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Maritime Archaeology and Ancient Trade in the Mediterranean

Edited by Damian Robinson and Andrew Wilson

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2: Developments in Mediterranean shipping and maritime trade from the Hellenistic period to AD 1000

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This paper attempts an overview of developments in maritime trade between 200 BC and AD 1000. It looks first at what the totality of shipwreck evidence may say about trade, then moves on to identify some relationships between ship design and construction and maritime trade, and compares these to parallel developments in harbour technologies.

Shipwrecks and maritime trade

Any survey of maritime trade over the *longue durée* must be heavily indebted to A. J. Parker's catalogue of 1,189 Mediterranean wrecks datable before AD 1500.[1] His graph of the number of wrecks per century (Figure 2.1) was seized on by ancient historians from Hopkins onward as a means of illustrating fluctuations in the levels of Mediterranean maritime trade, taking the number of wrecks in any period as a more or less straightforward reflection of the intensity of maritime shipping and therefore trade, and has featured in numerous discussions of the Roman economy, being made to bear a far greater interpretative superstructure than Parker himself had ever intended.[2] Parker's graph shows a progressive increase in the number of known wrecks from about 600 BC to 200 BC, followed by a rapid rise to peak in the first century BC, dropping very slightly in the first century AD, rather more so in the second century AD, and then sharply in the third century, with continued diminution in the fourth to fifth centuries. A slight recovery in the sixth century[3] is followed by further sharp drops and thereafter wreck numbers before 1500 do not regain even the levels attained in the sixth century AD. Overall, the Classical, Hellenistic, Roman and Late Antique periods stand out as having much larger numbers of wrecks than the Bronze Age or the Medieval period, and the last two centuries of the Roman Republic and the first two centuries of the empire have exceptionally high numbers of known wrecks.[4]

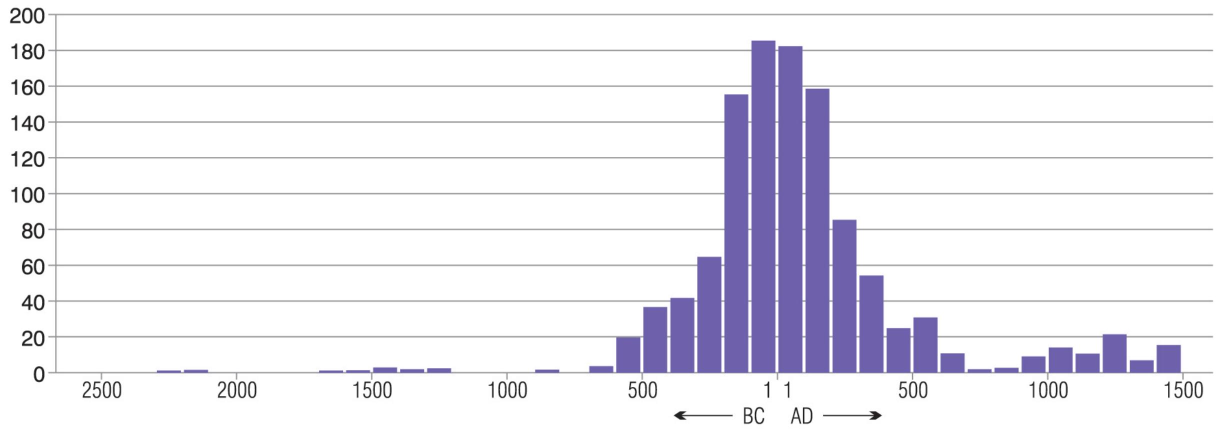

Figure 2.1. Mediterranean shipwrecks by century (n=1189), graphed using the mid-points of date ranges. (After Parker 1992a: fig. 3.)

1 Parker 1992a.
2 Hopkins 1980: 105–6 (using an early version); Gibbins 2001: fig. 10 (but n.b. pp. 273–83 on the strengths and weaknesses of wrecks as evidence for trade); de Callataÿ 2005; Davies 2006: 84–5; Jongman 2007: 188; Morley 2007a: 572–3; 2007b: 98 (with caveats about under-representation of African trade). Whittaker 1989 pointed out many of the problems in using these shipwreck data to chart changes in trade over time. See Parker 1992a: 8–9 for a discussion of the wreck statistics; Parker has since published an updated version of the graph (Parker 2008: 187 fig. 12).
3 Parker 1992a: 8.
4 As Parker 1992a: fig. 4 (presenting the chronological distribution of wrecks by periods in a pie chart) and discussion on p. 8 showed very clearly.

We shall see that there are several reasons why the graph of known wrecks is not a simple reflection of ancient maritime trade levels—and Parker himself did not assume it was; indeed, he stressed that the wrecks needed to be studied on their own terms and drew attention to biases in reporting, and to archaeological factors (transport of amphorae, roof tiles and marble cargoes) which might over-represent Hellenistic and Roman wrecks.[5] But first we need to consider a consequence of the method Parker chose to deal with imprecisely dated wrecks. He graphed all wrecks at the mid-point of the date range assigned to them,[6] thus a wreck dated 75 BC to AD 25 would be graphed in the first-century BC column because the mid-point of the range is 25 BC. A considerable number of the wrecks in Parker's catalogue were reported simply as 'Roman', which he quite reasonably interpreted as between 150 BC and AD 400. The mid-point of this range is AD 125, and a large part of the allegedly second-century AD column on the graph is accounted for by these generically 'Roman' wrecks, which is clearly misleading.

Figure 2.2 uses the data from Parker's catalogue, but assumes that there is an equal probability that a ship sank in any particular year within the date range assigned to a wreck. This probability is then accumulated for each time period on the *x*-axis (in this case, a century). Thus a wreck dated 75 BC to AD 25 has a 75 per cent chance of having sunk in the first century BC, and a 25 per cent chance of having sunk in the first century AD; it therefore counts as ¾ of a wreck in the first-century BC column and ¼ in the first-century AD column. The effect of this on the 76 Mediterranean wrecks in the catalogue reported as simply 'Roman period' (150 BC–AD 400) is to count each instance as 0.09 of a wreck in the second century BC and 0.18 of a wreck per century in each century from the first century BC to the fourth century AD. These wrecks thus account for a total of 6.8 wrecks in the second-century BC column and 13.7 wrecks in each of the columns for the first century BC to the fourth century AD.

The overall shape of the graph has changed somewhat; the gradual increase from 600 to 200 BC is still there, as is the sharp increase after 200 BC, but the absolute peak now occurs in the first century AD, not BC. The second-century AD column has now fallen to under half that of the first century AD, level with the third century; this is the result of spreading those generically 'Roman' wrecks across the six centuries in which they might have sunk, rather than concentrating them in the second century.

Parker's catalogue was published in 1992 and, obviously, more wrecks have been found and published since then. With the assistance of Dr Julia Strauss, the Oxford Roman Economy Project updated the wreck database with new material from the maritime archaeology literature since 1990.[7] This is still work in progress but has (so far) increased the number of known and datable Mediterranean wrecks before AD 1500 from 1189 to 1646 (Figure 2.3). The shape of the graph continues to change, so diminishing returns have not yet set in, and the accumulation of more data continues to be worthwhile. The new graph further accentuates certain features already visible in my regraphing of Parker's data. There is now a steeper climb in the Late Republic to a more pronounced first-century AD peak and the fall

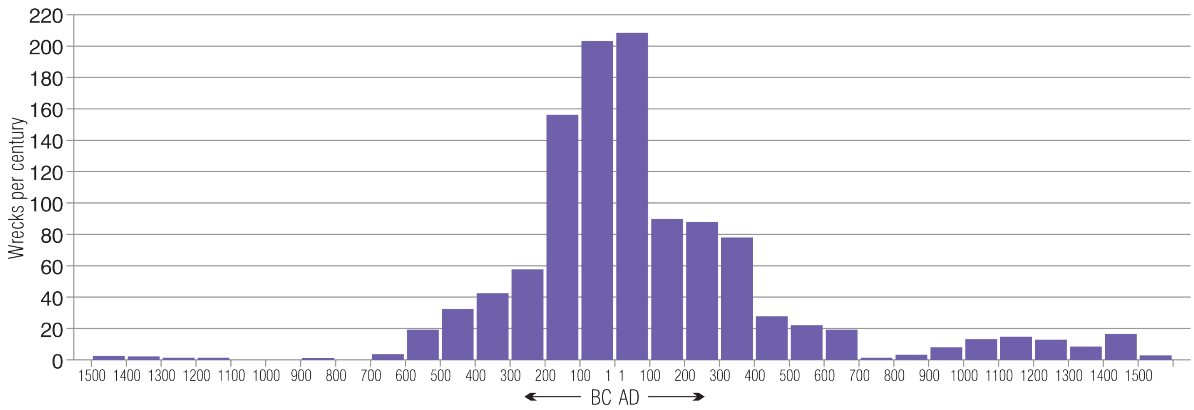

Figure 2.2. Mediterranean shipwrecks by century (n=1,189), but graphed according to an equal probability of sinking in any year during the date range for each wreck. (Data from Parker 1992a.)

5 Ibid.: largely ignored by many subsequent users of his graph.
6 Ibid.: 8.
7 Wilson 2009. The Oxford Roman Economy Project is directed by Alan Bowman and Andrew Wilson, and is funded by a 5–year grant from the AHRC and a benefaction from Lorne Thyssen; see http://oxrep.classics.ox.ac.uk.

to second- and third-century levels looks even more dramatic; under a third of the number of wrecks of the first-century column. Later centuries look similar to before: the number of fourth-century AD wrecks is not far short of the third century, but the number of fifth-century AD wrecks is less than half that of the fourth century, and below that even of the third century BC. There is another major step-change between the seventh and eighth centuries AD, with very few wrecks at all known from the period AD 700–1000. The Roman peak is therefore more pronounced, but the drop-off after AD 100 is very clear.

We can test the validity of this method of graphing of all wrecks by stripping out the noisy data—the wrecks with long date ranges—and comparing Figure 2.3 with the graph of only those 1,062 wrecks which are datable to within a century (Figure 2.4). The basic shape does not change much, inspiring some confidence in the method of graphing all wrecks. Can we probe the data further, by using smaller time periods? Figure 2.5 shows what the 1,646 wrecks look like if distributed across half-century brackets, a graph which suggests that whatever the reason for the second-century drop, it was not the Antonine Plague because the drop occurs already in the first half of the second century. The further drop in the fourth century does not occur until after AD 350.

This view receives some support from the graph of only those 596 wrecks which can be dated to within half-century brackets, graphed by 50-year periods (Figure 2.6). This is broadly similar, but intriguingly suggests dips in the second half of the first century BC (during the civil wars but also the subsequent Augustan peace), and an apparent slight recovery in numbers in the early fourth century AD.

What relationship do these graphs bear to levels of maritime trade over time? Figures 2.2–2.6 show a massive drop in shipwreck numbers between the first and second centuries AD, just when there was major investment in harbour works at Portus, and just when African Red Slip exports from North Africa take off. The pan-Mediterranean

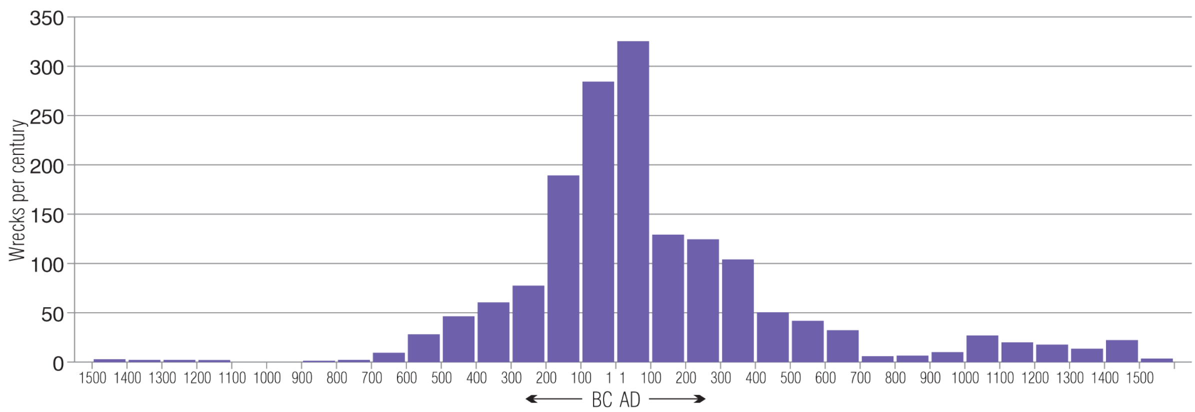

Figure 2.3. Mediterranean shipwrecks by century (n=1,646), graphed according to an equal probability of sinking in any year during the date range for each wreck. (Data collected by Julia Strauss.)

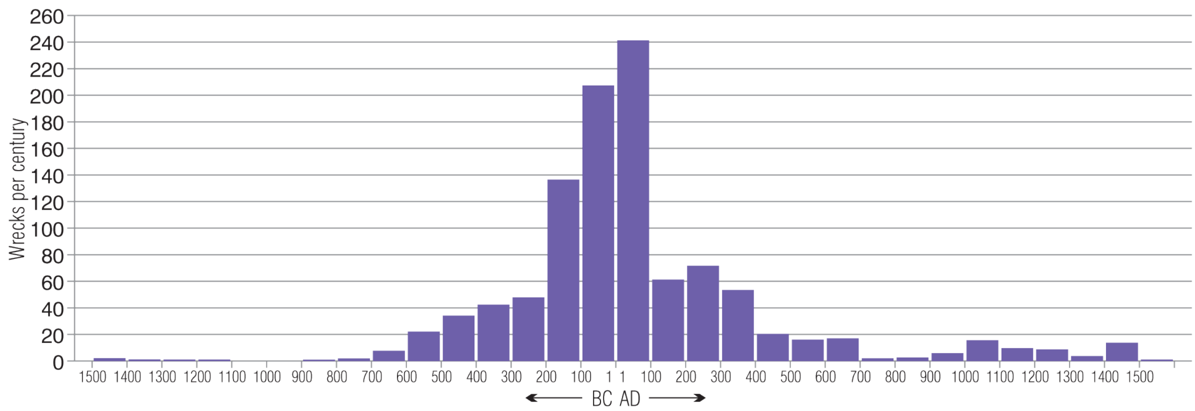

Figure 2.4. Mediterranean shipwrecks datable within 100-year ranges (n=1,062), graphed according to an equal probability of sinking in any year during the date range for each wreck. (Data collected by Julia Strauss.)

distribution of this tableware shows that maritime trade links were not declining; yet most of this evidence comes from terrestrial excavations. There is therefore something anomalous about the underwater evidence.

Attempts to equate the graphs of wrecks over time with fluctuations in maritime trade rest on two fundamental assumptions:

(1) The probability that any voyage will end in wreck is the same at all periods.

(2) Wrecks are equally visible archaeologically at all periods.

The first of these assumptions might be questioned, if climatic change is felt to have increased the incidence of storms at certain periods; or if changes in shipbuilding technology over time affected (reduced?) the propensity to wreck; or if there were changes in sailing practice and the balance of long-distance open-water voyages to shorter coastal voyages, entailing a difference in risk at different periods. Russell's analysis of stone cargoes[8] suggests that patterns of wrecking are indeed correlated with the relative risks of different sailing routes that may in turn be determined by fashions for particular marbles at different periods—in the case of stone cargoes, wreck numbers peak in the second and third centuries AD when transport of eastern Mediterranean coloured marbles to Italy and the central Mediterranean becomes more common, as these involved the traversing of dangerous waters off southern Italy and Sicily in a way which the transport of Luna marble down the coast of Italy from Carrara to Rome and the Bay of Naples did not. Moreover, if practices of winter sailing became more common at different periods—as there is some evidence that they did under the Roman empire[9]—then this will have increased the risk of sailing and therefore the likelihood of wreck.

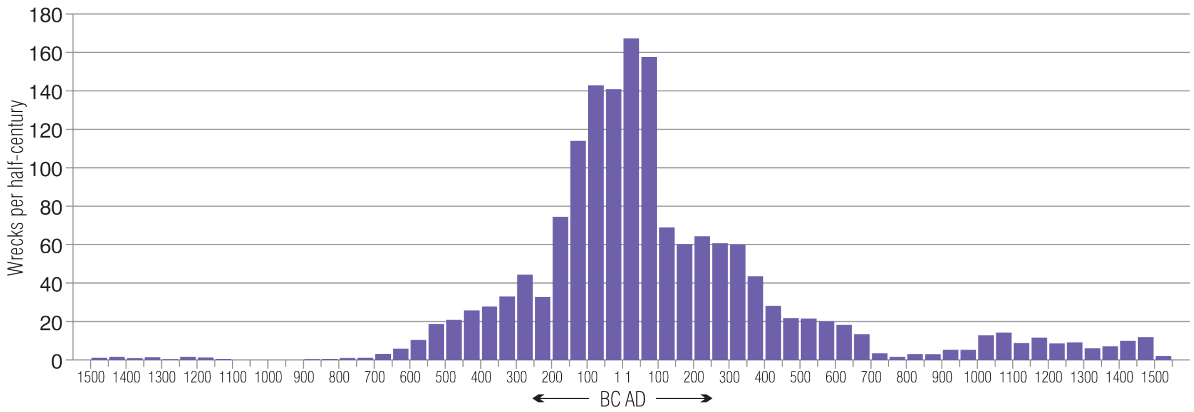

Figure 2.5. Mediterranean shipwrecks by half-century (n=1,646), graphed according to an equal probability of sinking in any year during the date range for each wreck. (Data collected by Julia Strauss.)

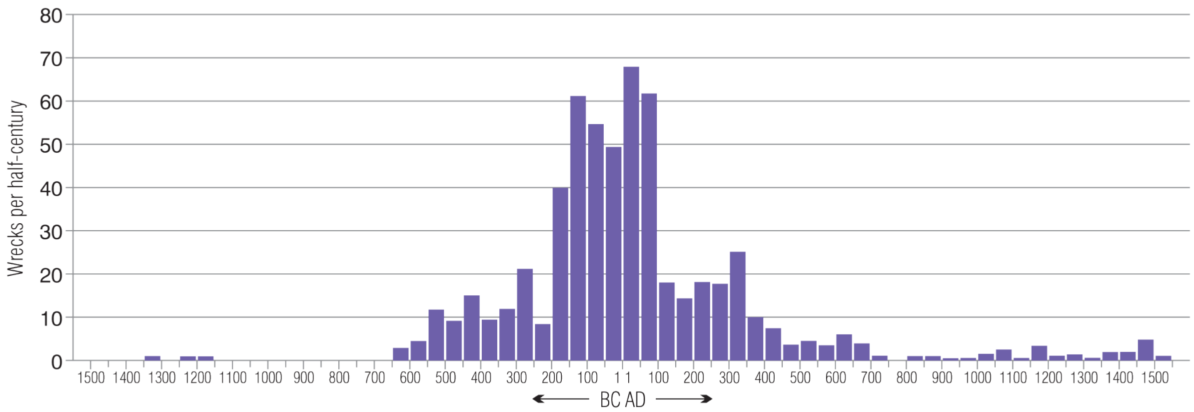

Figure 2.6. Mediterranean shipwrecks datable within 50-year ranges (n=596), graphed according to an equal probability of sinking in any year during the date range for each wreck. (Data collected by Julia Strauss.)

8 Russell, this volume (Chapter Eight).

9 Beresford 2005.

The second assumption is demonstrably false. Shipwrecks are found, usually by SCUBA divers in relatively shallow coastal waters, because they show up as a mound of cargo on the seabed, or, in the case of early modern wrecks, the iron cannon are seen. The ship's timbers, where not protected by the cargo, have usually rotted or been scattered. Ships are therefore unlikely to be found if they were carrying largely non-durable cargo, like slaves, grain, textiles, or other perishables in sacks. The main durable cargoes likely to preserve ancient shipwrecks are therefore cargoes of stone, or of goods carried in amphorae, the main container until at least the early Imperial period. Although a few of the wrecks in the dataset are represented only by shipboard equipment, or have been found as sunken hulls in terrestrial excavations of harbours or river ports, the vast majority were discovered because their cargoes were spotted on the seabed. The 'wreck' graphs may therefore be considered as graphs of known cargoes. Are they in fact primarily graphs of amphora usage? [10]

By the Medieval period, at least in the central and western Mediterranean, the barrel had largely replaced the amphora as the preferred transport container for liquids and even some solid goods, such as salted fish, having a better volume to weight ratio, more efficient stacking capability, and greater manoeuvrability on land. The relatively short-lived phenomenon of dolia shipwrecks, discussed by Heslin in this volume (Chapter Nine), may have been a Mediterranean effort to compete with the new container technology. In the southern and eastern Mediterranean, where timber resources were less plentiful, the amphora lasted longer in the early Islamic world; but it is safe to say that in the western Mediterranean during the second half of the first millennium AD the switch from amphorae to barrels was largely complete. Possible iron hoops from barrels have been found in the Port-Vendres C wreck of the second century AD,[11] but the construction of many Roman barrels with wooden tied hoops or withies further reduces the chance of survival.[12] The concomitant reduction in visibility of wrecks may therefore account for some of the reduction in the number of known wrecks of this period; in other words, we cannot be entirely confident that either the second-century or the early Medieval decline in trade was as sudden or complete as the graphs would seem to suggest.

The real question is when this shift in container technology commenced, and how fast it occurred. Barrels were an invention of northern Europe, probably of Celtic origin, and they are referred to in literary sources from the second half of the first century BC, and are known archaeologically, reused as well linings, from Roman sites along the Rhine frontier from the late first century BC.[13] From the first to third centuries AD they are not uncommonly shown in Roman reliefs, particularly in Gaul, Germany and Britain, but also in Lusitania (Portugal).[14] By the late third or early fourth century AD the tariffs for unloading and handling wine brought down the Tiber to Rome's river port called *Ad ciconias nixas* specify charges per barrel; there is no mention of amphorae in this riverine trade.[15] Is part of the apparent sharp drop in the shipwreck graph from the first to the second century AD due to an increasing use of barrels? But if so, it can hardly account for all of it—amphora usage in the Mediterranean remained common until the sixth or seventh centuries.

Another explanation worth considering, at least as a partial factor, for the apparent mismatch between the underwater and terrestrial evidence is the lack of modern underwater survey work along the North African coastline. If trade with Africa was increasing between the first and second century AD, as the ceramic evidence of North African exports on land suggests that it was, we should expect sailings to and from Africa to be under-represented in the wreck evidence, given that we are likely to find their wrecks only at the non-African end of the voyage.

Examination of the relatively small number of 87 Roman and Byzantine wrecks carrying stone cargoes gives a rather different picture chronologically and reinforces the idea that the shape of the main wreck graph is heavily influenced by chronological fashions in amphora usage, rather than necessarily being representative of all shipping. Russell's paper in this volume (Chapter Eight) deals with these wrecks in more detail; here I confine myself to noting that they start in the second century BC and climb sharply through the late Republic and early Empire to reach a peak in the third century AD (Figure 2.7). The fourth-century column is accounted for almost entirely by a proportion of the long-dated generically 'Roman' wrecks, as is apparent when we remove these from the dataset and concentrate only on the 42 wrecks datable to within a century (Figure 2.8). A single Byzantine wreck, carrying the stone fittings for a church, is found thereafter. The evidence for stone cargo wrecks is much more congruent with the evidence from

10 Cf. Horden and Purcell 2000: 371–5.
11 Parker 1992a: 332.
12 Barrel in Istres museum, first century AD: http://www.culture.gouv.fr/fr/archeosm/archeosom/istre-m1.htm (last consulted 1 June 2011). Barrels found reused as well linings at Silchester were six feet tall and made of silver fir, probably from the Pyrenees, bound with wooden hoops: St. John Hope and Fox 1898: 121–2 and pl. VIII; Reid 1901; Boon 1957: 159.
13 Marlière 2002: 27: 174–5. On origins, ibid.: 170–3.
14 Ibid.: 117–57.

sites on land, which shows high levels of imported marble for architecture from the first century BC to the early third century AD, and for sarcophagi from the second century AD through the third century AD.

The picture of Mediterranean trade suggested by finds on land certainly does not suggest a downturn of maritime trade in the early second century.[16] From the Augustan period through to the mid-first century AD, Italian Terra Sigillata pottery achieved a wide distribution throughout the Mediterranean, and was even exported to India. From the early first century AD onwards it was increasingly replaced by Gaulish Samian ware, the distribution of which centred on the central and western Mediterranean. From around AD 90 African Red Slip ware began to be exported in quantity from Africa Proconsularis (modern Tunisia) and rapidly became the dominant Roman fineware class in the western and central Mediterranean, achieving a pan-Mediterranean distribution from the third to seventh centuries AD, surviving the split between eastern and western empires.[17] Significantly, the distribution of known shipwrecks is concentrated around the northern shores of the Mediterranean, largely because of modern political circumstances limiting underwater survey along the North African coastline. But if, as the land evidence suggests, there was actually an increase in exports from North Africa in the second century AD, this will be under-represented in the wreck evidence, further complicating interpretation of the graphs.

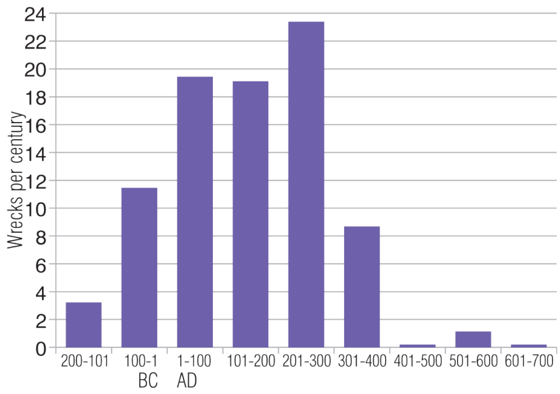

Figure 2.7. Wrecks carrying stone cargoes by century, 200 BC–AD 600 (n=87). (Data supplied by Ben Russell.)

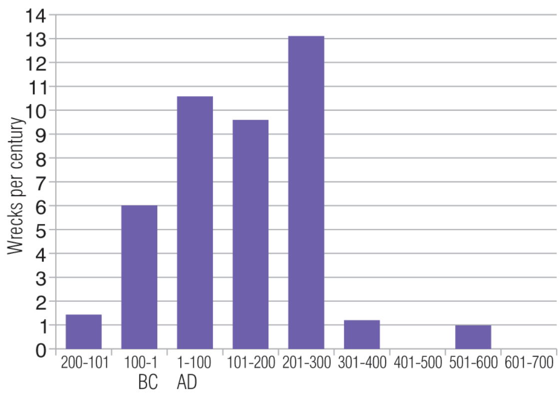

Figure 2.8. Well-dated wrecks, datable within 100-year ranges, carrying stone cargoes by century, 200 BC–AD 600 (n=42). (Data supplied by Ben Russell.)

The end of this intensive, connected trading system has been a matter for prolonged debate. Pirenne considered that Mediterranean long-distance trade continued essentially unchanged until the Arab expansion of the seventh century;[18] Hodges and Whitehouse showed that this view was based on an optimistic reading of the documentary sources, and that archaeological evidence suggested a steep decline in trade in the western Mediterranean in the sixth century,[19] a view largely supported by more recent analyses.[20] To the extent that state incentives, especially tax and customs exemptions for ship-owners providing services to the *annona*, stimulated maritime trade by subsidising the costs of particular voyages, changes in the *annona* system may be expected to have had repercussions on the entire system. Particularly significant in this regard were the loss of Africa to the Vandals in the fifth century, and the Persian capture of Alexandria in 617 which severed Constantinople from its Egyptian grain sources and brought an end to the *annona* traffic to the Byzantine capital.[21]

The ceramic evidence from land sites shows that the seventh century generally saw a further major downturn in the already diminishing volume of maritime trade, especially in the west and central Mediterranean. Following the Arab invasions of North Africa in the 640s, exports of African Red Slip ware dwindled and ultimately ceased by the time of the final conquest of North Africa at the end of the seventh century.[22] The majority of imports even to the city of Rome stopped, though the exceptional deposit from the Crypta Balbi shows that imported finewares from North Africa and amphorae from North Africa, southern Italy and the eastern Mediterranean continued to reach at least ecclesiastical or monastic consumers in the second half of the seventh century.[23] In the eighth century Rome's table pottery—Forum

15 *CIL* VI.1785 = 31931; Rougé 1957.
16 Cf. Rice, this volume (Chapter Four).
17 Hayes 1972; Fentress *et al.* 2004.
18 Pirenne 1937; 1952.
19 Hodges and Whitehouse 1983.
20 Hayes 1998; Wickham 2005: 693–824; McCormick 2001: 83–119; Reynolds 1995.
21 McCormick 1998.
22 Fentress 1998.
23 Saguì 1998; Fentress 1998: 5 on its exceptionality.

Ware—was locally produced or came from no further afield than 30 miles away; in the ninth century, Forum Ware began to be exported in small quantities around the central-west Mediterranean, from Sicily to Provence.[24] McCormick has shown that the ninth century saw some revival of shipping communications and trade, but that overall the Roman pattern of often direct, open-water sailing between principal ports had given way to habits of predominantly coastal voyaging.[25] Trade in the eastern Mediterranean, however, remained more vibrant than in the west, but overall the Mediterranean of the seventh and eighth centuries was much less connected than that of even the fourth to sixth centuries, let alone the first to third, when the levels of maritime trade were such that Italian bricks were exported as return cargoes for African exports of grain, olive oil and salted fish.[26]

Even though deriving levels of trade from graphs of shipwreck numbers remains problematic, the evidence from terrestrial distribution of amphorae and fine wares suggests that the Hellenistic and Early Roman periods saw a massive increase in trade, followed by a reduction in the seventh and eighth centuries. Despite the problems of archaeological visibility that seem to be affecting the shipwreck graphs from the first century AD onwards, the Hellenistic and Roman periods together with, to a lesser extent, the fourth to sixth centuries AD, look exceptional by comparison with any other pre-modern period. This observation is further supported by an examination of changes in the technology of ships, and developments in harbour construction.

The technology of merchant shipping in the Roman period

Size

The wreck evidence does suggest that there were important changes in the size of the largest shipping between the Hellenistic and early Medieval periods. Small ships were, of course, common at all periods, and we must keep in mind that ships of less than 75 tons were common throughout the Roman period, as they were before and afterwards.[27] Houston points out that the great majority of merchant shipping at any period before the mid-twentieth century was made up of small ships—of less than 100 tons each—and this will have been true for the Roman period too.[28] Nevertheless, during the period 100 BC to AD 300 we find wrecks of ships that carried cargoes of well over 100 tons, even over 350 tons, which we do not before about 100 BC or between AD 400 and 1000.[29] The attestation in wrecks of shipping of this size is important in the perspective of the *longue durée*, suggesting that the intensity and volume of Roman trade was such as to justify investment in larger merchant ships (and, as we shall see, of the harbour infrastructure to receive them) than was the case in the Classical or early Hellenistic periods, or in the early Middle Ages.

The sample of wrecks for which tonnage can be estimated is small, and there is textual evidence at least before 100 BC for larger ships—Hieron of Syracuse's superfreighter, the Syracusia, has been estimated at over 4,000 tons displacement including nearly 2,000 tons of cargo.[30] This was of course exceptional, but an indication of sizeable ships in regular use is given by the Thasos harbour regulations of the later third century BC which restrict use of one part of the harbour to ships of 80 tons or more, and of the other part to ships of 130 tons or more.[31] Archaeologically attested evidence for ships over 100 tons dates from *c.* 100 BC onwards, and two of the largest known Roman wrecks, the Albenga and Madrague de Giens wrecks, date from the period of the Late Republican wine trade between Italy and Gaul in the first half of the first century BC. The Albenga wreck sank off the coast of northern Italy *c.* 100–80 BC, with a cargo estimated at between 11,500 and 13,000 Dressel 1B wine amphorae, together with hazelnuts and grain (probably in sacks above the amphorae)—the total burden was

24 Wickham 2005: 735–6. On Forum Ware, see Whitehouse 1965.

25 McCormick 2001.

26 Wilson 2001; Wilson, Schörle and Rice forthcoming.

27 Confusion is caused by the different types and spelling of modern measurement units, and by different ways of measuring ships' tonnage, which may include total displacement of the ship, displacement when empty, the weight of the cargo, or various ways of converting the capacity of the ship from a volume measure to tons; see Lane 1964 on all this. Three different tons are in use: the tonne or 'metric ton' of 1,000 kg (2,205 lb), the UK 'long ton' of 1,016 kg (2,240 lb), and the US 'short ton' of 907.1,847 kg (2,000 lb). I use 'ton' here to mean the long ton, following UK English usage. Since even in the US, in writings on naval architecture the unqualified use of 'ton' refers to the long ton rather than the short ton which is the normal US usage in non-naval contexts, I assume that Casson (1971) and Houston (1988) both use the long ton. Because the long ton is very close to the metric tonne (1 long ton = 101.605 per cent metric tonne) used by non-Anglophone European authors, and because estimates of ancient tonnage are imprecise anyway, I have not considered the difference between the long ton and the metric tonne significant when reporting estimates of ancient tonnage. Therefore, when Pomey and Tchernia (1978: 234) calculate the burden of the Madrague de Giens ship as 375–400 tonnes, I have simply converted this as 375–400 tons rather than achieve a spurious precision by reporting it as 369–394 tons.

28 Houston 1988.

29 Parker 1990a: 340–1; 1992a: 26; 1992b: 89 and 90, fig. 1; Pomey and Tchernia 1978.

30 Athenaeus *Deipnosophistae* 5.206d–209b; Casson 1971: 185–6; Turfa and Steinmayer 1999.

31 IG XII. Suppl.: 151, no. 348, with *SEG* XVII: 417; Casson 1971: 171, n. 23.

probably in the order of 500–600 tons. At the Madrague de Giens, a ship of 375–400 tons sank off southern Gaul *c.* 75–60 BC while carrying a cargo of 6,000–7,000 Italian wine amphorae inserted into a layer of *pozzolana* for stability, with Campanian black gloss wares and cooking and coarse pottery packed in wooden crates above the amphorae.[32] The biggest amphora-carriers, in fact, belong to the first century BC.

Ships carrying stone cargoes show a somewhat different chronological pattern; as Russell discusses in his contribution in Chapter Eight, the majority were small ships: 68 per cent of stone cargoes for which a weight can be estimated weigh under 50 tons. But among the larger ships, of 200–350 tons, all the known wrecks except the Mahdia ship of the early first century BC belong to the second or third centuries AD, and are found off the southern coasts of Italy or Sicily, carrying eastern cargoes. Russell suggests that ships used to carry marble were getting larger—or, put another way, marble shipments became larger and more frequent as the marble trade developed over the Imperial period. The largest cargoes represented by wrecks of the Late Republican period are dominated by amphorae, while the largest cargoes of the High Empire are marble shipments. The transport of stone obelisks weighing between 200 and 460 or even 500 tons from Egypt to Rome in the reigns of Augustus and Caligula, and again under Constantine in AD 337, must give some indication of the size of the ships needed to carry these exceptional cargoes.[33]

Some of the largest ships, especially in the Roman period, may have been primarily grain transports which have not been found as wrecks for the obvious reasons of cargo perishability; the largest of these have been estimated at some 1,000 to 1,200 tons.[34] Most telling, perhaps, is the late second-century AD regulation exempting ship-owners from civic *munera* if they put at the state's disposal a ship of *c.* 340 tons, or several ships of *c.* 70 tons.[35] This implies that such ships might be affordable by some private ship-owners. Indeed, the financial burdens of *munera* were so heavy that elite landowners were thus encouraged to invest in large shipping to escape them. The larger merchant ships of the Roman Imperial period thus compare well, in terms of capacity, with Venetian shipping of the mid-fifteenth century: the Venetian merchant marine consisted of merchant galleys which carried 150–240 tons of cargo, and some 300 round ships of 100 tons or more, with perhaps 30–35 of these carrying 240 tons or more, up to *c.* 360 tons.[36]

Hull design

Several prior technological advances had been necessary prerequisites for the development of large shipping. The development of the keel is already attested in the Ma'agan Michael ship of *c.* 400 BC and the fourth-century BC Kyrenia wreck.[37] The keel and its associated wineglass hull section improved stability and reduced the leeway that a ship made when sailing into the wind. Although many merchant ships had rounded hulls, some, like the Grand Congloué, Dramont A and Chrétienne A, had sharp hulls.[38] The Madrague de Giens ship had a keel 1 m deep (Figure 2.9),[39] and a prow with a concave profile, ending in a jutting cutwater like those shown on later mosaic representations of merchant ships of the second and third centuries AD, from the *statio* of the shippers of Sullecthum in the Piazzale delle Corporazioni at Ostia, and from the baths of Themetra in Tunisia (Figures 2.10–2.11).[40] This prow and cutwater design would also substantially reduce leeway.

Maritime archaeology continues to produce new evidence on the techniques employed by ancient shipwrights, and while it is increasingly clear that shipbuilding technology did not remain static throughout the Roman period, the picture formerly held

32 Tchernia *et al.* 1978; Pomey 1982; Liou and Pomey 1985: 559–67; Parker 1992a: 249–50. The *pozzolana* that stabilised the amphorae may have been intended for subsequent sale for use in harbour construction.

33 Estimates for the weights of the largest obelisks moved to Rome vary. According to Wallis Budge (1926: 143, 181, 219 and 255, followed by Habachi and Vogel 2000: 103–6), the two obelisks now in Piazza Montecitorio and Piazza del Popolo, which were moved in 10 BC, weigh 214 and 235 tons; the Vatican obelisk, moved by Caligula in AD 37, weighs 326 tons, and the Lateran obelisk, shipped in AD 357, weighs 460 tons. Engelbach (1923: 30) reports estimates of 331 tons for the Vatican obelisk and 455 tons for the Lateran obelisk. Wirsching (2000: 274, Table 1) gives higher figures: 230 tons for Piazza Montecitorio, 263 tons for Piazza del Popolo, 330 tons for the Vatican obelisk, and 500 tons for the Lateran obelisk. *LTUR s.v. Obeliscus Constantii: Circus Maximus* gives a figure of 522 tonnes for the Lateran obelisk. With the exception of Engelbach, none of these authors gives sources for their estimates.

Pliny says that the ship transporting the Vatican obelisk also carried 120,000 modii of lentils as ballast (*Naturalis Historia* 16.76.201); its total tonnage has been estimated at 1,100 tons. The other loads will also have needed stabilising ballast and imply ships of substantially greater tonnages than the weights of the obelisks themselves. Wirsching's reconstruction (2000; 2003) of the design of obelisk-carriers is wholly unconvincing.

34 Casson 1971: 186–8, on the basis of Lucian's description of the *Isis*, which he purports to have seen in the Piraeus (Lucian *Navigium* 5–6).

35 Scaevola *apud Digestam* 50.5.3; cf. Casson 1971: 171 n. 23.

36 Lane 1966, especially 4–5.

37 Steffy 1994: 40–49.

38 Casson 1971: 175; Benoit 1961: 130 fig. 75 and pl. 28; cf. Throckmorton 1972: 68.

39 Parker 1992a: 250.

40 Pomey 1982: 140–51.

of a gradual evolution in methods of hull construction is now becoming increasingly complicated and regionally diverse.[41] The shell-first method of construction, using edge-joined planks held together with mortise and tenon joints and reinforced by internal bracing timbers or frames is attested already in the Uluburun wreck of the fourteenth century BC and persisted into the Byzantine period. By the mid-first century BC some large ships, like the Madrague de Giens wreck, had double-skinned hulls, adding strength.[42] Over time, the mortise and tenon joints became smaller and more widely spaced (Figure 2.12), and more reliance was placed on the internal structures of frames, keelsons, ceilings and decking.[43] This process was originally seen as adumbrating the transition to skeleton-first construction clearly attested in the eleventh-century Serçe Limanı wreck, in which the frames were laid first and the hull planking then nailed to them, without the need for edge joints.[44] However, this simple evolutionary picture is complicated by the recent discovery of wrecks in Tantura lagoon near Tell Dor, of the early sixth (Tantura A) and early ninth centuries AD (Tantura B), which already show skeleton-first construction, with planking nailed to the internal frames, and no edge-joints.[45] The earlier of these wrecks pre-dates the seventh-century Yassı Ada wreck, which was still built using the shell-first technique. Meanwhile the Dor D wreck, of the mid-seventh century, has hull planking which was edge-joined by relatively close-set but loose-fitting unpegged mortise and tenon joints, whose purpose was probably for alignment of the planking which was nailed to frames by means of treenails. This suggests skeleton-first construction, but with continued use of mortise and tenon joints.[46] The St. Gervais II wreck, also seventh-century, may have been built in similar fashion.[47] Evidently, the transition from shell-first to skeleton-first construction was a lengthy process and

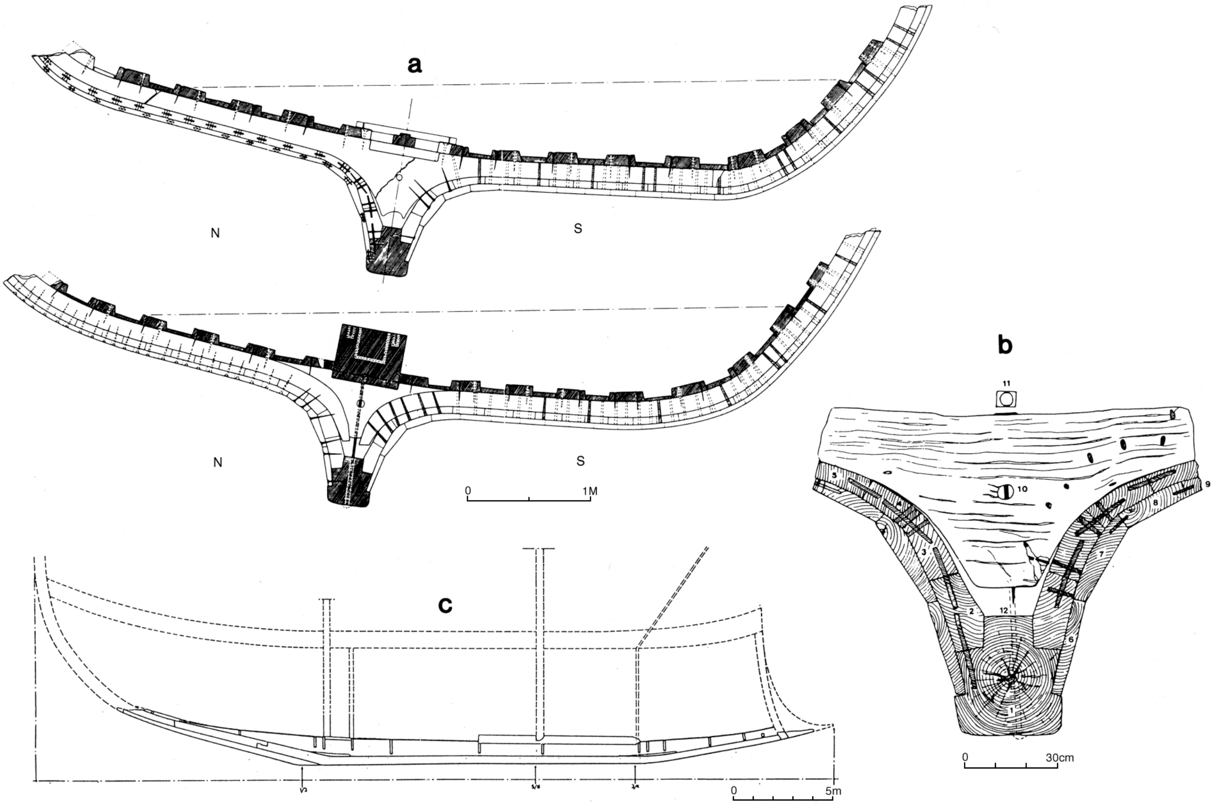

Figure 2.9. The Madrague de Giens ship, c. 70–60 BC. (a) cross-sections of the hull; (b) detail of cross-section of the keel; (c) longitudinal profile of the ship, with reconstructed elements dashed. (Reprinted from *Wooden Ship Building and the Interpretation of Shipwrecks* by J. R. Steffy 1994: 63, fig. 3-49, by permission of Texas A&M University Press.)

41 For syntheses see Steffy 1994; Hocker and Ward 2004; Pomey and Rieth 2005: 156–83. Rival 1991 discusses Roman carpentry techniques in shipbuilding.

42 Steffy 1994: 62–5.

43 Ibid.: 84.

44 Ibid.: 84–5 is cautious about adopting a simple evolutionary perspective, noting the importance of regional differences.

45 Kahanov *et al.* 2004.

46 Kahanov and Royal 2001.

47 Cf. Pomey 2004: 33.

Figure 2.10. Mosaic from the *statio* of the traders of Sullecthum (Salakta, Tunisia) in the Piazzale delle Corporazioni at Ostia, showing a three-masted and a two-masted ship. (From Pomey 1997: 85.)

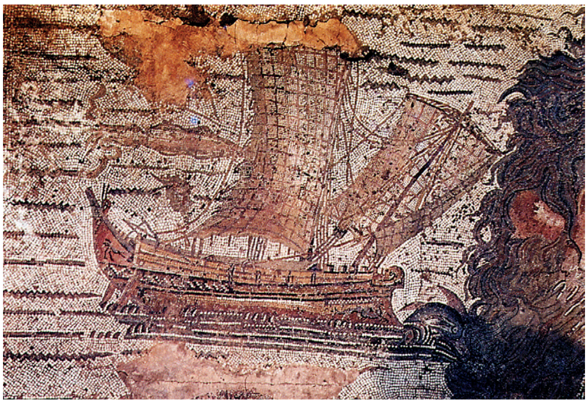

Figure 2.11. Third-century AD mosaic from the *frigidarium* of the baths at Themetra (Tunisia), showing a merchant ship with inclined foremast (*artemon*), concave prow profile and sharp cutwater. (From Pomey 1997: 89.)

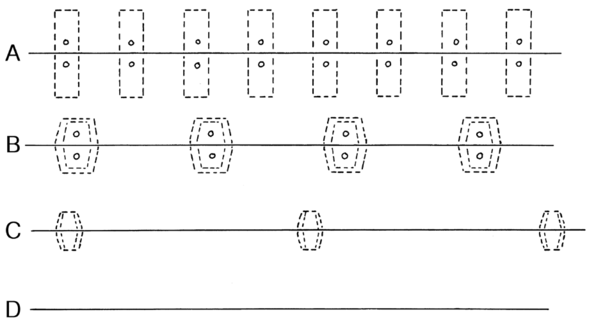

Figure 2.12. Development of edge-joining techniques for hull planking, using mortise and tenon joints (a) Kyrenia ship, fourth century BC; (b) Yassı Ada ship, fourth century AD; (c) Yassı Ada ship, seventh century AD; (d) Serçe Limanı ship, eleventh century AD. (Reprinted from *Wooden Ship Building and the Interpretation of Shipwrecks* by J. R. Steffy 1994: 84, fig. 4-8, by permission of Texas A&M University Press.)

both methods continued in parallel for a while. Different regional traditions of construction also persisted and further complicate an attempt to construct a simple evolutionary narrative;[48] the very ancient tradition of sewn-planked ships persisted in northern Italy, especially the Po Valley, for river and estuarine craft throughout antiquity and the Middle Ages.[49] In the North Sea and Channel regions, in the late Iron Age and the Roman period, ships were clinker-built, skeleton-first with overlapping hull planking, and the relationship of this tradition to the emergence of skeleton-first construction in the Mediterranean remains enigmatic.[50] The reasons behind the transition from shell-first to skeleton-first construction were probably connected primarily with the costs of ship construction. Shell-first construction, in which the hull planking determined the form of the hull and the frames provided internal strength, in fact conferred greater flexibility on the hull, giving greater resistance to stresses inflicted during rough weather. However, it was very labour-intensive. Skeleton-first construction, by contrast, was cheaper in terms both of labour and materials; and the limited evidence currently at our disposal possibly suggests that the transition to this new, cheaper technique may have taken place earlier in small coasters than in larger merchant vessels.[51]

Bilge Pumps

All wooden ships leak, and water must be bailed or pumped if the ship is not ultimately to sink.[52] The wineglass hull section enabled the water that seeped through weeping seams between the timbers, or was otherwise taken on board unintentionally, to collect at the lowest point in the hull, in the bilge, which could be floored over. This minimised humidity in the hold and kept the cargo drier. Larger ships would obviously collect more bilge water, and the height of a large ship would set a limit to bailing out the bilge water by hand. Or rather, unless a more effective method could be found, the problem of emptying the bilge would set a limit on the size of ships. Significantly, one of the features of Athenaeus' account of Hieron's superfreighter the Syracusia is the use of an Archimedes screw to empty the deep bilge.[53] However, the Archimedes screw was a suboptimal device for bilge pumping in a pitching and rolling ship, and although it had a high discharge rate it had a relatively low lift.

48 Pomey and Rieth 2005: 166–7.
49 E.g., the Commacchio wreck, first-century BC (Pomey and Rieth 2005: 164–5). Cf. Virgil *Aeneid* 6.413–4, where Charon's ferry is clearly a sewn boat. It is not irrelevant in this context that Virgil was from Mantua, in northern Italy.
50 Cf. Pomey and Rieth 2005: 173–5.
51 Kahanov *et al.* 2004: 126.
52 Oertling 1996: xv.
53 Athenaeus *Deipnosophistae* 5.208f.

By 100 BC, though, a new type of pump had been designed, not described by any ancient author but reconstructable from evidence in wrecks and similar in fact to known pumps from eighteenth-century ships.[54] The chain pump consisted of a series of wooden disks threaded on a loop of rope or chain, passing over a kind of cog-wheel at the top and guided by a roller at the bottom of the loop, which was in the bilge (Figures 2.13–14). On their upward journey the disks entered a tube which they fitted tightly. The lower end of the tube was below the level of water in the bilge and the disks thus drew water up into the tube, discharging it into a trough at the top, from where it was emptied through the gunwales via a pipe. How the loop was rotated is unclear; various scholars have suggested a windlass, crank or treadwheel attached to the upper wheel. Despite earlier doubts, it has in recent years been shown that the principle of the crank was known in the Roman world, and a wooden disk with an eccentric square socket from one of the Nemi ships has been interpreted as the disk from a crank handle for a chain pump. The one textual reference we have to the operation of a bilge pump is a passage of Paulinus of Nola, in which an old man was below decks pumping bilge-water.[55] It is difficult to believe, however, that this was a chain pump operated from below, since it would have been difficult and inefficient to attach any of the suggested drive devices for a chain pump to the lower wheel or roller. If it was a chain pump, it must have been discharging into scuppers between decks, to save lifting the water all the way up to the top deck, but still operated from the top of the chain, below the top deck. Oleson may well be right, however, to see this as a force pump.[56]

In Roman wrecks the wooden disks and lead tubing from the discharge pipe of a bilge pump are sometimes found; the Nemi ships, the Los Ullastres wreck, and the wreck in Ponza harbour also preserved parts of the upper wheel or the lower guide rollers.[57] The earliest evidence comes from the La Cavalière wreck of *c.* 100 BC.[58] The bilge pump on the Madrague de Giens wreck had been recovered in antiquity by salvage divers.[59] Elements of chain pumps are found in wrecks between 100 BC and the seventh century AD; after this the trail goes cold again until the fifteenth century AD. Mariano Taccola in 1451 regarded the chain pump as a Tartar device, while Portuguese and Spanish navigators of the sixteenth century found Chinese naval chain pumps alien and superior to the force pumps used in Mediterranean ships.[60]

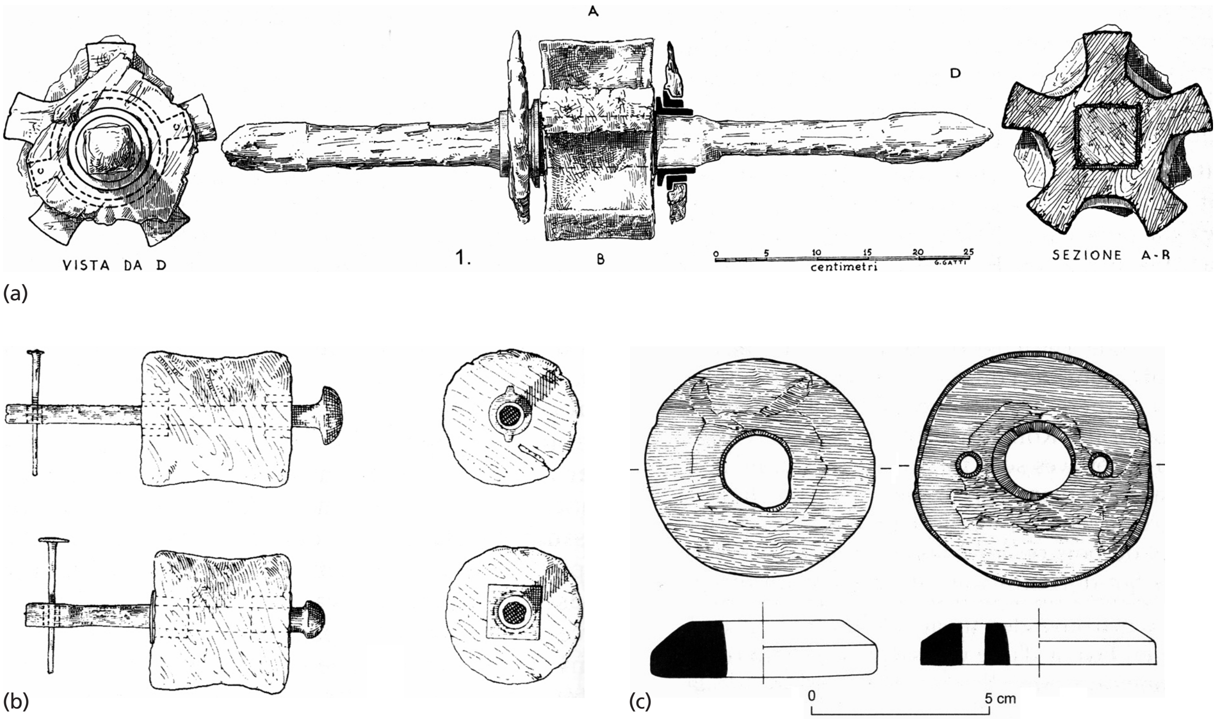

Figure 2.13. Elements of Roman bilge pumps: (a) upper sprocket from the Nemi ships; (b) lower guide rollers from the Nemi ships; (c) wooden disks from the Madrague de Giens wreck. (© Carre, M. B. and Jézégou, M. P. (1984). 'Pompes à chapelet sur des navires de l'antiquité et du début du moyen âge', *Archaeonautica* 4: 198, fig. 14. CNRS Éditions.)

54 Oertling 1982; Carre and Jézégou 1984; Foerster Laures 1984; 1989; Carre 2007.
55 Paulinus of Nola *Epistulae* 49 (discussed by Oleson 1984: 65–7).
56 Oleson 1984: 65–7.
57 Ucelli 1950: 183–5 (with incorrect reconstruction); Foerster Laures 1984; Galli 1996.
58 Foerster Laures 1984: 93.
59 Pomey 1982: 139; Parker 1992a: 250.
60 Oertling 1996: 56–8.

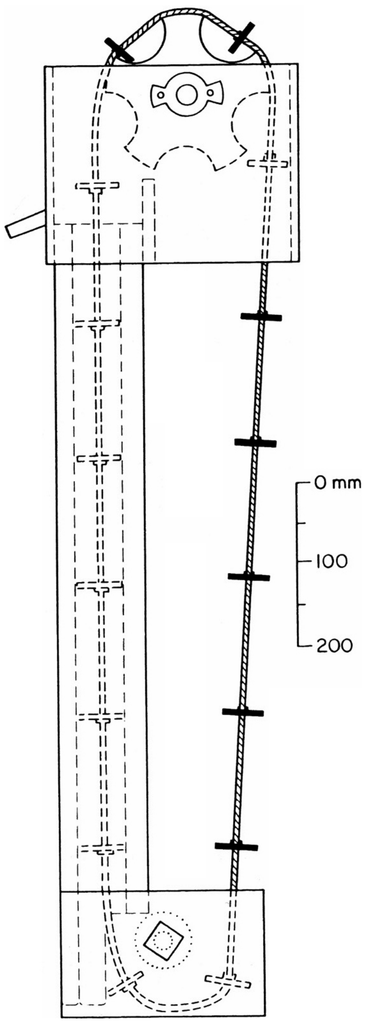

Figure 2.14. Reconstruction of the chain pump from the Los Ullastres wreck (© 1984 F. Foerster Laures, 'New views on bilge pumps from Roman wrecks', *International Journal of Nautical Archaeology* 13: 88, fig. 4a. John Wiley & Sons Ltd.)

The chain pump was a sufficiently effective means of lifting water through several metres, from the bilge to the gunwales of a large ship; like the Archimedes screw it was to some extent self-cleansing so could cope with sludgy dirty water, but it could also cope far better with the pitching and rolling of a ship at sea. Chain pumps were an important feature of wooden ships from the eighteenth to the nineteenth centuries,[61] and may be considered a key enabling technology for the construction of large merchant vessels in antiquity. Their disappearance from the archaeological record in the seventh century is probably related to the smaller size of shipping of the early Middle Ages, for which such pumps were less necessary; while the pump itself may not entirely have disappeared, the smaller number of wrecks known after the seventh century reduces the statistical likelihood of Medieval pumps being discovered.

Judging the efficacy of the Roman chain pump is problematic, not least because the sole evidence we have is archaeological, and therefore comes from wrecks which by definition were not prevented from sinking by the operation of the pump. Eighteenth-century experience suggests that the chain pump would certainly have been a help in many storms, but that ships could still be swamped by seas that overwhelmed the capacity of the pump.[62] Nevertheless, since the chain pump facilitated the building of larger ships, which, other factors being equal, could ride out storms more easily than smaller ships, it may have reduced the overall propensity to wreck. Under-representation of larger ships in the wreck assemblage, for reasons both of seaworthiness and because many were grain ships, may be suspected but seems impossible to prove.

Rigs

Large ships required more effective propulsion. The addition of a foremast is seen already on some ships of the sixth century BC,[63] and becomes a regular feature of larger Roman merchantmen. The Madrague de Giens wreck of the first century BC had a main mast and an inclined foremast,[64] and the same arrangement is common in iconography, as on an early third-century mosaic from the *frigidarium* of the baths at the small port of Themetra near Sousse—the foremast sharply raked forward and carrying a square sail (Figure 2.11).[65] The first three-masted ship of which we have a record is Hieron's superfreighter, the Syracusia, which also had three decks; but in the second century AD Lucian and Philostratus mention three-masted ships in the context of the grain fleet; and one appears in the mosaic from the *statio* of the shippers of Sullecthum in the Piazza delle Corporazione at Ostia, *c.* AD 200 (Figure 2.10).[66] The relatively small size of the third sail shown, at the stern, suggests that it would have contributed more to manoeuvrability and steering than to propulsion.

Large ships might also raise a topsail when sailing across open water—a flattened triangular sail on the mainmast.[67] Fore-and-aft sails were used in the ancient world for small ships, and a lugsail with a short luff is shown on the second-century AD tombstone of Alexander of Miletus, found near Piraeus (Figure 2.15).[68] The triangular lateen rig may also have been known,

61 Oertling 1982; 1996.
62 Oertling 1982.
63 Casson 1971: 70, 240.
64 Pomey 1982: 141–2.
65 Foucher 1958: 21–3 and pl. VIIIb, XIb, XIIb; 1967.
66 Lucian *Navigium* 14; Pomey 1982: 151; Meiggs 1973: pl. XXIVb; generally on the Piazzale delle Corporazioni, Meiggs 1973: 283–8, with references.
67 Casson 1971: 241–3.
68 Casson 1956; 1971: pl. 181; Guilleux La Roërie 1956; Bowen 1956; Basch 1989; Campbell 1995; Medas 2008.

and may have evolved from the square sail, brailed up or furled to present a triangular surface area to the wind (Figure 2.16).[69] By the seventh century the lateen had become the standard rig, and square sails largely disappear, until their re-emergence in the fourteenth century. The disappearance of the square sail has often been attributed to the supposedly superior sailing qualities of the lateen rig, which allowed sailors to point closer into the wind, but these have been exaggerated,[70] given the awkwardness of tacking in a lateen-rigged ship, which involves 'wearing ship'—turning downwind, setting the yard upright and then re-setting the sail, a procedure which involves a larger crew, and more free deck space. In fact, the general disappearance of the square sail from the seventh century onward is part and parcel of the return to the use of smaller shipping.

The hulls of early Medieval ships became more rounded and box-like, losing the wineglass section of some of the earlier vessels to allow more space for more cargo as overall ship sizes became smaller (Figure 2.17).[71] But the rounded hulls of early Medieval ships would have made a lot of leeway, and the combination of a lateen rig and rounded hull may have held a course not much closer into the wind than a brailed square rig and the more wineglass hull and straight cutwater of earlier, Roman, ships.[72] The change in rig is likely to be due instead to the disappearance of the larger merchant ships which required a square rig because large lateen sails would be too awkward to handle.

Some merchant ships, besides their sails, also carried oarsmen, both to enable them to make progress during calms, and for manoeuvring in port.

Sounding weights

By the sixth century BC the use of the sounding weight, usually a lead weight of hemispherical, conical, bell-shaped or similar form with a suspension lug for attaching a rope, and a cup on the underside for holding tallow to bring up a sample of the sea-bed, allowed sailors to measure the depth of water and assess the nature of the bottom, thus enabling them to judge when they were approaching land. There is some tendency over time for the weights to become taller, and perhaps some increase in the security with which tallow was retained in the cup by means of nails, or internal divisions (*septa*) which appear from the first century BC (Figure 2.18); weights with the suspension lug cast in one piece rather than added separately become near-universal after 100 BC,

69 Campbell 1995: 8; Medas 2008: 88–102.
70 Campbell 1995.
71 Cf. Castro *et al.* 2008; Steffy 1994.
72 Whitewright 2008. Cf. Pomey 1982: 152–3 and n. 37 on the likely sailing qualities of the Madrague de Giens ship.

Figure 2.15. Tombstone of Alexander of Miletus, from the Piraeus, showing a sprit sail with a short luff. (Athens, National Museum. From Pomey 1997: 41.)

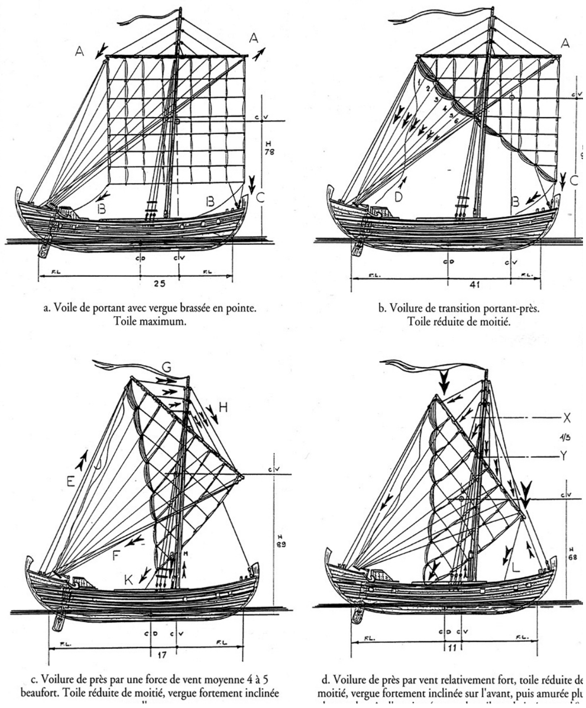

Figure 2.16. Square sail brailed to create a triangular surface. (From Medas 2004: 197, fig. 85.)

perhaps because it was realised that the lug was thus less likely to break off resulting in loss of the weight. However, overall little development of the sounding weight is visible over the Roman period, perhaps because already by the Classical period the design of the weight was well suited to its purpose.[73] Oleson has suggested that by the time of Aristotle the use of the sounding weight had enabled the acquisition of depth measurements for much of the waters of the Mediterranean and Black Sea.[74]

Iconography and literary sources thus combine to suggest that really large ships, of several hundred tons and/or with three masts carrying square sails, were built from the Hellenistic period to perhaps the fourth century AD, but not before, nor afterwards for some centuries; and this is congruent with the wreck evidence. We lack direct evidence for three-masted ships after the fourth century, but they are mentioned again by Anna Comnena at the end of the eleventh century (a three-masted pirate ship in the Adriatic).[75] Larger ships start reappearing in the twelfth and thirteenth centuries, with the rise of Italian dockyards at Genoa, Venice and Pisa building large round ships with two or three decks,[76] a single lateen sail on each mast; twin steering oars, and no deep keel. The square rig reappears on large merchant ships with the renewed rise of trade in the fourteenth and fifteenth centuries, and, this time with multiple square sails on each mast, once again became the standard rig for large sailing ships from the Age of Discovery onwards.

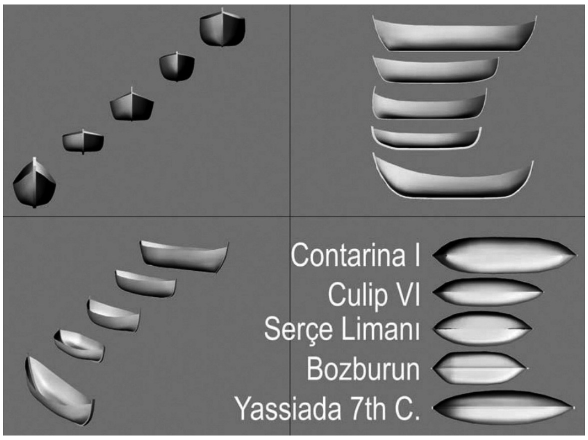

Figure 2.17. Development of hull shapes in the Middle Ages. Yassı Ada: 7th century AD. Bozburun: AD 874. Serçe Limanı: c. AD 1025. Culip VI: c. 1300. Contarina I: c. AD 1450. (© 2008 F. Castro, N. Fonseca, T. Vacas and F. Ciciliot, 'A quantitative look at Mediterranean lateen- and square-rigged ships (Part 1), *International Journal of Nautical Archaeology* 37 (2): 358, fig. 6a. John Wiley & Sons Ltd.)

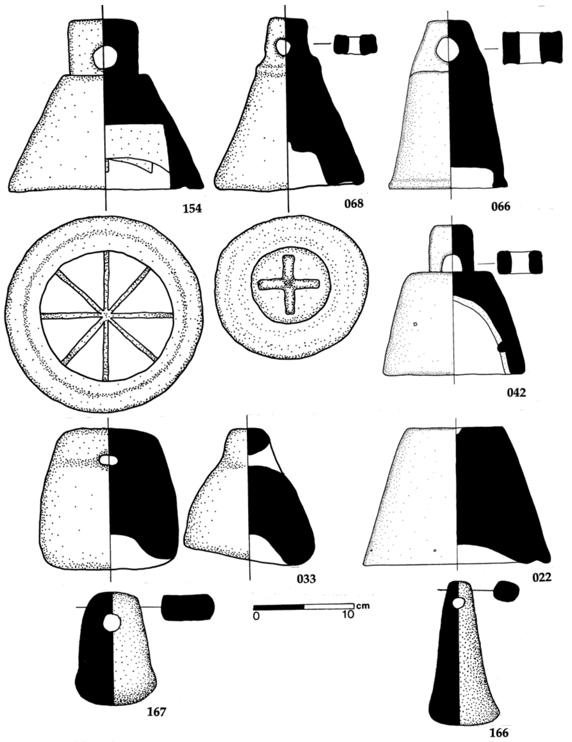

Figure 2.18. Roman lead sounding weights. (From Oleson 2000: fig. 4.)

Harbours and Ports

This peak in the size of the largest ships in the Hellenistic and Roman worlds is matched by an increase in the provision of port infrastructure; the story of Hieron's Syracusia, which was too large to dock at most Mediterranean ports except Syracuse and Alexandria,[77] illustrates the necessity for harbour facilities to keep pace with developments in shipping. While the practice of beaching small or even medium-sized ships or of unloading through the shallows existed at all periods before the twentieth century,[78] the number and scale of artificial harbour and port facilities built and maintained around the Mediterranean between 200 BC and AD 300 stands out as unusual for any period before the Industrial Revolution.

Harbour design

Phoenician and Punic *cothons* were artificial basins excavated on the landward side of the coastline, such as the well-preserved example at Motya in Sicily, or the famous commercial harbour and circular military harbour of Carthage. This design obviated the complex

73 Oleson 2000; 2008.
74 Oleson 2008: 127–30.
75 *Alexiad* 10.8 (trans.Sewter 1969: 315); Pryor 1988: 31.
76 Pryor 1988: 30.
77 Athenaeus *Deipnosophistae* 5.209b.
78 Houston 1988: 560–4.

engineering problems of building breakwaters out into the sea; the principal requirement was a large labour force to shift the volume of earth that had to be removed in digging the basin. The drawbacks were the relatively limited size of the basins thus created: 0.18 ha or less than 170 m of wharf space for the *cothon* at Motya; 0.78 ha or less than 370 m of wharf space for Mahdia in Tunisia (Figure 2.19). These figures are tiny by comparison with the data presented by Schörle in this volume (Chapter Five) for the sizes of Roman harbours along the Tyrrhenian coast.[79]

The Hellenistic period saw more ambitious harbour works, notably of course the vast harbour at Alexandria, with breakwaters and moles linking offshore islands and reefs to create a massive sheltered basin two km across, further subdivided into smaller port sections by artificial works and breakwaters, and equipped with the massive Pharos to signal the approach (Figure 2.20).[80] Harbour construction became a science to which Philo of Byzantium (*fl. c.* 260–220 BC) devoted an entire book.[81]

The Roman invention of hydraulic concrete, which set underwater, opened up entirely new possibilities for harbour development, enabling the construction of breakwaters, jetties and moles on shores without natural protection.[82] Schörle shows how this technology enabled the creation of artificial harbours along the Tyrrhenian coast of Italy, allowing the development of a *façade maritime* with a complex hierarchy of ports of different sizes, all of which, from the largest down to the smallest, relied on concrete construction.[83] First pioneered in Campania, the new concrete technology rapidly spread outside Italy in the wake of Rome's gaining control over the entire Mediterranean basin, from the Augustan period onwards, and was made available to Rome's client kings, such as Herod of Judaea, for the construction of the harbour of Sebastos at Caesarea. There, Roman technology and pozzolana imported from the Bay of Naples were used to create an artificial harbour using floating caissons that were filled with concrete and sunk, creating an outer harbour basin of 20 ha, with breakwaters wide enough to support warehouse space, and flushing channels to prevent silting (Figure 2.21).[84] The construction of moles or breakwaters sufficiently wide to accommodate loading and unloading facilities meant an extension of the area where large ships could dock, since they could unload anywhere around the harbour basin and were not merely limited to the landward side.

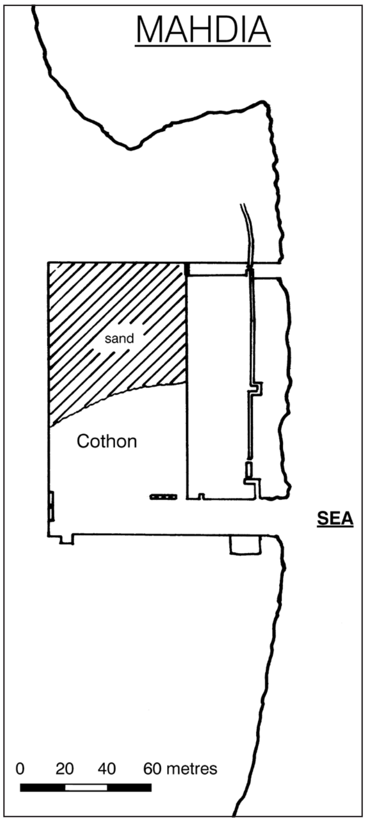

Figure 2.19. Plan of the Punic *cothon* at Mahdia, Tunisia. (© Yorke *et al*., Cambridge Expedition to Sabratha 1966 plan 6.)

The artificial harbour built at Portus by Claudius to provide a sheltered deep water harbour for the grain fleet and other merchant ships supplying Rome, which previously had had to anchor off the river mouth at Ostia, also relied on concrete construction for the breakwaters, mole and lighthouse foundation. The hexagonal basin which formed part of the Trajanic expansion of the facilities at Portus was dug as a kind of Roman *cothon*, but again with the use of concrete for massive quays, wharves and warehouses around its sides.[85]

The harbour at Lepcis Magna, extensively developed under Nero and remodelled on a more lavish scale by Septimius Severus, used a wadi mouth as a natural shelter further enhanced by concrete breakwaters and moles (Figure 2.22). Silting was prevented by damming the wadi further upstream and diverting it around the south-west of the town. The harbour basin enclosed some 10 ha, with *c.* 1,200 m of wharf space.[86] Again, the breakwaters were wide enough to accommodate temples and warehouses.

79 Cf. Wilson *et al.*, forthcoming.
80 Goddio *et al.* 1998; Goddio and Bernand 2004; Goddio and Fabre 2008: 266–74 for a synopsis of recent findings.
81 Philo of Byzantium *Limenopoeica* (now lost); Vitruvius *De Architectura* 5.12; cf. Blackman 2008: 643.
82 Oleson 1988; Blackman 2008: 644–9; cf. for recent work on Roman hydraulic concrete: Oleson *et al.* 2004; Brandon *et al.* 2008.
83 Schörle, this volume (Chapter Five).
84 Oleson 1988: 152.
85 Testaguzza 1970. Cf. Keay *et al.* 2005.
86 Bartoccini 1958: 12–13.

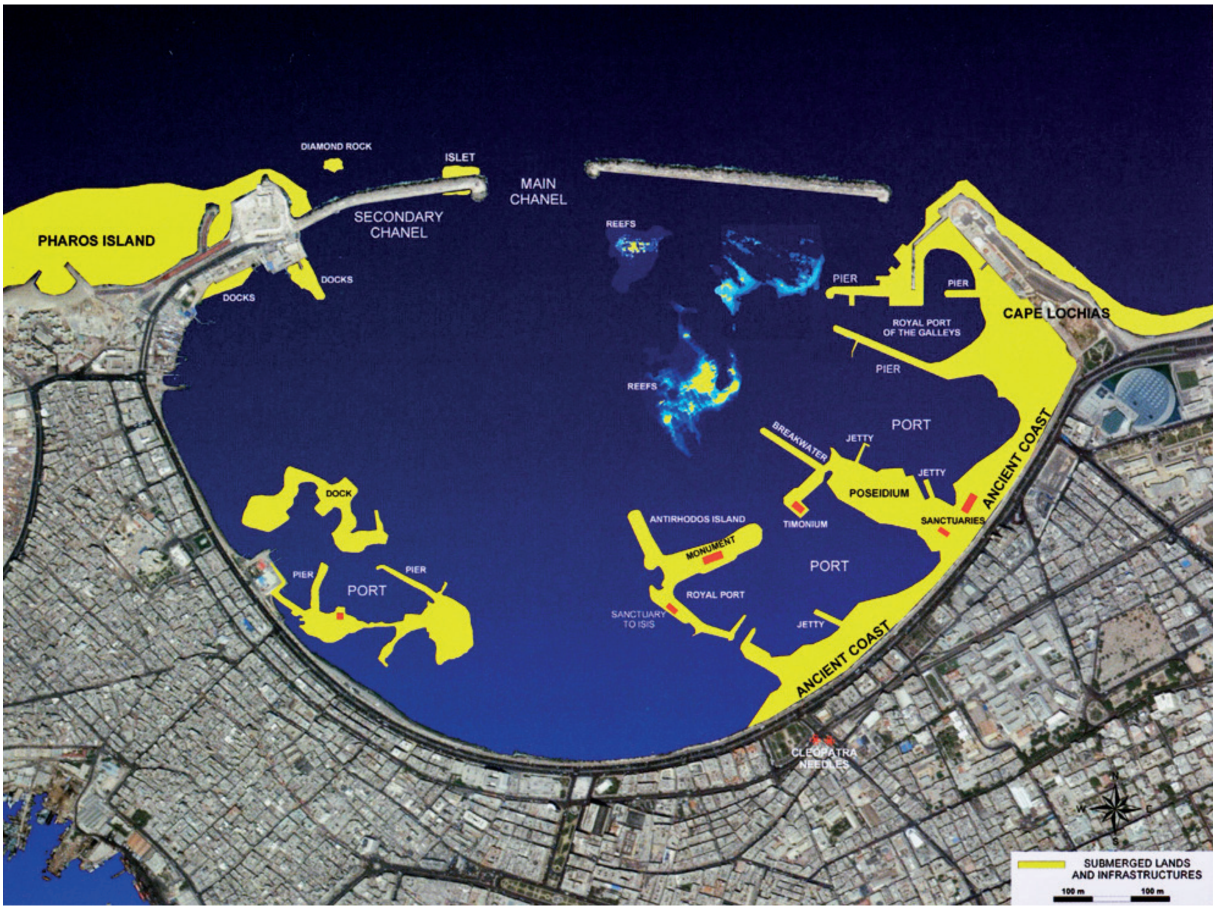

Figure 2.20. Plan of the eastern harbour at Alexandria. (© IEASM.)

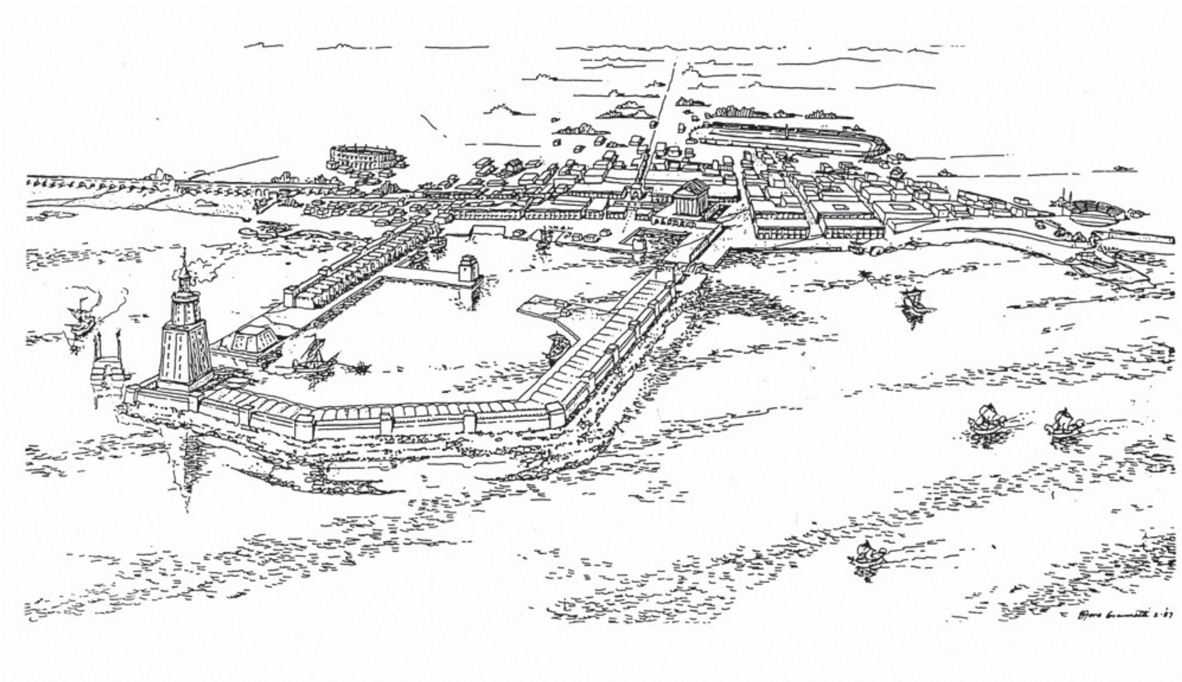

Figure 2.21. Reconstruction drawing of the harbour of Sebastos, Caesarea Maritima. (© 1992 A. Raban, 'Sebastos: the royal harbour at Caesarea Maritima—a short-lived giant', *International Journal of Nautical Archaeology* 21 (2): 122, fig. 18. John Wiley & Sons Ltd.)

Figure 2.22. View of the harbour quayside at Lepcis Magna, with steps and holes for mooring posts (foreground), and warehouses on the quayside behind the colonnade. (Photo: A. I. Wilson.)

The impact of the new Roman concrete technology is seen very clearly along the Tunisian coast, where a gently shelving bottom means that shallows extend hundreds of metres from the shore and prevent large ships approaching. *Cothons*, presumably of Punic origin, are known at Ruspina (Monastir) and Mahdia (Figure 2.19); but many of the other Punic towns along this coast were largely unsheltered and ships must have been drawn up on the beach or unloaded through the shallows, either way limiting the cargo capacities that could be easily handled. For smaller ships, such unloading through the shallows continued in the Roman period at some sites—a mosaic from Sousse shows the unloading of logs of wood which are being weighed on the beach (Figure 2.23),[87] and beaching like this may have been common for smaller ships in good weather at sites along the gently shelving coast of Tunisia which lacked long moles like those at Thapsus and Leptiminus. Such practices were in fact common around the Mediterranean and even on the coasts of Britain well into the nineteenth century.[88]

The introduction of concrete changed this: long moles could be constructed on this shelving coastline running for hundreds of metres from the shore out to where a depth of two or three metres, sufficient for medium to large cargo ships, could be attained. At Sullecthum the mole is *c.* 350 m long (Figure 2.24 published here for the first time), while that at Leptiminus the mole is *c.* 560 m long, with an angled end forming a rectangle whose sides provided some 300 m of mooring space (Figure 2.25).[89] At Thapsus, parts of the mole were visible as recently as 1987, until a fishing port was built on top; originally the mole extended for 1,000 m from the shore, in places 100 m wide, and is the longest known ancient artificial mole (Figure 2.26).[90] Long artificial moles were constructed at least five sites along the Tunisian coast (Table 2.1), vastly improving the access to large shipping for sites

Figure 2.23. Mosaic from a tomb at Hadrumetum (Sousse, Tunisia), showing unloading of firewood through the shallows, and weighing on the beach. (From Nieto 1997: 159.)

87 Foucher 1960: 77–8 no. 57.169 and pl. XLIa. Cf. Wilson *et al.*, forthcoming, for the interpretation of the cargo as wood (firewood?) rather than lead ingots.

88 Houston 1988: 560–1.

89 Yorke *et al.* 1966: 16 (privately circulated, now available at: http://www.societies.cam.ac.uk/cuueg/Archives/Sabratha_1966.pdf, last consulted 1 June 2011; Davidson 1992.

90 Yorke *et al.* 1966: 14–16 (privately circulated, now available at: http://www.societies.cam.ac.uk/cuueg/Archives/Sabratha_1966.pdf, last consulted 1 June 2011); Slim *et al.* 2004: 152.

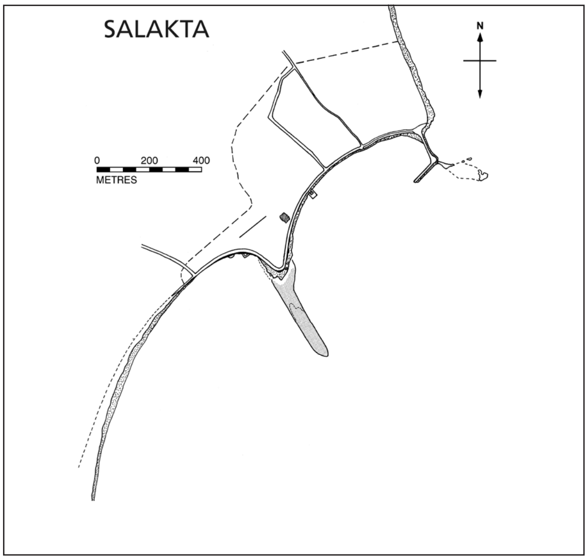

Figure 2.24. Plan of the Roman mole at Sullecthum (Salakta, Tunisia). (© Yorke *et al.*, Cambridge Expedition to Sabratha 1966, previously unpublished.)

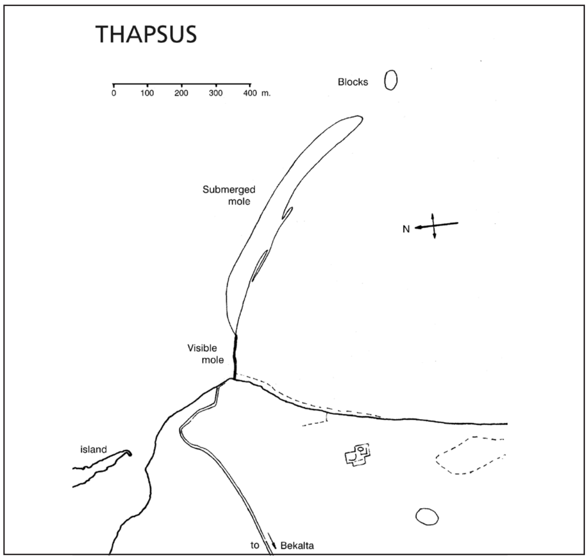

Figure 2.26. Plan of the Roman port mole at Thapsus, Tunisia. (© Yorke *et al.*, Cambridge Expedition to Sabratha 1966 plan 3.)

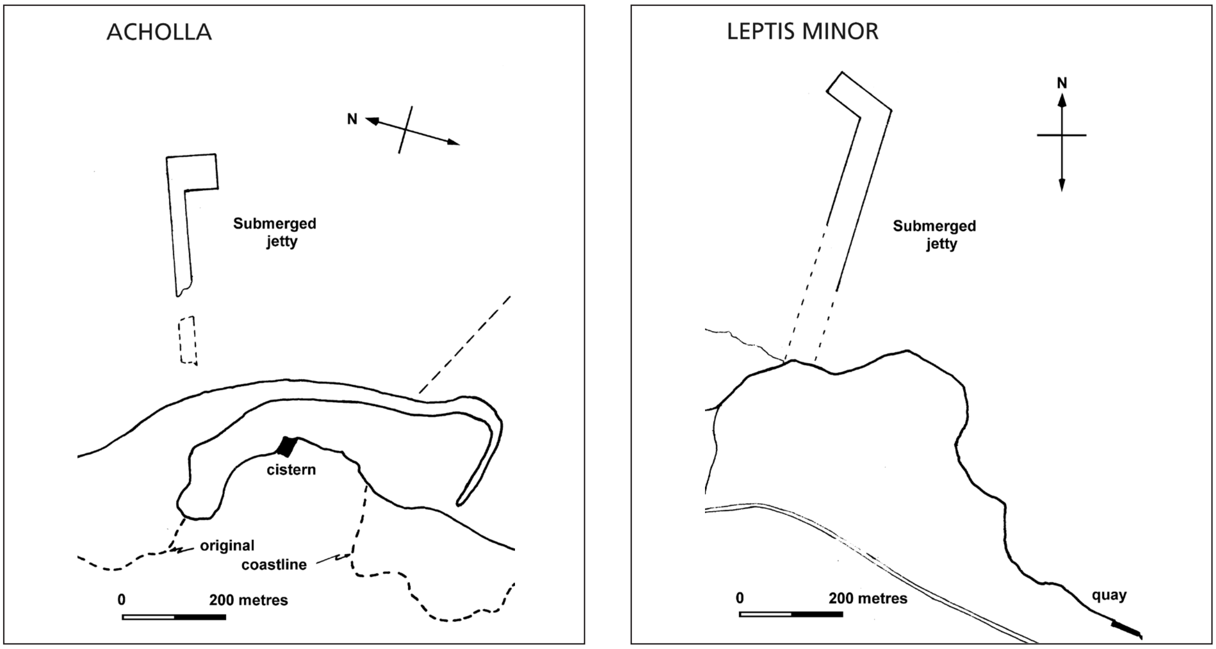

Figure 2.25. Plans of the Roman port moles at Acholla and Leptiminus, Tunisia. (© Yorke *et al.*, Cambridge Expedition to Sabratha 1966 plans 4 and 5.)

which became key centres of export for the olive oil and salted fish production of the Tunisian Sahel in the Roman period. It is not an exaggeration to say that this concrete port technology played a significant part in facilitating the development of the central and southern part of the Roman province of Africa Proconsularis as a major exporter of oil and salt fish.

Even villas had port or harbour facilities in the Roman imperial period, sometimes larger than those of Republican towns.[91] In Istria, for example, where numerous wealthy villas existed, many with multiple presses for the production of large marketable surpluses of olive oil, there are many small artificially constructed ports of Roman date, sheltered by projecting moles or

91 Schörle, this volume (Chapter Five).

Table 2.1: Ports with long moles on the Tunisian coast.[a]

Site	Length (m)	Width (m)	Platform at end
Leptiminus	560	15	rectangular
Sullecthum	350		
Thapsus	1000	100 in places	
Acholla	460+ (perhaps originally at least 500)	33	rectangular 100 x 70 m
Gigthis	140	17	semicircular

a Data from Constans 1916: 70; Yorke *et al.* 1966 Report: 7, 11–12, 14–16 (privately circulated, now available at: http://www.societies.cam.ac.uk/cuueg/Archives/Sabratha_1966.pdf ladt accessed 1 June 2011); Slim *et al.* 2004: 105–6, 138, 152, 154.

equipped with jetties. Some of these were demonstrably associated with villas, as at Medolino and Val Catena, while others were probably or possibly so, as near Isola (over 0.53 ha), or at Punta di San Simone (0.84 ha).[92]

Cranes

Other supporting elements of Hellenistic and Roman technology enhanced this harbour infrastructure and facilitated the continuous arrival, unloading and loading of cargoes.[93] Cranes, with multiple pulleys, enabled the loading and unloading of cargoes of large stone, heavy timbers, and even large amphorae such as the Tunisian and Tripolitanian olive oil and salted fish amphorae with capacities of over 60 l. Vitruvius, writing in the late first century BC, mentions slewing cranes and cranes mounted on a rotating base to enable them to swing loads between ships and the quayside;[94] he does not specify whether such cranes were mounted on the ships or the quayside, or both. The normal mooring arrangement in Roman harbours was prow-on, which required unloading to be done by manual porterage down a gangplank over the forequarters.[95] Since unloading by crane will have usually required ships to moor broadside-on to the quay, special parts of harbours must have been reserved for this. The upstream river port in the ninth region of Rome, where wine from the Tiber Valley was unloaded, was known as *Ad ciconias nixas* (literally, 'at the place of the straining storks', for the resemblance of the cranes to storks) after the dockside cranes there for the unloading of large wine barrels.[96] Cuttings in the rock surface at the early Christian quarries at Aliki on Thasos, adjacent to the sea, seem to have been intended as fixing points for the masts and stays of cranes for loading the marble onto ships.[97]

Dredging

To keep a harbour functioning, dredging was required and the excavations of the ancient harbour at Marseilles have revealed three Roman dredging boats of the first century AD each with a slot in the hull for the dredging mechanism (Figure 2.27).[98] Evidence for dredging during the Greco-Roman and Byzantine period has also been recognised from gaps in the chronological sequence of stratigraphy in Tyre's northern harbour.[99] At Ephesus, silting of the harbour was a considerable and recurrent problem;[100] Tacitus records a major dredging operation by the proconsul of Asia, Marcius Barea Soranus, in AD 61,[101] and in the early second century AD the *prytanis* C. Licinius Maximus Iulianus contributed 2,500 denarii to the city towards the costs of dredging the harbour.[102] Hadrian diverted the river Cayster to the north to try to tackle the source of the problem, for which he was thanked by the city in a decree of AD 129.[103] Under Alexander Severus, between AD 222 and 238, the *asiarch* M. Aurelius [. . .] spent 20,000 denarii on dredging the harbour.[104] Dredging the harbour at Side in Pamphylia in southern Turkey was a proverbial never-ending task, which had to be started again as soon as it was finished, like painting the Forth Bridge.[105] River ports also needed dredging; the river-bed at Antioch was dredged for the river port there in the reign of Antoninus Pius and again under Valens.[106]

Byzantine and early Medieval harbours

The construction of new ports, or the enlargement of existing ones, continued in some places through the

92 Degrassi 1962: esp. 833–8, 860–1, 864–70; Stokin *et al.* 2008: 64–7; Auriemma *et al.* 2008.
93 Rougé 1966: 160–66; Casson 1971: 369–70. On cranes generally, Wilson 2008: 342–4.
94 Vitruvius *De Architectura* 10.2.10.
95 As shown, for example, on a second-century relief from Narbonne, a third-century painting of the *Isis Geminiana* from Ostia, and the relief of the *tabularii* from Portus: Tchernia 1997: 117, 119 and 127.
96 Rougé 1957, discussing *CIL* VI.1785 = 31931, a third- or fourth-century AD tariff for the handling charges per barrel of wine, detailing charges for unloading by crane, transport to the state warehouses in the Templum Solis, receipt and opening. Cf. *LTUR s.v. Ciconiae*.
97 Sodini *et al.* 1980: 113–4, 119–22.
98 Pomey 1995: 463–9; Hesnard *et al.* 1999: 46–9.
99 Marriner and Morhange 2006.
100 Strabo *Geographica* 14.1.20; Zabehlicky 1995: 204–5.
101 Tacitus *Annales* 16.23.
102 *IvE* VII.1 3066.
103 *IvE* II.274.
104 *IvE* VII.1 3071.
105 Bean 1968: 100; *PECS* p. 835.
106 Rougé 1975: 182.

Figure 2.27. Wreck of a Roman dredger of the first or second centuries AD, from the Place Jules Verne, Marseilles, with a slot in the bottom of the hull for the dredging machinery. (Centre Camille Jullian, CNRS. Pomey and Rieth 2005: 50.)

fourth century AD, notably at Constantinople whose supply needs continued to grow at this period. As the two harbours on the Golden Horn were proving insufficient, the emperor Julian built a new port, the *portus magnus*, also known as the *portus Iuliani* or 'port of Sophia', in AD 362, the length of whose quay Mango estimates at some 1000 m. Towards the end of the fourth century a second new port, the Theodosian harbour, was built.[107]

But after the fourth century AD we do not find the construction of major new harbour works on the same scale as in Hellenistic and early Roman Imperial periods; and during the course of the second half of the first millennium AD some of the existing harbours fell out of use or began to silt up. Justinian did build two new harbours on the Bosphorus, at Heraeum and Eutropius, whose construction is described by Procopius.[108] Some of the larger Byzantine harbours were however maintained, at least until the sixth and seventh centuries: the dredging of the '*portus Iuliani*' at Constantinople under Anastasios in AD 509 was thought worthy of record in the *Chronicon of Marcellinus Comes*,[109] and the port of the Neorion at Constantinople was dredged in 698, perhaps when it became the main base for the city's naval fleet, which was stationed in it by 715.[110] But even at Constantinople, the capital of the Byzantine empire, the Theodosian harbour silted up through a combination of progressive sedimentation from the Lykos river and several violent storm events which deposited thick layers of sediment in the mid-sixth, the eighth/ninth, and the late tenth/early eleventh centuries. It was not effectively dredged and by the end of the twelfth century the harbour was usable only by small fishing boats and small coasting vessels.[111] Soon after Egypt fell to the Arabs, the Caliphate de-silted the port of Clysma at the head of the Red Sea in AD 642 or 643, though this suggests the degree to which it had fallen into disrepair in the Byzantine period.[112]

The northern mole of the harbour at Caesarea Maritima, which had sunk during the Roman period as a result of tectonic movements, was restored under Anastasios I in AD 502, but the effect was short-lived. Gertwagen argues that the repairs were not made using hydraulic concrete, but using wooden caissons filled with non-hydraulic mortared rubble; when the caissons rotted and disintegrated, the rubble spilled out and the mole collapsed.[113] There is debate over whether hydraulic concrete continued to be used in Byzantine harbour construction or whether the technique had already been lost by the reign of Justinian.[114] The Justinianic port of Anthedon had quays built of concrete using powdered ceramics, which would have had hydraulic properties, but this was not used underwater, and the Muslim construction of the port of Akko in the ninth century used caissons filled with non-hydraulic mortared rubble; as a result the lime deteriorated and the mole disintegrated to form a reef.[115] Similarly, the fourteenth-century Venetian harbour works at Candia (Herakleion,

107 Mango 1985: 38–40.
108 *De Aedificiis* 1.11.18–20. Cf. Hohlfelder 1988.
109 *Chronicon of Marcellinus Comes. MGH, Chronica Minora* 2.97 (under the year 509): *Portus Iuliani undis suis rotalibus machinis prius exhaustus caenoque effosso purgatus* est. 'The Portus Iulianus, first drained of its waters by lifting machines and newly dug out was cleaned.' Cf. Nollé 1993: 350, n. 89.
110 Mango 1985: 55–6.
111 Kocabaş 2008: 32–4.
112 Mayerson 1996: 125.
113 Gertwagen 1988: 149.
114 Hohlfelder 1988 (arguing for continued use of the technique); Gertwagen 1988: 150–1 (arguing that the technique was already lost). Procopius *De Aedificiis* 1.11.18–20, mentions the use of caissons in Justinianic harbour works on the Bosphorus, but does not state whether or not the concrete, whose use is implied, was hydraulic.
115 Gertwagen 1988: 150–1.

Crete) used non-hydraulic mortared rubble, and soon disintegrated. Byzantine and Venetian moles were not generally laid on rubble foundation layers, and they thus lacked protection against undermining of the seabed beneath them by currents and wave action.[116]

In the western Mediterranean one has the impression of far less activity in harbour maintenance between the fifth and eleventh centuries, though it must be admitted that archaeological research on Late Antique and Early Medieval port facilities is still very limited. Even from the twelfth century onwards, despite impressive works by the Venetian maritime empire in port construction, which included arsenals (shipyards) and warehouses, most Medieval harbours did not reach the size of the large artificial Hellenistic and Roman projects, and the smaller volumes of traffic that they handled may be gauged not only from their size, but also from the fact that after the fall of the western empire, harbour cranes are not documented in Europe again until the thirteenth century—the earliest being at Utrecht in 1244.[117]

The practice of beaching small ships, known throughout classical antiquity and the Roman period and discussed above for parts of the Tunisian coastline (Figure 2.23), seems to have become more common again with the increased prevalence of smaller vessels in the early Middle Ages. Accounts of early Medieval voyages also suggest a predominant pattern of coastal sailing, putting into shore to spend the night on land; this effectively halved the speed of sea travel by comparison with 24-hour sailing. Round-the-clock sailing did, however, necessarily persist on some long open-water routes, such as that across the Adriatic, and seems to have revived from the ninth century onwards.[118]

Trading patterns

Recent years have seen some debate over whether the dominant pattern of maritime trade in antiquity was cabotage, by which anglophone historians tend to mean speculative coastal tramping from port to port, selling a bit of cargo here and there, and picking up other wares to sell on further down the line, or direct shipping between major principal ports or emporia.[119] The argument is important because it carries implications about the overall scale of trade and levels of information about markets; tramping is speculative, opportunistic, and relatively small-scale, while emporia trading relationships imply organised, often regular traffic, and relatively good information about markets at the other end, often facilitated by agents or diaspora trading communities in remote ports. Several anglophone ancient historians have argued that cabotage was the normal trading mechanism in the Roman period, an idea given recent prominence by Horden and Purcell (who do nevertheless acknowledge the importance of 'le grand commerce maritime');[120] and which persists in some more recent writers.[121] A contributory factor to the longevity of this view may be confusion between the concepts of coastal sailing and coastal tramping, owing to misunderstanding of how the word 'cabotage' is used in French and Italian, where its primary meaning is 'coastal sailing'. One of the best discussions of the issue in fact remains that of Rougé, who gives a good, nuanced analysis, distinguishing between speculative coastal tramping, more or less regular coastal trading between a succession of ports which the shipper comes to know well, and 'le grand commerce', conducted between

116 Gertwagen 1988.

117 AD 1244 in Utrecht, 1263 in Antwerp, 1288 in Brugge and 1291 in Hamburg: Matheus 2001: 345; Matthies 1992: 542–3. In England the treadwheel is not recorded again until 1331: Matthies 1992: 524. Jörns (1979: 121) interprets a stone base measuring 2.2 x 2.5 m at the Carolingian river port of Zullenstein as possibly the base for a crane or a feature for tying up ships. McCormick (2001: 9) prefers to see it as a crane, but a problem with this idea is that, for ancient cranes at least, the diagnostic traces are generally cuttings into stone surfaces to take upright poles or attach stays, rather than built stone bases. Only the foundations survive, and other interpretations for this stone base could also be imagined.

118 McCormick 2001: 481–500.

119 The *Oxford English Dictionary* defines 'cabotage' as 'Coasting; coast-pilotage; the coast carrying trade by sea'; it is also a specialised term in the transport industry, where coastal traffic between ports in a single country, or between airports in a single country, may usually be operated by domestic companies. By contrast, in French 'cabotage' is usually used to mean 'coastal navigation', often without implying anything about the trading strategy underlying such coastal sailing (*Dictionnaire de l'Académie française*, 4th edn 1762: 'Cabotage. s. m. Terme de Marine. Navigation le long des côtes, de cap en cap, de port en port.'). Cf. Arnaud, this volume (Chapter Three) on the terminological confusion thus caused between the anglophone and francophone camps.

120 Woolf 1992: 287; Horden and Purcell 2000: 143–52; 365–70.

121 E.g. Bang 2008: 141–2, who believes, implausibly, of cities up to *c.* 10,000 inhabitants in the Roman world, that: 'These markets were normally served by a system often referred to as *cabotage*: small merchant ships would more or less casually tramp along the coast from harbour to harbour in search of a good bargain', though he does concede that more organised and directed trade was required to supply the very largest cities of the empire.

major ports or emporia.[122] As he emphasises, speculative coastal tramping was rare in the ancient Mediterranean; most captains knew their routes and markets.[123] Parker's study of the distribution of wrecks with cargoes of particular amphora types likewise suggests directed bulk traffic along certain routes between major ports, rather than coastal tramping.[124]

The idea that most Roman trade took the form of coastal tramping sits ill even with the ancient written sources, and is refuted by the archaeological evidence. Eratosthenes of Cyrene, writing in the third century BC, saw coastal voyaging as a practice of mythical antiquity, practised by Jason and the Argonauts, whereas in his day open-water sailing was the norm for long-distance merchant voyages.[125] The archaeological evidence from shipwrecks shows that mixed cargoes were normal, but these do not imply tramping; mixed cargoes enabled more efficient utilisation of hold capacity (e.g., with crates of pottery or sacks of nuts loaded in the space above a part-cargo of amphorae). Where cargo disposition within a single wreck can be studied it is clear that the large majority of mixed cargoes in Greek and Roman shipwrecks were loaded in a single go at one port, and must represent heterogenous cargoes picked up at emporia, being traded either to another distant major port, or being redistributed to lesser ports in the coastal foreland of an emporium.[126]

The cargo evidence from shipwrecks, the distribution of traded goods around the Mediterranean, the levels of investment in port infrastructure, and the evidence of resident trading communities in ports, all combine to show that commerce in the Hellenistic and Roman periods was emphatically not largely a matter of coastal tramping.[127] Instead, large merchant ships conveyed sizeable cargoes between principal ports or emporia; smaller vessels then loaded heterogeneous cargoes at these emporia and conveyed them to secondary ports in the economic foreland of the primary port. The coastal shipping of the Roman period was primarily engaged in supplying an emporium from smaller ports in the surrounding coastal zone, and in coastal redistribution towards those ports, as part of an organised system of trade. It was only after the collapse of intensive long-distance trade in the early Middle Ages that cabotage tramping again became a significant mechanism for trade in the Mediterranean. The patterns of trade and travel analysed by McCormick for the sixth to ninth centuries show an overwhelmingly dominant pattern of coastal voyaging, in relatively small ships, in strong contrast to the maritime world of the Hellenistic and Roman periods.[128]

Conclusion

The Hellenistic and Roman peak in Mediterranean trading activity that we may deduce from ship size and from harbour infrastructure, and, with due caution and some uncertainty as to its end, from the shipwreck graphs, was not simply a result of the maritime technology I have outlined. Technological factors enabled, but did not drive, the process; more important in this regard were institutional developments.[129] Laws of contract, maritime loans and sea laws existed from the Classical period on and provided a necessary framework for the organisation of large-scale maritime trade. The Roman integration of the Mediterranean under a single political system, and the virtual eradication of piracy by Pompey, together with the use of a single currency in nearly all of this area except Egypt, all greatly reduced transaction costs in supplying what had now became a vast pan-Mediterranean market. The Roman state introduced some incentives for shipbuilding, such as exemption from *munera* for *annona* contractors; although we tend to think of this as rewards for people who were ship-owners anyway, it is highly likely that such measures in fact encouraged other elite landowners to invest in shipping in order to escape the heavy financial burdens of civic *munera*. With the breakdown of the Roman empire, many of these institutions also disappeared.

A combination, therefore, of institutional factors (the political integration of the Mediterranean, the greater integration of *circum*-Mediterranean markets and the development of legal institutions and fiscal instruments encouraging trade) and technological advances (bilge pumps, harbour construction to accommodate large ships, and cranes for cargo handling) enabled the emergence of large merchant shipping in the Late Republic and High Empire. With the disintegration of this political system the institutions that it had created weakened or disappeared entirely, and levels of trade fell steeply. As a result, technologies changed or even vanished, to suit the lower levels of investment in both shipping and harbour technology justified by the smaller trade volumes of the time. Maritime trade never disappeared from the Mediterranean, but the world of the seventh to ninth centuries was a world of coastal voyaging by small lateen-rigged craft, between harbours that were often an inherited infrastructure from previous ages. It was not until the twelfth or thirteenth centuries

122 Rougé 1966: 415–21.
123 Ibid.: 418.
124 Parker 1990b.
125 Eratosthenes frag. 1.B.8 Berger = Strabo *Geographica* 1.3.2 C.43 (cited by Arnaud, this volume, Chapter Three).
126 Parker 1990a: 342–3 (on mixed cargoes); 1992a: 20–22; Rougé 1966: 415–21; Tchernia 1997: 124–7; Nieto 1997; Jézégou 2007; Arnaud, this volume (Chapter Three). *Contra*: McCann and Oleson 2004: 55–7, 120, 203, 207–8.
127 Nieto 1997; Tchernia 1997; Arnaud, this volume (Chapter Three); Wilson *et al.* forthcoming.
128 McCormick 2001: 481–500.
129 Cf. Arnaud, this volume (Chapter Three).

that large square-rigged merchantmen of several hundred tons began to ply the open water routes again with anything approaching the frequency with which they had in Classical antiquity.

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