Mediterranean ship technology in Antiquity

Julian Whitewright is an archaeologist at the University of Southampton, United Kingdom

Abstract. *This contribution reviews evidence from maritime archaeological sites, especially those dating to the first millennium BC and the first millennium AD, in order to trace the development of ship technology in terms of conception, design and construction. It shows that the main method of ship construction in the Mediterranean from the Late Bronze Age to the fourth century AD was shell-based, with some variations. It suggests that the introduction of a frame-based method and the adoption of lateen sailing rig in Late Antiquity were motivated primarily by economic considerations.*

Résumé. *Cette contribution examine les vestiges des sites archéologiques marins, et particulièrement ceux datant du Ier millénaire av. J.-C. au Ier millénaire ap. J.-C., afin de retracer l'évolution de la construction navale en termes de conception, d'élaboration et de fabrication. Elle montre que la principale méthode de construction des navires en Méditerranée, de la fin de l'Âge du bronze au IV^e^ siècle ap. J.-C., était basée sur la fabrication de l'enveloppe extérieure (ou « coquille ») de la coque, à quelques variations près. Elle suggère que l'apparition d'une méthode basée sur la fabrication d'une charpente et l'adoption de la voile latine dans l'Antiquité tardive furent principalement motivées par des considérations économiques.*

The Mediterranean has played, and continues to play, a critical role in the formation of our understanding of the past interaction between people and the sea. Maritime archaeological activity lies at the heart of our understanding of this and it is clear that from the earliest times human activity has taken place along its shorelines and across its waters. In particular, there is a great abundance of well-preserved maritime archaeological sites, especially those dating to the first millennium BC and the first millennium AD. In the period under review here the archaeological and historical narrative of the Mediterranean traces the expansion of Greek colonists into the eastern and western Mediterranean and the voyages of Phoenician traders along the southern coast and ultimately through the Straits of Gibraltar, heading ever westwards in their quest for mineral resources. We learn of naval engagements between fleets of oared warships numbering in the hundreds, upon which the fate of empires rested, and of mythical heroes engaged in all manner of quests ranging far and wide across the wine-dark sea.

The extent of engagement between those people ranged around the shores of the Mediterranean Sea and the sea itself is immense and has become a common theme in scholarly studies of the region.[1] However, we may only reach a full appreciation of the interaction between these people and their sea if we can fully develop our understanding of the vehicles of this interaction; the ships and boats that directly facilitated maritime activity. The following chapter therefore sets out to provide an overview of these vessels in a broad sense from the earliest archaeological example of a seagoing vessel in the late Bronze Age to the ships of Late Antiquity. It focusses upon the principle forms of ship construction within the ancient Mediterranean, taking into account their development and technological trajectories. It is critical, when embarking on such work, that we be inclusive of as many elements of such vessels as is possible. The spatial limitations of this volume preclude a discussion of propulsion systems, sailing rigs and the like. However, information on these elements of ancient shipping can be found elsewhere.[2] Throughout, the archaeological evidence is taken as representing the primary source material for these ships and boats, but in some cases well-documented gaps in that evidence are filled by iconographic and historical material (fig. 1). In this regard, the Mediterranean is unique as an area of study for maritime activity before the early-modern period because our study is informed by multiple sources of complementary evidence.

The extent of the maritime archaeological record dictates that an account of Mediterranean shipbuilding practices in Antiquity has far greater breadth than the confines of this chapter, but the main traditions and their key features are outlined below. The subject itself is one of on-going development founded upon continued archaeological investigation; consequently, trends and interplay, within and between building traditions are not currently fully understood. There are, however, some excellent published works that provide a general overview of the situation at the present time.[3]

[1] See generally Horden P. and Purcell N., *The Corrupting Sea*, Oxford: Blackwell (2000).

[2] For broad discussion of the overall development of Mediterranean sailing rigs see Casson L., *Ships and Seamanship in the Ancient World*, 3rd edn, Baltimore: John Hopkins University Press, (1995). The chronology of the introduction of the lateen/settee rig is provided by Whitewright J., 'The Mediterranean Lateen Sail of Late Antiquity', *International Journal of Nautical Archaeology* 38.1 (2009), 97–104. Discussion of the transition from square-sail to fore-an-aft rigs during late antiquity is outlined in Whitewright J., 'Efficiency or Economics? Sail development in the ancient Mediterranean', in *Maritime Technology in the Ancient Economy: Ship design and navigation*, ed. W. Harris and K. Iara, Portsmouth RI, *Journal of Roman Archaeology Supplementary Series*, no. 84 (2011), 89–102. Analysis of the potential performance of Mediterranean sailing rigs and the implications of this for our understanding of maritime activity is discussed by Whitewright J., 'The potential performance of ancient Mediterranean sailing rigs', *International Journal of Nautical Archaeology* 40.1 (2011), 2–17.

[3] An in-depth account and interpretation of a number of significant individual archaeological finds is offered by Steffy R., *Wooden Shipbuilding and the Interpretation of Shipwrecks*, College Station TX: A and M Press (1994), pp. 23–77. For a summary of the current situation see Pomey P., Khanov Y. and Rieth E., 'Transition from Shell to Skeleton in Ancient Mediterranean Ship-Construction', *International Journal of Nautical Archaeology* 41.2 (2012), 235–314.

Fig. 1 *A marble relief, excavated from Carthage and dating to c. AD 200 showing a two-masted sailing vessel (British Museum Catalogue Number: 1850,0304.32). Iconographic sources such as this example are important for filling in some of our wider understanding of Mediterranean shipping during antiquity. Although obviously stylised, the artist has effectively rendered the impression of a vessel rigged with two equally sized sails, probably representative of a relatively large merchant vessel. Our understanding of the chronologies of sailing rig development and related ship performance rely heavily on the basic information provided in images such as this one.*

Construction sequences

For interpretative reasons, maritime archaeologists have divided the construction sequence of shipbuilding traditions into two main types, termed frame-based building and shell-based building.[4] The former of these utilises a system of construction wherein the vessel's frames play the most important role in its construction sequence. Once the keel is laid and the bow and stern posts set up, the builder erects the frames, either all of them, or just the major ones. The outer planking, forming a watertight shell, is then attached to the pre-erected framing. If required, additional frames may then be added to the vessel for further reinforcement. The frames erected initially in the frame-based system of building play an important role in defining the shape of the planking and because of this the frames are described as 'active'.[5] In contrast, a builder using a shell-based approach begins by first erecting the planking (the watertight shell), once the keel, bow and stern post are in place. Because there are no frames to hold the planking they have to be joined together to make a self-supporting structure,

[4] For a succinct description of the development of these descriptive approaches within the Mediterranean, see *ibid*., pp. 235–6.

[5] For the origins of this terminology see Basch L., 'Ancient Wrecks and the Archaeology of Ships', *International Journal of Nautical Archaeology* 1.1 (1972), 15–18.

which is achieved by fastening the edges of the planks together. Edge-to-edge plank fastening of some sort is one of the characteristic features of shell-based building systems. Frames may then be added to the planking shell as a means to reinforce it, but, because they do not dictate the hull's shape, simply serving as reinforcement, they are described as 'passive'.[6] In both systems, the overall structural integrity of the hull rests on the mutual interconnection of framing and planking.

Of course, there are variations to these two rigidly defined construction sequences. In flat-bottomed vessels, such as river barges, the bottom of the hull (planking and frames) is built first, termed 'bottom-based' building, followed by the sides. An alternative method employs elements of both frame-based and shell-based building at different stages of a vessel's construction and is classified as 'mixed-construction.' In such an approach, for example, the vessel's lower parts might be shell-based with passive frames added after only a few planks are in place. These frames subsequently become active in dictating the shape of the vessel's upper portions, which is therefore frame-based and carries planking without edge joining. The presence, or absence, of edge-to-edge plank fastening is usually a good indicator of when a builder switches from one construction sequence to the other.

In Antiquity, Mediterranean shipbuilders utilised a mixture of all of the approaches just described. Prior to Late Antiquity, shell-based construction tended to dominate, with planks edge-fastened by mortise-and-tenon joinery,[7] or alternatively by sewing. The latter method is particularly associated with Greek shipbuilding dating to the mid-first millennium BC.[8] Vessels have also been excavated which use both these fastening methods together, still within a Greek context.[9] A strong tradition of bottom-based riverine vessels has also been identified from archaeological remains, dating to the Roman period, from the western Empire.[10] Meanwhile, the earliest frame-based vessel yet excavated dates to the early 6th century AD[11] and vessels built with a variety of mixed-construction approaches occur both before this date[12] and afterwards.[13]

6 *Ibid.*

7 For an example see Steffy R., 'The Kyrenia Ship: An interim report on its hull construction', *American Journal of Archaeology* 89 (1985), 71–101.

8 For an example see Pomey P., 'Les Épaves Grecques du VIe Siècle av. J.-C. de la Place Jules-Verne à Marseille', in *Construction Navale Maritime et Fluviale*, ed. P. Pomey and E. Rieth, Paris: CNRS éditions (1998), pp. 148–160.

9 For an example see Kahanov Y. and Linder E. (eds.), *The Ma'agan Mikhael Ship. The Recovery of a 2400-Year-Old Merchantman. Final Report Volume II*, Jerusalem: University of Haifa (2004).

10 For a recent example in a Mediterranean context see http://www.arles-rhone3.fr/

11 See Mor H. and Kahanov Y., 'The Dor 2001/1 Shipwreck, Israel: a summary of the excavation', *International Journal of Nautical Archaeology* 35.2 (2006), 274–89.

12 For example Van Doorninck Jr. F., 'The 4th century wreck at Yassi Ada. An interim report on the hull', *International Journal of Nautical Archaeology* 5.2 (1976), 115–31.

13 For example Navri R., Kahanov Y. and Cvikel D., 'The Byzantine-Period Dor 2006 Shipwreck, Israel: preliminary hull construction report', *International Journal of Nautical Archaeology* 42.2 (2013), 305–325.

The design of ancient ships

Compared to our understanding of these construction sequences, our view of their conception and design is far more limited. While this may seem surprising, given the abundance of archaeological evidence, our interpretation has for the most part been reliant on a single, largely unchallenged notion of how the system of shell-based construction was applied by the builder. Archaeologists have traditionally interpreted this via an approach based on the construction of the vessel being undertaken by a highly skilled builder, capable of guiding construction using their 'eye' alone as a means to define hull shape.[14] The plank-by-plank nature of construction is considered to have allowed shipbuilders to conceive and imagine the hull-form from a longitudinal perspective,[15] freely varying the shape of the hull as they went along, correcting any errors as they did so. Only when vessels were built using a frame-based system could the vessel, or more accurately the frames, be created to a pre-determined shape, based on the transverse form of the vessel, which could not be readily changed once the construction sequence was underway. In other words, shell-based construction relied on the eye and skill of the builder, while frame-based methods could utilise pre-designed plans of the shape of the hull of the vessel.

Preservation of the majority of an individual vessel's hull-form within the archaeological record allows individual shell-based vessels to be studied for the purpose of investigating the evidence for design, prior to construction. Generally, such investigation has sought to identify the presence of geometric formulas, repeatable rules of thumb, or other similar guides that could have allowed ancient shipwrights to build their vessels in a consistent, repeatable way.[16] Recent investigation has brought these areas of research together to demonstrate clearly and positively that such design processes existed within the context of Punic, Hellenistic and Roman shipbuilding, encompassing naval as well as merchant shipbuilding.[17] This research has concluded that Mediterranean shell-based shipbuilders relied upon methods of design that were based upon simple geometric rules of thumb in order to build their vessels in a reliable, repeatable way. In essence, there is now a demonstrable school of thought to suggest that from at least the later first millennium BC ships were conceived on

[14] For example Pomey P., 'Principles and Methods of Construction in Ancient Naval Architecture', in *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*, ed. F. Hocker and C. Ward, College Station TX: A and M University Press (2004), p. 27.

[15] *Ibid*. See also Steffy J., 'Ancient Scantlings: The Projection and Control of Mediterranean hull shapes', in *Tropis III. 3rd International Symposium on Ship Construction in Antiquity*, ed. H. Tzalas, Athens: Hellenic Institute for the Preservation of Nautical Tradition (1995), p. 422.

[16] See Bellabarba S., 'The Origins of the Ancient Methods of Designing Hulls: A Hypothesis', *The Mariner's Mirror* 82.3 (1996), 259–268; Bonino M., 'Evidence of Geometric Operators used to Shape Ancient Hulls', *International Journal of Nautical Archaeology* 41.1 (2012), 120–133; Olaberria J-P., 'The Conception of Hull-Shape by Shell-Builders in the Ancient Mediterranean', *International Journal of Nautical Archaeology* 43.2 (2014), 351–368.

[17] Olaberria, 'The Conception of Hull-Shape...', *op. cit.*

a transverse, rather than longitudinal basis, irrespective of their construction sequence.[18] Importantly, there is no single method of achieving this design, with vessels from different contexts demonstrating different methods for defining hull shape, albeit within the same overall transverse concept. Useful parallels can be made between this and the main traditions of construction and rigging, discussed below, both of which display considerable technological continuity, within which there is extensive heterogeneity of technique and technology.

Shell-based construction: mortise and tenon

The shell-based tradition utilising mortise-and-tenon joints to fasten the plank edges together was the primary shipbuilding tradition of the Mediterranean in Antiquity. This approach uses relatively thick planks, normally of softwood, such as pine, with a series of mortises cut into the plank edges (fig. 2).

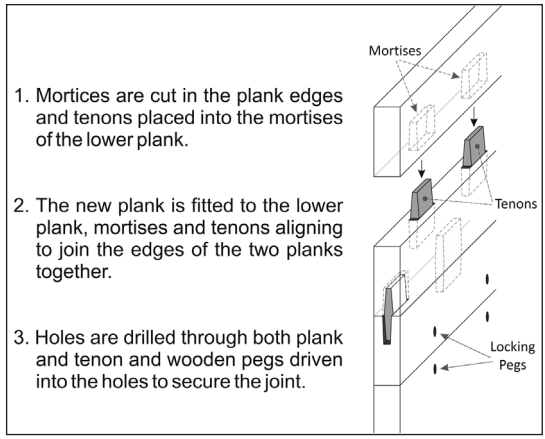

Fig. 2 *The key general elements of ancient Mediterranean mortise-and-tenon plank fastenings as understood on the basis of the archaeological evidence (Drawn by Julian Whitewright).*

Wooden tenons, usually of a hardwood (e.g. oak or olive) are inserted into those cavities and also into corresponding mortises on the adjoining plank when it is fitted in place. Wooden pegs, also of hardwood, are then driven through both plank and tenon to lock the joint in place. Planks are joined to the vessel's keel and posts using the same approach. Planks used in shipbuilding are normally not long enough to run a vessel's entire length, and so the planks are joined (scarfed) together at the ends, resulting in a length of planks, joined end-to-end, called a strake. In the mortise-and-tenon building tradition, the plank scarf joints are usually diagonal or S-shaped when seen from outboard with mortise-and-tenon jointing between the ends of the planks. Frames are then fitted inside the planking

[18] *Ibid.*

shell to provide the vessel with additional reinforcement and these were usually attached with either wooden treenails or with conventional nails, in either case driven from outboard, through the planking and into the frame.

This approach to shipbuilding is striking in its longevity of use and flexibility of application. Archaeologically, the application of a shell-based, pegged mortise-and-tenon tradition in seagoing vessels (when described in general terms) extends from the Late Bronze Age[19] through to Late Antiquity.[20] In between, this tradition was capable of constructing vessels of all shapes and sizes for a multitude of purposes ranging from harbour dredgers,[21] to fishing boats[22] and small sailing vessels,[23] through to giant 40 m long merchant ships capable of shipping thousands of amphorae.[24] Therefore, the most archaeologically common approach to conceiving and constructing ships and boats of all shapes, sizes and function is one with considerable technological continuity. It is important that such technological continuity is not confused with technological homogeneity. There are technical variations within this overall approach, many of which are now being identified through excavated archaeological remains and which occur on a temporal, spatial, cultural and functional basis. These may be expressed through the outward shape and size of vessels as well as the details of the internal structures.[25]

Shell-based construction: sewn

A significant alternative form of shell-based construction occurs in the first millennium BC in the form of vessels built using sewing with cordage as a means to edge-join the planks. To achieve this, holes must be made in the face of the plank with corresponding holes in the adjacent plank. Cordage is then passed through the holes and tightened to draw the planks together. If the cordage runs along the planks, passing through multiple holes, it is termed sewing. Meanwhile the practice of passing the cordage through only two adjacent holes (one in each plank) and using multiple individual fastenings is usually termed lashing.

[19] See Pulak C., 'The Uluburun Shipwreck: an overview', *International Journal of Nautical Archaeology* 27.3 (1998), 210–213.

[20] For example Santamaria C., 'L'épave Dramont 'E' à Saint-Raphael (V^{e} siecle apres J-C)', *Archaeonautica* 13 (1995), 1–198.

[21] Pomey P. and Rieth E., *L'archéologie navale*, Paris: Actes Sud (2005), p. 50.

[22] For example Boetto G., 'Roman techniques for the transport and conservation of fish: the case of the Fiumicino 5 wreck', in *Connected by the sea. Proceedings of the Tenth International Symposium on Boat and Ship Archaeology, Roskilde 2003*, ed. L. Blue, F. Hocker and A. Englert, Oxford: Oxbow (2006), pp. 123–9.

[23] See Steffy, 'The Kyrenia Ship...', *op. cit.*, p. 71–101. For a contrasting flatter-bottomed hull-form see Gassend J.-M., Liou B. and Ximénes S., 'L'Épave 2 de l'anse des Laurons (Martigues, Bouches-Du-Rhone)', *Archaeonautica* 4 (1984), 75–105.

[24] See Tchernia A. and Pomey P., *L'épave romaine de la Madrague de Giens (Var), campagnes 1972–1975*, Nanterre: Maison Renné-Ginouvès, Gallia Supplément n^{o}. 34 (1978).

[25] For an idea of the range of this variation see Pomey, Kahanov and Rieth, 'Transition from Shell to Skeleton...', *op. cit.*

As with other shell-based traditions, frames are inserted to provide additional reinforcement once the hull-shape has been formed by the planking shell. Frames can be lashed in place, or secured with treenails driven through the planks, or attached by a combination of the two.

It was common in sewn traditions for small dowels to be set into the plank edges as a mean to align the planks prior to sewing/lashing. Likewise, almost all sewn vessels utilise waterproofing wadding, placed over the plank seam and held in place by sewing/lashing. This can be either on the inside or outside (or both) of the vessel, and it provides sewn vessels with a distinctive appearance in comparison to non-sewn vessels. Further waterproofing and tightening is provided by driving wooden pegs into the sewing/lashing holes in order to seal them.

Within the ancient Mediterranean, two main distributions of sewn vessel can be identified archaeologically. The earliest has been called the 'Greek Archaic tradition' due to the vessels originating from sites known to have been contemporary Greek colonies or settlements.[26] Other generally contemporary examples have been found off Gela in Sicily, Giglio in Italy[27] and Bon Porte in Southern France.[28] Notably, these vessels are not always purely sewn in their construction and utilise mortise-and-tenon fastening in some areas of the hull. Shipwrights obviously possessed an ability to apply and mix together either construction tradition, perhaps depending on local requirements and context.

A second major group of Mediterranean sewn vessels, dating to the Roman period, is situated exclusively within the northern Adriatic, both on the Italian and Croatian coasts.[29] Again, these vessels often employ a mixture of sewn and mortise-and-tenon construction. Perhaps the best-known example is the late first-century BC shipwreck from Comacchio on the Italian coast.[30] The chronology of these vessels is less well established than the earlier Greek vessels, but it has been suggested that it extends as late as the seventh century AD.[31] While it may be tempting to view the Adriatic sewn vessels as a quaint survival of an earlier, simpler tradition of shipbuilding, in reality it is more helpful to view them as another regional variation on how Mediterranean peoples engaged with and utilised the sea that was so central to their lives.

[26] See for example the 6th century BC vessels from Marseille described by Pomey, 'Les épaves grecques du VIe Siècle av. J.-C.', *op. cit.* For a recent reconstruction of one of these vessels see http://protis.hypotheses.org/

[27] Bound M. , 'Early observations on the construction of the pre-classical wreck at Campese Bay, Island of Giglio: Clues to the vessel's nationality', in *Sewn Plank Boats*, ed. S. McGrail and E. Kentley, BAR International Series 276, Oxford: Oxbow Books, (1985), pp. 49–65.

[28] Pomey P., 'L'épave de Bon-Porté et les Bateaux Cousus de Méditerranée', *Mariner's Mirror* 67.3 (1981), 225–43.

[29] Beltrame C., '*Sutiles Naves* of the Roman age. New evidence and technological comparisons with pre-Roman sewn boats', in *Down the river to the sea: Proceedings of the eighth International Symposium on Boat and Ship Archaeology, Gdansk 1997*, ed. J. Litwin, Gdansk: Polish Maritime Museum (2000), pp. 91–6.

[30] Berti F. (ed.), *Fortuna Maris: La Nave Romana do Comacchio*, Bologna: Museo Archeologico Nazionale di Ferrara (1990).

[31] Beltrame, '*Sutiles Naves...*', *op. cit.*, p. 93.

Warship construction

The majority of the discussion in the preceding sections and the accompanying archaeological examples relate to the merchant vessels. In contrast to this large corpus of material, little is known archaeologically about warship construction during Antiquity, despite the extensive naval activity that is historically attested at certain times. Traditionally this has been attributed to the relative lightness of such vessels, carrying only ballast and crew, rather than cargo and so being prone to capture, rather than sinking. When such vessels did sink, the absence of a significant cargo is likely to have reduced their overall levels of preservation because the hull of the vessel was not sealed beneath the cargo in the manner of merchant ships, particularly those carrying amphorae.

The most complete set of vessel remains is probably a Punic warship off Marsala, Sicily, dating to the third century BC.[32] This find, along with other more fragmentary evidence, indicates that warships of the Hellenistic period and later were built using the same shell-based system of mortise-and-tenon, edge-joined planking described above. The Punic vessel from Marsala is also one of the vessels interpreted as demonstrating elements of a repeatable design process in antiquity.[33] This is perhaps not surprising given the assumed requirement for such naval vessels to be built to a standard, repeatable form that could ensure consistency of performance across a fleet.[34] The traditional viewpoint of earlier warships, such as the trireme of fifth-century Athens[35] is that they were built in the same way. But, given the extent of a sewn shipbuilding tradition in the Mediterranean, especially that associated with Greek cultural contexts (above) this is not proven beyond doubt. Consequently, it has been suggested, perhaps not unreasonably given the circumstantial evidence, that earlier warships were of sewn, rather than mortise-and-tenon construction.[36]

The advent of modern underwater survey technology had led to a considerable increase in our understanding of warships during antiquity through the discovery of archaeological evidence for warship rams, often recovered from the seafloor beneath naval battle areas.[37] This work, in conjunction with a well preserved ram from Athlit on the Levantine coast,[38] is beginning to shed detailed light on many of the construction techniques specific to warships as well as naval ramming

[32] Frost H., 'Lilybaeum (Marsala). The Punic Ship: Final Excavation Report', *Notizie degli Scavi di Antichità* 8 (1981), Supplemento al vol. 30. The excavators of the Marsala ship assumed that it was a warship, but that assumption has not been conclusively proven.

[33] See Bellabarba, 'The Origins of the Ancient Methods...', *op. cit.*, p. 264.

[34] See also Bockius R., 'Shape Markings and Pegs: Clues to Geometrical Procedures of Roman Naval Architecture', in *Creating Shapes in Civil and Naval Architecture. A Cross-Disciplinary Comparison*, ed. H. Nowacki and W. Lefèvre, Boston: Brill (2009), p. 74.

[35] See Rankov B. (ed.), *Trireme Olympias: Final Report*, Oxford: Oxbow Books (2012).

[36] Hale J., *Lords of the Sea: the epic Story of the Athenian Navy and the Birth of Democracy*, New York: Viking (2010), pp. 21–25.

[37] Tusa S. and Royal J., 'The landscape of the naval battle at the Egadi islands (241 BC)', *Journal of Roman Archaeology* 25 (2012), 7–48.

[38] Casson L. and Steffy R. (eds.), *The Athlit Ram*, College StationTX: A and M Press (1991).

tactics and this picture will inevitably increase in complexity in the future as more archaeological finds are located, analysed and interpreted. What is clearly notable is that the rams of such vessels were integrated into the structure of the vessel and were not simply 'bolted on' after the vessel was built. This is a further potential indicator for the presence of a high degree of pre-construction design in the ancient world, even within shell-based construction traditions where it is not traditionally thought to have been utilised.

Changes in construction: frame-first and mixed shipbuilding

Well-documented variations in Mediterranean shipbuilding have been illustrated above in the context of the mid-first-millennium BC example of sewn vessels. Around one millennium later, an even more profound and far-reaching change occurred, encompassing the traditions that governed how vessels were built as well as the sailing rigs that propelled them. Put simply, from the perspective of shipbuilding, Mediterranean shipwrights began to adopt and develop frame-based traditions for the first time as well as utilising a range of mixed construction approaches, drawing upon elements of both shell-based and frame-based building sequences.

Thus far, the earliest Mediterranean vessel built in a fully frame-based tradition that has been identified is a shallow-draught, flat-bottomed, coastal trading vessel dating to the early sixth century AD, excavated from a coastal lagoon at Dor/Tantura on the Israeli coast. This vessel, called the Dor 2001/1 ship was constructed in a totally frame-based sequence with no elements of any shell-based tradition visible in the hull of the vessel.[39] It is unlikely that Dor 2001/1 was the first frame-based vessel to be built in the region and so the tradition is likely to have begun before the sixth century AD. Exactly how much earlier remains an important future question to be answered by the archaeological record. In contrast, another eastern Mediterranean vessel, dating to the fourth century AD, excavated at the site of Yassi Ada was built using a mixed sequence of construction.[40] The lower hull was built on a shell-based system as far as the fifth strake, thereafter frames began to be added which must have been 'active' in their relationship to the remaining planking. One characteristic of the mixed-construction traditions is the reduced use of mortise-and-tenon fastenings to secure the vessel's shell, together with a corresponding increase in the strength provided by the vessel's framing. In general, there is a long-term trend throughout the later Empire and into Late Antiquity for mortises to be set further apart, with tenons looser in their fitting and sometimes left unpegged. At the same time, in many vessels the framing systems appear to be of greater structural significance than in vessels built in the purest form of the shell-based, mortise-and-tenon tradition.

[39] Mor and Kahanov , 'The Dor 2001/1 Shipwreck...', *op. cit.*
[40] Van Doorninck, 'The 4th century wreck at Yassi Ada...', *op. cit.*

Traditionally, this trend in construction methods has been viewed in a very unilinear way, with a logical progression from shell-based to fully frame-based construction, often incorporating an intermediary stage of mixed-construction.[41] Archaeological discoveries such as Dor 2001/1 have meant that such a rigid schema of transition has had to be abandoned because of the temporal and spatial variation, apparent through the archaeological record and inconsistent with the original linear model. Our current understanding of this transition in construction is far from complete and the present interpretation has focussed on attempting to understand some of the regional variation in the adoption of different shipbuilding technology in Antiquity, while accepting that change was at the very least multi-linear in nature.[42] Multi-linear development is visible in the sailing rigs of Antiquity, both as technological variations within established traditions, such as the Mediterranean square-sail, and as original innovations towards new traditions, for example the sprit-rig.[43] With this in mind, it is perhaps not surprising that similar themes are beginning to be recognised within ship construction during antiquity (fig. 3).

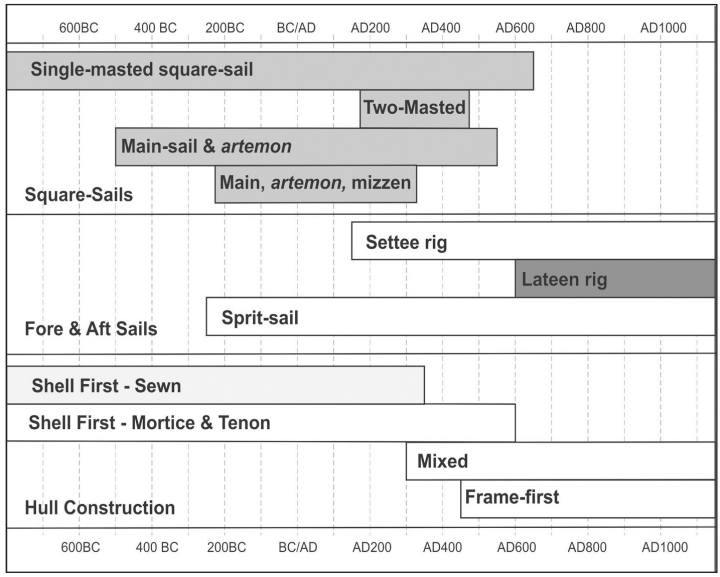

Fig. 3 *Overview of the relative general chronologies of hull-construction and sailing-rig technology in use in the Mediterranean during the antique and early medieval period. Long periods of continuity are punctuated by extended instances of variation and innovation within all forms of technology. All start and end points are estimates based on the available evidence and should not be considered definitive.*

[41] For example Steffy, *Wooden Shipbuilding…*, *op. cit.*, pp. 83–85.
[42] Pomey, Khanov and Rieth, 'Transition from Shell to Skeleton…', *op. cit.*, pp. 305–308.
[43] Whitewright, 'Efficiency or Economics?…', *op. cit.*, pp. 89–91.

Recent work into the design of Mediterranean shipping has been highlighted above and the further development of this work is likely to have a considerable impact on how the conception of ship construction in antiquity was undertaken. In particular, work indicating that the conception of a shell-based vessel was as reliant on the transverse form of the ship as was the case with later frame-based vessels provides a direct challenge to the traditional view of shell-based construction being longitudinally conceived.[44] If the early indications of this work are borne out, then we may arrive at an interpretation where the construction sequences of vessels undergo clear change over time, while the methods for conceiving, designing and repeating ancient hull forms demonstrate continuity. At that point, we may be able to investigate more fully and to appreciate some of the underlying reasons that drove such a profound shift in how watercraft were constructed during antiquity.

Conclusions

Mediterranean shipbuilding in Antiquity can be viewed broadly as comprising two successive forms from the perspective of a vessel's construction sequence. Firstly shell-based forms, both sewn and mortise-and-tenon, whose origins lie in the Bronze Age, or earlier. Of these, it is the latter method that comes to predominate by the second half of the first millennium BC. Secondly, frame-based forms of construction developed from Late Antiquity onwards. In addition, a hybrid form of building utilising a mixed construction sequence is visible during the first millennium AD. The individual traditions and their respective technical details that can be found within these over-arching methods of constructing vessels have been well-documented through archaeological investigation. However, the extent of technological interplay between traditions, either at the macro-level of shell-based/frame-based, or with regard to more specific, identifiable traditions (sewn, mortise-and-tenon, etc.), is much less clear. For example, the motives behind the predominance of mortise-and-tenon in the mid-first millennium BC, or the use of frame-, and not shell-based construction from the mid-first millennium AD are not yet fully understood.

Increasingly, our study of Mediterranean shipbuilding in Antiquity is offering a view in which there is significant variation between regions, and across time periods. Different building traditions are adopted and continue in use in different areas, for differing lengths of time. On the basis of the archaeological record it is now possible to note increasing technological heterogeneity within the shipbuilding traditions of the ancient Mediterranean, where previously there was perhaps a tendency towards a more homogeneous view of shipbuilding activity. This heterogeneity in approach should, perhaps, not be surprising given the large variation in vessel form (fig. 4) that is visible via the archaeological

[44] Olaberria, 'The Conception of Hull-Shape...', *op. cit.*

record across time and which encompasses almost every conceivable vessel type. Mediterranean shipbuilding traditions, whatever the construction sequence, were well able to adapt to the different requirements at different times. This last point can perhaps be highlighted as a possibly fruitful area for future work; as regional variations in shipbuilding and rigging are increasingly identified it will be interesting to address the ability of such vessels to operate on an inter-regional scale.

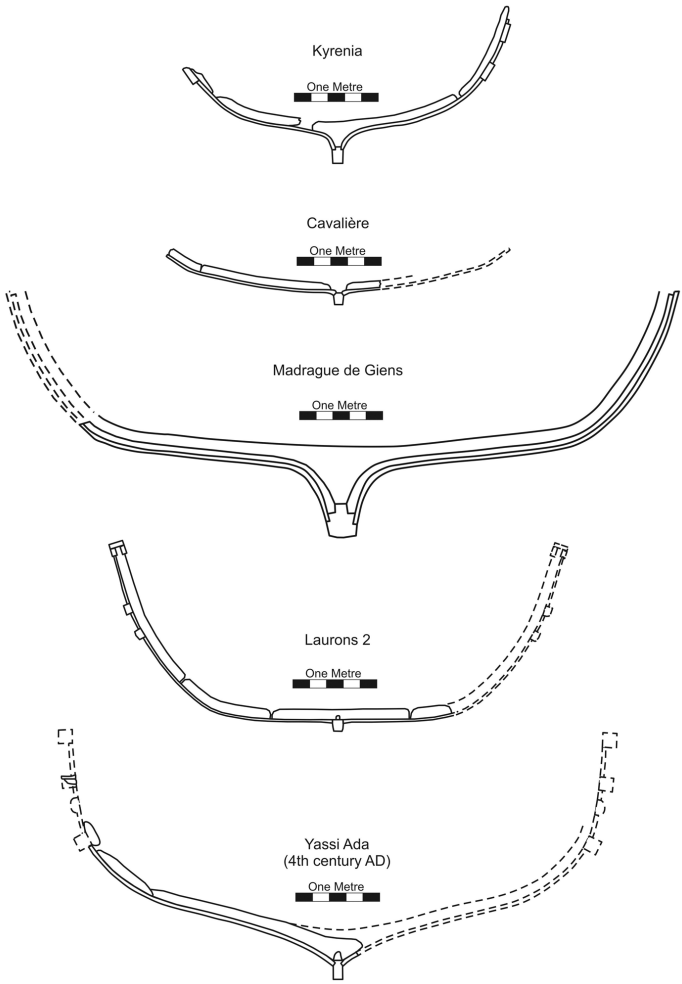

Fig. 4 *A wide variety of differing hull forms in sea-going ships is preserved in the archaeological record from the Classical, Roman and Late-Antique Mediterranean. The cross-sectional forms constructed by ancient shipwrights, range from flat-bottomed to relatively deep-keeled. These drawings are by the author and based on the Kyrenia, Cavaliére, Madrague de Giens, Laurons 2, and 4th century Yassi Ada wrecks.*

Despite the variation in technological systems alluded to in this contribution it is still worth emphasizing the clear technological continuity over the longer-term that is observable not only in shipbuilding traditions, but also in the rigging of vessels, specifically the Mediterranean square-sail. When generalized, such traditions or approaches can be seen to span many centuries and to encompass a wide range of cultural contexts. On those grounds it is therefore intriguing to question the reasons for change in the face of such apparent continuity. It is clear that Mediterranean shipbuilders and mariners were well able to develop existing maritime technology and to invent novel forms of comparable technology suited for operation in specific contexts. Understanding the motives, trends and themes behind such changes, especially some of the larger and more far-reaching examples, represents the main current challenge for maritime scholars of the field.

While traditional explanations have perhaps been overly functionalist, recent research is increasingly focussing upon economic considerations and factors behind the dramatic changes that took place in Mediterranean maritime technology during the mid-first millennium AD.[45] Viewing the changes from an economic perspective, it is possible to suggest that the development of frame-based shipbuilding practices may have allowed vessels to be constructed in a shorter time period, or using a smaller work force than with more time-consuming shell-based approaches. Both seem likely to have resulted in a reduction in the costs associated with shipbuilding, although probably not in the total consumption of materials involved. Well thought out experimental archaeology projects are probably the best course for addressing the latter point. Such developments may have had clear advantages within the context of the late antique and early medieval periods, when the overall economic situation appears more fragmented, along with a possible reduction in the availability of manpower and overall opportunity for profit. In short, the transitions in shipbuilding that are apparent in the Mediterranean may be linked with the wider economic context of the sea at that time.

Alongside this, it seems pertinent to consider the effects of such developments from a more performance-based view. From the perspective of hull-form, the variation in hull shape that is visible during most of Antiquity remains evident in later periods. Ships were built that were suited for the mode or place of operation, rather than to conform to a pre-existing 'one size fits all' ideal shape. This is to say that hull-forms continued to exist that were flat-bottomed for coastal and riverine use, as well as those with deeper keels intended for open-water routes. The need for specialized vessels to carry out certain functions, or carry on certain trades, often within a specific environmental context, continues to be reflected in the archaeological record. Similarly, there does not seem to have been a significant change in the general size of vessels, although very large merchant ships, of the size of the Madrague de Giens shipwreck, do seem absent from the later archaeological record. The shippers of Late Antiquity seem to have placed an emphasis on the use of many, smaller vessels, rather than a few very large

[45] See Harris and Iara (eds), *Maritime Technology ...*, *op. cit.*

ones. Perhaps this is an indication of a shortage of capital, or simply inclination, for the construction of very large vessels.

To this we can add a brief mention of the change in the primary sailing rig of the Mediterranean during Late Antiquity from the square-sail to the lateen-sail. The currently available research indicates that this alteration provided no improvement in overall performance, but instead did much to economize on the creation and maintenance of the Mediterranean sailing rig. On that basis, we return to the same theme as before: that technological change did not lead to an 'improvement' in maritime technology as we might now understand it on the basis of speed, hydrodynamics or cargo capacity. Instead, it is apparent that the developments described here allowed Mediterranean maritime societies to carry out their seafaring activities in a more economically efficient way than in previous centuries; making less use of manpower in the construction phases, and reducing the maintenance costs during the use-life of sailing vessels. No doubt, future archaeological discoveries will result in further revision, development and refinement to our understanding of this key element of the ancient Mediterranean.