demonstration and proof, or, rather, an analysis of the conditions under which we may be said to know something with scientific certainty. In this respect, "the complaint frequently heard from students of Aristotelian philosophy during the late Renaissance—that Aristotle had not dealt with method—was certainly justified" (Gilbert 1960, 7). However, the distinction drawn by Aristotle in his *Physics* between demonstration *propter quid* ("why something is the case") and demonstration *quia* ("the case") represented a cornerstone for the entire epistemological debate in the early modern age.

A third, very important, source was Galen, especially the beginning of his treatise *On the Medical Art*, known in the Middle Ages and the Renaissance as the *Ars Parva* ("the Small Art"). In this treatise, Galen distinguished three methods of teaching medicine: analytic, synthetic, and a third method for which Galen provided a number of possible denominations: "unwinding," "analysis," "division," "unfolding," and "explicating." Also, in regard to Galen, whose *On Demonstration* was already unavailable to Renaissance scholars, it is difficult to get a full, coherent picture of his logical and epistemological theories. Nevertheless, Galen played a key role in the early modern debates on the scientific method, debates characterized by an increasing awareness of the centrality of empirical observation and experiment in scientific practice. Galen was the only Greek thinker, and furthermore a physician, who espoused a "logical empiricism" that recognized the validity and applicability of method both to intellectual/logical and to sensory/experiential aspects of scientific enquiry.

Our fourth source encompasses the Greek commentaries on Aristotle´s logical works as well as Averroes' commentaries on the Aristotelian *Organon* and *Physics*. Most of these commentaries, largely rediscovered in the sixteenth century, provided invaluable materials for early modern debates on method and logic of discovery, as they frequently combined an interest in the exact sciences with a scholarly and philological approach to the exegesis of philosophical texts. Moreover, most of these commentaries stemmed from a Neoplatonic environment or, as in the case of Averroes' commentaries, mixed Aristotelian and Neoplatonic doctrines with materials derived from Galen's logical theories. This fact harmonized Platonic and Aristotelian dialectical methods on the one hand, and the "philosophical" and the "medical" methods on the other. This harmonization was one of the main concerns of Medieval and early modern commentators, who were always eager to solve contradictions and to recognize an overall coherence between their authoritative sources.

The early modern reception of ancient Greek theories of proof and scientific demonstration inspired an intense epistemological debate. Aristotelians such as Pietro Pomponazzi and Jacopo Zabarella attempted to combine the inductive and deductive methods as expounded in the theory of syllogism of the *Posterior Analytics*—a theory of proof—and Galen's analytic and synthetic methods into an integrated method of scientific discovery and a coherent science of hypothesis and demonstration. In order to do that, Zabarella and other Renaissance scholars developed the so-called "theory of regressus," which has many points of contact with Galilei's "anti-Aristotelian" method of scientific discovery and can be summarized as follows:

> Zabarella, and with him the whole new science, insisted that experience must first be analyzed carefully to discover the precise principle or cause of the observed effects, the universal structure involved in them. After this analytic way of discovery has been pursued, we are then in a position to demonstrate deductively how facts follow from this principle or cause: we can pursue the way of truth. Scientific method, that is, proceeds from the rigorous analysis of a few selected instances or illustrations to a general principle, and then goes from that principle back to the systematic and ordered body of facts, to the science itself formally expressed. Zabarella calls this the combination of the resolutive and the compositive methods. (Randall 1961, 49–68)

3. Physics

When speaking of the reception of ancient, namely, Aristotelian, physics in the early modern period, we must first clarify what is meant by "physics." It is widely recognized that the mathematized and quantified physics of Galilei and Descartes represented a clear break from the Aristotelian quality-based system. In the *Physics*, Aristotle addressed quantitative laws of motion as merely one of several topics. He was instead more concerned with the definition of "nature" and its "principles," the distinction and interaction between matter and form, and natural—that is, qualitative—change (Matter). In this regard, "physics" (*ta phusika*) in the Aristotelian conception covers "a little of what we call physics and quite a bit of what we call metaphysics" (Des Chene 1996, 1) and is therefore to be understood in quite a broad sense, that is, in the same sense that Medieval and Renaissance thinkers wanted to convey with the expressions *philosophia naturalis* ("natural philosophy"), or *physiologia* ("the study of nature and natural things").

Now, it is was just in the period between 1500 and 1650 that the very notion of "physics" underwent a deep reshaping and that "physics" as a scientific discipline was gradually reinvented as a post- and even an anti-Aristotelian science. Here it is worth briefly considering one of the main aspects of this process of "reception-cum-reinvention" of Aristotle's physics, that is, the early modern debate on the hierarchy of sciences and the place held by physics (viz., natural philosophy) within this hierarchy, and especially the position of one of the most influential Aristotelian philosophers of the time, Pietro Pomponazzi. Pomponazzi distinguishes between two possible hierarchies of the sciences: one, based on an ontological criterion, considers "the sciences as such" (*quoad naturam*), while the other, based on a methodological criterion, considers "the sciences in relation to us" (*quoad nos*). In Pomponazzi's view, different hierarchies of the sciences correspond also to different criteria, for, when establishing a hierarchical order of the sciences according to the methodological criterion, Pomponazzi ranks mathematics as

the noblest science, since its causes are perceptible, followed by natural philosophy, since only its effects are perceptible. Metaphysics, whose causes and effects are not perceptible at all, takes the third place. This hierarchy is, however, reversed when taking into account the ontological criterion, which would thus place metaphysics, whose object is by definition the noblest, first in the hierarchy. Natural philosophy maintains its middle position, and mathematics comes last. What is interesting in Pomponazzi's hierarchies is the idea, later shared by Galilei, that causes in mathematics are perceptible, and the distinction between the perceptibility of causes (pertaining only to mathematics) and the perceptibility of the effects. This distinction, not found in Galilei's and Descartes' understanding of the relationship between physics and mathematics, prevents physics from being counted among the purely demonstrative sciences.

Drawing a distinction between ancient and modern "physics" purely in terms of content, however, is not enough. One must also question to what extent ancient and modern physics are comparable disciplines regarding epistemological structure, that is, internal mechanics, didactic organization, and the form of written representation (Baldini 1999, 248). We must also investigate to what extent the early modern reception of Aristotle's natural philosophy plays a crucial role, since it combines transmission and legitimation of "old-fashioned" physics with the gradual development of new trends, which will finally culminate in the epistemological rupture represented by Cartesian physics.

The conceptual and didactic structure of Aristotelian "physics" pivots on the *quaestio* (question) form, that is, on problem points identified from the exegesis of Aristotelian texts and developed in dialectical form. These *quaestiones* represented the true basis of the entire university teaching in physics. In a course, the sequence of these *quaestiones* followed a textual rather than logical order, that is, the same order according to the arrangement of the contents in Aristotle´s works, often quite unsystematically. Baldini has argued that "this led to a considerable difference between a scholastic course of 'physics' and a modern one: a *quaestio* was not analyzed using laws and results obtained discussing other preceding questions, but by introducing hypotheses or rules which were often unrelated to these" (1999, 251). Interestingly, the epistemological and didactic structure of the Aristotelian "physics," as it were, as taught in the Italian universities started changing from about 1660, not as a result of an internal development, but rather under the strong influence of the new Galilean and Cartesian mathematics-based physics. This change is, of course, reflected also in how the contents of knowledge that constitute physics as an autonomous disciplinary field were organized and arranged, for it is in this period that some Aristotelian scholars started to adapt the *quaestio* form to the new trends, trying to integrate much of the new experimental knowledge in their questions; other scholars with an Aristotelian background even abandoned the *quaestiones* to write proper treatises on topics in physics considered from an experimental and mathematical perspective (for an example of this more radical trend: F. M. Grimaldi, *Physico-mathesis de lumine*, 1665).

4. Mechanics

The rediscovery of ancient mechanics in the sixteenth and early seventeenth century is certainly one of the most significant aspects of the process of reception of Greco-Roman science in the early modern age. This rediscovery coincided with and, in many respects, actively prompted various attempts to mathematize, formalize, and integrate the Medieval mechanical arts. Such attempts resulted in turning the Medieval mechanical arts

into a proper science endowed with a unified method. Before the sixteenth century, the topics that now constitute the core of Classical or Newtonian mechanics lacked any disciplinary coherence, since they were scattered in various sciences and arts including natural philosophy (in regard to the principles of motion and change), the Archimedean science of weights (as regards topics associated with the balance and lever), and the so-called *artes mechanicae* or *sellulariae* or *machinativae* ("mechanical" or "sedentary" or "mechanized" arts dealing with the construction and use of machines). The first signs of change in the intellectual attitude toward mechanics appeared in coincidence with, and as a consequence of, introducing and assimilating ancient mechanical and technological works into the scholarly debate. These treatises had been recovered thanks to the painstaking work of many humanists and started then to be copied, edited, printed, and translated into Latin. Works like those of Pappus, Archimedes, and Hero of Alexandria were now arousing the interest of an increasing number of scholars and scientists and began to be studied not only out of an antiquarian love for ancient texts but also as theoretical models to take into account the (re-)foundation of mechanics as a science (Drake and Drabkin 1969, 3–60). The text whose reception, no doubt, played the most influential role in this process was the *Mechanical Problems*, which we now recognize as a pseudo-Aristotelian text, probably written by Aristotle's student Strato in the fourth century BCE—Winter 2007 argues for Archytas of Tarentum—although in the sixteenth century it was widely attributed to Aristotle. This text holds a peculiar place in the early modern reception of ancient mechanics for various reasons, three of which are of special relevance. First, the *Mechanical Problems* "attracted the attention of numerous and diverse commentators, including humanists, philosophers, mathematicians, and engineers. Under its aegis they developed a program for mechanics that incorporated not only the Archimedean tradition and the practical tradition of machines, but also elements from peripatetic natural philosophy" (Laird 1986, 45). Hence the reception of this ancient text decisively contributed to the constitution of a unified science of mechanics from those strands whose epistemological status in the Middle Ages was still autonomous and heterogeneous. Second, the *Mechanical Problems* was the only ancient text of mechanics on which lectures were delivered in the sixteenth century, especially at the University of Padua, the first and perhaps only Italian university of the time to offer such lectures. Among those who lectured on the *Mechanical Problems* at Padua were Giuseppe Moletti, the author of one of the richest commentaries ever written on the *Mechanical Problems*, and Galileo Galilei, who read and commented on the pseudo-Aristotelian text when he was elaborating the theoretical and methodological principles of his new science of mechanics. Third, and perhaps most importantly, the process of commenting on the *Mechanical Problems* represented for many Renaissance scholars—independently of their relative adherence to Aristotelianism—a wonderful opportunity to raise questions about the epistemological status of mechanics and about its relationship with mathematics on the one hand, and natural philosophy on the other, for it is from the opening paragraphs of the *Mechanical Problems*, where subject, scope, and aims of mechanics are described, that the four main characteristics of sixteenth-century mechanics are derived:

1) mechanics is a theoretical science rather than a manual art;
2) mechanics is mathematical, although its subject was natural;
3) mechanics concerns motions and effects outside of or even against nature; and
4) mechanics produces those effects for human ends. (Laird 1986, 45–46)

Especially as regards the characterization of mechanics as a theoretical and primarily mathematical science, the sixteenth- and seventeenth-century commentators on the *Mechanical Problems* played a big role, since they succeeded in "mathematizing" mechanics by consistently developing the Aristotelian method of dividing, classifying, and hierarchizing the sciences. In light of this classification, all commentators agreed that mechanics was to be conceived of as a contemplative rather than operative science, as mathematical rather than natural, and equivalent in status to optics and astronomy. For example, Alessandro Piccolomini (1508–1579), among the first to comment on the *Mechanical Problems*, provided a detailed account of the position of mechanics in the system of sciences. On the one hand, he established the mathematical nature of mechanics thusly: he started from the Aristotelian distinction between the two species of quantity, magnitude and number, and the two kinds of corresponding sciences, geometry and arithmetic; and he defined mechanics as a science dependent on geometry. In this respect, argued Piccolomini, mechanics cannot be conceived of as an art, since mechanics provides causes and principles, which is peculiar to all theoretical (viz, scientific) knowledge. On the other hand, Piccolomini provided a careful discussion of the relationship between mechanics and natural philosophy. He proclaimed that mechanics and natural philosophy do have a point of contact, insofar as they both deal with natural matter, although they differ in two fundamental ways: first, natural philosophy deals with motions occurring according to and/or by nature, whereas mechanics is concerned with motions that physical bodies accomplish against nature; second, mechanics treats its subject in a mathematical way, whereas natural philosophy does not.

A similar account of the nature and scope of mechanics was provided by Giuseppe Moletti in his commentary on the *Mechanical Problems*. Moletti agreed with Piccolomini (and other commentators like Francesco Maurolico) that mechanics is a theoretical and mathematical science subordinated to geometry, but he went further to speculate on the very nature of this subalternation. According to Moletti, in order for one science to be subalternated to another, it must consider the same subject of the science to which it is related by attaching an accidental difference to this subject. In the case of mechanics, argued Moletti, the subject of mechanics "is not simply machines, but rather sensible quantity mobile in circular motion, or machines whose form or principle is circular motion or compounded from it" (Laird 1986, 61).

5. Medicine

In regard to the reception of ancient medicine in the Italian universities in the sixteenth and seventeenth centuries, one must first reaffirm the centrality and even the pre-eminence of the medical curriculum in the Italian academic system. As noted above, a triennium during which students attended lectures on theoretical and practical medicine as well as on anatomy represented the culmination of a five-year curriculum including disciplines like natural philosophy, logic, and, in some cases, mathematics as propaedeutic to the study of medicine. The entire medical curriculum was based both on theory and practice (the latter including therapeutics and pharmacology), as well as on reading and interpreting "authoritative" ancient texts such as the Hippocratic *Aphorisms* and *Prognostics*, Galen's *Ars Parva* ("Small Art") and *On the Usefulness of Parts*, and parts of Avicenna's *Canon*. For centuries, Mondino dei Liuzzi's *Anatomia* was the seminal reference for

anatomy lectures. Then, in the first half of the sixteenth century, Galen's anatomical masterpiece, *On Anatomical Procedures*, began to be read and taught in many universities as the primary source of anatomical knowledge (Cunningham 1997, 37–56, 88–142; Carlino 1999, 8–53; Lo Presti 2010, 29–31). Galen's treatise had been edited and translated into Latin by Guinther Andernacus, Andreas Vesalius' teacher in Paris.

Generally speaking, it is therefore possible to define the whole of medical knowledge taught in Italian universities as a *medicina hippocratico-galenica* ("Hippocratic–Galenic medicine:" Nutton 1989), for it was entirely based, especially as regards physiology and therapeutics, on ancient doctrines transmitted as part of the Hippocratic and the Galenic traditions, or, better to say, as part of a unified tradition in which the two streams of Hippocratism and Galenism were closely intertwined (Smith 1979). In this respect, as far as physiology and therapeutics are concerned, the reception of ancient medicine had quite a conservative outcome. Therapeutics was a much more conservative field, and no significant innovations were introduced until the nineteenth century. It is not by chance that the first important new theories developed in the field of physiology from the first half of the seventeenth century had a decisively anti-Galenic flavor. For example, the introductory chapter of William Harvey's *De Motu Cordis* ("On the Motion of the Heart") contains a number of explicit criticisms of Galen's account of the heart's functioning, the pulse, and the anatomy and physiology of vessels and arteries. Furthermore, a mechanistic approach to physiology was followed by Borelli and Malpighi, whose main theoretical premise was the firm rejection of any kind of teleology, in particular the Galenic notion of "natural faculties" (Meli 2011).

However, a completely different picture arises if we investigate the anatomical discourse as it developed in the Italian universities between 1500 and 1650 and consider how the reception or, as Cunningham (1997) has put it, the "revival" of the anatomical projects of the ancients influenced this discourse. For, on the one hand, the approach to ancient authorities proved much less conservative and dogmatic in anatomy than in other medical fields. On the other hand, the very idea of the unity and coherence of the ancient tradition, resulting in the adherence to the Hippocratic–Galenic model in physiology and therapeutics, remained somewhat foreign to the most important anatomists active in Italy in the sixteenth and early seventeenth century. Each of them looked at different anatomical projects of the ancients—namely, Galenic, Aristotelian, and "Alexandrian"—as alternative models to follow or to react against according to a specific pedagogy and specific theoretical aims.

Following Cunningham's (1997) reconstruction of the "anatomical Renaissance," let us consider three figures—Andreas Vesalius, Hyeronimus Fabricius d'Aquapendente, and Realdus Columbus—as paradigmatic for the reception and "resurrection," respectively, of the Galenic, Aristotelian, and Alexandrian anatomical projects.

Holding a chair of anatomy at the University of Padua, Vesalius wrote the *De humani Corporis Fabrica* ("Concerning the Construction of the Human Body," 1543), probably the most famous and celebrated anatomical treatise in the Western medicinal tradition. Vesalius' claims of intellectual indebtedness to Galen may appear at first glance antithetical, since he often criticized Galen's fallible descriptions of various parts of the body. Furthermore, and most importantly, Vesalius censured Galen for basing his account of human anatomy on the observation of animal bodies. In spite of this, Vesalius' underlying theoretical structure as well as his overall intellectual enterprise is Galenic in many respects: his emphasis on the importance of direct observation; his focus on human

anatomy (although Galen did not dissect human bodies); his careful anatomical descriptions of "structural" parts of the body, such as bones, muscles, nerves, and ligaments (in contrast with the Medieval practice of dissection, which focused almost exclusively on the organic parts); the order of composition of the *Fabrica*, following and clearly inspired by Galen's *On Anatomical Procedures*; the idea that the proper approach to anatomy is a combination of resolution and composition, since dissection must proceed from the surface to the body's interior (resolution), whereas the anatomical account must start from the interior and proceed, stratum by stratum, until the organic level and, finally, the body's surface (composition) is reached.

We can reconstruct the reception of Aristotle's "anatomical project," his zoological works and especially the *PA*, from the work of William Harvey's teacher, Hieronymus Fabricius d'Aquapendente, who held the chair of anatomy and surgery at the University of Padua from 1565 until 1613. Fabricius' anatomical project was a clear attempt to develop a "functional anatomy" of the animal, that is, of the animal body (neither exclusively nor primarily human) as endowed with a soul and with bodily organs, whose function was to carry out the activities and faculties of the soul. This project was quintessentially Aristotelian and very much in line with Aristotle's aims in the *PA, GA, On the Motion of Animals,* and *On the Locomotion of Animals* as proved by at least two factors: first, the whole of Fabricius' anatomical work can be ordered and classified according to the Aristotelian tripartition of the soul into vegetative, sensitive/motile, and rational parts. Among Fabricius' anatomical works that treat the parts and functions connected with the vegetative soul are *On Respiration*, various treatises on embryology (*On Semen, On the Formation of the Egg and Chick*, and *On the Formed Fetus*), *On the Ostiola in the Veins*, and *On the Gullet, Stomach, Intestines.* In other treatises, Fabricius investigated parts and functions connected with the activities and faculties of the sensitive and motile soul: *On Vision*, *On Hearing*, *On the Covering of the Whole Animal*, *On the Artifice of Muscle*, *On the Articulation of the Bones*, and *On the Local Motion of Animals.* In his *On the Voice*, *On Speech and its Instruments,* and *On the Vocal Communication of Brutes*, Fabricius examined the activities of the rational soul and the bodily parts responsible for carrying out such activities. Second, the criteria according to which Fabricius aimed at giving a full account of any organ or part perfectly correspond to the criteria followed by Aristotle in his own zoological works, insofar as such an account involved a fourfold presentation including:

1) *historia*, the description of the structure;
2) an enquiry into the action of the part;
3) the uses of the part; and finally
4) a demonstration of the truth and applicability of his findings. (Cunningham 1997, 175)

If the reception and rethinking of the anatomical projects of Galen and Aristotle inspired, respectively, Vesalius' and Fabricius' conception of anatomy as the science of the human (or animal) body, the reception and revival of Alexandrian anatomy, in particular the work of Herophilus and Erasistratus, was the keystone of Realdus Columbus, who first succeeded Vesalius as professor of anatomy and surgery at the University of Padua, before moving to the University of Pisa and finally being appointed to the chair of anatomy at the University "La Sapienza" in Rome. Columbus authored a major

treatise on anatomy in fifteen volumes, *De Re Anatomica* ("Concerning Anatomical Issues"), published in Rome just after his death in 1559. To what extent and in what respects Columbus' conception of anatomy reflected and sought to revive the anatomical approach of Herophilus and Erasistratus has been persuasively demonstrated by Cunningham (1997, 147–148), who argued that the key feature of Columbus' own anatomical project was "to put vivisection center-stage in the search to discover more about the actions of the parts of the human body." Hence, insofar as Columbus took as his models anatomists who lived four to five centuries before Galen, his project aimed to reach back before Galen; but, insofar as Galen had harshly criticized these anatomists, especially Erasistratus, Columbus' attempt "involved in many important matters not an emulation but a rejection of Galen in anatomy: doctrines, practice and all" (Cunningham 1997, 148). In this respect, the attitudes of Columbus and Vesalius toward Galen are very different, since the latter rejects just specific points of Galen's anatomical teaching, while adopting and further developing a number of Galen's theoretical premises, which provide the epistemological framework of Galen's account of human anatomy, whereas the former favored the anatomists who in their turn had been rejected by Galen.

6. Conclusion

We have provided here an overview of some of the characteristic aspects of the early modern reception of Greco-Roman science. As noted above, this overview is partial and encompasses only the reception of some, although highly representative, "scientific" disciplines or, better to say, "fields of knowledge." We treat only a selection of institutions, namely, the Italian universities, in which this reception took place. There is another aspect—and a major one—which we deliberately omit, that is, the reception of Greco-Roman science as a form of "orthodoxy," viz, the absolute and uncritical adherence to and blind acceptance of ancient theories and doctrines on the basis of an unquestionable principle of authority. This kind of approach to the "scientific" legacy of Greco-Roman antiquity is hardly marginal; a vast majority of men of letters, natural philosophers, and doctors used to read, understand, and make use of ancient scientific texts in exactly this way. Here we have decided instead to privilege the "progressive" over "conservative" or even "regressive" aspects of the early modern reception of Greco-Roman science for the simple reason that the former have long been neglected and underestimated. In every respect, the progressive facets of the transmission of Greco-Roman science represent a key to a better and deeper understanding of the centuries-long process that led to the formation of Western science and, more broadly speaking, to the rise of a "scientific mentality," one of the most distinctive features of modernity.

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APPENDIX

Major Scientific, Technical, and Medical Writers and Thinkers of Ancient Greece and Rome

Thinker	Provenance	Language	Approximate dates of activity	Major scientific works or area(s) of scientific contributions
Claudius Aelianus (Aelian)	Praeneste	Greek	195–235 CE	*Historical Miscellany* *On the Characteristics of Animals*
T. Aurelius Alexander	Aphrodisias	Greek	200 CE	Commentaries on Aristotle
Anaxagoras	Clazomenae	Greek	480–428 BCE	Cosmology, Physics
Anaximander	Miletus	Greek	580–545 BCE	Cosmology, Physics
Anaximenes	Miletus	Greek	555–535 BCE	Cosmology, Physics
Apollodorus Theriacus	Alexandria	Greek	280–240 BCE	Pharmacology
Archimedes	Syracuse and Alexandria	Greek	287–212 BCE	Mathematics, Engineering
Archytas	Taras	Greek	400–360? BCE	Pythagorean Mathematics
Aristarchus	Samos	Greek	280–270 BCE	*On the Distances of the Sun and the Moon*

(Continued)

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Thinker	Provenance	Language	Approximate dates of activity	Major scientific works or area(s) of scientific contributions
Aristotle	Stagira and Athens	Greek	384–322 BCE	*Metaphysics* *Meteorology* *On Generation and Corruption* *On the Enquiry into Animals* *On the Generation of Animals* *On the Heavens* *On the Parts of Animals* *Physics* and others
Flavius Arrianus (Arrian)	Nicomedia	Greek	120–170 CE	*Periplus of the Black Sea* *Indica*
Asclepiades	Bithynia and Rome	Greek	120–90 BCE	Methodist physician
Atheneaus	Attaleia (or Tarsus)	Greek	Second century CE	*Deipnosophists ("Learned Banqueters")*
Callippus	Cyzicus	Greek	350–320 BCE	*Parapēgma*
Marcus Porcius Cato (Cato the Elder)	Rome	Latin	Lived 234–149 BCE	*On Agriculture*
Aulus Cornelius Celsus	Rome	Latin	15–35 CE	*De Materia Medica* *(On Medical Matters)*
Chryssipus	Cnidus	Greek	385–335 BCE	Medicine
Marcus Tullius Cicero	Rome	Latin	Lived 80–43 BCE	*On Divination* *On the Nature of the Gods* *Tusculan Disputations*
Lucius Junius Moderatus Columella	Rome	Latin	Lived 4–70 CE	*On Agriculture*
Ctesibius	Alexandria	Greek	290–250 BCE	Pneumatics

Thinker	Provenance	Language	Approximate dates of activity	Major scientific works or area(s) of scientific contributions
Democritus	Abdera	Greek	440–380 BCE	Cosmology, Mathematics, Physics
Diogenes Laërtius	unknown	Greek	circa 300 CE	*Lives and Opinions of Eminent Philosophers*
Dioscorides	Anazarbus	Greek	40–90 CE	*Peri Hyles Iatrikes* (*Concerning Medical Material)*
Empedocles	Acragas	Greek	460–430 BCE	Cosmology, Elemental Theory
Epicurus	Samos and Athens	Greek	Lived 310–270 BCE	Physics Astronomy, Meteorology
Erasistratus	Ceos	Greek	Lived 315–240 BCE	Anatomy, Surgery
Eratosthenes	Cyrene and Alexandria	Greek	245–195 BCE	*Geographica* *Measurement of the Earth*
Euclid	Alexandria	Greek	300–260 BCE	*Elements*
Euctemon	Athens	Greek	440–410 BCE	Astronomy, Geography
Eudoxus	Cnidus	Greek	365–340 BCE	Astronomy, Geography, Mathematics
Sextus Julius Frontinus	Rome	Latin	Lived circa 40–103/4 CE	*On the Aqueducts*
Galen	Pergamon and Rome	Greek	129–215 CE	Physician, Anatomy, Surgery
Geminus	Rhodes	Greek	First century BCE	Astronomy, Mathematics
Heraclitus	Ephesus	Greek	510–490 BCE	Cosmology, Physics
Hero	Alexandria	Greek	60 CE	*Pneumatics*
Herodotus	Halicarnassus	Greek	circa 484 – 430/420 BCE	*Histories of the Persian Wars*
Herophilus	Chalcedon	Greek	lived circa 330–260 BCE	Physician, Anatomy
Hesiod	Acragus	Greek	Circa 700 BCE	*Theogony* *Works and Days*

(Continued)

Thinker	Provenance	Language	Approximate dates of activity	Major scientific works or area(s) of scientific contributions
Hipparchus	Nicea	Greek	140–120 BCE	Astronomy, Astrology, Geography
Homer	unknown (Chios?)	Greek	BCE	*Iliad* *Odyssey*
Gaius Julius Caesar	Rome	Latin	100–44 BCE	*On the Gallic Wars*
Leucippus	Abdera	Greek	460–420 BCE	Cosmology, Physics
Titus Lucretius Carus	Rome	Latin	lived circa 99–55 BCE	*De Rerum Natura* (*On the Nature of Things*) (Epicurean Physics)
Meton	Athens	Greek	440–410 BCE	Astronomy
Nicander	Colophon	Greek	150–110 BCE	Pharmacology
Palladius Rutilius Taurus Aemilianus	Rome	Latin	375–450 CE	*On Agriculture*
Pappus	Alexandria	Greek	285–320 CE	Astronomy, Geometry
Parmenides	Elea	Greek	490–450 BCE	Cosmology
Philo	Byzantium	Greek	240–200 BCE	*Mechanical Collections*
Philo	Alexandria	Greek	20 BCE–50 CE	*On whether Brute Animals Possess Reason*
Philolaus	Croton	Greek	430–400 BCE	Pythagorean Cosmology and Mathematics
Plato	Athens	Greek	Lived 428/427–348/347 BCE	*Timaeus* Astronomy, Cosmology, Mathematics
Gaius Plinius Secundus (Pliny the Elder)	Novum Comum	Latin	Lived 23–79 CE	*Naturalis Historia* (*Natural History*)
Plotinus	Alexandria	Greek	204/5–270	Neoplatonist Philosopher
Plutarch	Chaeronea	Greek	Lived 46–120 CE	*On the Intelligence of Animals* *Table Talk*
Polybius	Megalopolis	Greek	180–120 BCE	*Histories*

Thinker	Provenance	Language	Approximate dates of activity	Major scientific works or area(s) of scientific contributions
Poseidonius	Apamea	Greek	Lived 135–50 BCE	Cosmology, Geography, Hydrology, Mathematics, Meteorology
Praxagoras	Cos	Greek	325–275 BCE	Anatomy
Proclus	Lucia	Greek	430–485 CE	Neoplatonism
Claudius Ptolemaeus (Ptolemy)	Alexandria	Greek	127–after 146 CE	Astronomy, Mathematics
Pythagoras	Samos and Croton	Greek	570–495 BCE	Cosmology, Mathematics, Physics
Lucius Annaeus Seneca (Seneca the Younger)	Cordoba and Rome	Latin	Lived 4 BCE/1 CE–65 CE	*Naturales Quaestiones* (*Natural Questions*)
Simplicius	Cilicia	Greek	530 CE	Commentaries on Aristotle
Socrates	Athens	Greek	469–399	Ethics
Soranus	Ephesus	Greek	98–138 CE	*Gynecology* Methodist Medicine
Strabo	Amasia	Greek	Lived 64 BCE–24 CE	*Geography*
Strato	Lampascus	Greek	295–268 BCE	Physics
Thales	Miletus	Greek	600–545	Cosmology, Physics
Theophrastus	Eresus and Athens	Greek	340–387/6 BCE	*De Causis Plantarum* (*On the Causes of Plants*) *De Historia Plantarum* (*On the Enquiry into Plants*)
Marcus Terentius Varro	Raete	Latin	Lived 116–27 BCE	*On Agriculture*
Vegetius Renatus	unknown	Latin	Circa 450 CE	*Digesta Artis Mulomedicinalis* (*Digest of Horse Medicine*) *On Military Matters*

(Continued)

Thinker	Provenance	Language	Approximate dates of activity	Major scientific works or area(s) of scientific contributions
Publius Virgilius Maro (Vergil)	Mantua and Rome	Latin	Lived 70–19 BCE	*Aeneid* *Georgics*
Marcus Vitruvius Pollio	Rome	Latin	Lived 85–20 BCE	*On Architecture*
Xenophanes	Colophon	Greek	Lived 570–478 BCE	Physics
Xenophon	Athens	Greek	430/425–355 BCE	*Anabasis* *Economics*
Zeno	Elea	Greek	Lived 490–430 BCE	Physics
Zeno	Citium	Greek	Lived 335–263 BCE	Stoic Physics

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