

---

*The Oxford Handbook of Engineering and Technology in the Classical World* edited by J. P. Oleson

Oxford: Oxford University Press, 2008. Pp. xviii + 870. ISBN 978-0-19-518731-1. Cloth \$150.00

---

*Reviewed by*

T. E. Rihll

University of Wales, Swansea

T.E.Rihll@swansea.ac.uk

This book was designed ‘to survey the role of technology in the Greek and Roman cultures and their respective technological accomplishments, from approximately the eighth century BC through the fifth century AD’ [3]. More specifically, contributors were asked to provide critical summaries of what the ancients achieved in particular areas, to chart the development of their technology in these cultures over the period in question, to consider the historiography of important issues in their area, and ‘to help put an end to the myth of a ‘technological blockage’ in the classical cultures’ [6]. The book is not meant to be a compendium of all technological procedures, devices, and machines in the classical world [6]; but the title and size raise the expectation that it will serve as an introduction to the field as a whole, suitable both for undergraduate students and academics new to it. Generally that expectation is realized, though, as usual with this sort of volume, the level at which chapters are pitched varies considerably and some contributors stick to their brief better than others.

To what extent does this volume achieve its three principal aims—to summarize what the ancients achieved, to explain how their technologies changed through antiquity, and to explode the myth of technological blockage? The answer turns out to be bound up with how far contributors have engaged with those aims. With 33 chapters over nearly 900 pages, this review would become inordinately long were every contribution to be discussed equally and therefore it, like the volume itself, will be selective in its coverage, though every contribution is acknowledged to some extent. My selection is based on the apparent relevance of the material to *Aestimatío*’s principal audience, historians of science.

© 2008 Institute for Research in Classical Philosophy and Science

All rights reserved

ISSN 1549-4497 (online)

ISSN 1549-4470 (print)

ISSN 1549-4489 (CD-ROM)

*Aestimatío* 5 (2008) 92–131

### The contributions

The brief introduction offers a general outline of the book and its *raison d'être*, an overview of Greek and Roman attitudes to manufacturing, and some pointers for future work. Contributions originally submitted in German, Italian, and French have wisely been translated into English, thereby making this fraction of continental scholarship more readily accessible to the book's intended audience.

Serafina Cuomo leads the volume with a characteristically assured introduction to the literary sources, to produce one of the best chapters in the book. She proceeds chronologically (in keeping with the developmental aim), which means, concretely, beginning with the inscriptions that survive on the building of the Parthenon (completed in 432 BC). The next sources to receive attention are a pair of plays from later in the fifth century, Sophocles' *Antigone* and Aeschylus' *Prometheus Bound*, which provide insight into public discussion of technology at the time. Papyri provide the material for the next example, Cleon the ἀρχιτέκτων (whose life and work were the focus of Lewis 1986, ch. 2)—the accuracy of his title in Greek, literally, *leader of builders*, becomes apparent here. The first technical handbook that we meet with is next, Philo's *Belopoiica*, which Cuomo astutely characterizes as a

text [that] provides respectability, both for the discipline of mechanics in general and catapult-building in particular, to which it gives a history and epistemological and mathematical ratification, and also for its author, to whom it offers a platform for his claims and his designs. [23]

The lack of a similar text by his contemporary Archimedes, despite ancient reports that his catapults were 'versatile and impressive', and that he built not just catapults but burning-mirrors, massive ships, and astronomical globes, is rued. Vitruvius' handbook on architecture takes us into the Roman empire, where we also meet Hero, Frontinus, and the *Corpus agrimensorum romanorum*. We are introduced to two more kinds of inscriptional evidence for technology, quasi-legal and commemorative respectively, before Cuomo turns to consider the late antique period, when official edicts required those in possession of certain types of technical knowledge—mechanicians, geometers, and architects—to spend half their time teaching, thus ensuring the future of these skills, in return for tax breaks [29].

Of many fine points made in the course of this chapter, possibly her strongest arises with regard to the myth-debunking aim: *à propos* the *Babylonian Talmud Shabbath* 33b, she says:

The Roman reaction to dissenting rabbis is appropriate to their degree of technological appreciation: Judah is praised by the authorities, whereas Simeon is condemned to death. Evidently, criticism of the Roman infrastructures is perceived as criticism of the empire. The identification of Rome with its forums, baths, and bridges appears complete, and puts a dent in interpretations that see technological achievements, ancient or modern, as ‘objective’ or ‘neutral’. Roman technological achievements were arguably meant, and arguably perceived, as politically charged. [27]

One is reminded of possibly the funniest episode (and sharpest observation) in Monty Python’s *Life of Brian*: the range and length of the insurgents’ answer to the question ‘What have the Romans done for us?’

Roger Ulrich gives an overview of the range and scope of pictorial representations of technology on a variety of ancient media; and tabulates the results, achieving the aim of a critical summary splendidly. This chapter is a careful, comprehensive, and sensible discussion of the issues. The problems for anyone using this sort of evidence may be illustrated by the fact that a second century AD bronze statuette from Trier here identified as a ploughman (Fig. 2.13, and cited again in chapter 7 on agriculture) bears a striking resemblance to a bronze statuette from Athens that is some 500 years older and there identified as a Hermes figurine [acq. no. 13219: see my Figure 1]. Incidentally, we may have, represented in the principal difference between these statuettes, a Germanic innovation in clothing: the Trier figure wears what appears to be a *hooded* leather cape—the caracalla after which the emperor who adopted it was nicknamed?—whilst the Athens figure has a hat.

Kevin Greene provides an excellent survey of the historiography of ancient technology studies in chapter 3—which this reviewer found especially interesting on the 18th century—before he goes on to discuss some current trends in technology studies and classic works based on more recent periods, e.g., Bijker, Hughes and Pinch on *The Social Construction of Technology* [1987], and Edgerton’s eclec-



Figure 1  
© 2009 T. E. Rihll

tic theses and technologies-in-use concept [1999]. This is one of the few places in the book where one finds reference to, or awareness of, technology studies as a discipline in its own right from which classicists and classical archaeologists could learn much. Add now Edgerton's insights on the importance of old and creole technologies, put forward in *The Shock of the Old* [2006].

Paul Craddock opens the section on extractive industries with a clear and concise high-level description of the sources of ancient ores, mining technology, and mine organization, and also of ore dressing, smelting, and refining. Differences in treatment required by different metals are indicated, as are the methods used to reconstruct ancient practice and the areas of current debate. To fit all mining and metals processing into one chapter is very demanding and requires a degree of compression and generalization that is generally excellent but occasionally has unfortunate consequences. The description of the cupellation of silver [104], for example, is seriously misleading. Note too that the reference is wrong—it should be Pliny *Hist. nat.* 33.95 not 34.159.<sup>1</sup>

Craddock gives a very clear and concise explanation of ancient ideas about metals [106–107] that is relevant to anyone with an interest in alchemy: the ancients thought that metals grew in the ground; that the properties of metals [like plants] therefore varied with the environment in which they grew; and thus, for example, that gold from one place was not exactly the same as gold from another. Moreover, a variety of golds were all considered as gold *simpliciter* rather than as alloyed gold. They did not have the modern notion of elements with precise and invariant properties. But the invention and use of coinage generated a need for standards of purity, and refining and then other metallurgical procedures were viewed as rapid reproduction of natural processes. A striking example of the chronological lag that can occur between archaeological and literary sources arises with respect to brass. As Craddock explains, brass rapidly gained in popularity and became the regular material for certain types of artifact in the first century BC [110]. Yet the earliest surviving literary account of its manufacture (al-Hamdānī's) is from the 10th century AD [111].

---

<sup>1</sup> For a correct explanation of the Pliny passage, see Craddock 1995, 223 or Rihll 2001, 122–124.

Örjan Wikander deals with energy sources and power supply, covering direct solar energy, chemical energy, animal power, water power, and wind power. Solar energy was widely used for heating and drying. Chemical energy was the principal type employed in manufacturing as fuel for ovens, kilns and furnaces; although charcoal was the principal fuel in antiquity, coal was also used, especially in Britain, especially in the second century [139]. Animal power was largely confined to agriculture and water lifting [140]; overland haulage should be included. Wikander emphasizes the particularly provisional nature of current hypotheses on water power since they are so dependent on archaeological evidence, which is constantly growing: more finds of pre-medieval water mills have been published since the 1980s than the total number that were known to exist before 1980 [141]. Moreover, water power was exploited for other industrial uses too, such as sawing stone. As Wikander notes, we may not yet understand the ‘true economic importance of water power in antiquity’ [152]. Two genuine turbine water mills excavated in a late third/early fourth century context in Tunisia demonstrate a level of sophistication in milling technology that was not reached again till the 16th century [145]. Consequently, Bloch’s hypothesis [1935] that the breakthrough in water mill technology occurred in the early Middle Ages, which was based only on ‘the first *documentation* of a situation already established in the Roman Empire’ (emphasis added), is demonstrably wrong [149]; it occurred in the first century AD or slightly earlier. Wind power was widely exploited for sailing and threshing, and is mentioned by Hero [*Pneum.* 1.43] in connection with driving an organ, but remains a ‘dark horse in the field of ancient energy exploitation’ [153].

In one of the longest and most densely informative chapters in the book [175–222], Geoffrey Kron emphasizes the positive transformation of modern views about ancient animal husbandry over the last generation, largely as a result of archaeo-zoological research in tandem with the classical literary sources. For example, domesticated animal bones reveal that they were bred and fed to be consistently larger in classical times than in other periods before or after, un-

til the 19th century AD.<sup>2</sup> It is noteworthy that ancient agronomists' advice differs little from contemporary organic practice, and that most of the veterinary surgical procedures and instruments being employed in the mid-20th century were known to, and used by, the ancients [175, 185]. The scale and sophistication of commercial fish and game farming would not be matched again till the late 20th century [176, 192, 204, 205, 212–213], so too sheepfolds on the Crau and pigpens [183]. Intensification methods, like getting two litters from sows per year [181] and battery farming of poultry, were almost modern [177], while Roman hens were typically about 25% heavier than those found on Celtic sites [180]. Pigeon coops for 1,000 breeding pairs [192 and Fig.8.3] point to areas where the Romans still have no equal. More controversially, Kron suggests that, where the terrain allowed it, the ancients employed convertible husbandry, the most intensive and dominant form of mixed farming today [181–182].

Part 3 opens with Frederick Cooper's argument that the genius of Greek architecture lies in the engineering rather than the appearance, and that a deep appreciation of the properties of various building materials and a theory of construction which could cope with earthquakes were more important than proportion and the other things with which students of Greek architecture typically concern themselves [226–227]. The focus is on temples. He suggests that Theophrastus *Inquiry into Plants* 'contains all the earmarks of a modern-day handbook on wood construction' [226], a remark which I find bizarre. He makes a number of assertions that need references but lack them, such as that the buildings in the worst shape now were demolished in the late antique period to recover their metal clamps and dowels [230]; and he assigns intention without apparently considering accident or coincidence, for example, when discussing the aseismic properties of a mat foundation [230].

With regard to the editor's aims, I found this to be one of the least satisfying chapters of the volume. As a research paper it also failed to persuade me: the case for 'a body of scientific theory...behind the applications of scientific technology to building' [226] requires substantiation way beyond Theophrastus' appreciation

---

<sup>2</sup> This is true of both Greek and Roman domesticated animals [176]. Typically, the animals were up to 20% taller at the withers than Iron Age or medieval specimens, for example [180].

of the properties and proper treatment of various woods (on which see Ulrich's discussion, 448-450) and three inscriptions, whose interpretation by Cooper is very significantly more far-reaching than the surviving texts [250]. There are two issues here: practice *versus* theory and Theophrastus' working methods. The first requires proper analysis [cf. Rihll and Tucker 2002] and the second needs to be seen in the context of data gathering at the time: that Theophrastus learned about woods by talking to people who worked with wood (there was no other source of such knowledge then) does not demonstrate a scientific approach to construction in wood any more than Aristotle's talking to beekeepers demonstrates a scientific approach to honey production [cf. Beavis 1998]. Nor is it relevant that recent American practice lacked awareness possessed by the ancients [249]. Cooper ignores the crucial difference between modern construction handbooks and Theophrastus' account: mathematics and measurement, which is conspicuous by its absence in ancient handbooks and by its presence in modern ones. Moreover, as the next chapter demonstrates very clearly, the putative aseismic design principles and practice that supposedly explain Greek column construction by drums were ignored by the Romans, who preferred monolithic columns and developed the technology to cut, move, and lift these massive shafts.<sup>3</sup>

This takes us to the chapter on Roman engineering and construction by Lynne Lancaster, which offers an excellent overview of the topic and can be confidently recommended to students, unlike that on Greek engineering and construction. Lancaster has a very different view of ancient construction theory and practice, most of which cannot be attributed to differences between Greek and Roman practice; and it is a pity that these two chapters are not explicitly cross-referenced and the disagreements explored. Lancaster offers an excellent example of a technological development which was an improvement in one respect (speed of completion) whilst a decline in others (less stable, less durable), and which was recognized as such at the time [262]. This technology (*opus reticulatum*—building a wall using stones cut to the same size and shape) can also be seen now to have saved the wall builder the time that would hitherto have been spent choosing a suitable stone for each space as he built, and sepa-

---

<sup>3</sup> Compare also Roman foundations and wall compartmentalization [259, 265f].

rating the job of shaping the stone from laying the wall, thus allowing the former to continue off site and round the clock and speeding up production as well. The cost of this development was the liability that the wall would crack along the diagonal and its reduced durability in comparison with the ‘crazy paving’ type walling that preceded it (*opus incertum*). Thus, Lancaster’s account is sensitive to the compromising nature of most technological developments and to the role of organization as well as of materials and tools. This chapter is also particularly good on the variety that existed in the detail of solutions to particular problems, and on the diffusion of materials and techniques (such as those for vaulting) from periphery to core and thence or directly to other peripheries [266–278].

Andrew Wilson supplies a comprehensive, reliable, and up-to-date survey of hydraulic engineering, covering wells, cisterns, aqueducts, urban distribution and uses, irrigation, and waste water management, to which it is essential to add only Smith’s explanation [2007] of the routing, *via* high points within the depression being crossed, of some of the so-called inverted siphons. (Smith shows that this was probably done not in order to reduce the length run at maximum pressure [*pace* 297] but to facilitate filling and maintenance: air-locks can be a real problem in this sort of system, and relative high points facilitate bleeding.) To Wilson’s list of possible factors for the proliferation of aqueduct technology from Augustus’ time onward (increased prosperity, spread of the bathing habit, and export of the Roman urban model *via* the foundation of veteran colonies in the provinces [298]) we should add, emphatically, ‘peace’. This chapter is sprinkled with numbers that really help the reader grasp the scale and variety of the enterprise: falls on aqueducts vary between 0.07 m and 16.4 m per kilometer, roofed cisterns had a capacity up to 50,000 m<sup>3</sup> (that is about four times larger than the Piscina Mirabile in Baicoli, for those who know that remarkable structure), and there were 591 street fountains in Rome of the first century AD, for example.

Wilson’s second of three contributions is on Greek and Roman machines. Although this opens with a clear and accurate definition of a machine and a listing of simple machines, he subconsciously equates machine with complex machine when he says that ‘the use of machines in manufacture was relatively limited’, citing the loom and water-powered devices as exceptions [337–338]. Since most tools are, strictly speaking, simple machines, they are actually everywhere in

ancient manufacturing; thus, for example, potters use wheels, wood- and stone- and leather-workers use wedges galore in a variety of chisels and blades, metal-workers use levers (tongs), and so on. It is all too easy to overlook the fact that many basic and not-so-basic tools (machines) such as the carpenter's plane [446] were apparently invented and certainly developed by the Greeks and Romans. Unfortunately it has been overlooked here, which does not help the book's aim to help put an end to the myth of technological blockage. This is all the more surprising given that Wilson's section on simple machines [339–342] is excellent, and that during the course of the chapter he notes the earliest evidence for a variety of devices—e.g., the compound pulley, the winch, the gear, the rack-and-pinion, the worm gear, and so forth—thus implicitly or explicitly recognizing the probable Greek origin of a host of simple gizmos which formed the basis of all tool kits since, and which transformed people's ability to apply power to things and to harness natural forces like gravity, wind, and water. The Greeks also combined them to make complex machines of even greater power. For example, two of these simple devices, the pulley and the winch, were combined to produce a very important Greek invention, the crane; and this prompted the invention of the (anachronistically named) Lewis bolt. It is not clear on what basis the selection of complex machines has been made; it certainly illustrates range and diversity. There is discussion of cranes, traction devices (for reducing fractures and other medical applications), and engines of war—it is in this chapter, rather than the chapters on warfare, that we find the most detailed discussion of catapults [346–350]—water-lifting devices, water-powered mills and other applications, unusual types of transport such as odometers and paddlewheel boats, presses, and machines to entertain. Here the most important statement for the volume's aim to debunk the myth of technological blockage is that 'the archaeological (as opposed to documentary) evidence for water-mills and millstones also appears scarcely less abundant for the Roman than for the high medieval period' [362].

Robert Curtis' chapter on food processing and preparation concentrates heavily on the Mediterranean triad of cereals, grapes, and olives. This would have benefited from excision of mechanical material (water mills and various presses) that was already done well in chapters 6, 11, and 13. Some of the space thus saved could have been

used for an account of food processing—such as ways of cooking other than baking in a large oven—preservation, and storage techniques here omitted or for a fuller discussion of the other fruits, vegetables, and nuts eaten [384] or even for a discussion of fast food in antiquity. His observation that modern butchers use almost identical tools as did the Greeks and Romans [385] renders his use of precisely this trade as an example of the ancients' 'persistent conservatism' [388] rather bizarre. How conservative does that make modern butchers?! This is how the myth of technological blockage lives on, even in a volume that aims to explode it, and in spite of the evidence against it. The explanation for butchers' conservatism from ancient times to the present is rather that technologies have peaks and that once reached they cannot be appreciably exceeded except by a new technology (what Lienhard 2006 calls 'completed'). The cannon is not a catapult; the car is not a chariot. The tools in a modern butcher's shop are similar to their classical counterparts because the technology of hand butchery peaked early. Modern society has developed a new technology, the *abattoir*, which co-exists with the butcher's shop now, and which retains some ancient hand butchery tools but also includes devices for which there is no ancient version.<sup>4</sup>

We then have a third chapter by Wilson, this time on large-scale manufacturing, standardization, and trade. He emphasizes the interrelationships with the economy writ large, with real growth in productivity, and with mechanization. The discussion focuses on the mass- or large-scale production of pottery, bricks, and foodstuffs, the standardization of the marble trade, and the division of labour in a large bakery and in an imperial marble workshop—all of the Roman period. It is a pity that mining and metallurgy are omitted, since interesting things could have been said on all these themes and the reader could have been introduced to some Greek material too by discussing the Laurion silver mines (large-scale production), for example, or the production of bronze statues (standardization, see Mattusch, next chapter, esp. 426–431). Wilson writes with characteristic clarity and sprinkles revealing numbers throughout: he mentions, for example, the 12 potters and 30,000+ vessels attested in a single kiln firing [398], the 6.9 million bricks used in the baths of Caracalla

---

<sup>4</sup> The same or similar continuity is visible with many other ancient technologies; see, e.g., woodworking on 440, 446, 460.

[402], and the 466 m<sup>3</sup> of space devoted to gutting and salting fish at Plomarc'h in Brittany [411]. The throw-away suggestion that some *pueri* at La Graufesenque were slaves 'or perhaps apprentices' [398] is unfortunate, and appears to be innocent of the evidence for apprenticeships in the ancient world: an apprentice potter would be unique even in imperial Roman Egypt, which is the only place where apprenticeships are yet attested, and most of them concern weavers (see below). Indeed, this sort of anachronistic assumption about the organization of large-scale manufacturing, which also underlies Peacock's typology of manufacturing establishments (described by Wilson in his introduction [396]), creates difficulties for the interpretation of the Roman mass-production pottery facilities in France and Italy. Wilson astutely observes that the documentary evidence from these places (lists of vessels for firing, potters stamps, and so on) indicates that we are not dealing with employees. Rather, the landowners on whose properties these impressive facilities were developed may have either engaged the potters to produce a given number of vessels or rented space to them [400]. In either case, the potters are independent craftsmen, not employees in big ceramic production units. This is important.

John Wild writes authoritatively and concisely on textiles, covering Greek and Roman production with equal facility. He proceeds systematically from types of fiber exploited to dyeing. A sharp difference between ancient and later practice is observed with regard to the production of cloth: except for sailcloth, the ancients did not produce bolts of cloth but individual pieces that required little or no cutting and sewing [470–471]. Regional diversity, such as cut-loop pile in eastern Roman textiles, is noted [472–474]. One of Wild's last observations has the power to shock and ought to prompt students to more sophisticated thinking about hand- versus machine-made production: 'only an expert can spot the difference between a Greek or Roman textile and its modern equivalent' [477].

In a densely informative chapter on glass production, Marianne Stern suggests that the ancient Greek philosophers' association of glass with metals arose as a result of their familiarity with glass working only, not glass making, so that they did not see this manufacturing process as the true transmutation of materials that it is [521]. In light of that and of ancient notions about material composition (see above on Craddock's chapter), the issue of 'counterfeiting'

would bear re-evaluation [527–528]. (Glass making and glass working were two separate crafts, and glass making was undertaken in only a very few places [520].) Colorless glass features in a variety of ancient devices and experiments, such as Aristophanes’ burning glass and Ptolemy’s experiments on refraction [528–529]. The notorious ancient anecdote about unbreakable glass is explained—a vessel being blown was perhaps dropped on the floor, where it might ‘dent’ but it would not shatter; and it could be picked up, reheated, and restored to its former shape [535]. There is a particularly interesting case of technology transfer between crafts in the ancient glassworkers’ employment of wheels (like potters’ wheels), a technique since lost [532–535: see also 540]. The remainder of the chapter is divided into sections covering primary and secondary workshops, glassmaking, the working properties of glass, colored glasses, colorless glass, glassworking in classical Greece, glass pottery, glassblowing, other decorative techniques; Stern concludes with a section on the scale of glassblower’s establishments and outputs.

Part 5 concerns transportation and the relevant infrastructure, first land, then sea. Lorenzo Quilici deals with (Roman and Italian) roads and bridges, while Georges Raepsaet deals with what moved on them in a more theoretical as well as a historically more wide-ranging way. Technology transfer is raised again with respect to viaducts and aqueducts, gates and arches [569, 570]. But this time it seems inappropriate because, although these engineering projects may be ‘very different types’ by modern standards, they were not by ancient standards, and because these projects were carried out by the same personnel then. Raepsaet has to deal with one of the landmark publications in the ‘technological blockage’ thesis, Lefébvre des Noëttes 1931, and he does it well. The historiography is briefly given and the author’s own position clearly stated—land transport technologies were neither insignificant nor marginal [580–581, 590–591]; and the rest of the chapter substantiates his position through sections on the mechanics of forces and potential energy, on general categories of portage and harnessed transport, and on customs, context, and cost. The relative strengths and weaknesses, physical and economic, of a variety of draft animals in a variety of roles are compared. Indeed, Raepsaet constantly emphasizes the existence of that variety: see, e.g.,

This stability [of sources of energy available until the 19th century] did not stand in the way of either a great diversity of vehicles and harnesses or multiple forms of progress, innovations, and adaptations to the needs encountered in each type of society or preindustrial environment. [589]

Both the fixed and the turning axle coexisted, their contemporaneity more a question of quality of workmanship than of chronological evolution. [598]

This surety of touch does not unfortunately extend to economic issues [601], and the comments about distribution of goods should be tempered with Parker's account [2008, esp. 178–183]. In view of the importance of Noëttes' ideas about ancient traction to the myth-debunking aim of the book, it is not surprising that most of the chapter is focussed on vehicles and harnessing. But that leaves little room for portage and packsaddle, the fundamental importance of which is stressed [589–590] if not much discussed and barely illustrated. See my Figure 2, which shows the sort of structures employed, in this case in ancient Greece, where to make a child's toy of it the burden-bearing ox is fitted with four wheels!

Seàn McGrail cautiously discusses the methodological issues attending the study of ancient ship design, construction, and use. Methodology is a live issue because nautical archaeology is a relatively young subject. It is young because ancient written sources on the subject are almost non-existent, and because excavation or even study of known ancient wrecks generally requires the sort of equipment that has become available only recently (especially in the last 20 years or so). For example, sponge divers could bring up much of the contents of the Antikythera wreck *ca* 1900 AD, but study of the remains of the ship itself on the seabed was not begun until 1953 by J.-Y. Cousteau [see Moity, Rudel, and Wurst 2003, 127]. McGrail emphasizes that reconstructions and replicas are sometimes constructed on a rather small and uncertain evidential base using unexpressed assumptions, and that once built they can represent an impediment to understanding instead of an aid [612–613].<sup>5</sup> This is all very sound, and anyone with experience of reconstructions of any type of ancient machine or

---

<sup>5</sup> There are good color photos of what actually remains of some larger wrecks and of the practice of underwater excavation in Moity, Rudel, and Wurst 2003.



Figure 2

© 2009 T. E. Rihll

device will know how, despite the best intentions and with everyone in a multi-disciplinary team trying to make a genuine reconstruction using their combined talents, when ancient evidence and modern mechanics clash, the ancient evidence is usually ignored, with the result that the supposed reconstruction is neither what was built in the past nor what would be built today. McGrail's real interest is in hulls (the discussion of sails is very thin and omits topsails, depicted in Fig. 25.1) and in NW Europe rather than Greece and Rome. This chapter is highly technical; the glossary is essential and unfortunately incomplete—the reader insufficiently familiar with ship bits might re-

quire some additions (e.g., What is a hogging hawser? A stringer?). A couple of well labelled diagrams would have been helpful as well.

Part 6, entitled ‘Technologies of Death’, meaning warfare, consists of just two short chapters, despite warfare’s being ‘the most innovative and pervasive human technology from at least the Early Bronze Age through the present day’, and despite ‘the importance of the subject and the richness of the literary and archaeological evidence’ [7]. The editor excuses this brevity—this section is only 38 pages long; compare 75 on sources, 103 on technologies of the mind, 119 on transport, 129 on primary technologies, 141 on engineering, and 178 on manufacturing—by referring to the extensive existing literature on warfare. But that is a weak excuse, for it does not explain the prominence given in the volume to mining and metallurgy, Roman engineering, and hydraulic engineering, for example, all of which also have extensive literatures. The truth is rather that, although warfare and fortification do have an extensive literature, relatively little of it produced in the last 30 years has focused on the technology and engineering involved, a fact reflected also in the contemporary clutch of *Companions* to ancient warfare. Here perhaps is the most striking demonstration that the recent historiography of a topic does not just form part of a chapter’s content (consideration of which was one of the volume’s aims) but to large extent *determines* its content. Here too the reviewer should declare an interest, having published in 2007 a 400-page monograph on the history of the catapult, the first in English for 30 years and a topic chosen precisely because of its technological significance as well as for its rich literary and archaeological estate.

The Greek chapter is a routine overview of Greek armor, weapons, and fighting style that tells the reader very little about technological matters. We are told, for example, that this or that group favored this or that type of bronze, iron, linen, or leather armor; but we are not told about the properties or performance of these materials in this role, which could (would) have contributed to an explanation of the choices. Similarly, we are told about changes in fortifications ‘in response to improved assault techniques’ [685], and that the advantage moved from defense to attack in the latter part of the fourth century BC [684]. But next to nothing is said about those techniques or how this remarkable change was achieved. Bizarrely, the catapult, which was invented in Syracuse around 400 BC, is men-



Figure 3

© 2009 T. E. Rihll

tioned first in passing, in a paragraph on infantry training in the third century BC [682], and next as a component of ‘effective siege trains, with. . . numerous powerful, stone-throwing torsion catapults’ [685]. The one paragraph focussed on catapults [688] is inconsequential and wrong on the earliest evidence for torsion catapults [see Rihll 2007, 78–80]. The beginnings of mechanized warfare are thus skipped over; and the most complex mechanical technology in routine use across the length and breadth of the ancient world is not even described. The aims of the book are frustrated badly here, apparently because there was confusion about who was to deal with military technology and in what chapter (see below). Even the choice of photos is unfortunate: Eleutherai’s defensive strength at the principal pass into Athens from the north [686–687] is better shown by the approach from the would-be invader’s side [see my Figure 3] than by a photo shooting along the wall to show the plains of north Attica south of it [Fig. 26.4].

Some of these deficiencies are made good in Gwyn Davies' chapter on Roman warfare, e.g., in his discussion of the pros and cons of various sorts of body armor [701]. He understood that 'siege engines and related technical aids' [702] were going to be considered elsewhere, specifically, in chapter 13 (Wilson on machines); Greene meanwhile thought that military technology would be considered in these two warfare chapters [810]. Thankfully, Davies gives a brief overview of the origin and development of the catapult anyway [698–699] but then concentrates on fixed structures (fortifications, earthworks, and the like). However, apparently unbeknown to him, the only 'engine of war' considered in chapter 13 is the catapult [346–350], where it appears between 'surgical traction' and 'water-lifting devices'. Siege towers, ram-tortoises, borers, *sambucas*, pontoon bridges, and all the other ancient war technologies have thus fallen between stools. I note in passing that all the most spectacular, and for that reason famous, bridges in antiquity were constructed to facilitate or support military invasions: Xerxes' bridge over the Bosphorus, Caesar's bridge over the Rhine, Trajan's (Apollodorus') bridge over the Danube. Given the importance of the military in making and breaking the most famous Greek states (Spartan army, Athenian navy), the kingdom of Macedon (Philip II, Alexander the Great), and the Roman Republic and Empire (rise and fall), and the fact that the military possessed and trained most of the Romans' engineers (e.g., Vitruvius), one would have thought that exploration of the technological capabilities of these armies would be central to this book's project. Instead it seems to be a Cinderella section.

Part 7 takes us into fresh territory, 'Technologies of the Mind', which opens with Willy Clarysse and Katelijn Vandorpe's chapter on writing, book production, and the role of literacy. There are sections on writing, writing materials, roll and codex, book production and the book trade, libraries, record-keeping, and literacy. Here we find an excellent example of how one technology (parchment codex) supersedes another in the same domain (papyrus roll), how traces of the old may survive in the new, and the perseverance of habits even when their *raison d'être* has long gone [719–724]. Papyrus began to be used as a writing material in Old Kingdom Egypt, and the standard papyrus roll was about three and a half meters long—long enough for a single Greek tragedy, for example. Sticking many rolls together produced an unwieldy object (up to 20 m!); so large

works were typically divided across multiple rolls ('books'). The original codex, which goes back to the Assyrians, was a book of wooden sheets. Parchment was invented in the city from which it derives its name, Pergamon in Anatolia, sometime in the Hellenistic period when access to Egyptian papyrus was denied during the wars between Alexander's successors. The book as we know it combined the codex format with the parchment material but retained some of the habits of writing on papyrus scrolls, such as the multiple narrow column format on the page, so that the open book looked like the open scroll. In fact, what we now call 'front matter' was at the end because it was left to the next reader to rewind the scroll; thus, the end was inevitably the bit that they saw first. (Some nations, e.g., the French, still put the title at the end of the book.) This wonderful discussion also makes some important points relevant to notions of scholarship and plagiarism: the codex allowed for easier and more precise referencing than did the papyrus roll, and pagination in codices is more common than numbered columns in rolls; but, since every book prior to printing was an individual handcopy, pagination was not a reliable means for referencing [724]. The result was referencing by numbered paragraphs (as in religious, legal, and other texts) or lines (as in poetic works), which worked whatever the medium or handwriting in use.

Robert Hannah's chapter on timekeeping provides a clear and concise guide to the topic and is particularly relevant for students of ancient astronomy in that it describes and contextualizes the known technology associated with daily and seasonal observation and timekeeping. There are sections on *paraepemata*, which he glosses as almanacs rather than calendars [742], the Antikythera mechanism, sundials, hours, portable dials, and waterclocks. The discussion of the Antikythera mechanism [744–746, with a photo of the Wright reconstruction], was unfortunately outdated on publication, thanks to dramatic recent discoveries and developments concerning it (see below). Hannah himself will no doubt be fully conscious of this, and one would hope that material can be added before the book appears in paperback. He concludes with a caution against the interpretation of ancient instruments without the fundamental understanding that comes from careful study of the objects themselves [754].

The next chapter, entitled 'Technologies of Calculation', is another that one would expect to be of special relevance to historians of science. This chapter is in three parts: Charlotte Wikander writes

on weights and measures, Andrew Meadows writes on coinage, and Karin Tybjerg writes on practical mathematics. It is noted that the precision of weights was not good in ordinary contexts: finds both at Athens (in the agora) and Olympia (in a ritual context) suggest that there was variation of up to 20% [765]—though there are huge methodological problems attending analysis of ancient weights and these should not be considered acceptable tolerances. The significance of measurement for ancient cultural achievements is indicated [768], but this section could serve equally well as an ordinary *Companion* entry, as there is little attention either to the technological aspects or to the less ordinary acts of measurement in antiquity—how, for example, Archimedes measured the weight (or volume) of the wreath that Hieron commissioned or how finely and accurately the beam of a typical Roman unequal arm balance (steelyard) was calibrated. More interaction between Wikander and Tybjerg would have paid dividends because, at the end of the day, much practical mathematics was concerned with measurement. Finding ways to measure—i.e., attach numbers to—natural and manmade phenomena has been a key task in many scientific stories,<sup>6</sup> and it would have been good to have some discussion of this, even if only to note its apparent absence in most areas. That some of what now appears to be ‘pure math’ had a practical application or even origin is emphasized [e.g., on 782]; but Tybjerg does not venture into the more controversial areas such as the relationship, if any, between Archimedes’ *Quadrature of the Parabola* and his involvement in the design and construction of the largest ship that the world had then seen, or delve into the connections between his *On Floating Bodies* and allegations about fraudulent goldsmithing in Syracuse of the third century BC.

Örjan Wikander, however, is not afraid to go there when he returns for the chapter on ‘gadgets’ and scientific instruments, pointing out that Archimedes’ *Dimension of the Circle* contains something essential for Archimedes’ hodometer, namely, a tolerably accurate value of  $\pi$  [796]. This chapter is characteristically concise and solid, and there is a fair amount of debunking of modern myths on ancient automata. On the down side, ‘gadget’ is not defined and there is some overlap of material with chapter 13. After some background, historical and technological, there are sections on automata, water-

<sup>6</sup> Such as that of the measurement of temperature and pressure.

clocks, astronomical instruments, hodometers, and ‘gadgets’ in the Roman Empire, which last section draws the reader’s attention to some only lightly attested but nevertheless significant examples of Roman high-tech such as the rotating ceiling in Nero’s Domus Aurea [797], though a rotating ceiling is definitely not the sort of thing that most people envisage as a ‘gadget’. The same contributor briefly discussed the most famous ‘gadget’ of antiquity, Hero’s *aeolipile* (‘steam turbine’), in his earlier chapter on sources of power and energy [154], so its omission here is explicable, if unfortunate for readers of this chapter and not that.

My quibbles:

- There is no evidence that any ancient scientist or engineer was employed to work at or in the Museum [786, 787, 790]:<sup>7</sup> this is another modern myth, anachronistic in concept and fact [see Rihll 2009].
- Athenaeus should be credited for citing his sources rather than castigated as ‘a notorious name-dropper’ [786–787].
- A modern mantra denies Aristotle authorship of the *Mechanical Problems* attributed to him in antiquity, which treatise was handed to some anonymous presumed pupil [787]. The reasons for this view and the chronology need to be re-examined.
- The ‘armchair invention’ [789] is the last refuge of the stumped scholar: something is only called an armchair invention until someone works out how it worked, or better, builds a reconstruction—Archimedes’ hodometer, for example [795].
- I do not understand why devices that entertain are not considered practical [789]. The practical is not confined to mere survival. A very significant chunk of the modern economy is wrapped around the computer games industry, to say nothing of the wider leisure sector.
- While repeating another orthodoxy, Wikander rightly asks, ‘If the goal [of certain automata] was educational, why was there so much emphasis on the manifestation of marvels?’ [790]. Exactly. These machines are carefully designed to *conceal*, not to *reveal*, their workings [so Greene, 802]. The scholarly idea that they are ‘educational aids’ transforms a mechanical attention-grabber

<sup>7</sup> The same claim is made by Greene on 805–807.

into a respectable piece of laboratory apparatus—which is most interesting historiographically.

Kevin Greene appears again, now to write on inventors, invention, and attitudes towards technology and innovation. This is obviously a key chapter given the book's aims. It has sections on optimism, pessimism, human ingenuity, ancient perceptions of machines, ingenuity and the status of work, inventions, inventors (five are identified), as well as on stability, continuous development, and stepwise change in antiquity. It is dense with data, contains some excellent ancient sources in translation to demonstrate attitudes, and includes what are often the only mentions anywhere in the book of a variety of technologies, e.g., of musical instruments [812]. But, as in this case, discussion of such items is mostly descriptive and tantalizingly brief. One gets a real impression of the vast and multi-colored mosaic that is ancient manufacturing, but the discussion is untidy (e.g., the concept of technology-in-use is explained and referenced on page 813 although already used in context on page 812).<sup>8</sup> Nor are the components properly marshaled to support an argument. One senses that Greene does not yet have an overarching answer to questions about invention, innovation and change in antiquity [see esp. 815], but that he is still gathering the materials to form an answer; and, given the scale of the enterprise, this is not a failing. I have myself spent almost 20 years accumulating knowledge about ancient technology. Most classicists do not know of the existence of the wood, let alone what number and variety of trees are contained within it. Yet exposure to the trees makes one cautious about generalizing about the wood. Ancient technology and engineering is a young topic, and like most pioneering works, every chapter in this book is destined to be superseded, most sooner rather than later. As Wikander puts it, 'the presentation that follows here may be better founded than its forerunners, but it, too, should be taken for what it is: a working hypothesis' [141].

The last Part, mistitled 'Ancient Technologies in the Modern World', consists of just one chapter. Michael Schiffer closes the volume with a contribution that sits uneasily with the rest and would

---

<sup>8</sup> This concept has been used by Greene and others earlier in the volume, but that's an editing issue. Still, this is the only chapter in the volume without typographical errors.

be more comfortable in a collection on theoretical archaeology. He offers a manifesto for what he calls an ‘expanded ethnoarchaeology’ that uses historical sources as well as ethnology to model, i.e., to theorize generally, about artifacts and their use in technological processes. As noticed by the editor [8], this ‘simply makes explicit’ what many of us do already. The example by which he illustrates his vision is electrical technologies from the recent past—the typical sort of topic and period one finds in the technology studies literature. The applicability, for the book’s intended audience, of the methods discussed is recognized as only potential [823 *et pass.* esp. 832] and testing of them is explicitly postponed to the future [826]. A single worked example from before the 18th century would have sold the model more effectively; citing one example from a paper published 21 years ago [830] is no substitute. Some reference to the SCOT (Social Construction of Technology) school, launched by Pinch and Bijker in 1984, and to the classic statement in Bijker, Hughes, and Pinch 1987, would also have been appropriate in the discussion of deliberate non-adoption of a new technology [827], for example, especially since Hughes’ work is acknowledged as the catalyst for Schiffer’s own [830]. Readers interested in that topic should consult Oudshoorn and Pinch 2003. Some methods explained along the way (life-histories, performance characteristics) that are said to be in use in archaeology look rather positivist by the standards of recent technology studies: see, e.g., Bijker 1995, Bijker and Law 1992, and Edgerton 2006. I venture to suggest that the transfer of the technologies of technology studies between academic disciplines over the decades 1980–2010 would be an interesting historiographical project for someone!

Other chapters of less obvious relevance to readers of *Aestimatio* are interspersed between those discussed above. Clayton Fant writes authoritatively on quarrying and stone-working, paying particular attention to innovations even in this technologically relatively static industry. Evi Margaritis and Martin Jones survey agricultural practices, emphasizing the differences between those followed in the Mediterranean littoral and those followed north of the Alps where soils were typically wetter, heavier, and richer. They draw attention to developments provoked by the organization and management techniques employed by the Romans to extract surplus from imperial territories that had hitherto been populated by more self-contained communities less well connected to trade networks.

Klaus Grewe's chapter on tunnels includes translation and discussion of Nonius Datus' famous inscription and tunnel at Saldae, and the observation that methods of construction were not very different in the 19th century [333], which is relevant to the myth-debunking aim. An explanation of how a tunnel to drain a lake was dug from both ends would have been useful [325–326], particularly of how it was dug at the lake end—by means of a coffer dam? Moreover, we should now include the extraordinary aqueduct tunnel at Gadara [Schulz 2009].<sup>9</sup>

Carol Mattusch concentrates on bronze statue production, on the ground that most metal-working techniques are found here. But it naturally slants her discussion towards art-historical issues. Thus, for example, it is implied that it was 'the usual practice' to construct ancient foundries for a single large commission and then to close them down [434]. Surely this was not the case for those making everyday items such as nails, hobnails, knives, keys, tools, brooches and other accessories, or furniture knobs, handles, and feet? One gets very little sense from this chapter of the range and scope of ancient metal-working, or that 'miscellaneous metalwork', most of it unidentified, fills a significant amount of storage space for most classical excavations.

Ulrich appears for the second time in chapter 17, now writing to great effect on woodworking. He has a section on specialized woodworking tools, and is especially good on the non-obvious but fundamental uses of timber in construction (e.g., in piles and caissons) and on the continued use of old technologies alongside later developed ones.

Self-referencing reaches rarely plumbed depths with Carol van Driel-Murray's contribution, where her own work constitutes fully a third of all references: one could get the impression from the opening paragraph [483] that no one else has or does work on the topic of leather in antiquity.<sup>10</sup> That unattractive feature apart, van Driel-Murray's is a very concise and competent overview of leather produc-

<sup>9</sup> This recently discovered aqueduct has three tunnels of length 1, 11 and an amazing 94 km—which beats the tunnel at Bologna by 75 km.

<sup>10</sup> Schiffer's contribution is even worse in this regard: his self-references amount to almost a half of all his references, though almost half of his papers are co-authored and he does not always appear first in the name list.

tion, and one which could confidently be added to student reading lists.

Kevin Greene appears for a third time, now with Mark Jackson, to write on ceramic production in chapter 20. This is concise and readable, after a long front end focused on the modern reception of ancient pots which, rightly or wrongly, many students of ancient technology will deem irrelevant. The technical discussion is sprinkled with figures attesting to the scale, firstly of the ceramic industry, and secondly of the economies where they were produced and where their contents were consumed: Greene mentions, for example, the estimated 53 million amphorae, most of them made in Spain and shipped to Rome, that went into making Monte Testaccio in Rome [508].

Blackman's chapter on harbor development is the most up-to-date in the volume; indeed, it contains many 'forthcomings', which can be problematic when details have changed by the time an item appears.<sup>11</sup> That a variety of methods were in use simultaneously is apparent again, even within the same project this time, the Claudian harbor at Portus [645].

### The volume itself

There is no attempt to conclude the volume or synthesize the analyses offered by the various contributors, either *in toto* or by section; the volume simply ends disappointingly with Schiffer's superfluous chapter. Cross references are few and slight, and are sometimes lacking even when easy to supply: there is, for example, no effort to let the reader know that a frieze discussed in some detail on 408 (Eurysaces' bakery) is illustrated in part on page 38, or that the sundials mentioned on page 814 are discussed (and illustrated) in a section devoted to them on pages 746–749. On the other hand, when there are cross-references, they can leave the reader confused rather than better informed. For example, the editor should have asked the relevant contributors to address their disagreements about the date of the introduction of the truss or at least to lay out rather better the arguments for their own views [cf. 228, 266, 457–459]. Mislead-

---

<sup>11</sup> This has happened with at least one item: see page 668 and my List of Typographical Errors.

ing comments (and outdated references) regarding the Antikythera mechanism could have been clarified easily by reading the relevant part of chapter 29 instead of just referring the reader to it.<sup>12</sup> A similar problem arises regarding the codex: compare what's said on page 813 with the discussion on pages 721–724. It is a pity that more effort was not made to make the volume greater than the sum of its parts by providing contributors with copies of relevant other chapters or sections (which is very easy to do and very quick using email) and insisting on greater consistency in terms of what is offered to the reader. As it is, we have a fuzzy assemblage which seems unduly dependent on the initiative of the contributors. Glossaries would be helpful throughout, not just in chapter 24, as would a gazetteer of sites mentioned in the entire volume, not just in chapter 25. The benefits accruing from having all these chapters in the one very large volume (even a reader fascinated by the topic is likely to be flagging by page 500) are thus less than they might have been.

Despite its size, I note with regret that there is no chapter on training or education in engineering or technology in antiquity, which would have been particularly relevant to both the developmental and the myth-debunking aims. For example, some discussion of the development of apprenticeships in Imperial Roman Egypt, about which there seems to be little knowledge even amongst these experts, would have been welcome: 42 διδασκαλικαί contracts are currently known, of 1–8 years' duration, mostly for training free boys to weave; some are apprenticeships proper, some are for paid tuition instead [Bergamasco 1995]. There are no chapters on the production of bone and ivory (boars' tusk as well as elephant); on colors (dyes are treated *very* briefly at the end of the chapter on textiles, paints nowhere at all); on fuels (barring Wikander's theoretically-orientated section [138–139]); on glue and other binders; on hand tools (barring Ulrich's section on carpenters [444–447]; Mattusch's chapter is mistitled); on jewelry and intaglios (the later especially important in their role as signatures in antiquity); on *materia medica* and cosmetics; on mosaics; on ovens, kilns, and furnaces (required, as Pliny

<sup>12</sup> On 628: the 'certain stars' are the wandering stars, better known as those planets that are visible with the naked eye; and the gears do not just 'appear' to have been capable of modeling the motion of the celestial bodies, they really were capable of it. See also 792–793.

the Elder noticed, for most important production processes in antiquity, e.g., bread, ceramics, metals and glass); or on medical or musical instruments—even the famous, popular, and technically sophisticated water organ gets only one paragraph in the volume [360].

It is to me inexplicable how little mention is made of *the* most complex surviving technology from antiquity, the Antikythera mechanism, which is not really (actually, not even) a time-keeping device; and that no-one involved in the production of the book seems to have noticed or thought worth reporting on the scores of new fragments found and announced to the world in a conference on ancient technology in Athens in November 2005 (there are now 82 fragments). Granted, Hannah, who has the longest discussion of it [744–745], does know Wright’s article [2006] from the conference proceedings but not the papers by Andreopoulou-Magkou [2006] and Zafeiropoulou [2006] from the same, where the new fragments are announced.

This touches on a more general issue. Any enterprise of this scale and with this number of contributors must be rather long in the making, but most bibliographies (there is no consolidated bibliography) terminate around 2004/2005, which seems to correspond to their composition date. Only Curtis seems aware of Lawton 2004, though it is of relevance to many parts, e.g., to the discussions of simple machines, power generation, mills, transport, ships, attitudes to manufacturing, agriculture, mining, metalworking, textiles, and warfare. Lucas 2006 is also missed except by Wikander; but since Lucas’ article appeared after most contributions appear to have been finalized, this is more understandable. The delay in production is, thus, very regrettable, not only for the Antikythera mechanism, but in a number of areas where the quantity or quality of research being done makes them dynamic. To keep interested parties informed on this particular fast-moving topic, the Antikythera Mechanism Research Project (AMRP) has its own website ([www.antikythera-mechanism.gr](http://www.antikythera-mechanism.gr)). Latest news (August 2008) is that the month names are derived from the Corinthian calendar—a fact which to my mind certainly does not (contra the website) indicate probable production in a Corinthian colony in the Western Mediterranean (rather than somewhere in the eastern Mediterranean, as hitherto thought), firstly because human mobility was high in the first century BC when the device was made, so a maker with origins in Corinth or a Corinthian-colony could be working in Alexandria, for example; and secondly because if the de-

vice was bespoke (as is likely), it would be the client's preferences, rather than the maker's, that are shown.

There is very little explicit awareness (Greene and Cuomo are exceptions) of the history of technology as a discipline in its own right, with its own theories, insights, and agendas, so that questions relevant to the book's aims which could have been asked on issues such as the deliberate rejection of advanced technology (e.g., by the Roman army of most Hellenistic Greek military high-tech), are not even raised. There are many good contributions and most can be recommended to students as first ports of call to provide overviews of the topics covered; but other contributions wander excessively from the required frame of reference to summarize critically ancient technological achievements and to narrate their development through antiquity.

Taking the book as a whole, one does get a real sense of the scale, range, and scope of the ancient economy; but there are some important omissions on the one hand and some repetitions on the other, and almost all chapters were several years out of date on publication. There is also the issue of bulk without bond. Even production quality is not up to the standards usual for this press (and that one has a right to expect at this price). Production quality is acceptable, but the proofreading was far from meticulous, the claim to the contrary on page vii notwithstanding: there is, for example, a recurrent problem with miniscule 'f' where there should be majuscule 'F' throughout the first half of the book [see my List of Typographical Errors below]. However, once issued in a paperback that is affordable (as is planned) and, one hopes, corrected (at least on the easily fixed slips and oversights), enough chapters offer good introductions to their areas to justify setting it as a course text for undergraduates on ancient technology courses, and as a companion volume to Humphrey, Oleson, and Sherwood's excellent and pedagogically indispensable sourcebook on ancient technology [1998]. It will surely stimulate more interest and new work in this young and exciting topic.

#### Vital statistics

- 33 chapters, in 8 parts, plus front matter and introduction
- list of contributors
- abbreviations and a note on spelling norms

- a glossary of nautical and navigational terms used in chapter 24 appears on 630–632.
- a select bibliographical gazetteer of sites mentioned in chapter 25 appears on 664–665.

There are no notes; references are in brackets in text. The bibliography for each chapter follows that chapter; there is no consolidated bibliography. All of this is convenient for anyone photocopying individual chapters.

There are a significant number of figures, but there is no list of them. Likewise there is no list of tables. As a service to readers of *Aestimatio*, I supply both after the Bibliography along with a list of typographical errors.

#### BIBLIOGRAPHY

- Andreopoulou-Magkou, E. 2006. Εξετάση τοῦ μηχανισμοῦ τῶν Αντικυθέρων. Pp. 820–828 in Technical Chamber of Greece ed. *Second International Conference on Ancient Greek Technology*. Athens.
- Antikythera Mechanism Research Project: [www.antikythera-mechanism.gr](http://www.antikythera-mechanism.gr). (Seen 07 Apr 2009)
- Beavis, I. 1998. *Insects and Other Invertebrates in Classical Antiquity*. Exeter.
- Bergamasco, M. 1995. ‘Le didascalicali nella ricerca attuale’. *Aegyptus* 75:95–167.
- Bijker, W. E. 1995. *Of Bicycles, Bakelites, and Bulbs*. Cambridge, MA.
- Bijker, W. E., Hughes, T. P., and Pinch, T. J., 1987. edd. *The Social Construction of Technology*. Cambridge, MA.
- Bijker, W. E. and Law J. 1992. edd. *Shaping Technology/Building Society*. Cambridge, MA.
- Bloch, M. 1935. ‘Avènement et conquêtes du moulin à eau’. *Annales d’histoire économique et sociale* 7:538–563
- Craddock P. 1995. *Early Metal Mining and Production*. Edinburgh.

- Edgerton, D. 1999. 'From Innovation to Use: Ten Eclectic Theses on the Historiography of Technology'. *History and Technology* 16:111–36.
- . 2006. *The Shock of the Old*. London.
- Humphrey, J. W., Oleson, J. P., and Sherwood, A. N. 1998. *Sourcebook in Ancient Technology*. Routledge.
- Lawton, B. 2004. *Various and Ingenious Machines: The Early History of Mechanical Engineering*. 2 vols. Leiden.
- Lefèbvre des Noëttes, C. 1931. *L'attelage, le cheval de selle à travers les Ages*. Paris.
- Lewis, N. 1986. *Greeks in Ptolemaic Egypt*. Oxford.
- Lienhard, J. H. 2006. *How Invention Begins*. Oxford.
- Lucas, A. 2006. *Wind, Water, Work: Ancient and Medieval Milling Technology*. Leiden.
- Moity, M., Rudel, M., Wurst, A-X. 2003. *Master Seafarers: The Phoenicians and the Greeks*. London.
- Oudshoorn, N., and Pinch, T. 2003. *How Users Matter: The Co-construction of Users and Technology*. Cambridge, MA.
- Parker, A. J. 2008. 'Artefact Distribution and Wreck Locations: The Archaeology of Roman Commerce'. Pp. 177–196 in R. L. Hohlfelder ed. *The Maritime World of Ancient Rome*. Ann Arbor, MI.
- Pinch, T. and Bijker, W. E. 1984. 'The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other'. *Social Studies of Science* 14:399–431.
- Rihll, T. E. 2001. 'Making Money in Classical Athens'. Pp. 115–142 in D. Mattingly and J. Salmon edd. *Economies Beyond Agriculture*. London/New York.
- . 2007. *The Catapult: A History*. Yardley PA.
- . 2009. 'Science and Technology: Alexandrian'. In A. B. Lloyd ed. *Companion to Ancient Egypt*. London. (in press)
- Rihll, T. E., and Tucker, J. V. 2002. 'Practice Makes Perfect: Knowledge of Materials in Classical Athens'. Pp. 274–305 in C. J. Tu-

- plin and T. E. Rihll edd. *Science and Mathematics in Ancient Greek Culture*. Oxford.
- Schulz, M. 2009. 'The Ancient World's Longest Underground Aqueduct'. *SpiegelOnline* 03/11/2009. (Seen 13 March 2009)
- Smith, N. A. F. 2007. 'The Roman Aqueduct at Aspendos'. *Transactions of the Newcomen Society* 77:217–44.
- Wright, M. T. 2006. 'Response'. Pp. 833–835 in Technical Chamber of Greece ed. *Second International Conference on Ancient Greek Technology*. Athens.
- Zafeiropoulou, M. 2006. 'Συλλογή γαλκῶν: Ο μηχανισμός τῶν Αντικυθήρων'. Pp. 829–832 in Technical Chamber of Greece ed. *Second International Conference on Ancient Greek Technology*. Athens.

## LIST OF FIGURES

|      |   |     |
|------|---|-----|
| 2.1  | Corinthian pinax, mining scene              | 37  |
| 2.2  | Eurysaces' tomb, baking scenes              | 38  |
| 2.3  | House of the Vettii, metalworking           | 38  |
| 2.4  | Haterii relief, crane                       | 39  |
| 2.5  | Vatican gold-glass, bow drill               | 41  |
| 2.6  | Gallatin painter red figure vase, carpenter | 42  |
| 2.7  | Eutropos' tomb, strap drill                 | 43  |
| 2.8  | Caputi hydria, 3 male and 1 female artisan  | 44  |
| 2.9  | Corinthian pinax, large kiln                | 46  |
| 2.10 | Corinthian pinax, interior of kiln          | 47  |
| 2.11 | Amasis painter, women weaving               | 52  |
| 2.12 | Palazuelos relief, miners                   | 57  |
| 2.13 | Trier statuette, leather hooded cape        | 58  |
| 4.1  | Rio Tinto, mining tools                     | 99  |
| 4.2  | Três Miñas, stamping mill anvil             | 101 |
| 4.3  | Rio Tinto, Roman washing floor              | 102 |
| 4.4  | Greek shaft furnace                         | 103 |
| 4.5  | Early brass coins                           | 111 |
| 4.6  | Britain, Roman crucibles                    | 112 |
| 5.1  | Docimium, quarry trenches                   | 123 |
| 5.2  | Ephesus, quarry face                        | 124 |
| 5.3  | Docimium, quarry face and debris            | 130 |
| 5.4  | Portus, column with patches                 | 131 |
| 6.1  | Baths of Caracalla, wheel mills             | 145 |
| 6.2  | Three types of horizontal wheel mill        | 146 |
| 6.3  | Crocodilion Israel, twin mill               | 148 |
| 6.4  | Barbegal mill complex                       | 149 |
| 6.5  | Jarash water saw mill                       | 151 |
| 7.1  | Mediterranean polyculture                   | 160 |
| 7.2  | Modern use of an ard                        | 167 |
| 7.3  | Eared plow                                  | 168 |
| 7.4  | Moldbord plow with wheel, coulter           | 169 |
| 7.5  | Granary at Corbridge                        | 171 |
| 8.1  | Suovetaurilia relief                        | 177 |
| 8.2  | La Crau sheepfold                           | 184 |

|      |   |     |
|------|---|-----|
| 8.3  | Dovecote at Apollonia, Libya                          | 204 |
| 8.4  | Roman piscina at Torre Astura                         | 212 |
| 9.1  | Massive settlement of wall, Delphi                    | 231 |
| 9.2  | Polygonal foundation, Demetrias                       | 232 |
| 9.3  | Seismic action on Doric columns                       | 233 |
| 9.4  | Corinthian style tiled roof                           | 239 |
| 9.5  | Iron bars and beams                                   | 242 |
| 9.6  | Iron clamp and setting                                | 243 |
| 9.7  | Fissures on stone bedding planes                      | 245 |
| 10.1 | Methods of stabilizing foundations                    | 260 |
| 10.2 | Styles of Roman wall facings                          | 263 |
| 10.3 | Pier and hypocaust construction                       | 265 |
| 10.4 | Dome section  | 267 |
| 10.5 | Methods for countering lateral thrusts in vaults      | 269 |
| 10.6 | Types of brick vault construction                     | 271 |
| 10.7 | Types of other ceramic construction                   | 276 |
| 11.1 | A <i>qanat</i>  | 292 |
| 11.2 | An inverted siphon                                    | 295 |
| 11.3 | Channel of the Aqua Traiana                           | 300 |
| 11.4 | Arcade of the Carthage aqueduct                       | 301 |
| 11.5 | Stone pipeline, Dougga                                | 302 |
| 11.6 | Bronze stopcock, Pompeii                              | 304 |
| 11.7 | Vault of cistern, Oudhna                              | 306 |
| 12.1 | Eupalinos' tunnel, Samos                              | 325 |
| 12.2 | Junction, Eupalinos' tunnel                           | 326 |
| 12.3 | Titus' tunnel, Antakya                                | 327 |
| 12.4 | Drover Berg tunnel, Düren                             | 328 |
| 12.5 | Nonius Datus' inscription                             | 330 |
| 13.1 | Ancient cranes  | 343 |
| 13.2 | <i>Cheiroballistra</i> as inswinger and as outswinger | 349 |
| 13.3 | Noria, Hama   | 351 |
| 13.4 | Gresham St. bucket chain, London                      | 352 |
| 13.5 | Force pump, Sotiel Coronada                           | 354 |
| 14.1 | Cereal processing                                     | 371 |
| 14.2 | Grape and olive processing                            | 372 |
| 14.3 | Pompeian mills and oven                               | 377 |
| 14.4 | Trapetum, Boscoreale                                  | 381 |

|      |   |     |
|------|---|-----|
| 14.5 | Black figure skyphos, lever and weight press      | 382 |
| 14.6 | Fish-salting vats, Baelo                          | 387 |
| 15.1 | Plan of bakery, Ostia                             | 407 |
| 15.2 | Plan of marble <i>fabrica</i> , Chemtou           | 410 |
| 16.1 | Foundry cup, interior                             | 420 |
| 16.2 | Foundry cup, exterior                             | 421 |
| 16.3 | Foundry cup, exterior (2)                         | 422 |
| 16.4 | Riace bronze A                                    | 429 |
| 16.5 | Riace bronze B                                    | 430 |
| 17.1 | Longidienus relief, shipbuilder                   | 442 |
| 17.2 | Painting of decoy heifer, Pompeii                 | 443 |
| 17.3 | Relief, furniture shop, Rome                      | 444 |
| 17.4 | Painting carpenters' parade float, Pompeii        | 447 |
| 17.5 | Woodworking joints                                | 452 |
| 17.6 | Apollodorus' bridge over the Danube               | 455 |
| 17.7 | Prop-and-lintel roofing system                    | 457 |
| 17.8 | Timber truss                                      | 458 |
| 18.1 | Woolcomber, Ostia                                 | 468 |
| 18.2 | Structure of warp-weighted loom                   | 472 |
| 18.3 | Weft-faced compound twill silk tunic              | 474 |
| 18.4 | Fuller's tombstone, Sens                          | 476 |
| 19.1 | The spread of vegetable tanning                   | 484 |
| 19.2 | Tannery, Vitudurum                                | 489 |
| 19.3 | Offcut with clamp marks, Cuijk                    | 492 |
| 20.1 | Pottery kiln, Rheinzabern                         | 505 |
| 20.2 | Reconstruction of Rheinzabern kiln                | 506 |
| 20.3 | Selection of vessels (sixth to fourth century BC) | 511 |
| 20.4 | Vessels and sherds, Corbridge                     | 512 |
| 21.1 | Viscosity <i>vs</i> temperature of glass          | 523 |
| 21.2 | Operational viscosities                           | 524 |
| 21.3 | Operational temperatures                          | 525 |
| 21.4 | Beehive furnace                                   | 526 |
| 21.5 | Mouldpressing                                     | 533 |
| 21.6 | Tooling ribbed bowls                              | 535 |
| 21.7 | Lamp, glass workers (including blower)            | 537 |
| 22.1 | Route of Via Appia                                | 554 |
| 22.2 | Roads of Italy                                    | 559 |

|       |   |     |
|-------|---|-----|
| 22.3  | Paving, Via Praenestina                               | 564 |
| 22.4  | Section, Via Flaminia                                 | 565 |
| 22.5  | Arch, Via Flaminia                                    | 572 |
| 23.1  | Horses and wagon, Gorsium                             | 583 |
| 23.2  | Red figure vase, mule with pack-saddle                | 587 |
| 23.3  | Vase, Mule cart with amphorae                         | 591 |
| 23.4  | 2- wheel wagon with large barrel                      | 592 |
| 23.5  | 4-wheel wagon with large barrel                       | 593 |
| 23.6  | Operation of Diolkos, Korinthia                       | 594 |
| 23.7  | Aurelian column, Ox-drawn wagons                      | 595 |
| 23.8  | Wooden single yoke bar, Pforzheim                     | 596 |
| 23.9  | Single yoke harness, Belgium                          | 597 |
| 23.10 | Transport of marble on wagons                         | 599 |
| 24.1  | The ship <i>Cheops</i> , Giza                         | 608 |
| 24.2  | Sewn fastenings, <i>Ma'agan Mikhael</i>               | 610 |
| 24.3  | Mortise and tenon fastenings                          | 611 |
| 24.4  | <i>Olympias</i> under sail                            | 613 |
| 24.5  | Section of the ship <i>Kyrenia</i>                    | 622 |
| 24.6  | Fixing planking to frame                              | 627 |
| 24.7  | Steering by the stars, South Pacific                  | 630 |
| 25.1  | Relief, Portus  | 639 |
| 25.2  | Barge caissons, Caesarea                              | 646 |
| 25.3  | Reconstruction of Sebastos, Caesarea                  | 651 |
| 25.4  | Plan of Alexandria's port                             | 652 |
| 25.5  | Reconstruction of Munychia, Piraeus                   | 656 |
| 25.6  | Naxos shipshed, <i>Olympias</i> superimposed          | 659 |
| 26.1  | Vase, hoplites fighting                               | 675 |
| 26.2  | Red figure kylix, sword fight Greek <i>vs</i> Persian | 676 |
| 26.3  | Fortified entrance, Lato                              | 685 |
| 26.4  | Walls, Eleutheræ                                      | 687 |
| 27.1  | Roman panoply   | 696 |
| 27.2  | Assault ramp, Masada                                  | 705 |
| 27.3  | Urban defences, Autun                                 | 708 |
| 27.4  | City wall including spolia, Side                      | 709 |
| 28.1  | Greek and Latin, poetry and prose                     | 716 |
| 28.2  | Wax tablet, Egypt                                     | 720 |
| 28.3  | Construction of papyrus roll                          | 722 |

|      |   |     |
|------|---|-----|
| 28.4 | Menander papyrus reused as cartonnage               | 722 |
| 28.5 | Codex <i>vs</i> roll, classical <i>vs</i> Christian | 723 |
| 28.6 | Professional <i>vs</i> amateur handwriting          | 734 |
| 29.1 | The Antikythera Mechanism, Wright reconstruction    | 745 |
| 29.2 | Spherical sundial, Aphrodisias                      | 748 |
| 29.3 | The Tower of the Winds, Athens                      | 749 |
| 30.1 | Brass sestertius, Emperor Titus                     | 771 |
| 30.2 | Silver tetradrachm, Alexander the Great             | 773 |
| 30.3 | Electrum stater, Phanes                             | 774 |
| 30.4 | Silver denarius, Mark Antony                        | 775 |
| 30.5 | Salamis tablet (abacus)                             | 779 |
| 30.6 | Roman abacus, reconstruction                        | 781 |
| 31.1 | Gears and cam, Nysa automaton                       | 788 |
| 31.2 | Hero's magic drinking horn                          | 790 |
| 31.3 | Byzantine portable sundial calendar                 | 794 |
| 31.4 | Vitruvius' (Archimedes') odometer                   | 796 |

## LIST OF TABLES

|      |   |         |
|------|---|---------|
| 2.1  | Depiction of technological processes      | 49–50   |
| 8.1  | Principal domesticated species            | 178     |
| 8.2  | Greco-Roman hunting dog breeds            | 187     |
| 8.3  | Greco-Roman game species                  | 189–191 |
| 8.4  | Evidence for gamebird consumption         | 193–203 |
| 8.5  | Greco-Roman fishing methods               | 207–210 |
| 12.1 | List of principal tunnels                 | 320–321 |
| 17.1 | Mediterranean wood species and uses       | 449     |
| 19.1 | Procedures associated with tanning        | 486     |
| 23.1 | Relative capacity for dragged loads       | 585     |
| 23.2 | Relative potential force and power        | 586     |
| 23.3 | Human capacities for portage              | 588     |
| 23.4 | Animal capacities with pack-saddle        | 589     |
| 30.1 | Dry measures, Athenian and Roman          | 762     |
| 30.2 | Liquid measures, Athenian and Roman       | 763     |
| 30.3 | Weight standards, Aeginetan, Attic, Roman | 764     |
| 30.4 | Length and area measures, Greek, Roman    | 767     |
| 33.1 | Performance matrix for lighthouses        | 829     |

## LIST OF TYPOGRAPHICAL ERRORS

Errors are located by page number/paragraph number/line number/word number with a few self-explanatory exceptions.

|                           |  |
|---------------------------|--|
| 9.1.13.2                  | read 'provided' for 'providing'  |
| 18.2.7.5                  | read Ictinus for Icinus  |
| 83.3.9.13                 | read 2002 for 2003   |
| 97.4.8.4                  | delete 'used'  |
| 103.1.10–11.13–1          | read 'allow' for 'allowed'   |
| 106.5.5.13                | delete 'other'   |
| 121.1.9.6–7               | delete 'of operations'   |
| 153.1.9.7                 | read 'be' for 'he'   |
| 219.line 4 up.3           | insert “ before 'The'  |
| 228.2.fin                 | insert full stop at end of line  |
| 244.line 3 up.3           | read 'due' for 'dure'  |
| 307.1.3 up.3              | read 'Frontinus' for 'frontinus'   |
| 310.4.4.1                 | read 'Frontinus' for 'frontinus'   |
| 320.Table12.1,col.7,line2 | delete comma   |
| 320.Table12.1,col.7,line3 | read 'Eupalinos' for 'Eupalincs'   |
| 320.Table12.1,col.1,line9 | read 'Crypta' for 'Cripta'   |
| 320.Table12.1,col.1, 4 up | move this entry up six places (to follow the Claudius tunnel, unless the date is wrong and this should be mid 2nd c. AD) |
| 322.2.9.8                 | read, for,,  |
| 324.3.6.2                 | move full stop to after close bracket  |
| 325.1.5.11                | move full stop to after close bracket  |
| 325.1.7.13                | move full stop to after close bracket  |
| 335.2.11.2                | read 'France' for 'france'   |
| 339.1.3.3–4               | insert space   |
| 362.4.5.7–8               | insert space   |
| 372.2.2 up.5              | read '1980s' for '1908s'   |
| 373.1.9.3                 | read 'Finley' for 'finley'   |
| 373.3.2.6                 | read 'Foxhall' for 'foxhall'   |
| 376.2.8.13                | read 'fitted' for 'fit'  |
| 381.2.10.11               | read 'Foxhall' for 'foxhall'   |
| 381.3.1.fin               | insert 'the'   |
| 382.1.6 up.4              | read 'Frankel' for 'frankel'   |
| 383.2.4 up.2              | read 'Frankel' for 'frankel'   |

|                    |  |
|--------------------|--|
| 390.Lawton         | this book has two distinct titles that are confused in the publication itself; the one here given appears on the title page and the publication data inside the book, but on the cover and the recto of the series title page it is called <i>Various and Ingenious Machines</i> with ' <i>The Early History of Mechanical Engineering</i> ' as a subtitle |
| 397.2.3 up.5       | read 'Fülle' for 'fülle'   |
| 399.2.2 up.7       | delete full stop after 'Veyre'   |
| 419.2.3 up.12      | read 'in' for 'on'   |
| 432.1.1.6          | read 'Formigli' for 'formigli'   |
| 435.1.1.2          | insert 'are' after 'bronzes'   |
| 441.4.6.5–6        | read 'the most' for 'most the'   |
| 444.last line      | Matthäus is not in the Bibliography (except with Gaitzsche)  |
| 448.2.3.9–10       | insert space   |
| 450.1.5.3          | 'twenty' cannot be right if the Comacchio wreck is first century BC (444)  |
| 451.2.fin          | move '(figure 17.5)' to the end of para 1  |
| 470.1.2 up.3       | delete 'the'   |
| 512 figure caption | read 'photograph' for 'photogarp'  |
| 516. Greene 2007   | volume and page numbers missing  |
| 524.1.5.5          | delete space, delete close bracket   |
| 537.1.4.1          | read 'reasons' for 'reason'  |
| 541.4.2.3          | read 'contemporary' for 'comtemporary'   |
| 552.2.10.4         | read 'Syene' for 'Siene'   |
| 557.2.3.last       | read 'retaining' for 'retailing'   |
| 562.2.3 up.7       | read 'the animals' for 'te animal'   |
| 564.1.2.3          | after 'walls' insert 'of'  |
| 564.1.2.last       | delete full stop before '(figure'  |
| 566.1.7.14         | read 'M.' for 'M.'   |
| 568.2.8.8          | delete 'with'  |
| 580.1.2.3          | insert 'and'   |
| 580.1.3.4          | insert 'the'   |
| 581.1.17.1         | read 'produced' for 'producing'  |
| 590.1.4.7          | read 'figure 23.2' for 'figure 23.3'   |
| 592.2.last.1       | move '(figure 23.5)' up three lines and insert before full stop  |
| 602.2.16.9         | read 'growth' for 'grown'  |
| 604                | read 'Lefébyvre' for 'Lefebvre'  |

|                           |  |
|---------------------------|--|
| 605. Whitehead entry      | read ‘ <i>Athenaeus Mechanicus:</i> ’ for ‘ <i>Athenaeus: Mechanicus,</i> ’  |
| 609.3.1.2                 | insert ‘archaeologically known’ before ‘early’   |
| 620.3 lines up. 4         | delete full stop after 2005  |
| 634. Lewis/Linder entries | insert line break after ‘Press.’ to separate the entries   |
| 640.3 lines up.7          | insert ‘was’ after ‘latter’  |
| 648.1.14.13               | delete ‘)’ after ‘side’  |
| 658.6 lines up.3          | read ‘Citium’ for ‘Citium’   |
| 660.2.4.9                 | insert ‘maximum’ after ‘approximate’   |
| 660. last line.6          | read ‘capstan’ for ‘windlass’  |
| 661.1.2.7–8               | read ‘a ship of 10,000 talents burden, with wooden towers and bulwarks’ for ‘small boats’  |
| 661.1.8.9                 | read ‘any’ for ‘most’ (the ship couldn’t dock at Alexandria either; it was drawn up on the beach and never sailed again)   |
| 661.2.6.1–2               | insert comma after ‘Alexandria’ and delete open bracket  |
| 661.2.11.7                | delete ‘harbor’  |
| 668. Keay/Millett entry   | the paper in Hohlfelder is now published, pp. 97–104, has a third co-author, K. Strutt, and a slightly different title, ‘Recent Archaeological Survey at Portus’ |
| 684.2.7. end              | insert close bracket before full stop  |
| 685. picture caption      | I guess that ‘D’ is a typo for ‘P’ in the photographer’s name  |
| 686.2.12.6                | read ‘formerly’ for ‘modern’   |
| 703.2.7                   | swap the text in the two brackets  |
| 704. fin                  | insert full stop   |
| 717.3.8.7                 | delete full stop after ‘forth’   |
| 718.2.15.7                | ‘wordsearch’ is a more appropriate analogue than ‘crossword’   |
| 721.2.2                   | something has gone wrong with the references for the quotations (short quotes do not come from five/four pages)  |
| 760.2. fin                | delete colon and page numbers  |
| 766.4.12. fin             | delete full stop   |
| 768 Ioppolo entry         | the page numbers do not match with the citation on 769, so one or both is wrong  |
| 773.1.14.1                | read ‘way’ for ‘ways’  |
| 780.4.9. fin              | read ‘ $\frac{1}{12}$ ’ for ‘ $1\frac{1}{2}$ ’   |
| 785.1.5.6                 | read full stop for comma   |

|                  |   |
|------------------|---|
| 793.3.11.7       | read 'Vienna' for 'Vienne'  |
| 824.3.9.6        | read 'Differential' for 'Differential'                                      |
| 824.3.9.7        | insert close double quotation marks after<br>'adoption'                     |
| 833.Arnold entry | insert line break after the page numbers to<br>separate next entry (Barlow) |