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The development of maritime technical capability in the Mediterranean from 1500 – 400 BC

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Abstract

There is no secure evidence that 'round' ships (Casson, 1971:169) exceeded a length between 14-16 metres before c.400 BC, however vessels of 450 tons are reported to have been in use before this date. The following outlines a development process that explains why vessels were initially limited to this smaller size range, and the means by which they were later able to expand. This will be supported by evidence from literature, iconography and shipwrecks, along with the application of engineering principles, operational data from reconstruction archaeology, and other evidence from the naval architecture.

Key words

Evidence, Development, Historiography, Hybrid-rowed-sailed-round-ship, Merchant-galley, Square-Cube-Law

Introduction

The following study is based on my PhD thesis which examines the implications of maritime technical capabilities on Mediterranean trade routes up to 400 BC. This examines the subject in three sections, the first focuses on the evidence relating to limitations on the size of various vessel types through this period; the second examines the implications of these limitation upon the development of seafaring, the risks attendant upon this, and the necessary navigational skills; the third examines the implications of these factors on the trade routes of the period. The content of this paper is based on the first part of my thesis relating to the evidence of the development of vessel size and types. The conclusions presented in this paper concerning vessel size and types are a summary of the conclusions reached in this part of my research as presented at MAGS 2020.

Review of the evidence relating to large vessels in the Bronze Age

Within the history of maritime technology, a paradigm has become established that vessels of around 450 tons were in use in the Late Bronze Age. The source for this assumption however is a single translation of a text from Ugarit. The integrity of the detail in this then is key to the case. The resulting weakness is discussed by Monroe (Monroe, 2007:3). Reference to the use of vessels of this size has been made by a number of sources in nautical research (*cf*. Casson, 1971:36; Bass, 1974:23; Wachsmann, 2009:41). The case for large vessels is supported by Frost (Frost, 1989:168) who on the basis of finds of large stone anchors notes that, 'vessels as large as Roman grain ships', were in use through the Bronze Age. The use of these large vessels is part of the case presented by some academics writing about Mediterranean trade routes up to 400 BC (*cf*. Cunliffe, 2011:282; Cunliffe, 2017:267; Aubet, 2001:174; Sherratt & Sherratt, 1989:364). It is generally assumed that these were sailing vessels, and all assume that these vessels provided the means to sail long distance offshore routes. The evidence and analysis presented here suggests that these assumptions are incorrect and that vessels of this size were not in use until sometime later than 400 BC.

In the case of the 450-ton vessel the Ugarit text states: 'His Majesty has assigned to them two thousand (measures of) barley from Mukish. And you, give them one big ship and (its) sailors in order to transport this barley', (Monroe, 2000:83). Monroe bases his counter case on the inability to confirm the unit size of the measures referenced, and how without this the estimate of vessel size made by Casson (Casson, 1971:36) cannot be verified. The case made by Monroe appears to be strong but being based on his analysis of this single translation, the overall argument is weak in relation to countering a general case for vessels of this size. Additional evidence for a large-vessels comes from stone anchors found at a number of sites, many of them temple locations (Frost, 1989:167). The anchors themselves are large, some between 850 and 1350 kilos in size. It is clear that anchors of this size were not required for small vessels, they would have been impractical on vessels that lacked lifting equipment. The dates for the introduction of which will be discussed later in this work as part of a more general discussion on the operation of large sailing ships. In this case the evidence is not in question, rather it is the assumption that these anchors were representative of a working type in use on large vessels. This is clearly an assumption, as there is no direct evidence of these anchors being used to secure a vessel. On the other hand, it seems reasonable to assume that any anchor left in a temple location would be intended as a form of votive offering where the donor of the gift might be expected to leave the most ostentatious form possible. There is then no reason to make a direct link between the size of the vessels in use and the size of anchors in these locations.

In neither case are the presence of these large vessels confirmed by iconographic, literary, or archaeological evidence. Rather, the evidence that underlies the two assumptions of large vessels in the Bronze Age is interpretive, and is subject to easy and substantive challenge. What is lacking however is a clear articulation of a case explaining either the factors that limited the size of vessels, or those which subsequently enabled the development of larger vessels. The following attempts to articulate this case while noting the impact of this developing technical capability on the types of voyages the vessels were most likely to have undertaken.

Development sequence for vessels 1500 to 400 BC

At the start of the period evidence exists for early hybrid-rowed-sailed vessels throughout Egyptian iconography. In general these are marked by a long hull supported by a hogging truss, and a boom-supported sail. The limitations of the sailing rig shown on these vessels is twofold: it is largely confined to downwind courses and there is no quick way to reduce the sail area, (*cf*. Wachsmann, 2009:251 – 254; Vinson, 1993). The type of sailing rig then would be unlikely to result in the vessel making any leeway in use, while the use of the hogging truss suggests the vessel had a weak hull. Together these suggest the vessel did not have a structural keel to provide longitudinal support to the hull, and did not need an external keel to resist leeway. Although speculative interpretations of iconography and model boats of this period have associated external keels there appears to be no practical reasons to make this assumption. Given the limitations resulting from their weak hulls and the restricted sailing capabilities vessels of this type would probably be limited to largely coastal voyages.

Evidence from a mix of sources for an alternative form of vessel appears by the early fourteenth century BC. One representation of this is found in iconography in the tomb of Kenamun shown in Figure 1. McGrail (McGrail, 2004:130) notes that this might be an early development of the round ship. This vessel is also equipped with a boom supported sail. The ship wrecks found at Uluburun (Pulak, 2012) and Kumluca (Oniz, 2019) are probably representative of this general type. The former is 14–16 metres in Iength, the hull of the latter has not been fully examined but it appears to be around the same size. Pulak (2012) noted that the Uluburun vessel lacked an external keel, and that the hull used pegged mortice and tenons which probably contributed to a stronger hull structure. Neither of the wrecks contain evidence of the rig used, however the lack of an external keel in the Uluburun wreck suggests these were hybrid rowed-sailed vessels equipped with a boom-supported sail, implying these vessels were still largely limited to coastal voyages. The shorter more robust hull however would probably mean these vessels were more capable of safely undertaking short downwind offshore passages than earlier vessels that relied on a hogging truss to stabilise the hull.

There are suggestions of what might have been an intermediate form of sail that combined brails and a boom around the late fourteenth century BC as shown in Figure 2. The first unambiguous evidence of a loose-footed sail, however, appears in the early twelfth century BC, when the Egyptians confronted an opposing force at the Battle of the Delta, shown in Figure 3. Given that this is a battle it might be thought that these vessels were war galleys. However, the Egyptians are not recorded as fighting large scale naval actions before this time, and their opponents are recorded to have been transporting family groups with them on what was essentially a migration. On this basis it is more likely that both sides pressed into service whatever vessels were in day-to-day use for this action. The numbers of the rowing crews, at between 7 and 11 oars a side, then, is relevant to this discussion. Wallinga (2004:380) notes that a spacing of around one metre is required for each oar worked by a single oarsman. If correct in this context that would mean that if accurately represented, and allowing for 2 or 3 metres at the bow and stern, these vessels might be examples of hybrid-rowed-sailed-round ships 12–17 metres in length.

The development of the loose-footed sails marks a significant change in the potential capability of these vessels. The use of this type of rig provided the means to sail a wider range of courses, when used in conjunction with a hull that incorporated an external keel and a mast step. There is no physical evidence of these vessels, and so no confirmation of these features at this time. It is however possible to assess the probability of this.

The purpose of an external keel is to limit leeway when the vessel is sailed on any courses other than downwind. As noted above, a boom-supported sail did not allow vessels to sail courses that varied significantly from downwind. An external keel then would serve no function in vessel rigged in this fashion; it is unlikely then to have been developed for use in these vessels. There are further reasons relating to manoeuvrability and beaching that suggest an external keel might be a disadvantage on vessels that might be rowed for a substantial period of a voyage (Crumlin-Pedersen, 2004:77- 79). The loose footed sail however has advantages in addition to its ability to support sailing to windward. In particular it allows the area of the sail to be adjusted more rapidly and safely from the deck by a smaller crew. This provides a vessel with the means to sail safely, and for extended periods, in more variable weather conditions. It would be reasonable to assume then that this type of sail might develop in vessels that lacked a keel, as it would serve functions related to safety and flexibility in crew size and the operation of the vessel. The development of an external keel and mast step then may have followed this as, subsequent to its introduction, the experience gained with the rig demonstrated the wider range of courses that could be achieved. The introduction of these features is discussed below with the Mazarron 1 vessel.

There are insufficient wrecks in the Mediterranean to determine the timing of this development process in the region. There is, however, evidence of a similar development in the hulls of proto-Viking and Viking vessels from northern Europe. This is summarized in Figure 4. It is appreciated that these vessels are the product of a different shipbuilding tradition (McGrail, 2004:207-220) and that the construction of the shell of the hull of these is individual to this region. The relevance in this comparison however lies in the development of the hull forms and the time span over which this occurred, rather than the detail of their construction or the specific dates of the vessels. It can be seen that in northern Europe evidence suggests it required centuries to develop an optimized sailing hull in sea-going vessels from the round bottom form found in both the Nydam and the Uluburun vessels. If the timing of this development process can be taken as a relevant guide it suggests that early twelfth century BC Mediterranean vessels probably did not have the hull forms of true sailing vessels, and as hybrid-rowed-sailed vessels were probably still restricted to largely coastal voyages.

The next pair of vessels relevant to the development sequence are those found off Ashkelon and dated to late eight century BC (Ballard, et al, 2002). The debris mounds of these suggests they were round ships 14–16 metres in length, with a capacity between 20 and 30-tons. The interest here is that both vessels were loaded with amphoras suggesting a Phoenician origin and were found in close proximity, in a remote offshore location otherwise devoid of wrecks. Both wrecks have the same heading, bows to the west, which suggested to Ballard that both were blown offshore in the same storm and swamped, (ibid.:158-161). The question might then be asked, if larger vessels were in common use why use two vessels of this size to carry a common cargo to what appears to be a common destination. Why not use one larger one? The depth of water precludes any excavation of the hull to determine what type of vessels they were. It is possible however that Homer’s Odyssey, composed in the late eight century BC (Willcock, 2004:348), may provide some insight into this issue. In this Homer references Phoenician vessels and traders and differentiates Greeks from Phoenicians, implying denigration of the latter as traders (Od VIII.145-164). 'You seem to be the skipper of a merchant crew, rather than a trained athlete'. In this context the phrase 'it looked to us like the mast of a twenty-oared black ship, a broad-beamed merchant vessel' (Od, IX. 307- 359) might reasonably be assumed to describe a Phoenician vessel, and a 20-oared round ship would be around the size of that described by Ballard. It is never clear whether Homer is referring to historic or contemporary sources (Willcock, 2004:350-351). That said, Homer was clearly referencing a hybrid rowed-sailed vessel type which was familiar to his audience and which were perhaps similar in size at least to those described by Ballard. The evidence at this stage then is inconclusive. These vessels may have been rowed-sailed hybrid types as suggested in Homer or they may represent true sailing vessels. The evidence of the two vessels in this particular circumstance however suggests some factor may have impeded the development of larger vessels at this time.

The next piece of evidence confirms that a development in vessel type had taken place. Mazarron 1 is a small vessel around 9 metres in length but the hull remains contain both an external keel and a mast step (Tejedo, 2018). It is probable then that this vessel was capable of operating as a true sailing ship. This vessel is unlikely to have been the first of its type, rather being part of a sequence of the development of sailing technologies dating back to before the early twelfth century BC. However, from this date it is probably safe to assume the use of true sailing ships, and while oars probably continued in use the motivation was likely have been for manoeuvring rather than propulsion.

The final piece of evidence that will be presented in this sequence is that of an undisturbed wreck at Alonnesis dated to the late fifth century BC, (Hadjidak, 1996). From the debris mound, it appears this was a round ship around 25 metres in length with an estimated capacity of around 125 tons. This then marks a step change in the development of increasing vessel size. It is appreciated that the wrecks at Giglio, Grande Riband, and Gela, pre-date this and were also larger than the 14-16 metre vessels discussed to this point (Parker, 1992). Of these however only the hull of the latter is intact, well recorded, and free of disturbance, but at around 18 metres this is only slightly larger than the range discussed, and its late sixth century BC date accords with the conclusions discussed below. The Alonnesis wreck then provides the first direct evidence for the development of round ships substantially larger than those found from Uluburun to Ashkelon.

There is, however, an additional line of evidence of vessel type and size not covered in this short discussion – that is, merchant-galleys. Iconographic evidence from the late eight century BC, shown in Figure 5, and literary sources provide evidence for the use of this vessel type until late in the period. In this latter context Herodotus (Histories IV.153 & I.163), Plutarch (Life of Pericles, 26.4*)* and Schoff (The Periplus of Hanno the navigator, v1), all reference vessels of this type being in use for both trade and colonization but make no reference to large sailing ships operating at the same time. If large sailing vessels had been in use throughout from the Bronze Age it might be reasonable to ask why merchant galleys would continue to be applied in these roles.

Factors underlying the development of maritime technical capability

The previous section presented the evidence of a sequence of vessel types. The incomplete nature of the evidence however means that the absence of a particular size or type of vessel type from this sequence cannot be used as proof that it did not exist. The following examination of the factors underlying the development of vessel size and type attempts to bridge any gaps in the evidence. To do this it is necessary to diverge from purely archaeological or historic evidence and examine the case from an engineering perspective. A fundamental requirement when examining any issue of scaling up the size of an object in engineering, physiology, or bio-mechanics is to account for the impact of the Square Cube Law first explained by Galileo in *Dialogues concerning two new sciences* (1638). This states that when the linear dimensions of any regular solid are increased in a regular fashion then the surface area and volume increase in fixed ratios. An example of this for a cube is shown in Table 1. This shows that if the lengths of all the sides of cube are doubled, the surface area will increase by four, and the volume by eight.

The following is a worked example of this applied to a vessel around the size and capacity of that found at Uluburun: 15 metres long, 4 metres broad, and 2 metres deep with a capacity of between 20 and 30 tons. From the passage in Homer a vessel of this size might have a rowing crew of around 20 Each oarsman, then, pulled between 1 and 1.5 tons. This is in line with the range of loads in merchant galleys in the Renaissance, (Casson, 2004:123-124).

Now if that round ship was doubled in size to 30 metres long, 8 metres broad, and 4 metres deep, the Square Cube Law implies that it's capacity would increase to between 160 and 240 tons. The problem, however, is that the number of rowers in a single bank of oarsmen can only increase in relation to the length. If the shapes at the bow and stern were close to those of the smaller vessel then it is possible that a maximum of 50 oarsmen might fit in a vessel of this size. Each oarsman would then pull a load of between 3 and 5 tons. Clearly if that were possible then a 15-metre vessel would not require 20 oarsmen and the historic data provided by Casson might require review. It might be seen then that as long as vessels were dependent upon a rowing crew the implications of the Square Cube Law probably meant that round ships could not be scaled up much beyond 14-16 metres before they became unmanageable under oars.

If, however the same round ship was doubled in length, with only slight increases in the beam and draught, then it would be possible to keep the load on the resulting 40-50 oarsmen in the 1 to 1.5-ton range while increasing the capacity of the vessel between 2 and 2.5 times. This would however change the design of the vessel from a round ship to one associated with merchant-galleys. There is a further line of evidence related to oar mechanics that might support this form of development. This relates to the placement of oarsmen relative to the waterline, and the manner in which the efficiency of an oar-stroke is related to the angle made by the oar between the thole-pin and the water (Bondioli et al, 2004:181). An oar is more efficient when this angle is lower. The implication of this is that any vessel designed to be rowed from the main-deck should have a low freeboard. Scaling up a round ship would result in an increase in freeboard, whereas any development to a galley form would retain a low freeboard. The ability of this type of vessel to provide an increased cargo capacity while efficiently utilizing the technology of a hybrid-rowed-sailed vessel may explain its longevity as a cargo vessel through to the Archaic. Merchant-galleys however were restricted in the nature of the voyages they could undertake, being largely confined to coastal voyages (Pryor, 2004:208- 209). If they formed a dominant part of any merchant fleet then it might be expected then that the resultant trade routes would be largely coastal rather than offshore.

The evidence presented suggests a long time-frame between the first appearance of any vessel with an external keel and mast step, and the first large sailing vessels. To understand the factors underlying this it is necessary to examine some evidence of reconstruction archaeology. For this purpose, two vessels will be examined. These are the Kyrenia ship, which at around 16 metres was close in size to the Uluburun and Ashkelon vessels, and the Bremen Cog, which at around 23 metres was similar in size to the Alonnesis wreck. This latter vessel type is a reasonable analogue forming as it did the mainstay of the Hanseatic league maritime trading system in the Middle Ages (McGrail, 2004:232-234). Published work on the reconstruction of the Kyrenia ship suggest that this was a relatively simple vessel in which the sailing rig could be handled without the assistance of complex tackle, (Katzev, 1981:318). The same however is not the case with the Bremen Cog. The following is a comment on the working of one of these: ‘The original cog must have had a minimum of five crew because, on the replica, at least five people are needed to operate the barrel-winch and to handle the 300-kg yard’ (Hoffmann, 2009:289). The provision of a winch, then, is required in the handling of the yard and sail on this vessel. It should also be noted that the vessel is fitted with compound pulley blocks that further increase the mechanical efficiency of the crew in working loads aloft. Given the similarity in size between the Alonnesis vessel and the Cog it is reasonable to assume that a winch was necessary to raise and lower the yard and sail on this ship as well.

In this context the following statement is significant: 'There is no evidence for the use of cranes or hoists in architecture before the late sixth century BC' (Wilson, 2008:342). Wilson supports this by the dating of features in contemporary architecture. It seems reasonable to assume then that this is currently accepted as the date for the appearance of lifting equipment. On this basis it might be reasonable to assume that winches were not available to work a ship's yards, sails, and anchors before the late sixth century. The date of appearance of this enabling technology then might be seen as the factor that inhibited the development of sailing vessels substantially larger than 14-16 metres in length before this time. As an independent line of evidence, it is possible then that the dating of the Alonnesis wreck might provide additional confirmation to the date proposed by Wilson for the development of lifting equipment.

Conclusions

There is no evidence that either hybrid-rowed-sailed round ships, or true sailing round ships, significantly exceeded 16 metres in length before the late fifth century BC. The application of the Square Cube Law suggests that for any small increase in the linear dimensions of these vessel types the overall weight would increase substantially. This weight increase would reduce the manageability of both vessel types for the reasons outlined below;

- Any attempt to substantially increase the length of a hybrid-rowed-sailed round ship over 16 metres would result in a significant increase in the load on individual oarsmen.
- True sailing round ships could only substantially exceed 16 metres once the lifting equipment required to handle the heavier sailing rigs had been developed. Evidence suggests that this lifting equipment was not developed before the late sixth century BC.

The only hybrid-rowed-sailed vessel type that could exceed the carrying capacity of a 16-metre round ship was the merchant galley. In this design the resulting increase in cargo weight was directly related to the increase in length, so maintaining a manageable load on the oarsmen.

If trading voyages are assumed to have used routes involving lower risk in terms of seafaring and navigation then as long as small round ships and merchant-galleys were the dominant type of vessel in use these routes were likely to have been largely coastal in nature. The effects of the development process discussed here on seafaring, navigation and trade routes to 400 BC are the topics of the final two parts of my thesis.

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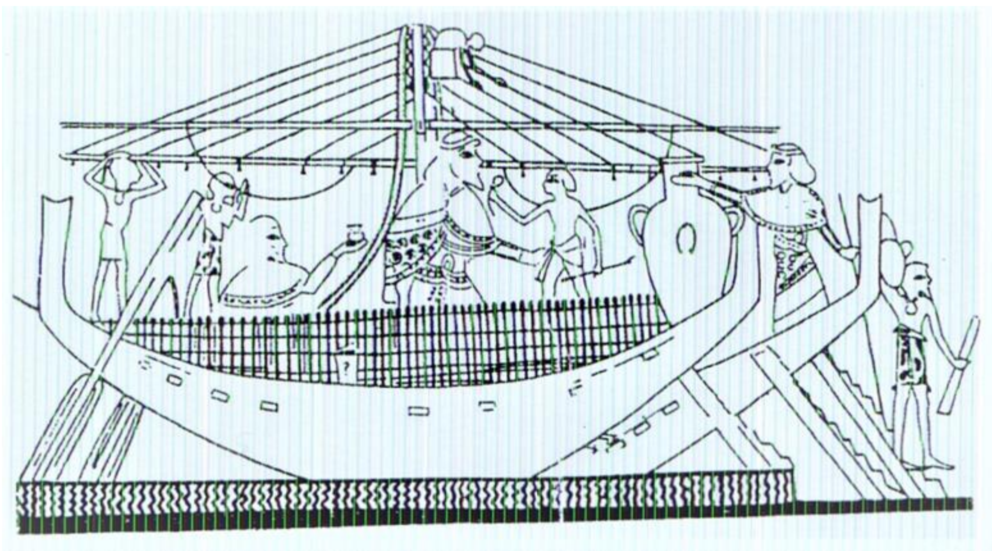

Fig 1. Early round ship from the tomb of Kenamun (McGrail, 2004:130).

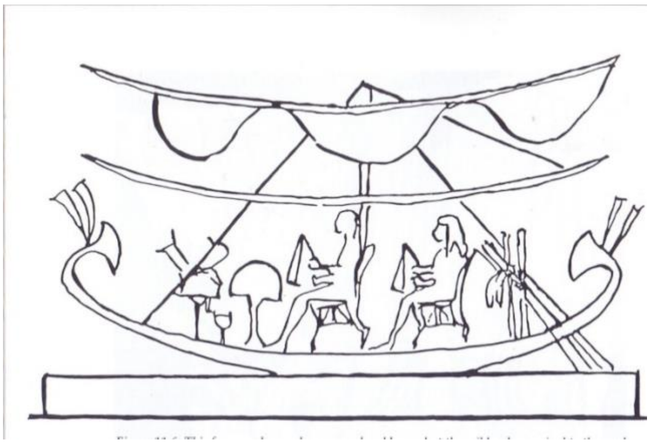

Fig 2. Early sail showing both boom and brailed characteristics (Wachsmann, 2009:251-252).

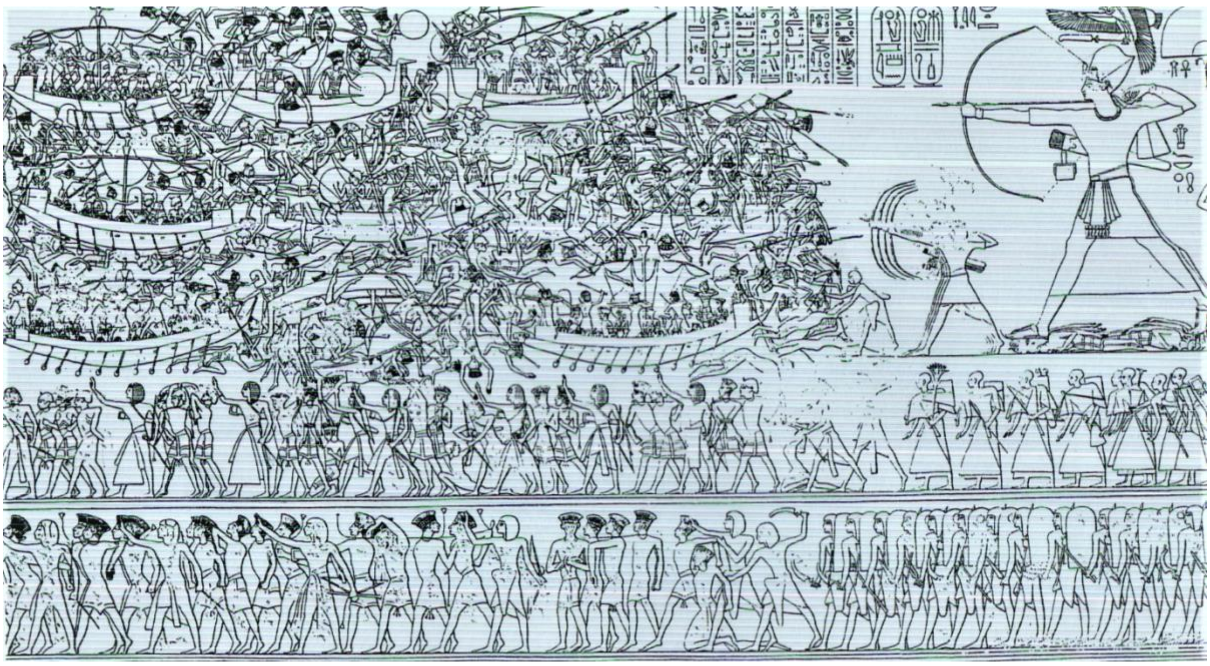

Fig 3. The Battle of the Delta (Wachsmann, 2009:165).

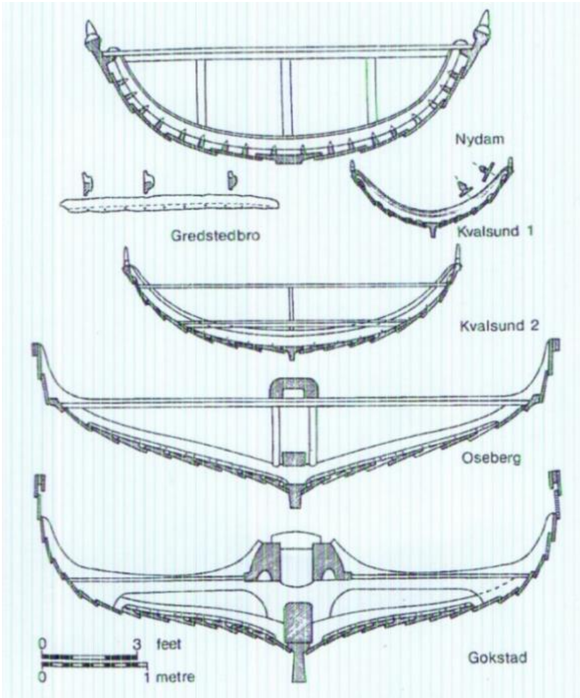

Fig 4. Development of hull form in Norse ship building over a 500-year period from a rowed vessel at top to a sailed vessel at bottom (McGrail, 2004:209).

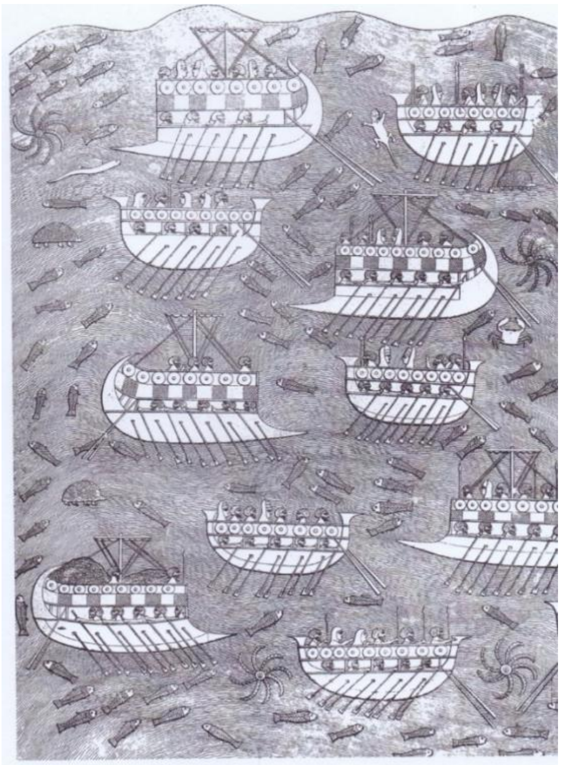

Fig 5. Merchant galleys at the siege of Tyre late 8th century BC (Casson, 2004:117).

Length of side of cube	Area of sides of cube	Volume / mass of cube	Impact of the same increase in size on a round ship with an initial capacity of 20 tons
1	6	1	20
1.1	7.3	1.3	27
1.2	8.6	1.7	35
1.3	10.1	2.2	44
1.4	11.8	2.7	55
1.5	13.5	3.4	68
1.6	15.4	4.1	82
1.7	17.3	4.9	98
1.8	19.4	5.8	117
1.9	21.7	6.9	137
2	24	8	160

Fig 6. Showing the impact of the Square Cube Law on vessel size