The role of learning in the development and use of maritime technology in the Mediterranean 1500 BC to AD 200.

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Abstract

The evidence available to the discipline of maritime archaeology, and the associated interpretation of textual and iconographic sources, has recently undergone a period of rapid growth due to the development of techniques used in underwater exploration. Unfortunately, the presentation and interpretation of this expanded evidence has neither a clear taxonomic structure within which to categorise vessels by type and capability, nor a comprehensive model for development that might explain how, why and when different vessel types arose. The result has been that most published works by specialists in the field do not clearly reference either topic. This in turn has resulted in a great deal of misunderstanding by scholars from outside the discipline regarding vessel types, capabilities and usage. My contention in this thesis is that an understanding of the nature of learning in the ancient world can provide a means to explain how the process of vessel development progressed. Any process of development based on learning will clearly be linked to both the construction and operation of the vessels in use. This in turn requires the definition of vessel types in the form of a system of taxonomy based on features related to their use. The aim and objectives of this thesis are to provide a model of this process of learning and system of taxonomy that fits the current evidence, while providing a basis of challenge for others researching in the field of maritime archaeology.

Contents

1.0 Introduction

This thesis focuses on the development of merchant vessels in use in the Mediterranean from 1500 BC to AD 200; however, where relevant to the case discussed military vessels are also examined. The ideas I present developed from the shortcomings in contemporary scholarship identified through the writing of my Masters dissertation *Examination of the impact of risk on Late Bronze Age Maritime Trade between the Eastern and Central Mediterranean* (2018). This highlighted how some archaeologists and historians writing about maritime trade in the Bronze Age assumed this to have been carried out using sailing ships of a wide range of sizes (Sherratt and Sherratt, 1989; Cline, 1994; Aubet, 2001; Cunliffe, 2011; 2017; Abulafia, 2011; Tartaron, 2013; Broodbank, 2014; Monroe, 2015). The problem with the assumptions underlying these works is that there is no evidence for the use of sailing ships in the Mediterranean before the late 7th century BC, and no evidence exists for the use of round ships larger than 16 metres until the late 6th century BC (Parker, 1992; [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022. The works of these authors are well researched and are sourced from standard works on maritime archaeology and ancient ship construction (Casson, 1971; 2004; Bass, 1967, 1974, 1986, 2012; Pulak,1998, 1999, 2002, 2012; Frost, 1989; Steffy, 1985, 2017; McGrail, 2004; Wachsmann, 2004, 2009). A number of these works use a selective range of ancient sources to support their conclusions (Homer, *Odyssey;* Pliny, *Natural History*). The manner in which these sources are used is the subject of much of the discussion through this thesis.

The case I will make in this thesis is that in many cases previous scholarship does not focus on the practicalities of seafaring in the ancient world. Similarly, none record the limited seagoing capabilities of either small sailing ships, or of the hybrid rowed and sailed vessels, that the evidence shows were in use. With the exception of discussions regarding galleys few reference the presence of this latter group as a distinct class of vessels with specific limitations and capabilities. I contend that part of the problem is the lack of a clear definition of what constitutes a sailing ship, as opposed to a hybrid rowed and sailed vessel. Similarly, there is a lack of discussion of the shading between the two vessel types, this oversight forms the basis of the discussions in the following chapters. It is also noticeable that, in most of the works by the historians and archaeologists noted above, the issue of risk appears to have been ignored. In particular there is an absence of discussion regarding the performance of reconstruction vessels based upon, or broadly similar to, those in use in the ancient Mediterranean. In this regard, in the following, particular note will be taken of the works of Severin (1985), Morrison and Coates (1986), Katzev, M. (1987), Gilmer (1987), Tilley (1993), Unger (1994), Roberts (1994, 1995), Gifford and Gifford (1996), Cariolou (1997), Crumlin-Pedersen (2004), Katzev, S. (2008) Whitewright (2008; 2011a; 2011b; 2017) Palmer (2009), Hoffman and Hoffman (2009).

It is my contention that the source of this problem lies in the lack of a description of vessel taxonomy, along with a structure and process that models how maritime technology progressed in the period 1500 BC to AD 200. I propose that a combination of these will provide an original and innovative means to present the evidence available at the present time. More importantly, it will provide the most constructive context in which to present the fresh evidence that ongoing research in the expanding field of subsea exploration will inevitably reveal. In the following I present a system of taxonomy and model of learning to support a process of development of maritime technology. I will then use the maritime technology suggested by this process to review the probable nature of voyages undertaken at different times through the period. The latter will be based on an examination of the role of learning in regard to risk and seamanship. The taxonomy I will present is based on the form of propulsion of the vessel. The importance of this will be highlighted in the later discussions in Chapter 2; its link to use will be more fully explored in Chapter 7. I appreciate that the issue of taxonomy is discussed by a number of authors; however, these cases tend to be based on descriptive criteria (Marangou, 1987; Wedde, 1996; Van de Moortel, 2015). Their output does not focus on the capabilities of individual vessel types; as a result, the limitations of the vessels discussed are not clearly defined in terms of size and function. I recognise that a taxonomy based on vessel type is only one way of categorising vessels through this period, an equally valid method may be that of the means by which the shell of the hull was constructed. However, the focus of this work is the link between development and use, and the evidence I present in Chapter 4 does not show a link between the development of the means of hull construction at any time and the use of merchant vessels. I appreciate the means of hull construction tends to be regional in nature, and, as such, is possibly linked to the shipbuilding traditions of particular societies; I make use of this link to highlight issues in my discussions on development in Chapter 6.

The provision of a taxonomy is only part of the answer; in addition to this, a process of development is required to explain why particular vessel types appeared at a particular time and place. Perhaps as importantly, this would also explain why they did not, or could not, have occurred at an earlier time. This process of development would presumably have been dependent upon the motivations that existed within the societies that built and used the vessels. It is not unreasonable then to expect that this process of development would have reflected the manner in which knowledge was exchanged within society. This in itself might be seen as a function of the nature of learning in place at the time. To gain a full appreciation of both taxonomy and development then it is necessary to link this to the manner in which learning occurred in ancient societies. These observations led to my choice of subject matter, the title, and the aim and objectives for this thesis.

1.1 Scope of work

In this thesis I will focus on the development of merchant vessels in the Mediterranean in the period from 1500 BC to AD 200. This period provides the archaeological evidence on which to judge the appearance, and the development, of key features of maritime technology. The vessels examined range from the small hybrid vessels of the Bronze Age to the large grain ships in use in the Roman era. It is also one in which a process of learning in a craft industry is recorded by a contemporary source. The period also marks a time when social hierarchies became widely established. Where these societies were based on maritime activity it is not unreasonable to assume that these hierarchies would in turn have given rise to a requirement for specialist shipwrights. This process, along with this group of craftsmen, will be fundamental to the discussions in establishing the nature of learning in maritime technology.

The evidence I will use will at times extend beyond the period outlined, beyond the Mediterranean basin, and beyond the subject of maritime technology itself. These digressions are short and are intended to provide a focus on the issue outlined in the title. I suggest that, within the craft industry of ship building in this period, it is unlikely that there was any differentiation in the personnel involved in the construction of merchant ships and of those used for piracy and warfare. It might be expected then that there would be crossover in the technical development between all vessel types. For this reason, I will reference relevant examples of alternative vessel types where this may have occurred within the development process. Throughout the following the link between vessels in use, and vessel development and risk, will be a key feature of the discussions.

1.2 Aim and Objectives

My aim in this thesis is to develop, and justify, a methodology relating learning to its role in the development and use of maritime technology in the ancient Mediterranean.

To meet this aim, it is intended to pursue the following objectives:

- To provide a system of taxonomy of vessel types detailing the structural and operational limitations of each.
- To use this taxonomy to show how these vessel types may be linked to a process of development.
- To support the proposed process of development with an appropriate model of learning, and through this, to show how the nature of learning in the period was fundamental to the process of vessel development and use.
- To highlight the iterative nature of learning in the ancient world, and to show that there is no evidence that invention and innovation was directed toward long term goals regarding particular technologies and their uses.
- To highlight how, vessel development and usage was influenced by two factors; the ability of seafarers to safely operate particular vessel types, and the ability of shipwrights to build new vessel forms.
- To show how, in addition to the technical issues discussed, many changes in the vessel types may be linked to contemporary socio-economic factors.

- To use simple principles from structural engineering to support the discussions on the limitations in size of particular vessel types, and to provide a demonstration of how the square cube law impacted on attempts to increase the size of hybrid rowed and sailed round ships.
- To link the process of vessel development to risk and learning in seafaring, and through this, to provide a timeline for how maritime technology may have influenced the development of trade routes in the Mediterranean.

1.3 Methodology

Figure 1.1 summarises the key issues I will discuss through the course of this thesis, and the manner in which these issues will be presented. I have placed taxonomy, and the evidence associated with this, as the issue to lead the following analysis. The suggested taxonomy is explained in detail in Chapter 2, this is presented along with a range of case studies highlighting the current confusion that results from the lack of a similar system. It is my contention that without this framework there is no possibility of explaining the development process at the core of the discussions that follow. The observation by Edgerton (1999, 123) that: 'Invention and innovation rarely lead to use, but use often leads to invention and innovation,' summarises the nature of the link between development and use, and by implication any taxonomy on which these are based. To borrow a parallel example from more authoritative works. It is difficult to imagine Darwin developing a theory of evolution, much less writing *On the Origin of Species* (1859), if Linnaeus and others had not first provided a logical system of taxonomy by which to categorise much of the natural world.

The case I make through the following chapters is that the development process relating to maritime technology is largely dependent upon the interlinking of the factors shown in Figure 1.1. To extend the Darwinian analogy; if evolution in the natural world is driven by a combination of genetic mutation, competition between individuals and species, and environmental change; then, technical development in the human world might be seen to be driven by use, learning and socio-economic motivations. I outline the case for this in Chapter 3. In this I discuss the model of learning I propose and examine a number of case studies on maritime technical development. Many of these case studies are based on works published by historians and archaeologists from outside of the field of maritime archaeology. These are, for the most part, widely read authors who base their work, and their conclusions, on a number of long-established sources from the field of maritime archaeology. My objective in using the works cited is to illustrate how these problems are largely the result of omissions in the presentation of the evidence by sources in the field of maritime archaeology. I contend that, by reaching a wide readership outside of the field of maritime archaeology, these works may go on to establish a poorly informed consensus regarding vessel types and uses. These case studies then should not be considered as a critique of the works used; rather, in using these, I am attempting to place a focus on the problems that have arisen from the lack of a clear taxonomy, and process of vessel development, in specialist works relating to maritime technology.

The model of learning I use through the remainder of the work is based on a combination of primary sources and more current academic works, including Philon (*Belopoeica 50.14-29),* Usher (1954), Coates (1987), Basalla (1989), Edgerton (1999; 2008), Buckley and Boudot (2007), Greene (2010), Cuomo (2010), Ulrich (2010), Ingold (2013), Adams (2013), Olaberria (2014), and Marchand (2020). All of these suggest that learning in craft industries, both today and in the period under review, are likely to have progressed in small steps based on practical experience. The key point being that each step has been intended to solve an immediate problem. None suggest a theoretical approach to problem solving in craft industries either today or in the past. Similarly, none of these authors suggest that long term objectives of development were identified and consciously worked toward, Adams (2013, 82-83) specifically cautioning of the dangers of a teleological approach of this kind.

Chapter 4 presents the evidence I will use as the basis of the case shown in Figure 1.1. The content of this chapter is intended to secure the basis of the system of taxonomy outlined. In addition, the content of this also provides the evidence required to support the discussions in later chapters relating to vessel development and use. In these later chapters I discuss the issues of motivation, use and risk, along with the possible impact of the societies in which the recorded change occurred. In all cases these individual areas are complex, and, perhaps with the exception of risk, the manner and form in which they influence development varies across societies and through time. In the model presented I think it is reasonable to assume that risk would only be reduced by learning. On this basis, if the observation of Edgerton noted above is accurate, risk could probably be minimised if learning relating to use also progressed in small extensions to existing practices.

The majority of the vessels I examine are merchant ships. I have made the assumption that as the populations of any maritime society increased there was likely to have been an increase in the volume of its trade. I have further assumed that this would provide the motivation to increase the size of the vessels in use. The discussions in the following chapters will show how this will have been dependent on the extent of learning achieved in the craft industries of the time. The link that Edgerton (1999, 123) makes between use and development suggests that the rate of this learning would be dependent upon the rate at which seafarers learnt to use these larger vessels, and in turn to develop more advanced forms of seafaring. The testing of these motivations, and the learning required to build and operate these larger vessels, will form a substantial part of Chapters 5, 6 and 7.

Before concluding this introduction, I wish to return to the first part of the initial objective outlined, the provision of a structure for the study of maritime archaeology. As a student of this subject, I may appear presumptuous in making a statement of this scope regarding the accepted works of many established authors. However, there is a reason for this. I have entered this field of study after a career as an engineer. In this I worked in the planning and implementation of many small-scale works, and the integration of these small-scale works into large multi-disciplinary projects. As a result, I have extensive first hand, and often bitter, experience of the issues that arise when the details of well planned and executed small works were not integrated into the overall requirements of large projects. The results are all too often expensive failures. The worlds of engineering and maritime archaeology differ in many respects; however, I see parallels to these problems in many of the case studies and publications that I discuss through the following. In many cases these are based on reliable academic sources themselves the products of sound research. Many of the problems I identify stem not from the details presented in these sources; rather, they arise from the lack of an overriding structure, and process, regarding maritime technical development in the ancient world. I contend that, in missing the relevance of both vessel taxonomy and learning, much of the content of these detailed studies lacks context. The result is that when these works are applied by scholars from outside of the field of maritime archaeology, who rely on this research to write more general histories of the period, serious errors regarding both the vessel types and their capabilities can arise. Rather in the manner in which the minor works I have been involved in in the past frequently failed when they were not integrated into the planned aims and objectives of larger projects. It is the nature and extent of many of the resulting problems that are discussed in outline in Chapters 2 and 3, and in more detail in Chapters 5, 6 and 7. As noted earlier, it is not my intention that the focus of the cases presented should be on the errors discussed in these case studies; rather, it is intended to be on the need for a structure and process to avoid their repetition.

It should also be understood that I am not suggesting that the structure and process that I outline in the following thesis should be regarded as definitive. The development process and the pattern of vessel use are presented as a hypothesis offered for challenge. However, I suggest that, as long as vessel taxonomy and development are overlooked the problems identified are likely to be repeated.

2.0 Taxonomy

The evidence presented in this chapter is based on a range of iconographic, archaeological and textual sources. The archaeological data I discuss is largely based on the wrecks shown in Table 2.1. This data only represents a fraction of the possible sources listed in Parker (1992) and [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] *1/1/2022*. The reason for this is that the archaeological data required for my analysis relates to the size of the vessel and the form of the hull. However, much of the data contained in these sources relates to wrecks comprising scattered finds that do not contribute to any determination of these details. In this chapter I largely focus on how modern scholars have presented and interpreted this data, the problems that have arisen from the lack of a clear taxonomy, and those that have resulted from a failure to appreciate the nature of vessel development. I contend that at the core of the problem is the widespread use of the term sailing ship without a clear definition of what is meant by this, and the assumption that vessels of this type, rather than hybrid rowed and sailed vessels, dominated seafaring from the Bronze Age. In Chapter 4 I will present a more complete review of the iconography, the textual sources and the archaeological data, and show how this assumption contradicts the currently available evidence. In later chapters I will go on to discuss the reasons why the practical, and iterative, form of learning in the period is unlikely to have resulted in sudden changes in seafaring following the introduction of true sailing ships.

The following summaries outline the nature of the problems that result from the lack of a clear taxonomy of vessel types:

Paddled or rowed vessels. These are the simplest vessel type; they are limited in terms of the voyages they can undertake by the ability of the oar crew to propel the craft for extended periods in a range of weather conditions. The size and cargo capacity of these vessel types will be limited for the same reasons. Within these limitations their use in the early colonisation of the islands of the Mediterranean is widely referenced in the literature (Marangou, 1987; 2001; Broodbank and Strasser, 1991; Farr, 2006; Broodbank, 2006; Papadatos and Tomkins, 2013; Cherry and Leppard, 2015; Tichy, 2016). This suggests that under suitable conditions it is possible for rowed vessels to undertake a range of offshore inter-island journeys while carrying limited cargos.

Hybrid rowed and sailed vessels. In the ancient Mediterranean these vessels took the form of both the round ship and the galley. As their forms and capabilities changed these may have ranged from rowed vessels with an auxiliary sail to sailing vessels with an auxiliary oar crew. As was the case with merchant galleys through to the Renaissance period these vessels would almost certainly have been sailed whenever possible (Guilmartin, 2003, 73; Pryor, 2004, 208-209; Dotson, 2004, 219-220; Higgins, 2012, 2). Indirect evidence for this might be found in the cargo loading, and the implied trim and stability, of the Uluburun vessel discussed by Lin (2003), reviewed here in section 4.1.3. This said, a hybrid vessel would almost certainly have been reliant on either means of propulsion at some time through the course of a voyage. This would mean that a hybrid vessel could not be constructed larger than the oarsmen could safely propel. In sections 5.1.1 and 5.1.2 I will show that this factor probably limited the size of hybrid rowed and sailed round ships to around 16 metres in length. In these sections I will show how the only means to increase the size of this round hybrid vessel type was by developing the merchant galley. The term round ship is one I use throughout to describe a broad beamed merchant ship with a length to beam ratio of between 3:1 and 4:1, Casson (1971, 189) notes that these dimensions were typical for wooden merchantmen. In Chapter 4 I will show that this 16-metre size limit for the length of round ships can be supported across all lines of evidence until the 6th century BC. The use of galleys for both trade and colonising voyages through the Archaic period is recorded in Herodotus (I.163; IV.153). The continued use of this vessel through the Roman period is supported by the textual and iconographic evidence presented in Chapter 4. These vessels were limited in the range of voyages they could safely undertake; however, as noted, under the right conditions they were efficient sailing ships. The implications of the extended use of this particular type of hybrid vessel on the development of sailing ships, and of the seafaring and navigational techniques in use, will be the subject of much of the discussions in Chapters 3, 6 and 7.

True sailing ships. A major source of confusion and misunderstanding in the works of many scholars writing on the subject of maritime technology is the generic use of the term sailing ship. Vessels of this kind are capable of operating independently of oarsmen when making courses in open water; however, this ability will always be limited by the predominant regional winds. The maximum size of sailing ships that could be built were limited to those that shipwrights of the time could construct, that the sails and sailing rig in use at the time could safely propel, and that the crews could safely manage with the technologies of the day. It is my contention that the development of these technologies is key to understanding the appearance of larger vessels. The discussions relating to the developments that facilitated this increase in size form a major part of Chapters 4, 5 and 6.

I appreciate that the taxonomy proposed by Marangou (1987) is broadly similar to the one presented above. However, what is missing from this is an explanation of the manner in which the means of propulsion sets absolute limits on the size and form of particular vessel types, and provisional limits on others. The reasons for these limitations are explained in detail in sections 5.1 and 5.2. Similarly, in failing to be clear on the features required for a sailing ship, as opposed to one dependent upon both sail and oars, the system proposed by Marangou lacks definition. For this reason, it is necessary to understand how I define the term true sailing ship. Tilley (1993, 309) records that: ‘A true sailing ship can be defined as one in which the prudent mariner is willing to go to sea without oar power to make headway against an appreciable wind’. In this statement Tilley makes clear the difference between sailing ships and hybrid vessels. Saying this, I appreciate that the transition between hybrid vessels, that depended in part on oars, and true sailing ships would have involved the use of both means of propulsion over an extended period. I discuss the possible manner of this transition in use in Chapter 7. I appreciate that even toward the end of this process sailing ships may have required oars to manoeuvre in harbours, and other sheltered waters.

In terms of meeting the aims and objectives of this thesis a definition of a sailing ship based on stated lines of physical evidence is clearly required. For this reason, in the following I propose to use Tilley’s definition as a starting point, the detailed discussions will then focus on when the first evidence of features in the hull design, the sail plan and the rigging, that contributed to the use described by Tilley are recorded. In this regard the key features most commonly associated with this usage are:

1. A sail plan that will allow the vessel to make progress on a range of courses other than downwind. This would almost certainly invalidate any vessel with a boom-supported sail being described as a true sailing ship. As a minimum it might be expected that a loose-footed sail was in use, and for reliable windward performance a foresail of some kind (Casson, 1971, pp243-245; Vinson, 1993; Wachsmann, 2009, 248-251; Whitewright, 2011a; 2011b; 2017; Davey, 2015; 2016).
2. A hull form capable of resisting leeway when sailing with the wind on the beam. The most common form of this would be a hull with an external keel. It is probable that this would also require a mast step to provide a secure basis for the sailing rig (Geannette, 1983; Gifford and Gifford, 1996, 146-150; Pulak, 1998, 210-211; Whitewright, 2011a, 5; Davey, 2015, 31-32).
3. Standing rigging capable of supporting the mast against loads applied when sailing too windward. This would require the fitting of forestays, backstays and shrouds.

Much of the material I present in the following will be concerned with establishing the evidence showing when these features appeared, and proposing a process of development that might account for how different vessel types arose. I appreciate that some scholars offer alternative means by which the capabilities of true sailing ships may have been achieved. Fabre (2004, 89) suggests that steering oars would have provided the same effective lateral resistance as an external keel. Fabre implies that this technique may have allowed Bronze Age Egyptian vessels to operate as true sailing ships. I revisit this issue in more depth at the beginning of Chapter 7.

The proposed system of taxonomy outlined is simple and self-explanatory. It might be expected then that all three means of propulsion would be addressed by authors discussing maritime technology, and that the limitations of all three means of propulsion would be discussed by scholars writing on vessel use. In the following I will show that this is not the case. Rather, I will show that discussions on vessel usage for the period are largely based on the presumed use of sailing ships of varying size and capability. An example of the failure to even record the use of intermediate hybrid rowed and sailed vessel type is shown in Figure 2.1 (Anderson, 2010, Fig.1). This chart lacks any intermediate form of vessel between those with no sails and those described as having a sail. This omission is one that will recur through the cases presented in the following sections of this chapter. The result of this is that hybrid rowed and sailed vessels tend to be ignored as a category in discussions involving maritime technology. This in turn has resulted in a failure to address the limitations imposed on seafaring by the use of hybrid rowed and sailed vessels.

2.1 A review of the technical literature concerning vessel types and sizes

Given the frequency with which he will be used as a source in the following it is perhaps appropriate to start this review with the works of Homer. In book nine of the Odyssey Homer describes a vessel in the following terms, 'the mast of some great dark merchant-ship with its twenty oars' (*9.322 – 23,* trans, Shewring, 1998). The presence of both a mast and an oar crew make it clear that this was a hybrid vessel. Homer located his narrative in the Bronze Age; however, it is the opinion of modern scholarship that societal and technical issues down to the 6th century BC may have influenced the final composition and subject matter (Willcock, 2004, 348-351; Dickinson, 2017, 9-10; Sherratt, 2017, 36-37). The relevance of this issue will be revisited at a number of points in the following chapters. This suggests that this vessel type may have been familiar to the audience of the 6th century BC as a merchantman with a recent history of use. If the translation is correct in this context, the use of the term 'great' may suggest this was a large size at this time; however, other translations are not specific on the size of the vessel. It is perhaps relevant that, despite the late date at which the works of Homer were finalized, there is no reference in these to sailing ships; rather, all the descriptions clearly relate to hybrid vessels. Despite this lack of evidence in Homer's texts it is not uncommon for widely quoted authors of authoritative works on maritime technology in the Bronze Age to use the term sailing ship. The problems with this usage are compounded by a failure to provide a definition of what is meant by the term (Casson, 1971, 38; 2004, 117; McGrail, 2004, 30). An example of the manner in which the transition from rowed to sailed vessels is discussed can be seen in Casson (1971, 65) where he states; ‘The first merchant ships used in the Mediterranean must have been oar-driven. As the pace and volume of overseas commerce grew, large sailing carriers came into being.’ In this Casson is describing a change in both the size and type of vessel in a comment on vessel development. In omitting any reference to hybrid rowed and sailed vessels, this statement then is similar to Anderson’s representation shown in Figure 2.1.

The significance of the cases presented in Casson lies in this work being one of the first comprehensive studies of maritime technology written following the development of scuba diving and underwater archaeology. However, Casson was a classicist and his publications are largely based on textual and iconographic sources. The date of publication, 1971, of Casson’s most significant early work *Ships and Seamanship in the ancient world,* and the scope and quality of much of its research, has resulted in its widespread use as a work of reference. For these reasons its contents have influenced a large number of more recent works. At a later date, Wedde (1996, 609), in establishing his terminology of vessel types, begins his list with a merchantman, this is described as having ‘a hull conceived to maximize cargo capacity, implying a minimal crew, and a reliance on the cheapest form of locomotion, wind power.’ Wedde then is describing a sailing ship; in the same paper he goes on to discuss the use of these vessels in the Bronze Age Aegean. The link between maximizing the cargo capacity while reducing the crew size made by Wedde is one that will form the basis of my discussions throughout section 5.2. However, these discussions relate to the period following the Late Archaic, not to the Bronze Age.

I will reference Casson (1971), Wedde (1996), McGrail (2004) and Wachsmann (2009) widely throughout this work both as factual sources and as sounding boards against which to test the cases I will present. In many instances I use these, and other secondary sources, as examples of authorative texts in which sailing ships are recorded to have been in use, but where this usage cannot be supported by secure evidence. In these instances, the discussions are intended to illustrate the insecure basis of some of the significant ‘facts’ that have entered the canon regarding ships and seafaring in the ancient Mediterranean. In regard to these sources, I would draw attention to the general caution found in *Greek and Roman Naval Warfare* by Rogers (1937). In this Rogers commented that: ‘Many learned writers of recent times, in dealing with the maritime affairs of the Greeks, make it plain that they consider little but the text of the classical writers.’ The point I wish to make is that the comment Rogers makes concerning classical writers might also be applied to the texts of these modern authoritative sources. The second sentence of Rogers’ comment certainly appears to be relevant to Casson, and to a number of the other writers who will be discussed in the following. In this Rogers goes onto say: ‘Even where they do consider the engineering and nautical difficulties raised by the text of ancient writers, they abide by the written word.’ Rogers concludes the paragraph by saying: ‘A bad design now must have been a bad design 2500 years ago’ (Rogers, 1937, 29). Prior to writing this work Rogers had served as a Vice Admiral in the US Navy; for this reason, it is possibly not surprising if he wrote from a practical viewpoint rather than one focussed solely on an academic study of history.

The emphasis in this chapter on the need for a system of taxonomy based on propulsion is my attempt to reflect some aspects of Rogers’ thinking, and the concerns he appears to have been discussing. I am; however, neither a naval architect nor naval engineer, and I do not have the same depth of nautical experience as Rogers. I attempt to compensate for this by reference to the following works that discuss reconstruction vessels and their voyages Severin (1985), Morrison and Coates (1986), Katzev, M. (1987), Gilmer (1987), Gifford and Gifford (1996), Cariolou (1997), Crumlin-Pedersen (2004), Katzev, S. (2008), Hoffman and Hoffman (2009), and Gal et al. (2021a; 2021b; 2022; 2023). I have sourced further information on the application of the forces involved in sailing vessels from Tilley (1993), Roberts (1995), Whitewright (2008; 2011; 2011a; 2017), Palmer (2009), and Gal et al, (2023). Wider practical issues around risk, and seamanship in square rigged sailing ships, are based on the works of Steel (1794), McGrail (1989), Unger (1994), Willis (2003), and Harland (2015).

2.1.1 The proposed early use of large vessels

An example of the evidence used to determine vessel size from the Bronze Age is found in a 12 century BC text from Ugarit, RS 20.212. This takes the form of a letter to the king of Ugarit concerning the shipment of barley to Ura. The following translation of this is from Hoftijzer and Soldt (1994, 341): 'Now, the people from Ura have requested food from his majesty (and) 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 to their country; they will bring it in one or two turns.' The problem with this passage is apparent from the lack of any reference as to what constitutes a measure of barley. The passage then provides no precise definition of the weight of the cargo this ship might have carried. The term big ship is clearly relative and one that has to be viewed in the context of the time rather than that of later periods. An earlier translation by Nougayrol (1960) of text RS 20.212 and the two thousand measures of grain is discussed by Astour. In this case; however, Astour states that: 'As remarked by Nougayrol, the cargo was evidently counted in the regular unit of grain measure, kor, each kor containing 300 qa, or approximately 300 liters. Thus, the ship's total capacity was about 6,000 hectolitres, or 450 metric tons' (Astour, 1965, 254-255). I would contend that the conclusions reached in this case match the earlier comments of Rogers (1937, 29) regarding the use of classical sources without reference to their practicality. This might indeed be almost an example of a case of this as Jean Nougayrol was a specialist in cuneiform writing rather than maritime technology. This original error was compounded by the manner in which Casson uses Nougayrol as a source. The problem resulting from this perhaps being clear in the following statement by Casson (1971, 36). 'These eastern merchantmen could run to a good size: a document of ca. 1200 BC refers to one of some 450 tons burden as if it was by no means unusual.' This appears to be the first reference to a vessel of this size in a work of maritime archaeology. Although it is not stated in this passage Casson's earlier reference to the increase in the size of vessels being linked to the introduction of sailing ships (Casson, 1971, 65) suggests that the author thought that this was a sailing ship. Casson makes plain that the size of this vessel was based on a calculation by Nougayrol; however, the implication that vessels of this size may have been in common use comes from Casson. I contend that by using the data in this way Casson has turned a speculative assumption of one scholar, working outside of the field of maritime technology, into what might be seen as an established historic fact. The status of both Nougayrol and Casson quite possibly providing the integrity that Rogers was cautioning against in regard to classical sources. This assumption of the use of large sailing ships at this date by Casson may be contrasted to his observation that 'merchant galleys stayed very much alive through the whole of ancient history' (Casson, 1971, 65). I will re-examine the implications of this use of two vessel types in the following chapters and discuss how this may be explained in the context of vessel development.

The weakness in this single line of evidence from Ugarit is highlighted in the more recent works of Monroe (2007; 2009; 82-84; 2015, 15). In his work of 2007 Monroe discusses the ambiguity in the text regarding the size of the measures of grain (Monroe, 2007, 3-4). In this work he explains how Nougayrol's assumption that a kor, or kurru, equated to 300 litres was itself based on an old Akkadian and Babylonian measure. Monroe goes on to record how 'the scribes of Hatti, Carchemish and Ugarit were using Middle Babylonian standards by this time, such as the 150 litre kurru, as Vargyas (1986: 110) has argued.' In doing so Monroe is clearly suggesting that there is no certainty over the size of the units used to estimate the size of the vessels. He goes on to argue that an equally valid translation would put the size of these at around 20 tons. Monroe bases this analysis on a multi-disciplinary approach using shipwreck evidence from Pulak (1998; 1999; 2002) and Ballard et al (2002) to support this smaller vessel size. However, I suggest that Monroe's work does not provide an irrefutable proof that 450-ton vessels could not have been in use in the Late Bronze Age, his argument being based solely on the problems of the analysis and conclusions of Nougayrol. Monroe (2015, 16) also notes 'that Bronze Age sailing ships probably never exceeded 20 meters in length.' In this description of vessel type Monroe appears to be working on the assumption that the smaller vessels he proposes were themselves sailing ships.

Monroe's conclusions then are the result of more recent academic and archaeological work. However, the earlier work of Casson clearly influenced the findings of Bass another early pioneer in the field of underwater archaeology. In his early work *A History of Seafaring* Bass (1974, 23) repeats much the same information as Casson in relation to large ships; stating that: 'Canaanite ships, it seems, were large and numerous…the king of Ugarit, asks for a ship and crew to transport 2000 measures of grain – estimated to be 450 tons – in one or at most two trips.' In doing so Bass references the relevant chapter from Casson as source material for this section of the work. I suggest that these endorsements of the widespread use of large sailing ships, by two authoritative scholars, may represent the development of a consensus in the academic world regarding the authenticity of text RS 20.212 as a source. It is possible that this may have influenced Wachsmann (2009, 41) who references Nougayrol's discussion on the size of the units used, and notes in regard to the vessel 'this calculates to a total burden of 450 tons.' He goes on to note 'until recently tonnage of this size seemed excessively large. However, the recent discovery and excavation of a large merchant vessel from the early fourth century BC, with an estimated length of twenty-six metres and beam of ten metres, requires a revision to this assumption.' This latter statement suggests that Wachsmann had not considered the possibility that vessels had undergone a process of development from the Bronze Age to this later period. Wachsmann in his bibliography links the statement on vessel size to Casson. Wachsmann also uses Parker (1992) as a source; however, Parker provides no evidence of round ships capable of carrying 450 tons before the Madrague de Giens vessel of the 1st century BC (Parker,1992, 249-250). Overall, I would suggest that the influence of the authoritative written word noted by Rogers was very much alive in the discussion of this large vessel by Wachsmann.

There is a second source of evidence that might support the early use of large vessels. This takes the form of the finds of large anchors, the most relevant source of data on these being Frost (1989). In this Frost (1989, 18) stated that: 'At Kition, the number of anchors weighing over half a ton suggests that some Late Bronze Age craft must have been giants, analogous to the great Corn Ships of Rome.' However, this assumption of the existence of these large vessels is based on isolated finds of large stone anchors, most of which come from temple locations. At no location are these large anchors found associated with the remains of a ship. The presence of these; however, has been assumed to be a guide to the size of similar objects in daily use, and this has in turn been used to estimate the size of the larger ships. It is apparent that this analysis excludes a range of alternative explanations for these finds. Given the temple context of many of these, their extreme size and their relevance to the safety of seafarers, their use as votive offerings is worthy of consideration.

An exception to this acceptance of large vessels in the technical literature is McGrail, who, in his 2004 work *Boats of the World* makes no reference to these. It is possible that this is because McGrail's work is laid out in the form of a regional chronology of vessels. In this format any reference to a 450-ton ship in the Bronze Age would be an obvious anomaly that would require an explanation. A further reason may be that McGrail had served as an officer in the Royal Navy before taking up an academic career. It is probable then that he had a similar range of experience and practical knowledge as Rogers. This possibly allowed him to put the interpretation by Nougayrol, and the later endorsement by Casson regarding the size of this large maritime vessel, into a practical context and dismiss it as impractically large. It is also perhaps relevant to note that McGrail references Parker (1992) in his work.

This said, it is clear that large vessels did exist in the Bronze Age. Evidence for these large vessels can be found in the iconography showing a barge used to transport obelisks in the reign of Hatshepsut shown in Figure 2.2 (McGrail, 2004, fig 14). However, it needs to be appreciated that these examples of large vessels were river craft. The stresses under which the hull of these was placed in use would be much lower than that experienced by a maritime craft due to the calmer water in which they operated. The very specialist nature of this barge, and its portrayal in the temple of the Pharaoh who commissioned its use, might suggest that the form shown is an accurate representation of the vessel.

2.1.2 Vessel types

The vessel types most frequently discussed by authors writing on vessel construction, design and use, are sailing ships and merchant galleys. Most of the discussions that follow concern the issues arising from the misuse of the term sailing ship, and the frequent failure to acknowledge the widespread role of hybrid rowed and sailed vessels. The development and use of galleys will form part of these discussions. The use of these vessels is referenced in Herodotus (I.163; IV.153) and Plutarch (*Life of Pericles,* 26.4) and discussed by Wedde (1996), Wallinga (2004), and Snodgrass (2006). The role of merchant galleys in the development of maritime technology through much of the period is reviewed in Chapters 4, 5 and 6. The impact of the widespread use of this vessel type on the nature of seafaring forms much of the discussion in Chapter 7.

Given Rogers' general observation of the dependence of later works on authoritative sources (Rogers, 1937, 29), and the absence of any reference to sailing ships in ancient sources such as Homer, Casson might be a reasonable starting point for examining how the appearance of sailing ships in the Bronze Age is presented. In this regard Casson states: 'The standard vessel in antiquity for hauling cargo was the sailing ship, and, when the destination involved a long voyage over open water, it was the carrier par excellence,' (Casson, 2004, 117). Once again, in this passage the problem relates to Casson's failure to clearly define what he meant by use of the term sailing ship, to present incomplete imagery in connection with the description, and to assume uses that are not supported by secure evidence. This can be seen from his use of the term sailing ship to describe the river vessel shown in Figure 2.3 (Casson, 1971, Fig 16). Unfortunately, Casson does not provide the full context which might allow a complete examination of this illustration. The vessel shown is one of a pair which appear in a facsimile in the Metropolitan Museum NY entitled The Viceroy's Boat. A copy of this facsimile is shown in Figure 2.4, the original from which this is taken is in the tomb of Huy at Qurnet Murai ca.1360 BC. From the oars in use in the upper image it may be seen that this is a hybrid rowed and sailed vessel rather than a sailing ship. The importance of this lack of clarity in Casson's descriptions is perhaps summarised by his earlier statement that 'the second millennium BC…a crucial period for Mediterranean maritime history. It witnessed the development of true seagoing ships, both galley and sailing craft…' (Casson, 1971, 38). From this it might be assumed that Casson considered that true sailing ships appeared in the 2nd millennium. The point I make here is not that Casson necessarily failed to appreciate that the vessel shown in Figures 2.3 and 2.4 was a hybrid rowed and sailed vessel, simply that he did not describe it as such. This perhaps underlies the problems that occur when vessels are described without the framework of an agreed taxonomy based on their use and limitations.

Casson is not alone in this loose use of terminology, McGrail (2004, Fig 2.15) shows a vessel he describes as a sailing ship shown here as Figure 2.5. However, he later notes (pp32-33) the limitations of this sailing rig in relation to its use on seagoing ships. He goes on to discuss how the vessel shown in Figure 2.6 demonstrates the manner in which the form of the sail changed over a period of time. He suggests in these discussions that this development may have been associated with an attempt to improve windward performance. However, McGrail provides no evidence for these activities, at the same time, he fails to discuss the importance of hull form and standing rigging in achieving this performance. There is a further potential problem with this line of discussion based on the evidence presented by McGrail (2004, Fig 2.7) which shows one of the earliest representations of an Egyptian seagoing ship. This is from the mid-3rd millennium BC and comes from the burial temple of Sahure at Abusir. This vessel is shown with oars rigged and is clearly a hybrid rowed and sailed vessel. The similarity in hull shape between this and Figures 2.4, 2.5, and 2.6 suggest that all of these were similarly hybrid rowed and sailed vessels. The presence of the crew lined up along the sides in these cases suggesting they were unemployed oarsmen. This might be supported by the shape of the sails in Figures 2.5 and 2.6 which suggests the vessels were making progress downwind. In this case it is probable that the oars were shipped as they were not required.

This is not to suggest that McGrail was unaware of these features and the relationship between them. Rather, as was the case with Casson, he is using a generic term more broadly than the evidence justifies. Any reader familiar with the limitations imposed on a vessel by this sailing rig and hull form could not fail to draw the same conclusions. However, when an authoritative technical work presents a case in this manner it can lead to a number of problems. In the following I will detail some of these problems, in particular the manner in which scholars have modelled trade routes based on the use of vessel types that are not supported by iconographic, textual or physical evidence. The broad limitations of all of the sail types shown in Figures 2.4 through to 2.7 are recorded by Wachsmann (2009, 253). In this passage he states ‘the square sail was designed primarily for travelling before the wind. When winds were contrary, crews either bided their time at anchor or took to the oars.' By combining the limitations of this form of sail, with the requirements for an oar crew, Wachsmann is effectively defining a hybrid vessel; however, he does not go on to highlight the importance of the vessel type to vessel development and use.

The same misleading use of the term sailing ship is not restricted to the Bronze Age, the same description is repeated by Friedman (2011) in relation to the much later Roman oared vessel shown in Figure 2.8. This is part of a mosaic from the Villa del Casale in Sicily dated to the early 4th century AD. The relevance of the projecting forefoot shown in the hull shape of what is clearly a merchant galley lies at the core of much of the discussion in the following chapters.

The implications of the hull form, and the presence of an external keel, on sailing performance is widely discussed in the literature (Roberts, 1995, 308; Gifford and Gifford, 1996; Pulak, 1998, 210-211; Wachsmann, 2009, 253; McGrail, 2010, 103; Whitewright, 2011a, 5; 2011, 92-93; Davey, 2015, 31). It is relevant then to review how this requirement is recorded in early vessels. Landstrom (1970, 123) states that: 'The Punt ships were shaped like ordinary travelling ships, with keels', examples of these Punt ships are shown in Figure 2.9. This figure shows the vessels to have been equipped with boom-supported sails. Both Vinson (1993) and Wachsmann (2009, 248-251) discuss the limitations of this sail type in sailing any course other than downwind. Landstrom provides no evidence or justification for the proposed use of the keels he shows in a projected reconstruction of these vessels shown in Figure 2.10. Similarly, Landstrom does not discuss why this feature would be required on a vessel equipped with a sail that could only sail broadly downwind courses, and where the necessary rigidity in the hull was provided by two hogging trusses.

The Uluburun vessel, which is one of only two reasonably complete Late Bronze Age hulls available at the present time, provides an opportunity to review the issue of hull form, and keel development, with more integrity. This wreck is also a good example of how the presentation of some unambiguous archaeological evidence may be unwittingly distorted through the continued use of early excavation reports. I have used Pulak as a primary source in relation to this wreck. The reason for this is that Pulak has been involved in work on the wreck from the early excavations, and has subsequently taken a major role in writing up the findings. It is relevant then to record exactly what he said with regard to the keel found on this 14th century BC wreck. Pulak (1998, 210-211) states that: ‘It is worth noting that the sided (width) dimension of the keel is greater than its moulded (thickness) dimension. Although the latter dimension is somewhat uncertain due to the poor preservation of the keel's outer surface, it appears, nevertheless, that this timber originally protruded beyond the outer planking surface by only a few centimetres. The keel timber would have served as the ship's spine, as well as to protect the planks and support the vessel when beached or hauled ashore, but un-like keels of much later sailing ships, it would have done little to help the ship hold course or point nearer the wind under sail. In other words, it appears to be a rudimentary keel, perhaps more of a keel-plank than a keel in the traditional sense.’

The phrase ‘much later sailing ships’ used by Pulak is repeated in his later works (2008, 302; 2012, 13) and is key to many of the points raised in the following discussions. Pulak, unfortunately, does not go on to identify what type of vessel this may have been. I suggest the lack of an external keel means that, within the taxonomy proposed in section 2.0, this was not a true sailing ship as described by Tilley (1993, 309), and, as such, it would have been dependent at times on an oar crew. On this basis, I suggest this was a hybrid rowed and sailed vessel. This case will be discussed in greater detail in section 4.1.3, and the impact on vessel development and use of vessels of this type will form a substantial part of the discussions in Chapters 6 and 7.

In the case of the Uluburun vessel the full extent of the keel below the hull is poorly defined for much of its length. Pulak explains his conclusion on the basis of an intact and preserved knot that only projects 2 cm below the hull, and, more importantly, by ‘a small patch protected by concretion at the forward extremity of the preserved portion of the keel that retained the keel’s original outboard surface’ (Pulak, 1999, 619). This description is the basis of Pulak’s portrayal shown in Figure 2.11a (Pulak, 1999, 636). Of particular interest in this regard is the fact that Pulak in this figure shows the form of the extant remains of the keel, along with the assumed line of the original. This might be compared to later representations by other authors, Figure 2.11b, (McGrail, 2004, 124), Figure 2.11c, (Steffy, 2017, 37) and Figure 2.11d (Wachsmann, 2009, 216).

There is a clear mismatch in the profiles shown in these figures, in addition, only that of Pulak shows the extant form of the keel along with a projection of the original profile. In the case of McGrail the profile shown is referenced to a 1998 edition of Wachsmann's *Seagoing ships and seamanship in the Bronze Age Levant*. Steffy's notes show his representation was published courtesy of Cemal Pulak; however, no date is provided for the provision of the relevant information. Steffy's 2017 edition of *Wooden ship building and the interpretation of shipwrecks,* used as a source in this thesis, is the fifth reprinting of a work originally published in 1994. The bibliography of this late reprint references no sources later than 1992, this suggests that the contents overall probably reflect those of the first edition. The illustration used by Wachsmann is recorded as being taken from Pulak 1987. Waschmann's bibliography shows this to be Pulak's thesis *A Late Bronze Age Shipwreck at Ulu Burun: Preliminary Analysis (1984-85 Excavation Campaigns)*. It would appear then that a number of factors may have contributed to these portrayals of the Uluburun keel. Both Wachsmann and Steffy have accessed data from Pulak's early work, both published and unpublished, rather than his more recent 1998 and 1999 papers. On the other hand, McGrail has used Wachsmann as a source. It is also possibly relevant that McGrail also references Pulak's 1998 paper *The Uluburun shipwreck: an overview* in his bibliography. This does not contain the illustration shown in Figure 2.11a; however, it does include the note on the dimensions of the keel repeated by McGrail in his text. In addition, this paper includes Pulak's comment 'it appears, nevertheless, that this timber originally protruded beyond the outer planking surface by only a few centimetres.' This may account for the difference between McGrail's portrayal of this feature and that of Wachsmann. This may also account for the fact that McGrail's figure is noted as being after Wachsmann, this in turn suggests he has modified the original. I suggest that this brief review of the Uluburun keel might show how uncertainties in early excavation reports can be included as factual representations in later authoritative works. They also suggest the obvious problems that can occur when authorative text books are reissued without revision. These misinterpretations of the Uluburun vessel are particularly relevant given the significance of this wreck, and the reference to this by later authors as representing an early example of a sailing ship. As I discussed earlier these issues will be reviewed in greater detail in section 4.1.3. The timing of the appearance of the external keel, and the implications of this on vessel development and use, will form a substantial part of the discussions in Chapters 6 and 7.

2.1.3 Review of how this data is used.

The manner in which the information presented in the previous sections is used by non-specialist authors makes it difficult to examine vessel size and type as individual topics, for this reason in the following I have combined these elements. Sherratt and Sherratt (1989, 364) discuss the case made by McCaslin (1980, 101) of vessels of the rather precisely calculated size of 225 tons in the 13th or 14th centuries BC. The authors go onto state that calculations based on stone anchors suggest even larger vessels were in use; however, they do not link this observation to any specific sources. In a later work they are more circumspect in terms of tonnage, they are; however, clear in the implication that large vessels had been in use in the Late Bronze Age, noting that: ‘The ninth century saw an intensification of this pattern, with the construction of artificial harbours at towns on the Levantine littoral like Tabat-el Hamman - a sign that larger cargo ships were once again coming into use’ (Sherratt and Sherratt, 1993, 365). In a later paper relating to trade in metal goods from the eastern to the central Mediterranean Sherratt (1997, 85) is more circumspect still, seeing this as being carried out in small vessels using coastal and Isthmus routes. The author relates this use to the risks involved in sailing these smaller vessels around exposed capes, in particular the passage around the southern Peloponnese. There is no accompanying explanation to account for the range of vessel sizes proposed.

Aubet (2001) makes a number of comments regarding Levantine and later Phoenician ships, in these she suggests there is evidence for ‘large merchant ships’ in Byblos. Aubet makes this suggestion without referencing a source for the statement, or clarifying what she means by the term large (Aubet, 2001, 172). Later in the same passage she describes Hatshepsut’s vessels as being ‘capacious and capable of sailing long distances…the space normally reserved for oarsmen was used for cargo so the boats travelled under sail.' However, Figure 2.9 shows Hatshepsut's vessels underway and show that these used both oars and sail. Later Aubet (2001, 166-175) references vessels used by the Phoenicians being: 'Propelled by a huge square sail…texts from Ugarit lead us to think that, around 1200 BC, a Canaanite merchantman could have a cargo capacity of up to 450 tons.' Aubet does not provide a source for this reference in her text. Cunliffe (2017, 267) records wide-bellied freighters: 'Depending on sail and needing only a small crew…their size and shape made them stable at sea and capable of carrying substantial cargoes estimated to be from about ninety to 450 tonnes…The basic type had already been developed before the end of the 2nd millennium and changed little over the next thousand years.' Cunliffe does not provide a direct reference for this statement; however, Casson 1971 is listed as a source for the chapter.

Broodbank (2014, 374) is more conservative in terms of vessel size but the logic by which he arrives at his figures is unclear. He agrees with Monroe (2001; 2007; 2015) in rejecting vessels of 450 tons based on the Ugarit texts. At the same time, he rejects as 'a minimalist analysis' Monroe's assessment that vessels of 20 tons might be more appropriate. However, he appears comfortable in accepting a size range of 'at least 25 and possibly almost 70 tons.' Broodbank refers to Marcus (2007) as the source for these figures. He records these as coming from 'bills of lading' found in inscriptions on a statue base at Mit Rahina. This statue dates from the reign of Amenemhet II in the early 2nd millennium BC, the text describing two voyages between Egypt and the Levant. As with text RS 20.212 from Ugarit it is worth reviewing the nature of the evidence regarding these two voyages.

One of these was a trading mission and the second a military expedition. The weight of cargo on the return of the military expedition voyage involved one ship that is assumed to have transported 1554 prisoners, each of whom weighed 40kg (Markus, 2007, 140-150). It is perhaps of relevance that this weight is the P50 reported for a 12-year-old child by the CDC [https://www.Growth Charts - Data Table of Weight-for-age Charts (cdc.gov)] 1.11.22. The statue base itself provides the number of prisoners; it does not; however, confirm they were transported home by ship, Marcus (2007, 144) commenting simply ‘a gap in the beginning of the preceding entry obscures whether the expedition to *Stt* returned to Egypt by land or sea.’ The army that captured this quantity of prisoners is not accounted for by Marcus and apparently marched home. Marcus does not explain why this large number of improbably small individuals might not also have marched to Egypt.

The trading voyage described on the statue base involved two ships which carried mixed cargoes. In one sub-section of the manifest labelled M20 three woods are listed, cedar, pine and olive trees, along with details regarding the relative quantities of each. In note 10 Marcus (2007, 141) discusses a number of alternative translations for the item which the text shows as olive trees. These discussions suggest uncertainty over the translation, on the basis of this possible uncertainty Marcus substitutes cedar for the quantity of olive trees shown. In doing so Marcus fails to explain why cedar may have been listed twice as part of the cargo, once correctly and once incorrectly. In regard to the volume of this cedar Marcus (2007, 153) notes: ‘Moreover, despite the absence of any details of their dimensions it is nonetheless instructive to model what this timber cargo might have represented to the Egyptian court and to the ships that carried it.’ On the following page Marcus states that: ‘Thus, both trunks and cut wood are simulated here (Table 2). For length, the maximum upper bound is based on the longest imported timber known from ancient Egypt, which is a 23 m long, 15 cm thick plank of cedar from the Cheops boat.’ Marcus then is assuming both the identity and volume of much of the cargo, neither of these assumptions being supported by the content of the inscriptions.

The result is that in Table 2 Marcus presents two cargo weights for these two ships. The first is an improbably large one based on the transport of cedar trunks; the second one of 68 tons is based on the transport of cedar planks. Coincidentally this latter figure is close to the calculated weight for the 1554 40 kg prisoners that Marcus assumes to have been carried home on the military voyage. The combination of these presumably being the source of the figure of around 70 tons that Broodbank uses in his estimate of vessel size. However, on the basis of this brief summary I suggest that the composition, volume and weight of the cargos assumed are insecure, and these weights appear to be the result of speculation on the part of Marcus. It is perhaps relevant to return to Broodbank's case that these are based on a bill of lading. This comes from the following passage in Marcus (2007, 154) where he states that: 'The final assemblage of these two ships' cargoes, as detailed in this entry, should be considered a "bill of lading" or "cargo manifest."' The lack of details regarding the means of transport of some items, and the identity and quantities of others, means, as was the case with the Ugarit ship, the interpretation of a vessel size by Marcus suggests more certainty than the record actually provides.

Abulafia summarizes Phoenician seafaring in the period 1000-700 BC and the wrecks found by Ballard off Ashkelon in the following comment, 'the Phoenicians and Carthaginians favoured heavier ships than those that were developed by the Greeks,' (Abulafia, 2011, 107). However, he provides no evidence that might confirm either the use of these large vessels or reasons why the Greeks might not also have used them. He notes the earlier reference to a large vessel in the text from Ugarit; however, in this case the vessel is only 45 tons rather than 450 tons. Unfortunately, his sources for this information on Phoenician vessels are Markoe (2000) and Aubet (2001) the former of whom uses Casson as a source. However, Casson does not refer to 45-ton vessels, on this basis it is not possible to resolve the source of this discrepancy. Abulafia then goes onto suggest that round ships of the period could be up to thirty metres in length. There is no evidence in Parker (1992) or [http://oxrep.classics.ox.ac.uk/databases/*shipwrecks database.html]* 1/2022 for round ship type vessels of this size at this time.

As for vessel types, it is clear from Aubet and Cunliffe that they are assuming the large Canaanite or Phoenician vessels they were discussing were sailing ships. Broodbank in regard to the 20-to-70-ton vessels in Marcus (2007) provides no description of vessel type. However, in an earlier work Broodbank (2010, 254) states that: 'The other maritime legacy of the 3rd millennium BC in the Mediterranean was the development of seagoing sailing ships…Hitherto, water transport had relied on muscle-power and could gain little advantage over its overland alternatives in terms of speed and bulk…The harnessing of wind power changed all that.' This text is accompanied by the map shown in Figure 2.12 (Broodbank, 2010, fig 20.2) which Broodbank labels as showing the expansion of sailing technology. On the other hand, I suggest that this perhaps exemplifies the problems that result from the lack of a system of taxonomy to categorise vessels in this period. The vessels shown in this figure all have oars, or an oar crew, as a result they are all hybrid rowed and sailed vessels rather than 'seagoing sailing ships.' The presence of oars show that these were still reliant, at least in part, on muscle power. As such their size, and any voyage they undertook, would have been limited by the requirements and capabilities of the oar crew.

The observation by Pulak (1998, 210-211) in regard to the keel of the Uluburun hull is relevant to this discussion. Pulak in this comment is making it clear that the technologies associated with sailing ships were not restricted to the sails. However, Broodbank appears to assume that the representation of a single feature of sailing technology means that the vessels were true sailing ships. Overall, it is perhaps difficult to imagine a passage, or illustration, that better summarises the requirement for a clearly defined taxonomy of vessel types relating to all of the requirements of the various systems of propulsion. The statement regarding vessel usage reflects those by Casson (1971, 65; 2004, 117) discussed earlier. Broodbank (2014, 374; 393; 417; 442; 477; 537) goes on to make numerous references to the early use of sailing ships. In doing so, Broodbank largely links the developments in seafaring and trade he is discussing to the use of vessels of this kind. This is perhaps a particularly clear indication of the confusion that may result when misleading descriptions are used in early scholarship and subsequently become accepted in mainstream publications.

Knapp (2018, 65) in turn refers to Broodbank (2010, 254-255) when he notes 'the emergence of newer larger, seagoing ships under sail' in the late 3rd millennium BC. Knapp in this statement is unfortunately referencing an archaeologist who has himself been misled by insecure sources. In a later work Knapp (2018, 169) is less specific on size while being specific as to the types of vessels, 'seagoing sailing ships emerged earliest in Egypt and the southern Levant, by the mid-3rd millennium BC.' Abulafia (2011, 18) records later dates when he says 'sailing ships appear to have been introduced only during the 2nd millennium BC'. This date is more conservative than some while suggesting the same failure to appreciate the difference between a ship with a sail and a sailing ship. Once again Abulafia does not reference any source for this date.

Tartaron (2013, 57-58) uses Wedde (1996, 609) as a source, noting that a merchantman was a sailing ship optimised to maximise cargo capacity, at the same time, he accepts that these may have had a small rowing crew for manoeuvring the vessel. Tartaron goes on to describe the Uluburun vessel as being 'probably typical of merchant vessels plying the Aegean in the LBA.' Taken together this might imply that Tartaron is assuming the Uluburun vessel to have been a sailing ship. This appears to contradict the interpretation of the evidence from the wreck by Pulak in a work listed by Tartaron in his bibliography. In this Pulak (2002, 619) stated that: 'the Uluburun keel projected no more than a few centimetres beneath the hull…Unlike the keels of later sailing ships, therefore, such a keel would have done little to help hold the ship on course when sailing against contrary winds.' The same paper includes a representation of the keel shown in Figure 2.11a. It might appear then while Pulak was implying that the Uluburun vessel was not the same as a later sailing ship, perhaps with the characteristics outlined by Tilley (1993, 309) in section 2.0, Tartaron appears to be making this interpretation despite referencing Pulak as a source.

However, these opinions are not held by all archaeologists who write in regard to trade in the ancient Mediterranean. Snodgrass (2006, 223) discusses comments by Herodotus *I.163*; *IV.153* and Plutarch in the *Life of Pericles,* 26.4 regarding trade carried out by the Phocaeans and Samians in the Archaic period. In these discussions he notes that: 'If two of the most prominent Archaic trading states at least sometimes preferred oared galleys, then the burden of proof is on those who believe that purpose-built, sail driven merchantmen were the norm elsewhere in this period. The archaeological evidence will not support them.' The evidence I will present in Chapter 4 will reinforce the accuracy of this statement. What neither Snodgrass nor the evidence in Chapter 4 can do; however, is provide any evidence that sailing vessels did not exist. It is probably never possible to categorically prove absence of this kind. However, I would contend that the contents of Chapters 5 and 6 which outline the limitations of particular vessel types, and go on to provide a process of vessel development, may reduce this uncertainty.

There is a further point that might also be considered in regard to the use of large sailing ships, this relates to the lack of evidence regarding a hierarchy of vessel sizes for the period up to the 5th century BC. Houston (1988) in writing on later Roman ships makes an observation that will inform much of the discussion throughout this work: 'First, preindustrial merchant fleets seem always to include a large percentage of small vessels for the coastal and short to medium length trade. Second, the percentage of the fleet made up of the largest ships allowed by technology of the time is low, regularly below 10% and usually less than 5%' (Houston, 1988, 554). It is possible to examine data relating to routine commercial shipping from a later period to gain a clearer idea of this distribution of vessel sizes in maritime communities where these larger vessels were in use. Figure 2.13 is based on data contained in the first Lloyds Register of 1764 [https://archive.org/details/HECROS1764] 01/06/2021. The relevance of this is in the details based on a sample size of over 4000 vessels.

A number of relevant details can be seen from Figure 2.13 regarding the use of the 450-ton vessel suggested by Nougayrol, along with those described by Frost as being as large as Roman grain ships. The first of these confirms the findings of Houston (1988) in showing that even in 1764 vessels of 450 tons and above were rare. What is equally clear is that large vessels at this time operated within a maritime trading system dominated by smaller vessels in the range 50 to 200 tons. This same pattern is shown in the shipwreck data from the Hellenistic and Roman periods in Table 2.1, Parker (1992) and the [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022. The question then is: if this pattern of vessel usage might be assumed to be common across all periods, and 450-ton vessels were in use in the Bronze Age, why is there no evidence for the use of this range of vessel sizes in the textual, iconographic or archaeological records for the period prior to those of Classical Greece?

2.2 Seamanship and navigation

The issue of risk as revealed through experimental archaeology, and an assessment of operational issues arising from seafaring under sail in small open vessels, is not covered in the following discussions. These will be taken up through the course of Chapter 7. However, it is relevant to record that the reason these are not covered in this section is that neither topic is raised in a meaningful manner by most of the authors discussed in the following case studies. From the discussions to this point, it is apparent that most authors writing about the use of maritime technology from the Late Bronze Age assume that merchant vessels were sailing ships. I will present evidence to refute this assumption in Chapter 4. However, this assumption shapes the manner in which many of the sources referenced in the following assess the nature of seafaring and the trade routes in use. The works of the authors quoted use a number of primary sources to support the forms of seafaring and navigation they describe. These are most commonly Homer and Pliny; the latter being used mainly as a source on navigation. As I discussed earlier, the only reference to merchantmen in the Odyssey is to hybrid rowed and sailed vessels; Homer makes no reference to sailing ships. Any reference to vessels used in raiding or warfare might be assumed to be galleys which would also be hybrid vessels. Any uses of Homer as a reference to seafaring should then take the associated limitations of the vessel types into account.

Taking Homer as a source for issues around seafaring first requires that a secure translation is used. Following this it is necessary to assess the extent to which the content is dealing with issues in the real world, rather than those in a parallel one of fantasy and myth. This latter issue is particularly important as the narrative of the Odyssey, one of the most common textual sources for seafaring in the Bronze Age, is clearly a mix of both. The earlier caution of Rogers regarding the over reliance on the written text is then something to be particularly aware of in this instance, and any accounts of voyages need to be examined for this possible failing. This said, there are references in the Odyssey that support the use of some short range, offshore, inter-island routes for the Greeks returning from Troy. Although this war might not have a secure basis in history the routes may be seen as involving voyages that might take place in the real world. In regard to one of these McGrail (1991) references Rieu's translation of Homer *Odyssey 3.165-175,* this discusses a direct open sea route from the 'north of Chios to the southern end of Euboea'. I do not dispute that this is an offshore voyage; however, I contend that this is a very specific type of offshore voyage. The presence of surrounding islands, and particularly those in the Cyclades and Crete that lay downwind, reduces the overall risk of a vessel and crew being blown to a distant and unfamiliar destination.

A second category of realistic offshore voyage referenced in Homer is that comprising a downwind passage such as that between Cyprus or Crete and north Africa. A voyage of this kind is recorded by Homer in the *Odyssey* (*XIV.250-260*, trans, Shewring, 1998) where Odysseus says ‘and leaving the plains of Crete we began to sail with a fine strong north-wind behind us. It was easy sailing, as if downstream, none of my ships came to grief. With no harm…we sat on board while the wind and steersmen carried us forward on our course: on the fifth day we came to the Nile’s majestic waters.’ The relatively routine manner of the seafaring discussed in this description suggests that voyages of this kind were familiar to listeners in the Bronze Age and Archaic period. Kelder, Cole and Cline (2018) discuss the links between Egypt, Crete and the Mycenaean states throughout the 2nd millennium. These links were almost certainly dependent in part on the use of this route. In terms of the risk experienced by seafarers these voyages were downwind, and, as a result, they were probably of predictable duration. In addition, the destination was large and was impossible to miss from a navigational viewpoint. The overall risk then was likely to be low.

There is a second type of voyage in Homer where reality and fantasy mix. McGrail (1991) references one of these in the voyage of Odysseus from Calypso’s Island. In this Homer describes the use of astronomical navigation; despite being a mix of reality and fantasy the details of this voyage are relevant to the discussion overall. Homer describes this in the following manner: ‘Sleep never fell upon his eyelids as he watched the Pleiades, …Calypso the goddess had bidden him in his sailing to keep the Bear on his left hand…on the eighteenth day there loomed before him the shadowy hill of the Phaeacians,’ *Odyssey (V.270-280*, trans, Shewring, 1998). So, this voyage was from one mythical location to another, sailed single handed, with Odysseus apparently going without sleep for eighteen days. These elements of the voyage are unlikely to be realistic and are more likely to have been used for dramatic effect. What is more relevant is the use of the Bear as a marker and the injunction to keep this on the left-hand side, this records an accurate means of how to make a course to the east. In this respect the passage contains some realistic astronomical information mixed into a voyage of fantasy. It will be discussed in Chapter 7 that a course of this kind might be seen as broadly downwind in the eastern Mediterranean.

The core of the problem I will examine in the following relates to a prose translation of Homer by Rieu. The widespread use of this appears to have resulted in a great deal of confusion regarding the use of offshore voyages from the Bronze Age. I discuss the practicalities of this range of voyages in more detail in section 7.3.1. These discussions will record how vessel capability, and learning in regard to seafaring, may have influenced this type of voyage at this time. My discussion in this section focuses on the manner in which a single translation may have influenced how historians and archaeologists consider trade routes from the Bronze Age.

The relevant passage in Homer comes from the following translation by Rieu of O*d, XIV, 295-305*, this states that*:* 'With a good stiff breeze from the north the ship took the central route and ran down the lee side of Crete'. Rieu then is not specific regarding the details of this central route, this leaves open the question: was he referring to one from north to south from what is now Turkey to Africa, or was he referring to one from east to west from the Levant to Crete? Depending upon the viewpoint taken, both of these might be viewed as a central route. Taylor (1951, 64) discusses Rieu's translation of this passage stating that: 'Odysseus tells the tale of how he went in a Phoenician ship to Libya. They took the 'central route' running under the lee of Crete.' Taylor then makes no specific reference to which of these routes Odysseus may have taken, although the east to west route might be implied. Reference to the same voyage is made by McGrail (1991, 311) who noted that: 'Odysseus recounts to Eumaeus how he sailed in a Phoenician ship from the Levant bound for Libya**.** In a northerly wind, "they took the central route and ran down the leeside (i.e., the southern coast) of Crete". McGrail goes on to discuss the alternatives to this central, mainly open sea, route would seem to be coastal passages, and notes how these routes might either run clockwise along the North African coast, or anti-clockwise along the coast of Asia Minor. McGrail then is using Rieu's translation to imply that Odysseus was making an east to west offshore voyage from the Levant to Crete.

The nature of the problem associated with this translation is demonstrated by a later translation of the same passage, this reads that: 'On the high seas, beyond Crete, the ship sped on with a fine strong north wind behind' (Shewring, 1998). There is no mention of running under the lee side of Crete and no mention of a central route. I contend that this raises significant questions regarding McGrail's identification of the nature of the central route introduced in Rieu's translation. This problem is compounded by the singular nature of this evidence. There are no other textual sources that might confirm an offshore voyage of this type in the Bronze Age.

The problem that has arisen from McGrail's identification of this voyage as being mainly an open sea passage can be seen in its possible influence on later writers. Cunliffe describes a similar offshore route to that suggested by McGrail in regards to Odysseus' voyage to Crete. However, Cunliffe embellishes this by adding an unsourced reference to latitude sailing, stating that: 'One particularly interesting detail is that from the Levantine coast the ship sailed due west and ran down the lee side of Crete, a route that suggests the ship's master was sailing on a latitude' (Cunliffe, 2017, 228). Cunliffe does not provide a source for this but its use of the term 'ran down the lee side of Crete' suggests either the direct or indirect use of Rieu's translation. This assumption might be supported by Cunliffe's earlier use (64) of a long passage taken directly from Rieu's translation from *Odyssey 3.165-75* describing Nestor's return journey from Troy. Cunliffe expands on this case for seafaring and navigation in other parts of the work, (65) where he suggests that 'the concept of latitude was well understood in the ancient world and would probably have featured large in navigation.' He goes onto discuss how Phoenicians used this to navigate the length of the Mediterranean. This repeats an earlier case made by the same author where he discusses the links between Phoenicians and Cypriots in terms of trade with the central Mediterranean. In this he records the use of open sea routes and the use of latitude sailing as a technique for navigating along these (Cunliffe, 2011, 274-277).

In proposing a number of offshore routes Broodbank (2014) covers many of the same issues as Cunliffe. In Chapter 8 covering the period 2200–1300 BC he suggests in Map 8.67 (442), that, both coastal and open sea routes to Sicily were in existence, and, that it was 'as if the sea traders of Cyprus were intent on cutting out circuitous routes via mainland Italy…' (444). While later (491) in relation to the period 1300 to 800 BC he appears to be drawing similar conclusions regarding latitude sailing, recording, '...no indication of breakthroughs in nautical technology or navigation since the late 2nd millennium BC. Pre-existing techniques…and principally latitude sailing of the kind that had already enabled seafarers to cover two-thirds of the basin to Sardinia...'. In relation to Phoenician trade routes Broodbank discusses the background to navigation in the earlier Cypriot period, and to latitude sailing, as providing the means to cut 'east-west straight across expanses of open sea to a target on the far side, at this juncture best attested by ultra-long-range links between Cyprus to Sardinia…'. Broodbank then goes on to outline a proposed 'route to the Isles' spanning the entire Mediterranean basin (Map 9.1, 446-447). It is perhaps necessary to recall the points raised in section 2.1.3 that Cunliffe and Broodbank consider the seafarers of this period to have been using sailing ships to make these voyages. Through the course of Chapters 4, 5 and 6 I will explain the large vessels assumed for these voyages can only have been sailing ships, in these chapters I will present the evidence showing why vessels of the proposed size were not in use at this time.

In the sense of realistic voyages, the issue of navigation is frequently run together with that of seafaring and seamanship; however, there are specific issues associated with this skill that require it to be considered separately. In this respect it is worth considering what authors have to say about the use of navigational instruments in the period under review. Taylor (1956, 35) notes that: 'The oldest navigating instrument of which we have definite evidence is the familiar lead and line.' She goes on to comment that: 'The ancients, we must remind ourselves, were satisfied with very rough measurements.' Taylor further notes that while astronomers divided circles into minutes and seconds laymen used cubits to measure the elevation of the sun and stars, noting that a cubit equated to around 2 degrees of angular displacement. Taylor (1956, 50-52) goes on to discuss the Periplus that came into use toward the end of the period under review. It is clear from these discussions that these were largely works intended to aid coastal, rather than offshore, navigation. McGrail (1991, 311) makes much the same point, noting that: 'Throughout the world, from earliest times until well into the medieval period, seamen used non-instrumental navigational techniques…The only navigational aid for which there is any evidence being the sounding lead.' It is perhaps relevant to note that McGrail (2010, 628-629) records that the earliest instrument used for celestial navigation, the astrolabe, dates to the 9th century AD. He goes on to record that later European navigation from the Renaissance onward was only able to determine latitude with any certainty at sea following the introduction of more complex instruments than these. Tartaron (2013, 118-121, Table 4.1) provides further confirmation of the navigational aids used in the Bronze Age. In this he lists these under three headings of land, sea and sky, all of which relate to the observation of natural features or phenomena.

Many authors link the Phoenicians to the development of astronomical navigational techniques. McGrail (2010, 629) stating in regard to the Phoenicians that: 'Pliny claimed they were first to apply astronomical learning gained from the Chaldeans to navigation at sea'. Pliny is also used by Aubet (2001, 166) as a source, noting that: 'We are assured the Phoenicians invented the art of navigation…' referencing this to Pliny *NH VII. 57*. In her subsequent discussions on the same page Aubet notes how it is possible to 'reconstruct Phoenician systems of navigation from the historical references of the period and from pictures of Phoenician ships that appear in Assyrian reliefs.' In this latter case she is possibly referencing the galleys from the palace of Sennacherib at Khorsabad shown in Figure 4.14. These vessels will be discussed in Chapter 4. Aubet (2001, 166) goes on to record: 'Thus they faced no serious difficulties when it came to embarking on regular sailings from one end of the Mediterranean to the other. So, we can dispense with the traditional idea that ships in such a remote period were of such shallow draught that they were incapable of facing the dangers of the open sea.' The problems with making such a wide-ranging claim will hopefully become clear through the evidence and discussions in the remainder of this thesis.

From the comments of McGrail and Aubet, Pliny is clearly a relevant source on issues relating to navigation. In this regard the following comment by Purcell (2012, 1162) is perhaps relevant: 'For all his defects of accuracy, selection, and arrangement, Pliny achieved a real summation of universal knowledge.' If correct, this might suggest that the contents of Pliny's *Natural History* may be more a guide to contemporary opinions, and understanding, than the result of Pliny analysing these to determine their accuracy. This observation is particularly relevant to the passage regarding navigation. This comes from the book *Man and his inventions* which is composed of a mix of myth and apparent historical facts. Examples of the former may be seen where Pliny (*NH VII,* trans, Rackham, 2015) states that: 'Working in iron was invented by the Cyclopes,' and goes on to say: 'Carpentry was invented by Daedalus, and with it the saw, axe, plumb-line, gimlet, and glue.' Where inventions are ascribed to recognisable people or societies the same passage attributes the following inventions, trade by the Phoenicians, and slavery by the Spartans who also apparently invented the helmet, sword and spear. The passage concluding with the comment that 'the Phoenicians invented observing the stars in sailing.' All of these statements probably derive from the universal knowledge noted by Purcell; however, as long as it is unrealistic to accept the earlier examples as historic facts it is probably unsafe to use that relating to the Phoenicians as meaning they developed astronomical navigation. On this basis I suggest that any attempt to use this chapter in Pliny to make a determination of which society was responsible for any particular invention should be treated with caution. To pick one from this mix and assume it is correct because it supports a wider case is perhaps to fall into the trap noted by Rogers (1937, 29) that I discussed earlier in this chapter.

In regard to the comments on latitude sailing, it is worth noting that both Taylor (1956, 49) and McGrail (2004, 84-85) discuss the technique of using finger widths or hands as a rough means of establishing the altitude of stars. In the same passages both Taylor and McGrail discuss the difficulties and inaccuracies of applying this technique on a ship at sea. McGrail (1991, 315) goes so far as to say in regard to latitude in the ancient Mediterranean: 'Now, by latitude I do not mean what is understood by that term today,' and then goes on to qualify how it should be used as a relative assessment. In addition to these qualifications, the use of latitude sailing at this time clearly assumes a knowledge of the relevance of latitude in establishing the location of any destination. In this respect it is perhaps worth noting what is recorded by Cunliffe himself concerning a possible early use of latitude to determine locations. In this respect, Cunliffe (2011, 6-8) discusses the travels of Pytheas in the 4th century BC. In these discussions he notes Pytheas' measurement of latitude to determine the relative position of sites he visited. Pytheas is perhaps most notable for his voyage to Britain, his possible journey to the Baltic, Iceland and Norway, and his reported use of astronomical observations to determine latitude on these journeys (Hawkes, 1977;

McPhail, 2014). However, rather than these wider travels the issue here relates to Pytheas' use of latitude in determining the location of sites in the Mediterranean region. In this regard, Warmington and Spawforth (2004, 584) record Pytheas as an individual who determined a figure for the latitude of Massalia, and at the same time, provided the basis for the measurement of latitude in that region of Europe. Taylor (1956, 43-44) discusses how Pytheas used a gnomon to make the required measurements. This instrument needed to be static, and upright, and required the use of a number of plumb lines to confirm its vertical orientation, as such, this was unsuitable for use onboard a moving vessel. However, the wider question that perhaps needs to be asked is; if a means to determine latitude with the accuracy needed to support maritime navigation had been used for the previous millennium, how likely is it that the use of this technique at this time by Pytheas would have been worthy of record by later authors? It seems more likely that this became a subject of record at this time because it was among the first recorded uses of the technique.

It is perhaps relevant to conclude with the voyage of Hanno the navigator, who possibly sailed as far as Cameroon in west Africa. Hanno's voyage will be more fully discussed in sections 6.3.3 and 7.4.1 where Schoff's comment relating to the use of 50-oared ships are of relevance to the wider case presented (Schoff, 1912, v1). At this point; however, it is of more relevance to note how Hanno came to fix the location of a proposed colony at Cerne. In this regard the record states: 'From our journey we judged it to be situated opposite Carthage; for the voyage from Carthage to the Pillars and thence to Cerne was the same,' (Schoff, 1912, v8). There is no reference to any determination of the use of latitude to assist with the location of this colony. Rather the technique used compares the time for an east to west journey with that of one that was largely north to south. This suggests that latitude may not have played much part in determining coastal locations, but rather, that journey times may have been of more importance. This might not be surprising if hybrid vessels were used as part of a coastal voyage on which the ships came into the beach to rest the oar crew overnight. In these cases, the mileage made in a day's progress might be relatively consistent and the voyages made recorded in terms of the days required for the passage. A voyage recorded in this fashion might also align with the general comments of Taylor (1956, 50-52) regarding the later use of the Periplus and the longstanding practice of coastal voyaging. Clearly this assessment may not be an accurate reflection of the totality of Carthaginian knowledge on latitude. I suggest; however, that if latitude sailing had been common in the previous millennium, it might have been referenced in some way in this situation.

Further indirect evidence regarding the lack of use of latitude sailing may be found in Davis (2009, 143-148) who notes the lack of evidence for the use of this as a navigational technique from the Greek and Roman period. In his thesis Davis does not discuss the period from the Late Bronze Age to the Archaic; however, it is difficult to see the situation in which this skill was in use in this earlier period but failed to transfer to the time when large sailing ships were in use.

2.3 Summary

The material I have presented to this point is only a small part of the evidence that I will examine in the following chapters. A summary of the contents is presented in Table 2.2. My intent in this chapter has been to point out the impact of the lack of a clear taxonomy of vessel types in most of the works relating to maritime archaeology, and how an apparent unquestioning acceptance of many sources, both ancient and modern, has led to a series of impractical assumptions regarding vessel sizes and capabilities. I should be clear that I do not dispute the factual accuracy of much of the content of the sources on maritime technology discussed to this point. My contention is rather that the output is limited in scope, and largely presented as a series of individual vessels. This has resulted in the technical literature lacking any discussion of these vessels regarding a process of development in terms of construction or use. This problem is discussed by Adams (2013, 82), the issues that arise from these failings will be discussed in more detail in the following chapter. The authors I discussed in this chapter have used the information on individual vessel types from these sources to build their cases for seafaring and trade through the period. It is my contention that the oversights in the sources outlined have led to many of the errors discussed to this point.

The following then summarise the main points I have raised:

1. There is a general failure by authors writing on the technical aspects of maritime archaeology to appreciate the need to provide a taxonomy based on vessel size, form, propulsion and usage.
2. Much of the technical literature lacks a consistent explanation that particular vessel types had operational limitations that would restrict the nature of the voyages they could undertake.
3. There is a widespread assumption that sailing ships were in use in the 2nd millennium despite the lack of evidence for the use of this vessel type in textual, iconographic or archaeological sources.
4. The assumption that large vessels were in use from the Bronze Age is largely based on the indirect evidence in the translation of text RS 20.212 from Ugarit.
5. The risks in seafaring that might be identified from the voyages of reconstructed vessels of the period do not form part of the discussions on vessel use.
6. Many authors appear to reuse passages from a narrow range of primary sources without determining if the content can be corroborated from alternative sources.
7. The facts and interpretations of older authoritative works on the subjects of maritime archaeology and technology are often referenced without reviewing their contents against more recent archaeological finds, or fresh interpretations of old ones.

These two latter issues are among the most consistent throughout this review. It is my impression that the descriptions and interpretations of a limited number of long-established authors have come to form much of the established factual base in maritime archaeology. In this form these sources are frequently used in an unquestioning manner by contemporary scholars as sources for the types of vessels in use. Much of the problem is similar to that presented in Rogers' cautionary comments on the need to test the written word by an examination of its practicability. The problem of course lies in authors understanding the uncertainty around their assumptions regarding vessel type, usage and practicality. This returns to the central issue I raise in this chapter, that is, the need for a system of taxonomy based on the means of propulsion and the operational limitations this might impose. It is my contention that if this could be established it would assist by removing many of the false assumptions around vessel identification and capability, and provide a more secure source of reference regarding maritime archaeology.

3.0 Learning and Development

The nature of learning related to technology, and the manner in which this may have taken place in the ancient world, is a field that has attracted increasing attention from the early 20th century. A number of sources, covering a range of disciplines, will be used to support the cases I present in this thesis (Usher, 1954; Coates, 1987; Basalla, 1989; Edgerton, 1999; 2008; Buckley and Boudot, 2007; Greene, 2010; Cuomo, 2010; Ulrich, 2010; Ingold, 2013; Adams, 2013; Olaberria, 2014; Schiefsky, 2015; Marchand, 2020). Primary source data on learning relating to technology in the ancient world is less common. In this thesis I have used the comments by Philon of Byzantium (3rd century BC) writing in *Belopoeica* as a general guide to learning in the ancient Mediterranean. The connection between learning, technology and ancient society will underlie much of the discussion throughout this chapter, and in those that follow. In this regard, I use some of the comments of Aristotle in *Metaphysics* and *Politics* (4th century BC), and Seneca *Epistles* (1st century AD), as a guide to how artisans working in craft industries were considered by the elites from Classical Greece to the rise of Rome. In addition, I refer to more recent works in regard to the same issues (McClellan and Dorn, 2006). The following comprises an initial brief examination of the models of learning and development suggested by these authors. This will be followed by a number of short case studies, these will highlight how many academic publications ignore the processes of learning suggested by these authors when they discuss the development, and use, of maritime technology.

3.1 A model of learning and development

Much of the period in question predates the appearance of widespread literacy and written records, and for this reason much of the evidence I will present regarding learning is indirect. To bridge this gap, I have assumed that it is possible to extrapolate from the patterns found towards the end of the period under examination in this thesis to establish those that were likely to have been in use in earlier times. An example of the nature of learning and invention in Hellenistic Greece was outlined in the 3rd century BC by Philon of Byzantium in the *Belopoeica*. Much of this work focussed on the construction of artillery at a time when major powers were interested in the development of the relevant technology. I suggest that this might be taken as being representative of learning in a well-funded and important field of technical development. In *Belopoeica* (*50.14-29,* trans, Schiefsky, 2015, 625) Philon notes in regard to changes in design, that: ’It was impossible to obtain it except by increasing and diminishing the perimeter of the hole on the basis of experience…For the fact that it is not possible for everything to be grasped by reasoning and the methods of mechanics, but that many things are also discovered through experience.’ Marsden (1971, 109) provides essentially the same translation of this passage by Philon. The approach described is broadly similar to the observation of Marchand summarising his recent experiences with traditional skilled craftsmen in the field of both boat building and construction in the Middle East. In this he notes that: ‘The relevant point here for archaeologists (and anthropologists of material culture) is that learning and discovery are not confined to abstract thinking about the problem, one step removed from the physical activities of implementing a solution. Instead learning – whether it is in craftwork, anthropology or archaeology – demands situated perceptual experience and physical activity’ (Marchand, 2020, 51). Given the extended period of time over which the same form of learning is recorded in these two examples of craft industries, I suggest that, it is not unreasonable to assume the same process to have been in place in craft industries in the period from Philon back to the Bronze Age.

The lack of any proven link between theory and practice in the ancient world will underlie many of the points I raise in this chapter, and the conclusions I present will shape how I discuss learning and development in the remainder of the work. For this reason, it is perhaps necessary to appreciate how societies of the time may have shaped this issue. In this regard I suggest that Aristotle may provide an indication of the attitudes of the period to artisans and their work. In *Metaphysics* (*1.12,* trans, Tredennick and Armstrong, 2015) he observed that ‘artisans perform theirs through habit. Thus, the master craftsmen are superior in wisdom, not because they can do things, but because they possess a theory and know the causes.’ Aristotle then makes a distinction between two kinds of labour and appears to suggest that theory involves superior wisdom. Aristotle goes on to make reference to the relative social positions of artisans in *Politics* (*1.V.9-11*, trans, Rackham, 2015) where he notes that: ‘The slave (and relatively the artisan) needs virtue for his tasks, and the master's admonition supplies it…for the mechanic artisan is under a sort of limited slavery.' Seneca *Epistles* (90. 13, trans, Gummere, 2014) writing in the first century AD appears to make much the same point in comparing the types of learning that might be expected across social classes. In this he notes 'the hammer or the tongs came first into use. They were both invented by some man whose mind was nimble and keen, but not great or exalted; and the same holds true of any other discovery which can only be made by means of a bent body and of a mind whose gaze is upon the ground.' Taken together these observations might suggest that from Classical Athens to the Roman Empire elites did not hold the learning, or the social status, of the artisan in high regard. If this assumption is correct for the period overall, then there might have been limited overlap between theoretical and practical learning relating to the development and use of maritime technology.

McClellan and Dorn (2006, 1) reference the points raised by Aristotle when they note the general social and academic differentiation between the artisans, who worked in the field of technology, and the academics, who worked in the fields of science or natural philosophy. They expand on this to make the point that: 'The belief in the coupling of science and technology is now petrified in the dictionary definition of technology as applied science…That belief, however, is an artifact of today's cultural attitudes superimposed without warrant on the historic record.' Ingold (2013, 6), in his discussion of the art of inquiry, makes a pertinent observation on the different ways of thinking of the two approaches to solving problems; 'The theorist does his thinking in his head, and only then applies the forms of thought to the substance of the material world. The way of the craftsman, by contrast, is to allow knowledge to grow from the crucible of our practical and observational engagements with the beings and things around us.' The consistent theme appears to be that learning in craft-based activities progressed through the application of practical experience rather than an understanding of an underlying theory. On this basis, I suggest, that it is not unreasonable to assume that in the ancient Mediterranean the application of theory was unlikely to have played a significant role in the development of craft-based industries.

In conjunction with this model of learning what needs to be considered in terms of maritime technology is the shell first nature of vessel construction at this time. This subject is discussed by Olaberria (2014, 366) who recorded how stimuli like the mass warship building programmes of the Roman empire in the 1st Punic War may have influenced the widespread introduction of moulds to assist with fixing the shape of a hull. However, much of my discussion in the following predates the period covered by Olaberria for the proposed use of this technique in vessel construction. In the absence of moulds, or a frame comprising the keel and ribs, the final shape of any vessel that was built shell first would be the product of the shape and number of the timbers that made up the shell. In a pre-literate society the form of these, and the number and spacing of any joints, would be likely to have been learnt by experience and practice. Olaberria (2014, 352-353) notes, how, when building by eye, the process would be dependent upon the experience and skill of the individual craftsmen, the same point having been made earlier by Pomey (2004, 27). In these discussions Olaberria notes the difficulty in making an exact copy of an existing vessel when constructing a hull by this method. Olaberria does not expand on this to discuss the greater difficulty that might be experienced in attempting to make major changes to the size, or form, of an existing vessel type. When building shell first, any changes to the shape, or number, of the timbers used would be likely to result in changes in the final shape of the vessel, which in turn are likely to have resulted in unpredictable changes in the stresses and loads at a range of points in the hull. The same problem might arise even if moulds were in use, any radical change to the size and number of moulds would result in the same range of changes in the individual timbers required. On this basis, it seems probable that in ship building at this time, perhaps more so than in other industries, changes would in general be small in scale to provide maximum assurance that any new hull form was safe in operation. This suggests that the construction of a large vessel would have been preceded by the construction of smaller vessels of incremental size. The result of this process being a sequence of vessels of increasing size coming into use over an extended period of time. An alternative means of achieving this may have been to have modified the form of an existing large vessel to create a new vessel type, possibly intended for an alternative form of seafaring. In section 6.3.4 I will use the Madrague de Giens vessel as a possible example of how this process may have taken place. This form of learning in small stages where the risks involved in change are perceived by the craftsmen undertaking the work is recorded by Torrence and Van der Leeuw (1989, 10). The lack of evidence for any incremental series of smaller vessels that may have contributed to the construction of large ships before the late Archaic and early Classical period is apparent in Table 2.1. The lack of evidence for vessels of these intermediate sizes will form the basis of much of the later discussion in this thesis.

On the basis of the evidence presented in regard to Philon, and the later writers noted, the model of learning that perhaps best articulates the case is the one proposed by Usher (1954). This work was originally published in 1929 and has subsequently been used by Basalla (1989) and Greene (2010) to support their discussions on learning and technical development. This suggests that despite its age the concepts raised, and ideas presented, are still considered relevant by scholars working on the subject up to the present day. In the context of how invention may occur Usher (1954, 60-61) presents two possible models for learning. The first is based on 'the inspiration of genius' which, as the quote implies, relies on the input of singular efforts by outstanding individuals. Usher notes this theory to have a long history with links to a theological tradition, but goes on to remark that the process in general does not allow for rational analysis or explanation. The second, which Usher refers to as 'cumulative synthesis,' is, in Usher's words, based on 'more serious recent literature on the theory of invention,' the process itself comprising 'the accumulation of many small acts of insight by individuals' (Usher, 1954, 68). Usher (1954, 69, Fig 8) provides a model for this process, shown in Figure 3.1. In this the stage gates, representing what might retrospectively be seen as major steps in technical development, are represented by the numbered squares; these in turn being dependent upon the cumulative development of the series of small steps indicated by the subsidiary lines. It should be emphasised that, although laid out in this fashion, Usher's model makes no assumption that learning and development was directed either toward these intermediate stage gates, or toward a single long-term objective.

Figure 3.1 should be understood to be a simplified representation of development. The focus within this should be on the small steps shown in the side lines, each of these showing the resolution of a small-scale issue. The cumulative result of which is a significant change in a specific, but often minor, line of development. It is perhaps important to note that in regard to the development of maritime technology these subsidiary lines may comprise a range of technical, economic and social inputs. A more accurate representation that showed all the minor paths of development might be represented by a number of dendritic subsidiary lines. This complexity was discussed by Buckley and Boudot (2017, 20-21) in the conclusions to their paper on weaving techniques in Asia: 'The particular group of technologies that we studied display branching evolution. Some lineages cannot be completely explained, however, without invoking hybridisation. It is these combinations of individual lines of development that often provide the means to generate a more fundamental change.' This comment perhaps illustrates the need to review technical development across a wide range of technical and social inputs in order to determine how important developments may originate. A further point to be made in regard to this model is the manner in which the subsidiary lines are shown as continuous, this might suggest that these comprise uninterrupted lines of development. To be correct, this might assume that all development occurred in societies that had an efficient means of passing on knowledge, and learning, before these societies, or the craft groups within them, went in to decline. In Chapters 4 and 6 evidence from structural elements found on the Cheops funerary barge will be used to demonstrate that this assumption is insecure (Jenkins, 1980; Lipke, 1984; Steffy, 2017).

However, Usher's model poses a number of further questions. How does change along any of the lines shown take place, and, perhaps from a historic perspective as important, how fast does this change occur? Taking the first of these questions, if invention is regarded as the process by which a new idea arises, then the processes of innovation and diffusion might be regarded as those that determine its acceptance and widespread use. The issues of innovation and diffusion are discussed by a large number of authors, in the following particular reference will be made to the observations of Edgerton (1999, 112-113) and Greene (2010, 77). These note that innovation is the process by which any invention is subsequently turned into a technology in everyday use. Greene (2010, 79) going on to note that innovation is not restricted to technical inventions but may be applied to any new way of doing things. This aspect of innovation will be used to examine developments in the use of maritime technology through the course of this thesis. In regard to the final term, diffusion, Greene (2010, 79) notes Rogers (1995) as referring to this as 'the process by which an innovation is communicated through certain channels over time among members of a social system'. Progress along any of the lines in Usher's model then may be seen as the sum of all these processes. In the following discussions I suggest that the rate at which learning progresses along these lines will largely depend on communications within, and across, the societies involved in the process.

However, there are some circumstances where more obvious factors might drive faster rates of diffusion. An example of this is the observation by Unger (1994, 7) regarding the development of maritime technology in Medieval Europe. In this he states that: 'The development of the full rigged ship was to a great degree a result of the drawing together of boatbuilding traditions already well established by the fourteenth century.' Unger then is discussing the link between invention, innovation and diffusion, while the context suggests a possible link between this process and the economic benefit that might be gained in maritime societies. Adams (2013, 40-41) makes much the same point regarding interconnected traditions when he comments that 'it is in the cross fertilization of ideas and technique that many aspects of change are initiated'. These might be examples of a point made by Edgerton (1999, 112) linking societies and the use of technology, 'so banal is the point it rarely merits attention'. This link between the nature of any particular society and changes in maritime technology will form the basis of much of my discussion in the following chapters.

As it is clearly fundamental to the working of Usher's model it is worth considering how the three factors of invention, innovation, and diffusion may have progressed in the period covered by this thesis. I suggest a reasonable starting point for this may be the comparison made between shipbuilding today and the same industry in the ancient world. An example of this is provided by Coates who had experience of constructing modern warships. Coates (1987, 111) made the following comment regarding the development of the trireme: ‘Without benefit of our present knowledge of the physical world and its laws, such a development would more probably have followed a course of groping steps of trial and error, seeking a design better than the extant pentekontor in some particular ways. Even with modern knowledge the prototype would not be quite right first time.’ Later in the same paragraph Coates assesses the possible time taken for this, in this he states that: ‘It is likely that the best part of a century of highly motivated development would have been needed to reach something like a trieres from a two-level pentekontor.’ The suggestion is that even late in the period, when innovation may have been directed by a prevailing military doctrine toward the further development of an existing vessel type, the time required for a development process to reach a conclusion was likely to be quite long. This extended time period should be considered in the military context of the development described. In this case it might be expected that this would be the subject of increased motivation deriving from the security and preservation of the state.

The points raised by Coates may also suggest a contradiction in the model I have presented to this point. The implication may be made that the development described was directed to building a trireme, a vessel that did not exist at the start of the process. I would dispute this; the process of development Coates is referring to does not suggest that the trireme was the intended objective. Rather, the suggestion is that the development of the trireme was the product of the nature of naval combat at the time, the objective of which was the production of a fast, manoeuvrable, galley suited to ramming its opponents. The first step in this process being the short bireme form. The shorter hull of this vessel type affording it superior speed and manoeuvrability compared with a single bank vessel with the same number of oarsmen. The focus of the ongoing process was likely to have been to pack the most oarsmen into the shortest hull. Pressure to increase the performance of the bireme form leading to a vessel type that allowed a greater number of oarsmen to be fitted into each metre of the hull. The fact that the resulting trireme form of galley was superseded after a short period of time as the premier warship by larger and slower polyremes, optimised for a different form of combat, suggests that this was only one possible outcome within the overall process of vessel development. The fact that it was the trireme form that developed at this time, rather than these more radical solutions that involved a change in the nature of naval warfare, may itself lend support to the iterative learning process outlined.

It is possible to summarise these points by stating that, in the ancient world, the process of an invention moving on to the development of a usable technology would depend on a number of local social, political and economic factors. The process; however, might be expected to be broadly the same; any individual invention, or innovation, would result from an attempt to satisfy an immediate need that was identified by shortcomings in the use of existing technology. Success in this process being marked by achieving the desired goal without adding significantly to the risks, or costs, experienced by the user. Risk in this case was probably dependent upon the motivation. In the case of war bigger steps, and higher risks, may have been adopted than would be the case in trade. In terms of maritime trade in the period McGrail (1989, 850) perhaps best describes the issue of risk in the following: “The aim of a Ship’s master ancient or modern is the safe and timely arrival of his ship at the next destination. One of the principal concerns of a Bronze Age master was thus the safety of his ship.” With this caution in mind, I suggest that, without a strong motivation, it might be expected that seafarers would be reluctant to make significant changes to established forms of seafaring based on familiar vessel types.

In addition to these factors there is the issue of the rate of change in any technology. When changes in maritime technology were tested in such a varied activity as seafaring, in a politically and socially fragmented Mediterranean, it would not be surprising if diffusion to all potential areas of use was slow. This might mean that the most significant benefits of an invention were most clearly seen far from home, and possibly a long time after its first appearance, rather than in the location in which the development occurred. In any process of iterative learning this may mean that individual steps along any of the subsidiary lines in Usher’s model, as shown in Figure 3.1, might take place in locations separated in both space and time. A general guide to the time taken for this may be gained from Usher (1954, 68-69) who wrote in regard to the rate of progress through the history of mechanical inventions that: 'Great insight may be required to perceive the inadequacy of a pattern of thought or action that has been sanctioned by tradition for so long a period that most members of the social group do not question the adequacy of a mechanism or a concept or a symbol that is in fact utterly inadequate.' It is perhaps necessary to be particularly conscious of this remark from the viewpoint of the present day when it is normal to regard change as a fact of life, and rapid technical development as the norm.

To put the scale of these different rates of change into perspective it is relevant to compare the vessels in use at the end of this period (Houston,1988, 554; Nantet, 2020, 75-90) with those in use in the mid-18th century. In the first Lloyds register of shipping prepared in 1764 over 4000 vessels are listed; however, only 28 were between 500 and 700 tons. The register records a single vessel larger than this range of sizes, the P Ferdinand which is listed at 900 tons [https://archive.org/details/HECROS1764] 01/06/2021. If the Lloyds register is assumed to be a guide to the range of vessels in widespread commercial use, then this might suggest that there had been little development in the range of sizes of many of the vessels in use for this purpose through the millennium and a half between these dates.

By the beginning of the 20th century; however, when shipping routes had changed little from the mid-18th century, the largest sailing ship was the German vessel Preussen. This vessel was 124.5 metres long and had a cargo capacity of over 5000 tons. The key technical change regarding this vessel was that it was constructed of steel, it was fitted with steel masts and its standing rigging was made up of steel wire. Sailing Ships: "Preussen" (1902) (bruzelius.info) 1/12/22. The change from wood to steel as a construction material was fundamental in this change in vessel size. The relevance of this short derivation relates less to the precise size of the ships, but rather to the speed and the extent of this later change, and the manner in which this was dependent on factors unconnected with the world of maritime technology. The development of vessels of this size then might be seen as a reflection of a society that was becoming more industrial, and one in which the application of theoretical knowledge to technology was becoming more widespread. The comment by Edgerton (1999, 112) linking societies and the use of technology is clearly relevant in this regard, as are the comments of Buckley and Boudot (2017, 20-21) regarding hybridisation in the development of technologies. The same link between society and the hybridisation of enabling technologies from outside of a local shipbuilding industry will be made at a number of points in Chapters 5 and 6. These will be used to provide a possible explanation for the rapid step change in particular aspects of vessel construction around the late Archaic and early Classical periods.

An example of a further contributory factor specific to the industrial era is that shown in Figure 20.5 in McClellan and Dorn (2006, 427). This shows the exponential growth in journals from the mid-18th century, and the similar rate of growth in abstracts from around the mid-19th century. This increased rate in published material was clearly linked to printing, and to the increase in literacy through the same period. Collectively it is probable these factors both impacted, and reflect, the growth in the rate of diffusion of knowledge. It seems probable that this in turn contributed to an increase in the knowledge base available to craftsmen and engineers. It is also the case that, by the dates shown in Figure 3.2, the expansion of scientific disciplines resulted in the underlying knowledge base in many industries being increasingly based on theoretical principles, rather than the earlier method of learning solely from practice.

My purpose in this short derivation to more recent history has been to illustrate how, within the learning environment of the 21st century, it is perhaps difficult to appreciate the slow rate of learning and technical development in the ancient world. This said, there were a number of specific locations and periods in the ancient Mediterranean when technical development appears to have occurred at an increased rate. McClellan and Dorn (2006, 79-82), Greene (2010, 802-803) and Wikander (2010, 787) all note periods of rapid increase in the rate of development from the 5th to the 3rd centuries BC. These ranged from that experienced in Syracuse under the rule of Dionysus, to similar increases in Classical Athens and latterly to Ptolemaic Egypt. In all cases these spurts in technical development occurred in local areas and may be linked to particular social, political and economic factors specific to the societies in which they occurred. In the case of Syracuse and Ptolemaic Egypt these periods of accelerated development were closely linked to threats posed to the security of the state. In the case of Classical Athens, it appears to have been less connected specifically to craft industries but rather linked to wider artistic expression, itself probably linked to social, political and economic developments. Many of these developments were probably themselves the result of the increased military status, and subsequent economic power, of Athens in the 5th century BC.

It seems probable that the slow rate of learning noted in most early societies compared to the later periods suggested in Figure 3.2 relates to the lack of widespread literacy in the earlier period. The generally low rate of literacy in the ancient world is discussed by Clarysse and Vandorpe (2010, 717; 733-736). This fact was reinforced by the lack of printing, this further limited the circulation of the written information that was available to literate members of society. If the case observed by Marchand (2020, 51) and Ingold (2013, 6) in modern craft industries might serve as a model, then learning in the same industries in the ancient world might be assumed to have progressed through copying, and modifying, earlier forms rather than reading about these. In these circumstances the rate of learning might be determined by the frequency with which beneficial new forms, comprising innovative vessel types, appeared in any area. This would presumably itself depend upon the trading links of the region, this in turn might be expected to reflect both its location, and its social and economic importance. This might emphasise once again the points raised by Unger (1994, 7) and Adams (2013, 40-41) on the beneficial impact of interlinked societies on the rate of learning.

There is perhaps a further problem in examining Usher's model as a record of history rather than considering the contents from the viewpoint of the participants in the process. This might be understood by re-examining Figure 3.1. Using this to record development of a particular technology it might appear clear in retrospect when a major development, representing a step change in vessel type represented by a numbered square, may have occurred. However, this may be arbitrary and based on the particular line of development of interest to the individual that populates the model with the relevant details. It is probable that to the craftsmen working in the relevant industry at the time, the importance of any particular change on the main line may have been no more significant than any of those on one of the subsidiary paths. Possible examples of this might be seen in Figure 3.3 from McGrail (2004, 209). This shows the development of hull forms in Nordic shipbuilding from the 4th to the 9th centuries AD. Many intermediate forms are clearly missing from this sequence; however, it can be seen that the final vessel is very different to the first example. What is not clear is the point at which any changes may have become apparent to the seafarers who used the vessels. Similarly, it is not clear when contemporary craftsmen would have acknowledged that innovation had resulted in the development of a new vessel type. It is probable then, that, when using textual and iconographic evidence, it is unlikely that any particular record will have been made regarding the appearance of what scholars today may consider significant features of maritime technology, or indeed vessel types. The picture is perhaps further complicated by the fact that in a fragmented Mediterranean, where local factors were likely to be major drivers to both invention and innovation, the adoption of new technologies was likely to have been uneven. This would almost certainly result in the use of 'obsolete' vessel types for extended periods by particular societies in regions of the Mediterranean throughout the period.

These qualifications aside, I suggest that the evidence from Philon, in conjunction with the model shown in Figure 3.1, can be used to establish a process for the development of maritime technology through the period. For this reason, Usher's model will form the basis of the process of development proposed in this thesis.

3.2 The development of maritime technology in existing scholarship

In the following I present a series of case studies that show how the process of development is frequently ignored in the works of both specialist and non-specialist authors. The factual accuracy regarding much of the maritime technology in the content of these is not generally questioned. My purpose is rather to highlight how, even in the cases where change is described, there is no reference to a model of learning, and none link any development described to a process involving invention, innovation and diffusion. A further common error in these is that where a process of development is described, this appears to assume, or imply, an understanding of the theoretical principles that underlay the change recorded. This is frequently linked to an assumption that the end point of a process of development was an objective consciously aimed at through a long period of change. The problem with these approaches has been discussed at some length in the preceding section.

Perhaps one of the most important issues that needs to be appreciated is that maritime technology underwent a process of development through this period. This need might be implied from Casson's and Wachsmann's statements discussed in section 2.1.1 regarding the early use of large sailing ships (Casson, 1971, 36; Wachsmann, 2009, 41). However, it appears to be more definitively stated by Morton (2001, 1-2) when he says: 'The main consideration here is the extent to which the performance capabilities of ancient Greek ships brought their crews freedom from the influence of dominant aspects of the physical environment such as prevailing wind and current patterns, and periods of dangerously severe weather.' In this Morton appears to be referring to skills and techniques that might be most closely associated with seaworthy sailing ships. The problem associated with this is laid out in the follow up statement by Morton where he goes on to say: 'I have also elected not to impose strict chronological limits to the study…The principal reason for this is the relative lack of development or change in either the physical environment or maritime technology during the whole period from the reformation of the Greek world in the Dark Age to the Hellenistic period, and to a lesser extent on into the Roman Empire.' This suggests that Morton is assuming the use of sailing ships from around the Bronze Age/Iron Age transition; similarly, it might imply that the capabilities of the sailing ships in use, and possibly their sizes, changed little through the subsequent centuries. The aim and objectives of this thesis is to demonstrate that this was not the case.

The opposing viewpoint is taken by Bresson (2020, xi-xiii); in this he discusses developments in maritime technology in the Hellenistic period. Bresson discusses how this development was linked to an increase in the size of vessels; he goes on to relate this increase to a change in the means of hull construction from stitched to mortice and tenon joints. This change in the manner of hull construction is also discussed by Kahanov and Pomey (2004) and Pomey (2020). In this later work Pomey (2020, 27-46) discusses a range of hull features and concludes with the statement that the change from stitched to mortice and tenon joints '…enhanced the strength of the hulls and their longevity. This evolution led to the building of larger ships…'. There is little doubt that the association between longevity and the nature of the joints used related by Pomey is correct; however, the implied cause and effect relationship, and the singular nature of the role of the joints in this development, is less certain. I discuss this issue in more depth in sections 5.2, and 6.2.1 through to 6.2.3.

The lack of a process of development underlies some of the contradictory comments in Casson (1971, 65) where he discusses the extended history of the use of merchant galleys. From the point of view of a process of development, the question that might be legitimately posed is, why should this have been the case? The problem in this regard being the suggestion of Casson (1971, 36) that large sailing ships were in use from 1200 BC. Given the means of hull construction discussed in section 3.1, and the problems that may have arisen from this in relation to changes in both the size and form of vessels, it might not be unreasonable to assume that these large sailing ships represented the apex of a hierarchy of smaller sailing vessels. The problem in this instance is the date Casson provides for the use of these large sailing vessels, and by extension presumably their smaller precursors. This date itself precedes any secure evidence for the use of merchant galleys of the type that primary sources describe in use through the Archaic period. Now if the timeline showed that merchant galleys had preceded large sailing ships, then it is possible to imagine the case made earlier by Usher (1954, 68-69) relating to conservatism, and a slow rate of learning and change, accounting for their continued use. In this, inertia in the take up of the new technology, or a reluctance to change an established pattern of seafaring such as coastal sailing, may be used to account for the extended use of galleys. The situation might be analogous to the extended use of sailing ships following the introduction of steam powered vessels through the 19th century. However, if large sailing ships, accompanied by a hierarchy of smaller sailing vessels, had preceded the development of merchant galleys, as suggested by the dates proposed by Casson, then the situation would be different. In this case it might be assumed that these larger sailing ships would have formed the basis of a system of offshore trade. Within this system of trade, local routes might have been served by the smaller vessels that the model of learning I have proposed suggests existed along with these larger ships. In this situation it is difficult to see what niche in maritime trade might have motivated the later development of merchant galleys which Snodgrass (2006, 223) records as being the bulk carriers of the Archaic period. If Casson had presented his work in the form of vessel development, the motivation for the appearance of merchant galleys might have been explained, and, the reasoning behind this apparent anomaly clarified by the author.

There is a further potential problem regarding the presentation of the archaeological evidence, this is discussed by Adams (2013, 81) where he records that: 'Shipwreck research often retained a predominantly functionalist approach in projects focussed around single vessels.' An example of this might be seen in Figure 3.4, where McGrail (2004, 5-7) proposes a comprehensive model of how research relating to an individual boat excavation may be organised. As noted by Adams, this approach appears to bias the research toward the investigation of individual vessels. The lack of reference to where any individual vessel lies in a system of taxonomy, or any sequence of maritime development, is noticeable given the extent and detail of the work programme outlined. This is in part offset by the fact that the work of McGrail in which this table is presented comprises a chronological sequence of vessels. However, this does not provide any overall classification of vessel type and capability based on the examples discussed. Neither does it propose a process of vessel development through this sequence. This presents a problem when a scholar is attempting to determine the capability of an individual vessel that McGrail himself does not describe in his work. In a later work McGrail provides what appears to be a combination of a taxonomy and development chart (McGrail, 2010, Fig 8.3) shown here as Figure 3.5. However, this categorises vessels solely on the basis of their means of construction. As a result, it is difficult to make a link between vessels in any group and their use, or their limitations, in the context of seafaring. The same point concerning a lack of context and process can be made concerning the content of Steffy (2017). Within this Steffy (2017, 235-

236) presents seven elements of good ship reporting; however, all of these appear to relate to the individual find without reference to its precursors or subsequent vessel types.

I contend that the differences between the use of sailing ships and hybrid vessels is key to understanding many aspects of vessel development through the period overall. For this reason, the development and use of a particular form of hybrid vessel, the merchant galley, will form a significant element of later chapters. To put these discussions in to context it is necessary to understand how the development of galleys is addressed in academic works. An example of this is provided by Wedde who describes a merchantman as having 'a hull conceived to maximize cargo capacity, implying a minimal crew, and a reliance on the cheapest form of locomotion: wind power. Oars constituted a viable alternative only in the limited context such as manoeuvring.' The vessel being described then is a sailing ship. In the text Wedde clearly assumes vessels of this type were in use from the Bronze Age, although no evidence for their use at this time is presented. In the same work, Wedde (1996, 609) goes on to describe a galley as 'designed to seat a large crew of rowers so as to attain high speeds.' In the model proposed by Wedde merchant vessels required the protection of galleys, or the control of the sea by a regional power, to operate safely, but again, at the time of their early development no direct evidence for either of these cases are presented. In terms of the development of maritime technology Wedde (1996, 612) observed that 'a hybrid hull type midway between a galley and merchantman, combining speed under oars with an increased cargo capacity, existed in the Archaic period.' In conjunction with Wedde's earlier observation on the early use of sailing ships this might suggest that both galleys and sailing ships existed before the development of the merchant galley. Wedde unfortunately does not explain how the power-to-weight ratio of these hybrid hull types allowed speed under oars to be maintained when the cargo capacity also increased. If the number of oarsmen in these merchant galleys was similar to that in a war galley, then any increase in the cargo capacity would result in an increased load on each oarsman. The speed and endurance of the vessel when rowed is likely to have been reduced as a consequence. This raises the question; if a merchant vessel could not match the speed of the faster vessels described, what was the purpose of this speed, and, what was compromised to achieve it? The problem with the points made by Wedde is the lack of any reference to the rowing speed of merchant galleys in the most widely quoted primary sources (Herodotus, I.163 and IV.153*;* Plutarch, *Life of Pericles,* 26.4). These issues will be more fully reviewed and discussed in Chapters 5 and 6. Overall Wedde's conclusions may suggest that the characteristics of the vessel types that existed in the Bronze Age shared design objectives with the multi-bank galleys of the Archaic and Classical periods. This suggests an approach that sees the development of maritime technology as being linear and directed toward foreseen long-term goals. The case I have made to this point, and that might be supported by Adams (2013), suggests that this is not a secure model on which to base learning, or a process of technical development, in the ancient world.

The taxonomy I outlined in Chapter 2 provides a comprehensive system of categorisation encompassing a number of vessel types over an extended period of time. This need is perhaps emphasised by examining some current works that describe the development of maritime technology over the same period. Gertwagen (2014, 154-158) provides a summarised form of vessel development from early paddled or rowed vessels through to Roman grain ships. However, the process outlined lacks any reference to learning. In addition, the extended period covered, and the limited length of the work, prevents the presentation of a detailed examination of individual finds and their characteristics. The result is that while a sequence is presented, and some characteristics listed, the timing and probable nature of many intermediate forms, along with the limitations of the vessels described, is not explained. Wilson (2011) presents an analysis of the development of vessel sizes from the Bronze Age through to the Roman period, the content of which appears to be largely based on the data from Parker (1992). The issue of technical development presented in this work appears to focus on examples of technology exploited by Roman shipbuilders, and in doing so, fails to present a comprehensive review of technical development over an extended period of time.

The final case I examine in this chapter is a paper by Whitewright (2017), this looks at the development of a type of sail the author suggests might be used to optimise sailing to windward. This provides a more detailed model of technical development than either Wilson (2011) or Gertwagen (2014). I examine this in some depth as it provides a case of a well-researched study that has significant gaps through the failure to relate its content or conclusions to a model of learning and development. As important, it focusses on a single vessel type at a time when it is probable that a number of types were in use, any one of which may have influenced the changes in the sailing rigs discussed. For this reason, it fails to address the possible impact of hybridisation discussed by Buckley and Boudot (2017). At the outset of the work, Whitewright highlights the following four areas that need to be considered in the study of ships, cargoes, hull construction, rigging and crew. Much of the focus of the study; however, relates to the development of sailing rigs and the seafaring skills that might have been associated with these. Within this already narrow field the focus of this work is largely on a proposed sequence of development of the artemon sail, this sequence is shown in Figure 3.6.

In other published work Whitewright (2008; 2011a; 2011b) discusses the linked development of hull forms and sailing rigs, and the combined impact of these on the ability of vessels to sail particular courses. In the sequence shown in Figure 3.6 Whitewright presents a linear process of development based on the use of an artemon sail by sailing ships. This appears to have been based on the assumed development of a number of seafaring skills and techniques which were again specific to sailing ships. An example of this linear approach is apparent in a passage from an earlier work by Whitewright (2011a, 8), in this he states that: 'The mizzen and artemon sails in iconographic and literary sources can explicitly be associated with the practice of sailing on courses above 90° to the wind.' Later Whitewright (2017, 224-226) comments 'the artemon is a sail whose sole purpose was to aid in balancing the interaction between hull and sailing rig. In this regard, it is one of the surest signs that ancient mariners were attempting to sail on courses to windward and reacting to the problems that they encountered when attempting this.' In both of these cases Whitewright appears to be suggesting a process of directed development, the artemon being developed to provide the means to accomplish something either difficult, or impossible, in vessels that lacked this sail type. As recorded in section 1.3, Adams (2013, 82-83) specifically cautions against teleological assumptions of this kind. It is also relevant that in Figure 3.6 Whitewright shows this development beginning at some time in the mid-6th century BC. However, there is no evidence at this time for the use of sailing ships substantially larger than 16 metres, and no evidence that vessels of this size used, or required, an artemon sail (Parker, 1992; [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022). Similarly, as I will discuss in sections 4.2.3 and 4.3.3, there is no evidence for vessels with the more sophisticated wine glass hull form of later sailing ships at this date. This suggests that Whitewright has failed to address the importance of the hull form on sailing performance and vessel use raised by Roberts (1995, 308), Gifford and Gifford (1996), Pulak (1998, 210-211), Wachsmann (2009, 253), McGrail (2010, 103), and Davey (2015, 31). On this basis, if Edgerton (1999, 123) is correct in his assessment that use preceded invention and innovation, it is difficult to determine the motivation for the development that Whitewright proposes in the sailing rigs of ships of the 6th century BC. Perhaps of equal relevance, the use described would not apply to merchant galleys as these were unable to safely sail courses of the kind described by Whitewright (Guilmartin, 2003, 73; Pryor, 2004, 208-209; Dotson, 2004, 219-220).

It is perhaps worth considering that in his earlier work Whitewright (2011a, 5-6) notes in relation to the variation in hull forms in later Roman vessels: ‘The failure of such hull-forms to become ubiquitous gives an indication of the relative importance of the ‘need’ for windward performance when set against other social, economic or environmental factors. Quite simply, windward performance was not as important as other factors.’ Gifford and Gifford (2013, 150) discuss the limited sailing capabilities of reconstructions of Anglo-Saxon vessels, observing that ‘modern sailors always ask 'how does she go to windward?’’ I would contend that this comment is particularly pertinent and it raises a point that will recur through this work; that is, the danger of viewing learning in the past in the context of 21st century perceptions and knowledge. Seafarers who operate sailing vessels today know the equipment and techniques required to sail to windward. As largely recreational sailors, they also perhaps relish the challenge and enhanced risk of pushing a vessel to its limit in sailing courses of this kind. This reaction; however, is largely the result of the nature of the sailing undertaken, combined with the learning from centuries of experiment. To assume that ancient mariners, who were sailing in order to make a living, would seek to achieve this objective without a considerable period of learning and development, and some kind of genuine motivation, is probably unrealistic. The range of problems associated with sailing to windward are discussed throughout works by Steel (1794), Cariolou (1997), Willis (2003), Harland (2015) and Gal et al. (2023) in regard to the more sophisticated vessels in use up to the 19th century. The earlier observation by McGrail referencing risk in seafaring should perhaps put any discussions of the use of this technique into context. Risk will form a substantial part of my discussions in Chapter 7 where the issue of vessel usage is examined in more detail. The suggestion made in these later discussions is that sailing to windward was perhaps not a major factor in sailing in the past, and, on this basis, might be unlikely to have provided the motivation for major changes in technology or seafaring in the 6th century BC.

The failure of Whitewright to provide a path of development of the artemon sail before its proposed use in sailing to windward suggests he sees this sail as having been developed, at least in part, to achieve a future goal. In discussing invention in the industrial age of the 19th century Edgerton (1999, 124) observed that: ’Inventive activity was obviously not shaped by the future, it was shaped in its own present and past.’ This is an apt summation of the content of his later work *The Shock of the Old*, (Edgerton, 2008). Applying this comment to the issue of sailing in the ancient Mediterranean might suggest that the artemon sail had an established use before any widespread application in sailing to windward. This might be confirmed in an earlier work of Tilley (1993, 312) where he comments that: ‘It seems likely that this sailing rig, (the artemon), so clearly associated with merchant ships, had its origin in the sailing rig of war galleys.’ Tilley in this paper discusses the handling problems arising from the hull shape, and extended forefoot, of the reconstruction vessel Argo. Tilley discusses how the problem occurred as a result of the sail being located at the centre of the vessel, this resulted in it being unable to provide the necessary force at the bow to assist with manoeuvring. Severin (1985, 168-170) records this followed an incident in which the Argo had lost one of its steering oars. This resulted in the extended forefoot contributing uncontrollable leverage at the bows when the vessel was steered on particular headings. Severin goes on to explain how it was only by rigging an improvised jib sail on the forestay that disaster was avoided. The implication being that normally the two steering oars might overcome any adverse effect of the extended forefoot; however, the inherent dynamic instability that the configuration generated when used in conjunction with a single sail is clear. It is also possible that the constant load on the steering oar required to counter this in normal conditions itself contributed to the failure of this item in this instance. In this discussion, Tilley reasons that the problems observed in the Argo could be alleviated by a small fore sail. Morrison and Coates (1986, 176-177) note this sail type featuring in Athenian naval inventories for triremes in the 5th century BC. However, as with Whitewright neither Tilley, nor Morrison and Coates, discuss a possible route by which this sail may have been developed. The possible role of the merchant galley in the development of the artemon will be discussed in more detail in section 6.3.3. In focussing on sailing ships Whitewright has limited the scope of his examination of the evidence, and, in doing so, fails to consider the introduction of the artemon to sailing ships from an alternative vessel type.

In regard to the evidence, all of the iconography relating to the use of an artemon sail on sailing ships is considerably later than the date of its assumed appearance in Figure 3.6. Davey (2015, Fig 4) shows an early artemon sail in graffiti from Pompeii, this is shown in Figure 3.7. This representation clearly predates the destruction of the city in AD 79. The hull form of this suggests it was probably a sailing ship. However, the later vessels shown with artemon sails in Figure 3.8 (Friedman, 2011, Fig 3.7.20) have two distinct hull forms. Interestingly, Friedman describes both as sailing ships. The hull form of the vessel on the left perhaps confirms the problem with Whitewright's association of the artemon sail with sailing ships. Casson (1971, Fig 140) shows what is clearly a Roman merchant galley with an artemon sail, shown here in Figure 3.9. This has a similar hull form to the vessel on the left in Figure 3.8, this suggests that this vessel may also have been a galley rather than a sailing ship. A further example of the association of artemon sails with galleys in Roman iconography can be found in Morrison and Coates (1986, Fig 32), shown in Figure 3.10.

Taking all of the evidence into account it is difficult to see that the introduction of the artemon, and its later use, was strictly related to the purpose of sailing to windward. To resolve this, I return to the comment by Edgerton (1999, 123): 'Invention and innovation rarely lead to use, but use often leads to invention and innovation.' On this basis it seems likely that the artemon was in use in an application associated with routine seafaring before it was adopted to facilitate a new technique such as sailing to windward. In this context Unger (1994, 7) makes a relevant point relating to the Medieval period which was also probably relevant to the period under review, in this he notes that: 'Shipbuilders have long enjoyed a justified reputation for being highly conservative, and old ways die hard…More important however in the context of ship design was the unforgiving environment in which the ship operated: failed experiments were very costly to crews and shipowners, so a reluctance to take chances reflected rational calculation as much as, or more than, an adventurous frame of mind.'

Overall then I would contend that the problem with Whitewright's process of development is not in the accuracy of the technical detail regarding how the artemon might operate, or its ultimate benefits to seafarers. I contend the problem is rather the failure of Whitewright to locate the appearance of this sail in a wider process of learning and development relating to maritime technology. In failing to do this, Whitewright appears to have shaped a case that directs development toward a pre-determined outcome, rather than examining the full range of possible alternatives.

3.3 Summary

The key lines of evidence raised in this chapter are summarised in Table 3.1, the main discussion points are listed below:

1. It is important to understand that maritime technology in the period 1500 BC to AD 200 was dynamic, and was undergoing a process of development in terms of vessel type, size and use.
2. Where development is discussed in current scholarship it is fragmentary in nature and tends to focus on either a specific technical issue or a limited time period.
3. The link between learning and technical development is not referenced or discussed in those works that describe the development of vessel types and usage. Possibly as a result of this, it is not uncommon to find that in these cases it is often assumed, or implied, that development was directed toward a particular goal.
4. From the development process outlined in this chapter it is apparent that any new invention or innovation should be based on a precursor form already in use, or, on a motivation that might arise from risks or shortcomings experienced in an existing form of seafaring.
5. To fully understand the process of development the impact of social, economic and political factors on technology needs to be addressed.
6. Studies relating to development should be of sufficient scope that the impact of hybridisation of learning across different vessel types, differing areas of technology, and across all regions of the Mediterranean basin, can be fully appreciated.
7. There is no discussion in the cases examined that explains how iterative learning may have resulted in the processes of invention, innovation and diffusion. Similarly, there is no discussion on the extended time probably required to effect major changes in the development and use of maritime technology in the ancient world.
8. The issue of risk was probably of fundamental importance to seafarers in the ancient world; however, this is rarely referenced when discussing changes in either maritime technology or seafaring techniques.

In the remaining chapters I present the evidence to support the system of taxonomy proposed. At the same time, I will present a proposed process of development based on the models of learning and development discussed. I stress once again that the conclusions drawn represent a hypothesis for challenge; however, I would contend that to be valid, any challenge should be based on the presentation of a system of taxonomy and a process of learning and development.

4.0 Presentation of evidence 1500 BC to AD 200.

The aim of this chapter is to provide the iconographic, textual and archaeological evidence necessary to support the taxonomy outlined in Chapter 2, and the development process I will discuss in the following chapters. Where the context and presentation of the iconography and texts may be relevant this will be discussed. The content is presented in three time periods, a summary of the evidence used in each of these is presented in Tables 4.1, 4.2 and 4.4. I am cognisant of the potential problems around using these lines of evidence as summarized in Wachsmann's paper *On the interpretation of Watercraft in Ancient Art* (Wachsmann, 2019). It is probably never possible to resolve all of the uncertainties Wachsmann discusses; however, in the case of the examples chosen I have attempted to justify the interpretation I place on them. Wachsmann (2019) refers to the need to integrate iconographic and archaeological evidence to compensate for the incomplete nature of much of the latter. In the following I have attempted to follow this suggestion including textual evidence where relevant.

4.1 1500 to 1000 BC: the appearance of round ships.

4.1.1 Iconographic evidence

The manner in which Egyptian vessels from the preceding millennium have contributed to problems with the description of vessel types was discussed in Chapter 2 (Landstrom, 1970; Casson, 1971, 14-22; 1996, 40-41; Bass, 1974, 16-33; McGrail, 2004, 41-43; Wachsmann, 2004, 11, 21-23; 2009, 13-32; Polzer, 2012, Steffy, 2017, 29). The earliest iconography reviewed here are the vessels used on Hatshepsut's voyage to Punt, these are taken from the early 15th century BC temple at Deir el-Bahri and are shown in Figure 2.9. These ships share many of the characteristics of the early river vessels shown in Figures 2.5 and 2.6, all having a long hull supported by a hogging truss, a boom-supported sail and a rowing crew. The consistent representation of these vessels with 15 oarsmen may suggest that this was the size of a vessel type in use at the time. The use of vessels of this type with 120 oarsmen is suggested by the contents of a text *The Shipwrecked Sailor,* an Egyptian tale of seafaring from the

Middle Kingdom (Der Manuelian, 1992). However, there is no iconographic evidence, or hull remains, that support the use of maritime vessels of this size at this time. In the context of the learning process outlined in Chapter 3 I suggest that Hatshepsut's vessels, and possibly the longer type suggested in the text, represent a development of the technologies used on the earlier river forms. Both Vinson (1993) and Wachsmann (2009, 248-251) discuss the lack of operational flexibility of the sailing rig shown in Figure 2.9. Both note that the sail could only be manoeuvred into a limited range of orientations, both also note that this was most secure when arranged across the vessel to take the wind from the stern. Vinson and Wachsmann also discuss the inflexibility of the rig in terms of reducing the area of the sail in use, this is a critical safety requirement in the changing weather conditions that might be experienced at sea. Both assume that to reduce the sail area on vessels equipped in this fashion the crew would need to position themselves on the lower boom, the process suggested by the authors involving the change of the entire sail. Figure 2.9 shows members of the crew working in this position, presumably to manage the sail. The difficulty in achieving this in rough seas, when a rapid change might be required for the safety of the vessel, can be easily imagined. If the limitations suggested by Wachsmann and Vinson are correct, it is not unreasonable to assume that any maritime vessel equipped with this type of sail would require a rowing crew, and, as a result, would be a hybrid rowed and sailed ship.

One feature that does appear to change through the period covered in this section is the position of the mast. The early seagoing vessel shown in Figure 2.7 suggests that the mast was located toward the bow of the vessel. However, in the later vessel in Figure 2.9 the mast is shown in a more central position. This change is discussed by both Casson (1971, 19) and McGrail (2004, 33) who link this to a development in the courses the vessel might steer. This issue is discussed in more depth in sections 4.2.1 and 6.3.3 in relation to the position of masts on later galleys. Roberts (1995, 310) suggests that boom supported sails may have allowed vessels to sail a wider range of courses. However, this suggestion is devoid of any evidence that these courses were actually sailed by Egyptian seafarers at this time, and similarly lacks any discussion on the risks that were likely to have been incurred if they attempted to do so.

It is perhaps worth noting the date of these examples. The earliest examples of boom-supported sails on Egyptian vessels are in the tomb of Ipi at Saqqara shown in Figure 2.6, these date from the mid-3rd millennium BC. This is from the same period as the early example of a long hull supported by a hogging truss on the vessel in the tomb of Sahure at Abusir shown in Figure 2.7. Both technologies have clear shortcomings in terms of maritime applications. However, both were represented as being in use in the 15th century BC on the vessels used on Hatshepsut's voyage to Punt. These features then appear to have been in use for over a thousand years. Rather than conservatism in shipbuilding, it is possible that this may have been the result of conservatism in the portrayal of ships in Egyptian art. The issue of conservatism in Egyptian art was addressed by Plato in *Laws* (2. 656-7) when he observed 'it was, and still is, forbidden to painters … to introduce any innovation or invention …And if you look there, you will find that the things depicted or graven there 10,000 years ago are … wrought with the same art' (Bury, 1926). Davis (1979, 122) qualifies this exaggeration but links this statement to Plato's contrasts between pure forms and illusions in art. The wider issue of conservatism in Egyptian art is recognised and discussed in *Canon and proportions in Egyptian art* (Iversen, 1955), this is a work that focusses on the long-standing conservatism in Egyptian figurative art. In *A World History of Art*, Honour and Fleming (2002, 66) discuss conservatism in Egyptian art in general, noting in regard to the comment by Plato that 'only art of a well-marked character could have provoked them.'

Accepting that an element of conservatism may have influenced the representation of these ships, the scene shown in Hatshepsut's tomb is noticeable for the accuracy of much of the portrayal of the marine life of the Red Sea, and the features of the land of Punt and its inhabitants (Wachsmann, 2009, 19-22). Although in a later work Wachsmann (2019, 15) records that some of the fish shown are examples of Nile species. If the portrayal of Red Sea fish may be taken as a guide to the fact that the scenes shown were taken from life, this may reinforce the case for the vessels portraying a type in use at the time. If the comment by Edgerton (1999, 123) on use driving invention and innovation is correct, then the consistency of the vessel type portrayed may suggest that a lack of change in use resulted in a lack of motivation to innovate in terms of vessel form. It is probable that the combined limitations of both the boom supported sail, and the weak hull equipped with a hogging truss, would not be exposed on coastal voyages when used in sheltered waters. Similarly, they might not expose seafarers to excessive risks when attempting downwind offshore voyages. It is also possible that the long use of these features may have been indicative of a conservative society in which seafaring itself played only a minor role.

Evidence of a different vessel type is apparent in the form of an engraved cylinder seal from Tell El Dab'a dating to the 18th century BC shown in Figure 4.1 (Porada, 1984, 486). This suggests there may have been a change in the type of vessel in use in the Levantine communities when these Egyptian vessels were also in use. Similar vessels occur on a number of Minoan seals, shown in Figure 4.2, which Van de Moortel (2015, 265-266) dates to the Middle Bronze I–III, ca.2000– 1700/1650 BC. Van de Moortel (2015) suggests that an analysis of the shapes of the hulls of the vessels shown in these figures may be used as the basis of a system of categorisation. She compares this to a system proposed by Wedde (1996) which appears to be based on an analysis of decorative features. I suggest that the stylised form of these vessels, and the lack of clarity in the detail of their decoration, means that neither of these systems of analysis are likely to provide unambiguous results. Van de Moortel (2015, 265) notes that 'most Minoan ship images of the Proto- and Neopalatial periods represent sail-powered merchantmen; many are depicted with both sail and oars or paddles to show that they relied on multiple modes of propulsion'. The initial emphasis is again on a description of these as sail-powered ships. The later qualifier to this means of propulsion perhaps underlines the problems that result from the lack of a clear taxonomy that I highlighted in Chapter 2.

By the early 14th century BC clear evidence for the development of this alternative vessel type is apparent in the ship portrayed in the tomb of Kenamun shown in Figure 4.3 (Artzy, 1987, 80). Compared to the earlier Egyptian ships this is a shorter vessel with a high vertical bow and stern post. The vessel itself is shown rigged with the same boom-supported sail used on Hatshepsut's ships. There is no hogging truss implying the shorter hull did not require this form of support. It is not possible to determine if the vessel had a keel to provide this support, or whether the construction of the shorter hull itself provided the necessary rigidity. The continued use of a boom-supported sail suggests the vessel would also require a rowing crew, it should then be considered to be a hybrid rowed and sailed vessel. The detail of the rope lashing supporting the lower mast on this vessel is similar to that portrayed in Figure 2.9 showing Hatshepsut's vessels. The presentation of this feature on two distinct vessel types, which are portrayed as being different in so many ways, may suggest a long-standing feature linked to the sail type, and the nature of seafaring undertaken. McGrail (2004, 130), Pulak (2008, 300) and Wachsmann (2019, 4) suggests from the style of clothing of the crew shown unloading the vessel that this may have been a Syrian ship. In the same passage McGrail goes onto note that this shorter hull form may be an indication of the development of the round ship. The archaeological evidence presented later in section 4.1.3 confirms the use of this vessel type by Levantine seafarers of this period.

Vinson (1993) discusses variations on the boom-supported sail that may be early representations of the later brailed sail. He records the rig shown on a vessel in the tomb of Neferhotep, shown in Figure 4.4 dating to the late 14th early 13th century BC, as perhaps the most reliable representation of an intermediate form. A further example of Egyptian iconography from this period is shown in Figure 4.5. This illustration has been substantially reconstructed and shows a vessel from the 18th Dynasty. Fabre discusses how this might suggest that Egyptian sailors of the period were altering the geometry of the square sails in use at the time in order to make progress to windward. He extends this discussion to suggest that 'the peaking of the yards must have been practiced on the ships of Hatshepsut,' (Fabre, 2004, 117-118). Fabre makes no reference to any evidence that this technique was employed in these vessels, or how vessels of this size and form may have benefitted from the manoeuvre. Similarly, the practical difficulty of manoeuvring a sail of the size of those shown in Figure 2.9 is not discussed. It may be relevant to record that Vinson (1993, 135) discusses this iconography and its lack of context; in footnote 9 he notes 'I have no reason to question the block's authenticity, but it seems prudent to retain at least some scepticism of any such object that has neither a certain provenience nor any parallel.'

The final examples of vessels from Egyptian sources relevant to the cases made are those in Figures 4.6a and 4.6b. These are from the 12th century BC temple of Medinet Habu and show the Battle of the Delta (Nelson, 1943, 41-47). The scene shows vessels of an Egyptian fleet opposing those commonly referred to as the Sea Peoples. The portrayal of this battle provides for a range of interpretations. Roberts (2009, 60) suggests that: 'The main purpose of these reliefs and inscriptions was not to record an invasion by hostile northerners, but rather to record the actions of Ramesses III.' Aspects of this interpretation may be supported by the large size of the figure of Ramesses in Figure 4.6a. The possible link between art and power implied in this representation is discussed by Beard and Henderson (2001, 147). In the chapter *Sizing up Power,* they record how, in relation to art: 'Extremes of scale lie at the heart of ancient political culture.'. In the scene portrayed there is no consensus on the identity of the invaders; however, it seems generally accepted that many originated in the central Mediterranean and swept up a large number of displaced people in a mixed process of invasion and immigration (Bell, 2006, 12-16; Knapp, 2013, 447-449; Cline, 2014, 1-13). It is significant that neither side are shown using war galleys such as the Kynos ship from mainland Greece shown in Figure 4.7. On this basis, whatever the underlying motivation for the portrayal may have been, it seems a reasonable assumption that the artist represented vessels in general use to portray the scene.

For this reason, the characteristics of these are of relevance to any discussion on the development of merchant vessels. What is of particular relevance in this scene is that it shows all of the vessels rigged with loose-footed sails. This might imply the widespread adoption of the brailed sail by this time. It does not; however, provide any information on where this feature may have originated, or the date of its introduction. The hull form of the vessels used by the presumed invaders is similar to that of the earlier round ship discussed by McGrail, with the same high bow and stern posts. The vessels used by the Egyptian forces on the other hand appear to be of a different design, in form these appear closer to those shown in the wall paintings from Hall 64 at Pylos shown in Figure 4.9. These vessels will be discussed in more detail later in this section. The portrayal of two types may be representative of the use of two different vessel designs, alternatively, it may have been an attempt by the artists to differentiate the two protagonists. If this is the case, then the vessel type shown in use by the invaders might be the one associated with long distance voyages, which, it might be assumed, they had undertaken. The form shown for the Egyptian vessels might then be that associated with coastal voyages, or those in and around the Nile delta. Where the oarsmen are shown the vessels have a rowing crew of between 7 and 11 men to each side. It is widely reported in relation to later war galleys, that, where a single oarsman worked an oar, each required around one metre spacing between the benches (Morrison, 2004, 63; Shaw, 2004, 168–169; Wallinga, 2004, 38). If the same provision is made in these vessels, and allowing two or three metres at the bow and stern to develop the full hull shape, these vessels might be a maximum of around 17 metres in length. As shown in Table 2.1, this length would place them into the same range as the largest round ships for which archaeological evidence exists in the Bronze Age. In the absence of evidence for a keel at this time it is not possible to determine if these were capable of operating at sea without an oar crew.

In the same period that evidence for these shorter merchant vessels appears, an alternative vessel type is shown in the iconographic record of the Mycenaean world. An example of this type is the Kynos ship dating to the transitional LH IIIB/C, this is shown in Figure 4.7 (Dakoronia, 1987, 122). The vase on which this is portrayed was found at the settlement of Kynos in East Lokris opposite the Gulf of Euboea. If the one metre spacing required for oarsmen applied in this case, then the 19 oars shown implies a vessel considerably longer than those shown in Figures 4.6a and b. Dakoronia (1987, 118) notes the obvious military purpose of this vessel. While this link is clear it is also apparent that these vessels lack a ram, the stem and stern being similar to those shown in Figures 4.3 and 4.6a and b. Morrison and Williams (2008, 9-10) use Vermeule (1964,259, Figs 43a, 43b and 43d) as a source in regard to a number of alternative galley types of the period, these are shown in Figure 4.8. The earliest of these shown in the upper figure is described by Vermeule as, 'Middle Helladic, on a sherd, Iolkos (after Theochares, Archaeology 1958, 15).' The vessel shown on the lower left is described by Vermeule as, 'Late Helladic III C, on a sherd, Tragana tholos (after Kourouniotes, Ephemeris 1914, 108).' The vessel on the lower right was described by Vermeule as, 'Late Helladic III C, on a stirrup jar, Asine (after Kirk, BSA 1949, 117, Fig5).' All of these vessels show an extended forefoot to the hull resembling a ram. In this respect it is perhaps relevant to consider the passage from Thucydides (*1.13.4,* trans, Smith, 2015) where he notes that: 'The earliest sea-fight, too, of which we know, was fought by the Corinthians against the Corcyraeans; and this was two hundred and sixty years before the same date.' Thucydides' estimate might be supported by current works by modern scholars who suggest that the earliest rams appeared following the Bronze Age/Iron Age transition (Mark, 2008, 270; Emanuel, J.P. 2013, 9; 2015, 202). It is also perhaps worth considering the observations of Averdung and Pedersen (2012, 129-130) in regard to model testing based on the Marsala I wreck dated to the mid-3rd century to early 2nd century BC (Parker, 1992, 263). This revealed that an extended forefoot greatly eased the issues of running the bows of a galley up onto a beach, this feature then may then have a practical function relating to seafaring rather than warfare. I will revisit this discussion in more depth in section 7.3.1. The manner of the portrayal of the vessels shown in Figure 4.8 does not suggest the features shown were exaggerated to enhance the status of the users. As such, I think they are probably realistic representations of vessels in use at this time.

This longer galley form was not the only vessel for which evidence exists in the Mycenaean world. A vessel from the reconstructed wall paintings in Hall 64 in the Southwestern Building of the palace at Pylos is shown in Figure 4.9. Brecoulaki et al (2015, 263) record that: 'Hall 64 must have been rebuilt in LH IIIB', this suggests that these paintings were produced later than the 14th century BC. The hull form of this vessel clearly differs to those shown in Figures 4.7 and 4.8 from the same region. If these reconstructions are broadly accurate then the relatively small size of the vessel portrayed might suggest that there size was not distorted to boost the status of the ruler who commissioned the work. The comment by Brecoulaki et al (2015, 273) that the vessels 'are long and svelte, as is appropriate for seagoing vessels' is not substantiated by evidence relating to their use. If the Kenamun vessel was typical of those involved in Mediterranean trade of the period, it might rather be assumed that maritime trade was based on the use of hybrid rowed and sailed round ships with a squared off hull with high stem and stern posts. It is perhaps relevant to note the similarities between the Pylos vessel and those portrayed as being used by the

Egyptians in the Battle of the Delta. This is not to suggest that these were vessels from Pylos: rather, that the hull form may have been a common one more suited to inshore sheltered waters such as the Nile Delta, and short inter-island passages in the Ionian or Aegean seas.

A further line of iconography from this period is that of clay models of vessels, I do not dispute the historic relevance of these models; however, in appearance they might almost be caricatures of vessels in which the scale and features have been distorted, possibly to meet the requirements of the material used to make them. The nature of these distortions are apparent in Figures 4.10, 4.11 and 4.12. The graphic representation in Figure 4.10 shows a vessel from Argos dating to the Late Helladic. The dimensions of the timbers representing the internal keel and strakes of this model are clearly not accurate representations of the timbers in use on a seagoing vessel. For these reasons, I do not think the details from this model can be reliably matched to other lines of evidence regarding vessel construction and development.

These same limitations are apparent in models from later periods. In Figure 4.11, which Casson (1971, figs 103-104) describes as a Phoenician trireme of the 3rd or 4th century BC, the length of the model is not representative of this well-known vessel type. I suggest that this distortion of scale possibly resulted from the limitations of clay as a material when attempting to model a long, thin, vessel. Much the same might be said about Figure 4.12 which Casson (1971, fig 94) describes as a Cypriot merchantman of the 6th century BC. This is clearly representative of a known vessel type with many features known from shipwrecks of the period. However, of particular relevance to the issue of vessel development, and particularly their increase in size, it is not possible to be certain of the size of the vessel represented due to the relatively crude nature of the modelling, and the lack of any sense of scale.

The contradictions that arise from these shortcomings may be summarised in the discussions associated with the two Bronze Age vessels shown in Figures 4.13 and 4.14 from Wachsmann (2009). In a section entitled, *ships misinterpreted as Syrio-Canaanite*, Figure 4.13 is recorded as being from Byblos and is described by Basch as ‘a Late Bronze Age Syro-Canaanite merchantman’ (Wachsmann, 2009, 52). On the same page Wachsmann records Dunand’s opinion that the vessel is ‘a small Syro-Canaanite fishing vessel.' Wachsmann goes on to record his personal opinion that the model is a compressed form of 'a known Egyptian ship type' (Wachsmann, 2009, 53). A similar range of opinions can be found relating to the vessel in Figure 4.14 dated to the Late Cypriot I-II. Wachsmann (2009, 65) recording that Basch assumes these to have been 'skin-covered ships', while Wachsmann expresses the opinion that these 'represent beamy wood-planked craft constructed with a keel.'

Overall; the uncertainties outlined suggests that any use of models of this type is likely to require so many qualifications regarding accuracy that any conclusions are likely to be meaningless. For these reasons I have chosen not to use these models as the basis of discussion in this thesis.

It is clear from the evidence presented that the iconography of the period shows no examples of round ships that relied purely on sail power. All the evidence from this source suggests the use of vessels that relied upon a combination of both sail and oars.

4.1.2 Textual evidence

In Chapter 2 I discussed at some length the Ugarit text that is used to support the case for vessels of 450 tons, and the case presented by Marcus (2007) for 70-ton vessels in use by the Egyptians, for this reason these will not feature in the following discussions. The work *Texts from Ugarit pertaining to Seafaring* by Hoftijzer and Van Soldt is provided as an appendix in Wachsmann (2009). This contains a number of pertinent texts that appear to reference the crews required for the king's ships. One of these, KTU 4.40, (Hoftijzer and Van Soldt, 2009, 336-337) provides information on crew numbers that is close to that of Homer's description of a twenty oared merchantman. Both of these then share characteristics to those shown participating in the Battle of the Delta. A further text, KTU 2.47, requests the king to supply 150 ships to 'protect your country'. It seems unlikely that the king of Ugarit would maintain 150 war galleys, the implications of this assumption might be that Ugarit was a regional power which was involved in constant maritime warfare. Rather, I suggest it is more realistic to imagine that in times of need vessels of the size and type as those represented in the relief from the temple of Medinet Habu shown in Figures 4.6a and b, or perhaps those from hall 64 from Pylos shown in Figure 4.9, were requisitioned for military purposes.

A further source of textual evidence from the period relating to seafaring are Pylos tablets AN 610 and AN 724. These enumerate the number of men expected to respond to calls for service as oarsmen. In regard to AN 610 Chadwick (1976) states that: 'A total of 569 men can be counted on the preserved part'. However, he goes on to note that entries may be incomplete and the true total may be between 600 and 700. Palaima (1991, 285-286) records a requirement for 'ca.600 rowers.' He goes on to accept that the recruitment of the rowers requested was part of the regular system for calling up naval personnel. Vitas (2012, 27) suggests that this call up was 'an obligatory military service in accordance with a landholding system'. No specific incident or emergency that may have triggered this requirement is identified. Later, on p34, Vitas notes that almost 500 men were involved in this call up. The problem with using this data is the inability to directly relate the number of rowers to any specific vessel type or size. The iconography presented in section 4.1.1 suggest a wide range of possible vessel sizes upon which these rowers may have been deployed.

A final literary reference to vessels and oarsmen alluding to the Bronze Age is that of Homer (*Od. 9.322-23*) which mentions the mast of a merchantman with twenty oars. This is clearly a hybrid rowed and sailed vessel, and the number of oarsmen would mean this was likely to have been around 15 or 16 metres in length. A vessel of this size would have been broadly similar to those shown in the scene from the temple of Medinet Habu at the close of the Bronze Age; as noted, it is also close to the size suggested in the Ugarit text KTU 4.40. In section 2.1 I recorded how a number of sources considered that the content of the works of Homer reflected features of society down to the 6th century BC (Willcock, 2004, 348-351; Dickinson, 2017, 9-10; Sherratt, 2017, 36-37). If these authors are correct, then I would contend that these works were addressing an audience familiar with the use of hybrid rowed and sailed vessels of this size. This may have been because vessels of this type were still in use, or that their recent use maintained them in the memories of the listener. I suggest that evidence from this range of sources might imply an extended period of use of vessels of this size and type from the Bronze Age through to the Archaic period.

As was noted in regard to the iconographic sources discussed in 4.1.1, the textual sources for this period make no reference to the use of sailing ships.

4.1.3 Archaeological evidence

For the reasons outlined in the introduction, the focus of the evidence presented in this chapter is on ship size and construction. For this reason, in the following I place emphasis on wrecks that can provide input to these areas from either the debris mound or from the physical remains of the hull. The earliest evidence in this regard comes from Egyptian vessels that predate the period under review. The earliest remains of these are those from the Abydos boat graves dating from between 2770 and 2649 BC (O'Connor, 1991). These are incomplete; however, from the remaining timbers it is clear that the hulls were constructed by stitching (Ward, 2004). There are more complete remains of later river vessels, the most notable being the 4th Dynasty Cheops funerary barge, ca.2500 BC. This vessel was found in pieces in 1954 in a pit adjacent to the great pyramid of Giza. The complete vessel was around 43 metres in length, a cross-section of the midships section of the hull is shown in Figure 4.15 (Lipke, 1984). The work of Lipke was based on interviews with Hag Ahmed Youssef Moustafa who led the reconstruction of the vessel. It is perhaps significant that the timber marked 'a' is described by Lipke as 'the central girder', and the two timbers marked 'd' are described as 'longitudinal girders.' The long hull of this vessel, and the heavy load it was designed to carry, required that this had some means of stiffening. However, the structure and use of the vessel as a funerary barge probably required an unobstructed deck, this would have prevented the use of a hogging truss. I will revisit the form and location of these timbers as I consider them to be of particular significance both in terms of their shape and orientation. In this regard I will draw comparisons with the keel of the later Uluburun hull shown in Figure 2.11a. The failure to carry this form of beam forward for use as a keel in later vessels is perhaps an example of a technical innovation that was lost, and subsequently re-invented, as discussed in Chapter 3.

The use of a hogging truss noted on both the vessels from the 5th dynasty tomb of Sahure at Abusir in Figure 2.7, and Hatshepsut's vessels in Figure 2.9, is widely interpreted to be a means of supporting an over-long hull which lacked sufficient longitudinal integrity. This suggests that a keel taking the form of the spine used in the Cheops barge was not employed in these vessels. The manner in which the hulls of

Hatshepsut's vessels were constructed cannot be confirmed. It is possible that these were stitched, in which case the hull is likely to have been relatively flexible and in need of longitudinal support. However, in the case that these used mortice and tenon joints there is a question as to the nature of these. The only evidence of mortice and tenon joints from Egyptian vessels are the unpegged form of these found in the hulls of river vessels (McGrail, 2004, 40; Steffy, 2017, 33-37). These are similarly likely to have resulted in a flexible hull in need of longitudinal support. An example of how these joints were widely spaced along the hull, and the associated absence of a keel, may be seen in Figure 4.16 showing one of the Dashur boats. These were discovered by Jean-Jacque de Morgan in 1894 near the 12th Dynasty pyramid of Sesostris. Steffy (2017, 33) discusses the interpretation of elements of this vessel's construction. In these discussions he comments on the length of the mortice and tenon joints, noting that they could be up to 24cm long, going on to record how these would have served to act as small internal frames to stiffen the hull.

The issue of the means of hull construction will form a core part of my discussions throughout Chapter 6. For this reason, it is worth briefly reviewing the evidence relating to this in the Mediterranean, and the ancient world, beyond Egypt. The paucity of intact remains for early Mediterranean vessels outside of Egypt prior to the Late Bronze Age means that any assessment is speculative. This said, Van de Moortel (2009, 20-21) discusses the incomplete remains of a vessel from Mitrou on the Euboean Gulf, this has been dated to the early 19th century BC and was estimated to have been between 5.5 and 6 metres in length. From the thickness of the hull timbers and the lack of evidence of any metal fastenings Van de Moortel suggests this vessel was constructed by stitching. The general use of stitching in vessels across Europe in the Bronze Age is confirmed by finds at North Ferriby, Dover and a number of other sites in the UK (McGrail, 2004, 31-38). The later Iron Age vessel found at Hjortspring off the coast of Denmark, which also had a stitched hull, is noted by Christensen (1974, 162) to 'exemplify plank-built vessels of the Late Bronze Age'. The lack of any evidence in these areas for the use of mortice and tenon joints, such as those found on the Dashur boats, suggests Egypt may be regarded as a single point of development for this joint type.

Before examining the evidence of shipwrecks, it is worth revisiting the archaeological evidence presented by Frost to support the contention that the finds of large anchors mean that large merchant ships were in use. Frost (1989, 167) notes that in addition to a temple at Kition these were also found in 'various sacred contexts at Ugarit Ras-Shamra in Syria, particularly in one…dedicated to the Weather God, Baal Sapounah; whereas its twin temple, …… dedicated to the Earth God Dagon (the latter, being of little use to sailors, got no anchors offered to him).' I suggest that this comment implies that the anchors may have been votive offerings rather than functional items for use at sea. Marcus (2007, 155-156) makes the same general point in regard to a number of locations dating to the Bronze Age. In these comments he records that anchors described as 'ex-voto offerings' are found in temple locations in Egypt and the Levant.

The earliest maritime wreck in Table 2.1 is that dating to the second half of the 18th century BC found at Pseira, an island off Crete. This was excavated in the period 2003 to 2009 by Elpida Hadjidaki, the excavation being recorded in *The Minoan Shipwreck at Pseira, Crete* (Hadjidaki-Marder, 2021). This wreck was identified from a debris field, no hull remains have been found. The evidence from the debris field suggests that the vessel may have been around 16 metres in length. The description of the remains does not allow for its positive identification as a round ship, it may have been a vessel of the type shown in the Cretan seals in Figure 4.2. However, this is currently the earliest date at which there is archaeological evidence for the use of this hull size in a sea-going merchant vessel in the Mediterranean. The second vessel is one found recently at Kumluca in Turkey, the excavation of this is ongoing (Oniz, 2019). The shape and dimensions of the debris mound, and the nature of the finds, suggests that this was a round ship dating to the 15th century BC. The hull had not been completely exposed when Oniz's paper was written, as a result the final length cannot be confirmed; however, at the time of writing this thesis it was estimated to be around 16 metres long. This then appears to be the earliest confirmed archaeological evidence for the use of a round ship of this size. The limited extent of the work published so far prevents the determination of a precise place of origin of the wreck. The cargo revealed to date largely comprises copper ingots, given the point of discovery off the coast of Turkey, this may suggest a vessel engaged in trade between Cyprus and the major trading centres of the Levant or Aegean.

Perhaps the most significant Bronze Age wreck relevant to the discussions throughout this thesis is that of the 14th century BC vessel found at Uluburun. The evidence relating to this will form the basis of much of the discussion in this thesis, for this reason the following is presented in two parts. The first presents a summary of the evidence from the wreck, the second comprises an interpretation of this in the context of my earlier discussions relating to vessel taxonomy in section 2.0.

The vessel itself has been the subject of a number of papers (Bass, 1986, 1989; Pulak, 1998, 1999, 2002, 2008, 2012; Lin, 2003). The evidence presented in these show that the wreck contained a cargo comprising a large quantity of copper ingots from Cyprus, tin ingots, resins and glass probably from the Levant, and a mix of Egyptian, African, Canaanite and Mycenaean items. From the possessions found the merchants onboard appear to have been Canaanite, but the vessel may also have been carrying Mycenaean passengers. The evidence of the remains also allowed it to be determined that the vessel was built of Lebanese cedar (Pulak, 2012, 13). The nature of much of the cargo, and the source of the crew, suggests that the vessel was built and operated out of the Levant.

The excavated hull shows no evidence that this was fitted with frames, its form and rigidity being fixed by the use of very long, pegged, mortice and tenon joints as shown in Figure 4.17. Pulak notes that: 'The live oak tenons from the Uluburun ship are 28-30 cm long, 5.9-6.2 cm wide, and 1.6-1.7 cm thick.' Pulak goes on to discuss these features, noting in one instance that tenons apparently penetrate three strakes, while making the more general case that these were found 'extending from one plank edge sometimes to within less than two centimetres of the opposite plank edge' (Pulak, 2002, 626). In doing so he notes that these tenons were 'clearly much more than simple plank fasteners and acted as small internal frames providing considerable stiffness and integrity to the shell.' He goes on to record that these were intended to 'compensate for the scarcity or lack of proper frames.' It is clear that the mortice and tenons used on this vessel could not have been much longer without the construction becoming prohibitively complex. From this it seems likely that this was a vessel towards the end of a process of learning and development in regional shipbuilding. The nature and limitations of the keel in this vessel was discussed in section 2.1.2. A keel of this type may have provided a marginally stiffer spine to the vessel; however, the fact that both dimensions were increased suggests that the factors that provided additional stiffness were either not fully understood at this time, or that a stiffer keel was not required. The low angle that the hull timbers make with the keel, shown in Figure 2.11a, suggest a hull with a shallow concave curve in its lower section. The proposed reconstruction of the hull shown by Lin (2003, Fig 1.8) repeats this hull form.

In any attempt to determine the form of the upper hull and deck of the Uluburun vessel the observations by Lin (2003, 25-26) should be considered: 'The greatest handicap in trying to reconstruct the Uluburun ship is the glaring poverty of physical hull remains … and relegate all results to being hypothetical.' Lin goes on to record in regard to the possible presence of a deck, that: 'Whether or not the ship was fitted with a full deck or only partial decks at the bow and stern can only be surmised.' In the same passage Lin also notes that there was no evidence for a mast, mast step, or rigging found at the wreck site. It is clear from these comments that the physical evidence results in considerable uncertainty as to the exact form, and nature, of the vessel. In his thesis Lin (2003) used 3D computer generated modelling to show the possible form of the hull, and layout of the cargo, much of the focus of the work being to examine how these factors may have influenced the vessel's trim and stability. A possible alternative form based on a projected reconstruction of the lower hull of the Uluburun vessel, along with the upper works and sailing rig of the Kenamun ship, is shown by Wachsmann (2019, Fig 3), shown here in Figure 4.18, this was used by the author to show how iconography may assist in the interpretation of archaeological evidence.

As discussed in section 2.1.2, the present lack of a taxonomy of vessel types that includes hybrid vessels is summarized in Pulak's comparison of the keel of the Uluburun vessel with those found on later sailing ships (Pulak, 1998, 210-211). Pulak (2008, 302) expands on this earlier discussion regarding the keel of this vessel, noting that: 'Unlike true keels in later sailing ships, however, it did not offer much lateral resistance, which is needed for the ship to hold course when sailing. This rudimentary feature therefore limited the headway a ship could make against counterwinds, which probably resulted in favouring certain maritime routes during certain sailing periods.' I will return to this issue in my discussions in Chapter 7. The problems arising from the lack of a clear description of this vessel is perhaps compounded by Lin, who, having noted the lack of evidence for a mast (Lin, 2003, 25-26), goes on to state in regard to the reconstructed 3D model used in his paper that 'the mast structures were located aft of the preserved sections of hull and still be forward of midships, as expected in this type of sailing merchant ships' (Lin, 2003, 36). Lin then appears to be identifying the Uluburun ship as a specific type of sailing ship; however, he presents no unambiguous iconographic or textual evidence that might confirm this assertion. It is also relevant that he fails to link this capability to his own description of the vessel's keel, which he notes as being: 'Unlike a true keel, however, it would not have helped the ship to hold course or to point nearer the wind when sailing against contrary winds' Lin (2003, 13).

It is my opinion that it is the lack of a system of vessel taxonomy based on propulsion, and vessel use, that has led to the problem inherent in these apparently contradictory statements by Lin. The problem with this might be determined by reviewing the complete range of iconographic and textual evidence presented in sections 4.1.1 and 4.1.2, along with the reconstruction shown in Figure 4.18. None of the evidence presented in these sections, nor the reconstruction shown in Wachsmann (2019), provide evidence of the use of true sailing ships as described by Tilley in section 2.0. Rather, the totality of the evidence suggests the use of hybrid rowed and sailed vessels in this period. If this evidence can be relied upon; then, based on the spacing required for oarsmen presented in section 4.1.1, this vessel may have required up to 20 oarsmen to operate safely. I appreciate that there is no evidence for the presence of these oarsmen; however, it is clear from the comment of Lin that there is a similar lack of evidence for the mast required by a sailing ship. In summary it is perhaps relevant to return to the point I raised in section 2.0 relating to the probability that any hybrid rowed and sailed vessel would be sailed whenever possible. For this reason; I suggest, it might not be surprising if the two vessel types shared common requirements regarding trim and stability, and that their cargo loadings would reflect these.

I am aware that the lack of evidence for a deck on the vessel may raise questions on where any oarsmen may have been seated. If it is assumed that the Uluburun vessel lacked a deck; then, the reconstruction of the Kyrenia ship may provide an insight in to how a vessel that lacked this feature may have been rowed. Figure 4.19 (Katzev, 2008, 78) shows a reconstruction of this ship and the walkways provided to facilitate the movement of the crew in working the vessel at sea. I suggest that if the Uluburun vessel had a similar layout, with the same open hold, it could have had wider walkways to provide for both the movement of the crew, and the seating of the oarsmen. This solution is clearly hypothetical, other systems can surely be advanced that might provide the means for a rowing crew to propel a vessel which lacked a complete deck.

The earlier observation that the type of joints used on the Uluburun ship suggests a long process of use and development may be confirmed by evidence from the late 13th century BC wreck found at Cape Gelidonya. The size of this wreck, and the nature of the finds, suggests this may have been used by an itinerant trader (Bass et al, 1967, 1991, 2012; Sherratt, 1997, 2000, 2016; Singer, 2014; Monroe, 2015). Bass (2012, 3) notes that it is only in the light of evidence from later excavations that it has been possible to determine that this smaller vessel was also, at least in part, constructed of pegged mortice and tenon joints. This might support a case for the widespread use of this type of joint across a range of vessel sizes in the eastern Mediterranean in the Late Bronze Age.

The final wreck of relevance is that found at Zambratija in the northern Adriatic, these remains date from between the last quarter of the 12th and the last quarter of the 10th centuries BC. The remains of this are shown in Figure 4.20 along with details of the stitching used (Pomey and Boetto, 2019). The remains suggest a vessel of around 9 metres in length, and as such, it was comparable to that found at Cape Gelidonya. The remains included a keel plank, which Pomey describes as varying from 30mm thick amidships and 200mm thick at the preserved end. From Figure 4.20 it can be seen that the larger of these measurements refer to the width of the timber rather than its depth. I appreciate that this vessel came from a different culture to the one that constructed the Uluburun and Cape Gelidonya vessels. However, the physics relating to the operation of these vessels would have been the same. In this context, if Pomey

(2004, 26) is correct in linking function and usage then it might be expected that both vessels might have been intended for broadly similar types of use. On this basis, if Pulak's observation that the keel of the Uluburun vessel shows it was not a true sailing ship, then the same can probably be said in regard to the Zambratija hull. While the evidence from two wrecks cannot be regarded as definitive for the Mediterranean in general, it is apparent neither provide evidence for the development of a hull form optimized for sailing in this period. The contrast between these two types of vessel construction and the possible relevance of the locations in which they were found will be revisited in the following chapters.

I wish at this point to briefly discuss a final piece of indirect evidence in regard to shipbuilding in the Late Bronze Age; this relates to the tools used for this purpose. Maragoudaki and Kavvouras (2012) discuss the use of a Mycenaean shipwright's tool kit in shaping hull timbers and making mortice and tenon joints. These timbers and joints having been modelled on those used in the Uluburun hull. The conclusions of this paper are informative in relation to the manner in which the tool kit could have facilitated the construction of this hull. Unfortunately, what it does not do is provide evidence that the Mycenaeans constructed vessels using mortice and tenon joints in the manner of the Uluburun hull. Rather, the evidence available at the present time suggest that in this period the hulls of vessels from Greece and the central Mediterranean were stitched. The paper then may show what is possible with this tool kit, and possibly how a common range of tools and skills were employed by shipwrights across much of the Mediterranean in the Late Bronze Age. I also take issue with the point raised in the introduction to this paper (Maragoudaki and Kavvouras, 2012, 199) where they state that: 'The need to produce stiffer hulls, to allow sailing in rougher seas with increased loads, led to the transition from the laced ship construction to mortise-and tenon construction.' I discuss this transition in some detail in sections 6.2.1, 6.2.2, and 6.2.3. The evidence I will present in these discussions suggest that the size of the vessels constructed in the Late Bronze Age, and the nature of seafaring undertaken, did not require this change in construction.

4.1.4 Summary

The main points raised regarding the evidence of this period are summarised below, these will provide the factual basis of my discussions on maritime technical development in the same period covered in section 6.1.

1. There is iconographic and textual evidence showing that maritime trading vessels in use through the period were hybrid rowed and sailed ships, and that these were to some extent dependent upon oars for their propulsion. There is no evidence for the development, or use, of true sailing ships in this period.
2. The evidence shows that through the period 1500 to 1000 BC a shorter form of vessel came into use. The lack of frames, and the type of joints used on some of the later vessels of this type, suggest that in the Levant vessel development shared features with earlier Egyptian river vessels.
3. There is strong support from the iconographic, textual, and archaeological evidence that this shorter vessel type was widely used in the north eastern Mediterranean, and may have originated in the trading centres there.
4. In addition to this change in the hull form the sailing rig also changed from the earlier boom-supported type to a loose-footed design.
5. The evidence from the hull remains of the Uluburun vessel does not suggest that there was any development of an external keel in the Levant by the middle of the period. The evidence from the central Mediterranean wreck at Zambratija dated to the end of the period shows a similar lack of an external keel. This might suggest that seafaring in the Mediterranean in this period did not require this feature which Pulak (1998, 210-211) notes to be characteristic of 'later sailing ships.'
6. Perhaps as significant in regard to the discussions in Chapter 2 is that the longest vessels were those based on the early Egyptian river vessels. It is not possible to be categoric concerning the exact length of the largest round ship in use at the end of the period. On the basis of an oar count the iconographic evidence suggests it was probably in the range 15 to 17 metres. This size agrees with the evidence from the Kumluca and Uluburun wrecks.

4.2 1000 to 500 BC

4.2.1 Iconographic evidence

In the period following 1000 BC there is increased iconographic evidence from the Phoenician cities and the Greek world. One of the best-known examples of Phoenician iconography is from the late 8th century BC. This shows a number of Phoenician ships in a relief from the palace of Sennacherib at Khorsabad, these are shown in Figure 4.21. This relief was excavated in 1848 by Layard. The work was fragmentary at the time and all current reproductions are either based on Layard's sketches or photographs taken in 1903-04, by which time the work is reported to have suffered further deterioration. McGrail (2004, 132) notes that Basch (1987, 303-318) suggests that Layard may have modified the original in his portrayal, but that overall, they represent a reasonable portrayal of the relief as found. In the following discussions this assumption is accepted as being the case. The illustration shows a section of Layard's drawings from the British Museum which includes two vessel types. The scene is interpreted to show the evacuation of the people of Tyre from the siege in 701 BC (Morrison and Coates, 1986, 156; McGrail, 2004, 132; Wallinga, 2004, 44).

I suggest that the context and purpose of this relief should be considered in any interpretation of the vessels portrayed. Earlier, in section 4.1.1, I discussed how Roberts (2009, 60) had suggested how artists of the period used scale as a means to represent power in artistic representation. In regard to Layard's picture, shown in Figure 4.21, the relief was created to decorate the palace of an aggressive Assyrian king who was celebrating victory in a war in the Levant. The work was part of a larger relief that included the siege of the city of Lachish, these scenes in turn being part of an even larger decorative scheme which included royal hunts (Reade, 2003, 65-68). Taken together they might support the comment by Honour and Fleming (2002, 107) that: 'Assyrian art was produced … for a limited but related purpose: the promotion and glorification of Assyrian power and military strength.' This observation is similar to an earlier one by Albenda (1998, 29) in the conclusion to her work on the monumental art of the Assyrian Empire. In this she recorded that: 'The production of the palace wall reliefs originated with the expressed purpose of the Assyrian kings to record in visual form the military successes encountered during their respective reigns.' In respect to Figure 4.21, this glorification of strength and success might be emphasised if the vessels used by his defeated opponents were representative of the largest available at the time. On this basis, I suggest that while the vessels shown may be representative of a type in use, the purpose for which they are shown being used may not be realistic.

In Figure 4.21 the two vessel types shown are thought to be a war galley equipped with what appears to be a ram, and a slightly shorter vessel which lacks this feature. This latter type is generally assumed to represent a merchant vessel. Both types are shown carrying passengers and being rowed by two banks of oars. However, there are a number of anomalies in this scene which are rarely discussed in the literature. Perhaps the most obvious of these being the only vessels shown with a mast and boom for a sail are those with what appear to be a ram, which are identified as war galleys. On the other hand, the vessels that lack a ram and which are assumed to be merchant ships lack a mast. As a comparison Figure 4.22 shows a second frieze from the palace of Sargon II at Khorsabad (McGrail, 2004, Fig 4.29). These vessels share features such as high bow and stern posts with earlier round ships from the Late Bronze Age. It is possible then that they represent simplified forms of typical Phoenician working and trading vessels. Both friezes were produced in Assyria. If these were the product of local Assyrian artists it is quite possible that these had not witnessed the scenes portrayed, and possibly had never seen a ship. There is then no way of determining how accurate a portrayal either is of the use of the individual vessel types. In this context I would suggest that the possible distortions of scale discussed in regard to art related to the display of power may be relevant. Figure 4.22 appears to show a scene of everyday life, it seems unlikely that this would have been distorted to enhance the status of the patron, on this basis, the vessel type shown may be less likely to have been distorted to serve this purpose.

Some details of the vessels in Figure 4.21 may be confirmed by the more detailed relief of a Phoenician war galley from the palace of Sennacherib in Nineveh shown in Figure 4.23 dated to ca.700 BC. The general similarity between the form of this and the war galleys in the earlier frieze suggests these may also have been based on the same bireme vessel type. It does not; however, help clarify the nature of merchant vessels. I will examine the issue of when the bireme form of galley came into use, and the motivation for its introduction, in later discussions in this section. All that can be said from the combined evidence of these works is that Phoenician cities of this time had a fleet that comprised a mix of both war galleys and merchant vessels equipped with oars. These latter vessels may have been either merchant galleys, or they may have been smaller vessels that shared characteristics with those of the Bronze Age. The iconographic record then suggests that hybrid rowed and sailed merchant vessels were used as merchant ships by the Phoenicians at this time. There is no iconographic evidence from this period to support the case for the use of sailing ships by the Phoenicians.

Greek iconography of the period provides evidence for a long history of galley type vessels, these are shown depicted on Geometric pottery from around ca.760 BC. However, the following examples are taken from later in the Archaic period, the forms of these are simplified, as a result, these may in some cases be representative of the type rather than being detailed representations of the vessels. This said, Morrison and Williams (2008, 93-97) discuss the detail shown in the examples in the following as being accurate representations of features in use. On this basis I have assumed this iconography may be used as the basis of the following discussions. Typical examples of these vessels are shown in Figures 4.24a, b, c, and d (Morrison and Williams, 2008, Plates 13, 17 and 21). These are shown with both a mast and single bank of oars, the hull having what appears to be an extended forefoot. However, of more relevance to the development of sailing rigs is the position of the mast that might be slightly forward of a midships position.

It is not claimed here that this portrayal is universal, Morrison and Williams (2008) show many examples in which the mast is located close to amidships. However, there are no examples that show the mast located closer to the stern of the vessel than the midships position. This might suggest that galleys at this time may have been rigged with a mast in a range of positions between one at the centre of the vessel and one closer to the bows. The problems experienced by Severin (1985, 168-170) when sailing a galley fitted with a single sail in a midships position were highlighted in section 3.2. This issue, and the link between the placement of either a single mast or multiple masts will be reviewed when the development of larger galleys is discussed in section 6.3.3. The placement of the single mast in the figures in Morrison and Williams (2008) might be counter to the earlier case presented by Casson (1971, 19). In this he noted that in early Egyptian vessels the mast was located close to the bow, but that by 1500 BC this had moved to the centre. Casson relates this to the development of an ability to sail courses other than downwind. McGrail (2004, 33) makes much the same observation regarding Egyptian vessels of this time. Tilley (1993, 421) takes issue with this, noting that: 'Actually, the mast should be more like one third of the ship's length from the prow. Modern yacht designers know this of course. They find the centre of the underwater profile of the hull, and then put the centre of sail area further forward of this.' However, in this case Tilley is discussing modern sailing ships rather than galleys.

As noted, there is no iconographic evidence of true sailing ships in this period from Phoenician sources. Examples of these are similarly rare in the Greek world and are uncommon up to the Roman era. Casson (1971, 173) and Davey (2015, 32) discuss the vessel on a black figure Kylix, dated to the 6th century BC, shown in Figure 4.25, now in the British Museum, as being the earliest iconographic representation of a sailing vessel. Morrison and Williams (2008, 97-116) discuss the representation of oared vessels in vase paintings for the period in which this kylix was made. In these they appear confident that their portrayal was sufficiently accurate that the form and function of the vessel could be assessed. On this basis it would appear to be reasonable to assume that the representation of the ship on this kylix may also be an accurate representation of a vessel type in use at the time. There is unfortunately no means to determine the size of this vessel. The single brailed sail shares characteristics with earlier vessel types from the end of the Late Bronze Age. However, the hull form has undergone a change from those shown in Figures 4.6a and b and the Phoenician vessels shown in Figure 4.22. It seems unlikely that a vessel of this distinctive form was the first sailing ship in use, and it must be supposed that this was the result of an ongoing process of development.

4.2.2 Textual evidence

The use of Homer as a literary source for vessels in the Bronze Age does not preclude his relevance as a source for the vessels in use in this period; the case for this was addressed in section 2.1. Specifically in this regard, Morrison and Williamson (2008, 44) note the discussion in Wace and Stubbings (1962, 541) on how Homer reflected nautical procedures of the period in which the Epics were compiled. If these observations are correct, it is not unreasonable to assume that vessels similar to those recorded in Homer may have been in common use down to as late as the 6th century BC. On this basis, there may be relevance in the references in Homer to Phoenicians as traders as in *Il.* (*23.740-45*), and *Od.* (*8.145-164*). These links may suggest that the description of Homer's 20-oared merchantman in the *Odyssey* (*9.322-23*) applied to contemporary Phoenician vessels such as the Ashkelon wrecks as discussed by Ballard et al (2002).

The use of an alternative form of hybrid vessel around this time is recorded in Herodotus (*I.163*, trans, Godley, 2015). In this passage Herodotus makes reference to the use of what appear to be galleys in a trading role, stating that: 'These Phocaeans were the earliest of the Greeks to make long sea-voyages: it was they who discovered the Adriatic Sea, and Tyrrhenia, and Iberia, and Tartessus, not sailing in round freight-ships but in fifty-oared vessels.' Wallinga (2004, 47) suggests that this contact between Phocaea and Tartessus took place in the mid-6th century BC. Herodotus clearly understands the differences between the two vessel types; unfortunately, in the context of understanding vessel development and use at the time, he does not suggest a reason for the use of the 50 oared vessels. In regard to these, Morrison and Coates (1986, 30) commented that: 'The pentaconters must have been capacious vessels with a single file of 25 oarsmen a side'. The authors later specifically note how this single bank arrangement of the oarsmen provided the necessary space for cargo. I will discuss this point later in section 5.1.2 as the means by which hybrid rowed and sailed vessels were able to increase in size over the apparent 16 metre limit for round ships. The possible reasons for the development of the alternative bireme galley are discussed by Morrison and Coates (1986, 33-35) and Coates (1987, 112-113). In this they link the development to the increased speed and manoeuvrability generated by a vessel with a large number of oarsmen in a shorter hull. These qualities being most advantageous in a war galley equipped with a ram as its main offensive weapon. However, a shorter hull, coupled with bireme propulsion, would limit cargo capacity and so offer few advantages to a merchant galley. On this basis, I contend that it is difficult to see the justification for identifying the vessels shown in Figure 4.21 that lack a ram as being accurate representations of merchant galleys.

This continued use of hybrid rowed and sailed vessel types is confirmed in further literary sources that describe the use of galleys by the Greeks and Phoenicians on colonising voyages. One of these voyages was discussed in section 2.2 and comes from *The Periplus of Hanno the Navigator* (Schoff, 1912). This text has been dated to the late 6th or early 5th centuries BC and recounts the voyage of a Carthaginian seafarer who led a colonising expedition down the coast of west Africa. Schoff's own discussions on this notes that: 'The narrative of Hanno was certainly extant in Greek at an early period…The authenticity of the work may be considered as unquestionable. The internal evidence is conclusive on that point. There is considerable doubt as to the date of the voyage' (Terrel, 1972). The manner in which the content is discussed in this thesis means that the evidence relating to vessel types, and the means of navigation used, is more relevant than the precise date of the voyage. The key issue in the text in regard to vessel type is found in the opening verse, this states in regard to Hanno's voyage that 'he set forth with sixty ships of fifty oars…' The use of the term 50-oared may by this time be a literary device used to describe any large galley type vessel rather than a precise description of the vessels in use. This convention also being found in works such as Herodotus (*I.163*), the contemporary authority of this work possibly contributing to other authors of the period using similar phrasing to describe a range of vessels of broadly similar type. However, the account does suggest that at the dates proposed a city, renowned for its maritime activity, was still using some kind of galley for colonising voyages. What is perhaps of equal relevance is that there is no reference in the work to the use of sailing ships.

Literary reference to the use of this vessel type for colonizing activity was not restricted to the Carthaginians. This is supported by Herodotus in *Histories* (*IV.153*, trans, Godley, 2015) who notes in regard to the Therians' claim to the colonisation of Cyrene: 'Then they manned two fifty-oared ships and sent them to Platea.' Osborne (2009, 114-115) records two possible dates for this colonisation, the first in the mid-8th century BC, the second in the late-7th century BC. It is not the absolute truth of the claim to colonisation, or the exact dates, that is relevant in this context; rather, it is the reported use of 50-oared ships. It might be assumed that this history was presented to a contemporary audience who were aware of the nature of maritime activity. Clearly, if this use had not been practical, or if more suitable alternative vessels were known to have been used on these voyages, it might be expected that Herodotus would have referenced these. On the basis of this evidence, I contend that the reference to what appear to be galleys suggests that their use on this particular type of voyage was common practice.

A further source on the use of galleys at this time is Plutarch. However, Plutarch was writing from the viewpoint of the 1st or 2nd century AD. Russell (2012, 1165) makes a number of relevant qualifications regarding Plutarch's writing on the period in question, commenting that: 'Much depends of course on the sources available to him', and that: 'The *Lives* … have sometimes led to despair about their value as source-material.' In an earlier work Russell (2004, 547) notes that 'in his writing he was an active exponent of a partnership between Greece the educator, and Rome the great power.' Taken together these may suggest he relied on authorative Greek sources such as Herodotus for his information when writing about this period of history, and perhaps used these in an unquestioning fashion. Accepting these qualifications, Plutarch comments that on Samos the regime of Polycrates developed the *samaina,* a modified form of a pentaconter, in the second half of the 6th century BC. In regard to this vessel, Plutarch (*Life of Pericles, 26.4*, trans, Perrin and Cohoon, 2015) commented that: 'Now the samaena is… more capacious than usual and paunchlike, so that it is a good deep-sea traveller and a swift sailer too.' Wallinga (2004, 47) goes on to discuss how this vessel type was used for trading grain with Egypt, and that: 'For the transport of this grain to Samos the samaina's cargo capacity was needed.' If Plutarch was using a reliable source, this suggests that at this time it was still worth adapting the long-established galley form to make it suitable for bulk cargo. If correct, I contend that this development is of particular significance to the development of merchant ships, and to that of galleys themselves. In the first place the use of this vessel for bulk transport implies that it was a single bank form of merchant galley. In the 6th century BC this form would be limited in its use as a war galley, Figures 4.21 and 4.23 showing that the more advanced bireme form of war galley had been in use for some time prior to this. The development of this then was almost certainly related to a need to increase the cargo capacity of merchant vessels. Secondly, the development of this vessel type suggests that there was a reason why the contemporary round ship form could not fulfil the same function. It is also of relevance that none of these texts imply that single bank merchant galleys were used because of their speed under oars. The only reference to speed is by Plutarch, and, if the translation is accurate in this regard, this relates to sailing rather than rowing. Similarly, there are no specific references to security issues that may have necessitated the larger crews in merchant galleys when compared to round ships. These points are in contrast to the case made by Wedde (1996). I appreciate that it is possible that the lack of these references in primary sources may mean that these facts were common knowledge to the audiences of the works.

4.2.3 Archaeological evidence

Following the wrecks found at Uluburun, Cape Gelidonya and Zambratija, there is a gap in the relevant archaeological record, the next two wrecks, dating to the second half of the 8th century BC, being those found off Ashkelon (Ballard et al, 2002). These wrecks are located in deep water and their evaluation has been carried out by ROV rather than divers. In both cases the debris mounds suggest the vessels were around 16 metres in length and had the proportions of a round ship. The difficulty of excavation in deep water means it is not possible to easily remove the cargo to expose the hulls of these vessels. For this reason, it is not possible to determine if these were hybrid rowed and sailed ships or were true sailing ships. Similarly, it is not possible to determine if they were built with frames, or, to confirm the nature of the joints between the hull timbers. The cargoes of both vessels suggest they were Phoenician in origin and had sailed from the same port at around the same time. Their proximity in a remote offshore area suggests the probability that they were sailing together and were lost in the same incident. The fact that the area was devoid of reefs or other subsea obstructions suggests that the reason for their loss may have had its origin outside of the area in which they were found. Gertwagen (2014, 156) suggests the location of the wrecks implies that the Phoenicians of the time were utilising an offshore route from the Levant to Egypt. Ballard on the other hand suggests these vessels were more likely to have been blown offshore in the same storm and foundered at around the same point. He bases this conclusion on the fact that there are no other wrecks in the area, and that both vessels were orientated with their bows to the west, suggesting they may have been driven to this point by an easterly wind and possibly swamped by high seas (Ballard et al, 2002, 166). It is; however, not possible to be definitive on the reasons for their loss, or the route they were sailing.

The evidence I have presented to this point, and perhaps confirmed by these vessels, suggest an upper size of around 16 metres for round ships at this time. Given the similarity in dates between the Epics and the dates of these wrecks, I suggest, it is possible the Ashkelon vessels may have been representative of the 20 oared merchantmen described by Homer (*Odyssey*, *9.322-23*). There is further indirect evidence to support the size limit of around 16 metres for round ships at this time that might be derived from these wrecks. These two 16 metre round ships were carrying the same cargo, and may well have been sailing on the same voyage. If this latter assumption is correct, this suggests that larger vessels suitable for this voyage may not have been available. The range of vessel types that might be expected in a mature maritime society are shown in Table 2.1 and is discussed in relation to later Greek and Roman societies by Houston (1988, 554) and Nantet (2020, 75-90). The evidence presented in Markoe (2000) and Aubet (2001) suggests the Phoenician centres in the Levant were part of the most mature maritime trading society of the period. It would not be unreasonable to assume that if this hierarchy of vessel sizes existed at this time, it would be reflected in the vessels in use by the Phoenicians. I suggest, that the lack of evidence for this hierarchy of sizes in the Ashkelon wrecks may be indirect evidence of a size limit of around 16 metres for round ships at this time.

The issue of the manner in which the shell of a vessel's hull was constructed will be of increasing relevance to the discussions in the following chapters. This is particularly relevant to the mix of both mortice and tenon joints and stitching in the hulls, along with the use of frames in all vessels. There will be increasing focus on these issues from this point. The first wreck from this period in which the hull has been excavated is Mazarron 1, shown in Figure 4.26. This wreck was found in Spain and is dated to the turn of the 7th century BC. Tejedor (2018) links this with the presence of Carthaginians in the region, although Pomey and Boetto (2019, 6) suggest this might belong to an Iberian tradition that had been influenced by Punic contacts. This vessel was around 9 metres in length and is the first Mediterranean wreck to show evidence of an external keel and mast step. I suggest that the hull of this vessel is of further interest when comparing its construction with that of the Uluburun ship. Mazarron 1 was built with short mortices between 6 and 8 cm deep (Tejedor, 2018, 304), rather than the longer 14 to 15cm examples used on the Uluburun vessel. The shorter mortice and tenons probably resulted in a more flexible shell which required the use of frames to stiffen this. In addition, there is evidence of stitching between the strakes, this is shown in Figure 4.27. In this case the stitching is there to retain caulking in the seams, this caulking itself perhaps confirming the flexible nature of the shell of this vessel. In the following chapters I will discuss this link between the shorter mortice and tenon joints, the resulting flexible nature of the hull, and the need for frames to support this. It is of relevance to these later discussions to note the shape of the hull of the Mazarron 1, the right-hand illustration in Figure 4.28 showing the keel and first hull timbers of this. The low angle of these two elements of the hull suggests that the shape of this did not differ significantly to that of either the Uluburun or Zambratija vessels described in section 4.1.3.

Pomey and Poveda (2018) discuss two similar sized fishing vessels from Marseilles and provide details of the reconstruction and testing of one of these in open water trials. Both of these wrecks date to the late 6th century BC. The reconstructed vessel tested was based on the Jules Verne 9; this was 10 metres in length. This vessel had a stitched hull that was supported by frames. The second vessel was larger, in the range 13 to 15 metres in length, and was at least in part constructed with mortice and tenon joints. Both were identified as being built by Greek colonists, it is possible then that both represent contemporary regional Greek ship building techniques in use through the latter half of the 6th century BC. The details of the construction of the Jules Verne 9 are shown in Figure 4.29, and the form of the reconstructed hull is shown in Figure 4.30. In Chapter 3 the sequence of development of proto-Viking through to Viking vessels was summarised in Figure 3.3. I suggest that if a similar process took place in the Mediterranean, it is possible to see the Uluburun and Zambratija hulls as matching an early vessel in this sequence, while the much later Kyrenia ship shown in Figure 4.35 is closer to the later examples. In this context both the Mazarron 1 and Jules Verne 9 hulls might represent vessels at a mid-point in the sequence. This said, I appreciate that it is possible that all of these vessels served different purposes, and as a result, did not lie on a direct line of development in terms of hull form.

The contents of Table 2.1 suggests that there is no evidence for round ships larger than 16 metres prior to the 6th century BC. Following this time the archaeological record provides evidence of an increase in vessel sizes. There are a number of vessels that might possibly be viewed as providing the first evidence of this, although the exact vessel type is not clear in all cases. The earliest example is that found at Giglio which dates from around the early 6th century BC, Polzer (2009) suggests the estimated length of this was greater than 20 metres. Parker (1992, 192) does not provide a size but notes that the remains of the hull are fragmentary. Bound (2001, 170) suggests on the basis of the stitching by which the hull was constructed that this may have been an Etruscan vessel, noting that the style perhaps confirms a north central Mediterranean origin; however, Kahanov and Pomey (2004, 13) suggest a Corinthian origin. The evidence does not allow a definitive assessment of the precise size of the vessel, or whether it was a round ship or a type of merchant galley. A wreck found at Pabuc Burnu off the south coast of Turkey is further evidence of a possible increase in vessel size. Based on the distribution of finds this early 6th century BC wreck may have been 18 metres in length; however, it is recorded that the scatter of finds may have been influenced by the slope of the seabed and more conservative estimates put the length at between 13 and 15 metres (Polzer, 2007, 28). The hull was largely constructed by stitching; however, this also provides early evidence of the use of mortice and tenon joints in a Greek vessel. These were a very short form of this type of joint, the assumption being that these provided a means of temporarily fixing the hull timbers in place prior to these being stitched together. The evidence from a later wreck, the Grand Ribaud F, dated to the late 6th or early 5th centuries BC, is again ambiguous. Polzer (2009, 66) provides an estimate of its length at around 25 metres; however, the data base [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022 suggests a length ca.30 metres, while Davey (2016, 37) suggests a length of ca.20 metres. If the estimated cargo weight of between 30 and 38 tons represents the full load then this may offer a guide to its size and type. If the vessel is assumed to be a round ship, then this capacity might be appropriate for a vessel of around 20 metres. If on the other hand, this cargo was only a percentage of what the vessel may have carried, then it may have been a galley.

4.2.4 Summary

The evidence presented in this section is summarised in the following and will be used to support the development process outlined in section 6.2.

1. In the period from 1000 to 500 BC there is evidence for the use of sailing ships with an external keel.
2. The period provides the first evidence of maritime vessels using frames to support a flexible shell constructed with short mortice and tenon joints. This development was fundamental to the later development of both the round ship and the galley.
3. There is no evidence that the shapes of the hulls of round ships in use at this time were radically different to that used on the Uluburun vessel.
4. The use of stitching in hull construction in this period appears to be linked to vessels from Greece and the central and western Mediterranean. Although the Mazarron 1 vessel was found in this area its links to local Carthaginian trade may link this to the Phoenician shipbuilding tradition.
5. This is the period in which the first evidence for the use of merchant galleys appears.
6. The use of merchant galleys such as the samaina (Plutarch, *Life of Pericles, 26.4*) for bulk trade at a time when sailing ships came into use suggests a motivation to build larger vessels of this type.

7. It is only toward the end of the period that sailing ships increase in size over that of the earlier 16 metre rowed and sailed hybrid round ships. The use of larger merchant galleys through the period may suggest an inability to either build, or operate, large sailing ships at this time.

4.3 500BC to AD200.

There is substantial iconographic, textual and archaeological evidence from this period, it is clearly impractical to attempt to review all of this. In the following I will focus on the evidence that will allow the case for learning and development outlined in the earlier chapters to be pursued through the discussions in Chapters 6 and 7.

4.3.1 Iconographic evidence

One of the most significant pieces of iconography early in this period comes from the Etruscan Tomba della Nave in Tarquinia, shown in Figure 4.31. Steingraber (2006, 306) records this tomb as dating to around 450 BC. The image shown has undergone significant reconstruction, in its present form this shows a vessel with a deep hull suggesting a round ship. The vessel is shown fitted with two vertical masts; the main mast having a slightly larger sail than the foremast. The image is dated to around the same period as that suggested by Morrison and Coates (1986, 176-177) for the use of two masts on Athenian triremes. There is no way to determine the size of the vessel, this said, it can be seen to have a hull form similar to that in the black figure kylix dated to the 6th century BC shown in Figure 4.25. The singular nature of the image means there is no way to determine if this was copied from life, or was an adaptation of a vessel copied from an earlier kylix.

Much of the iconographic evidence relating to merchant ships in this period relates to the later Roman era. In regard to the pictures of his time Vitruvius (*VII. v. I.* trans. Granger, 2014*)* records that: ‘For by painting an image is made of what is, or of what may be; for example, men, buildings, ships.’ This might suggest that portrayals of the early imperial period may in general be realistic representations of the ships in use. The setting of the works discussed are also relevant, in this regard the following examples are taken from a number of sarcophagi and public mosaics that show a range of vessel types and sailing rigs. Wheeler, (2003, 9) notes in regard to Roman art and architecture that ‘the patron was now the man who counted.’ Taken together these comments might suggest that merchants and traders who sponsored these works were portraying the vessels that they were using in their trading ventures. Figures 4.32 and 4.33 represent vessels that highlight particular features discussed to this point. These examples were found in a wide range of public locations in, and around, Ostia and represent everyday scenes associated with the port. The consistency in the content of these suggest that they are reliable sources of evidence of the range of vessels in use at this time. The number of masts suggest these vessels were larger than the round ships from the Late Bronze Age, and were also possibly larger than those of the 6th and 5th centuries BC shown in Figures 4.25 and 4.31. Two of the vessels shown in Figure 4.32 have two masts, with the second mast carrying an artemon sail. All of the vessels have brailed sails, and all have the same raked bow as the vessel shown in Figures 4.25. Other Roman scenes show vessels with a third mizzen mast, as shown in Figure 3.8 (Friedman, 2011, fig 3.7.20) while Figure 4.33 shows a triangular topsail. In terms of the development of seafaring it is interesting to note that Figure 4.33 also shows evidence of shrouds on the mainmast. The complexity of the form of these suggests that this was not the first instance of their use. A comparison of the vessels in Figures 4.32 and 4.33, with those shown in Figures 3.7 to 3.10, raises the issue of which sailing rigs were used on which vessel types in this period. A comparison of the hull forms displayed suggest two different types of vessels were being portrayed. One of the vessels depicted in Figure 3.8 has a hull form that is similar to those in Figures 4.32 and 4.33, this hull form is commonly associated with sailing ships. However, the other vessels shown have the protruding bow that might be more commonly associated with the galleys in Figures 3.9, 3.10, 4.18, 4.21 and 4.23. The use of either two or three masts on both vessel types will form the basis of much of my discussion in later chapters.

4.3.2 Textual evidence

Early Greek texts that provide an insight into common vessel sizes are cited by Casson (1971, 183-184), this is based on information from Greek cities in the 4th century BC. These texts record citizens who were honoured for donating either single or double cargoes of grain in times of need. A summary of this is provided in Table 4.1. The list provides ten donations most being between 95 and 120 tons, with occasional donations over 150 tons. If it is assumed that these donations related to the capacity of a single vessel then they probably provide a guide to the size of merchant vessels in use at the time. Casson goes on to note a similar donation of oil which implied a vessel of around 100 tons. Further evidence regarding the size of sailing ships in use in this period may be found in Thucydides (*VII. 25.5*, trans, Smith, 2015) regarding events in the Peloponnesian War. The relevant passage stating: 'The Athenians brought up against the piles a ship of ten thousand talents burden.' The matter-of-fact manner in which this vessel is described suggests that vessels of +/- 250 tons may have been in common use at this time.

While accepting the qualifications noted in section 4.2.2, Plutarch in *Marcellus* (*14.8*, trans, Perrin and Cohoon, 2015) records in relation to a large ship of the period that: 'Hiero was astonished, and begged him to put his proposition into execution, and show him some great weight moved by a slight force. Archimedes therefore fixed upon a three-masted merchantman of the royal fleet.' The interest here might be that the description refers to a ship, rather than the ship, perhaps suggesting that a number of vessels were equipped in this manner. If this is an accurate account of the event, then vessels of a size that required three masts may have come in to use by the 3rd century BC. This may suggest that some of the features noted in the 2nd century AD Roman vessels from the Piazzale della Corporazioni may represent examples of earlier Greek usage. It is also possible that this was a case of Plutarch projecting Roman technology, with which he was probably familiar, back to an earlier period. It is perhaps relevant in terms of the points raised in 4.3.1 that the term ship in this context might relate to either a galley or a sailing ship.

The mid-3rd century BC port regulations of Thasos discussed by Nantet (2020, 79) provide further insight into the hierarchy of vessel sizes in use. These state the sizes of vessels that may use different parts of the harbour and prohibited vessels of 3000 talents or less (+/- 61 tons) from using the outer harbour, while restricting the inner harbour to those of greater than 5000 talents, (+/- 102 tons).

A brief review of Roman trade in grain, and the size of the vessels used to supply this, provide further evidence of vessel size along with the attempts made by the Roman state to influence and regulate their use. Suetonius records the attempt by Claudius to manage this in *Claudius* (*18-19*, trans, Bradley and Rolfe, 2015). This records how the state assumed the risk, and any resulting expense arising from the loss of ships in storms, and 'offered to those who would build merchant ships large bounties, adapted to the conditions of each.' This legislation then does not discuss vessel size. However, it implies that the state was attempting to influence the construction of ships optimised for grain transport, and providing incentives for their use in this regard. Later, in the 2nd century AD, the issue of size is recorded by Gaius (*Institutes 1.32c*, trans, Gordon and Robinson, 1988) where he records: 'Again, by an edict of Claudius, Latins acquire the right of citizenship if they build a sea-going ship with a capacity of not less than ten thousand bushels of grain, and that ship, or any replacement for it, carries corn to Rome for six years.' Houston (1988, 558-559) suggests that the phrasing of the legislation outlined implies that, at this time, owners of small vessels were involved in the trade, but that the state may have been acting to discourage this. His conclusion being that, rather than an inability of smaller vessels to transport grain, the legislation represented attempts by the Roman state to simplify its logistics. In this respect it would presumably have been easier, and provide more assurance, for the authorities to deal with a small number of large ships making regular deliveries, rather than a large number of small vessels working on an ad hoc basis. Overall; however, it is clear that the literary evidence supports the shipwreck evidence in Parker (1992) and [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022, both of which show a wide range of vessels in use at this time.

Evidence for perhaps one of the largest ships of the period may be found in Lucian, this was recorded in a satire *The ship or; The wishes* (*V. 5,* trans, Harmon et al 2015). This recounts the size of a large vessel of the 2nd century AD '… a huge ship! A hundred and twenty cubits long, the ship-wright said, and well over a quarter as wide.' In the measurements of the present time the dimensions of this vessel would be around 55 metres in length, and around 13.7 metres in width https://www.convertunits.com. Houston (1987, 444-450) comments on the probability that vessels of this size were unlikely to have been part of regular commercial usage, but rather were more likely to have had a particular, possibly state sanctioned, purpose. As such, they might be viewed as the extreme size possible for vessels of the period. It is noticeable that this size exceeds any vessels recorded in either (Parker, 1992) or the [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022.

Textual evidence of this period is not restricted to references to large sailing vessels. Cicero in *Orations concerning Verrem 2.5.44* (trans, Greenwood, 2014) records the use of 'a cargo-ship, a very large one, as big as a trireme.' This statement being part of a case in which Cicero was accusing Verrem of corruption, in particular that Verrem had the people of Messana build this large vessel for his use at public expense. It may be significant in this context that Cicero is using a trireme, that is a galley rather than a sailing ship, as a basis for measuring a large ship. This might suggest that the vessel being described was itself a galley, or that sailing ships of the period were in general smaller than large galleys. The possible implications of this on the development of large sailing ships at this time will be discussed in relation to the Madrague de Giens vessel in sections 4.3.3 and 6.3.4...

The textual evidence then supports the iconography in showing that large sailing ships came into use in this period. It also provides evidence that these were used in conjunction with large merchant galleys, along with a substantial fleet of smaller sailing vessels, and that all of these types may have been used to trade in the same range of products, presumably over the same trade routes.

4.3.3 Archaeological evidence

The first available archaeological evidence from this period is the wreck Gela 1, this 18-metre vessel was found off Gela Sicily and has been dated to the early 5th century BC (Kahanov and Pomey, 2004, 18). This was a further example of a vessel constructed by a combination of stitching and mortice and tenon joints. Interestingly the wreck site also contained some lead sheeting which Panvini (2001, 24) records may have been fitted to the hull as an anti-fouling measure. The hull of this shows that it was a sailing vessel with an external keel and mast step (Panvini, 2001; Kahanov and Pomey, 2004, 18; Polzer, 2009, 73-78; Davey, 2016, 37). A second wreck from the same area Gela 2, also constructed by a combination of stitching and mortice and tenon joints, is estimated to have been between 17 and 18 metres in length. This vessel has been dated to the third quarter of the 5th century BC, at the present time this is the first recorded instance of the use of a wine glass hull form (Kahanov and Pomey, 2004, 18). Further examples of vessels with this hull type will be discussed later in this section.

A more substantial wreck from this period is that found at Alonnesos in the Northern Sporades dating to the late 5th century BC. This vessel is estimated to be around 25 metres in length and its cargo of Amphorae suggests a capacity of around 125 tons (Hadjidaki, 2009; Polzer, 2009, 88-90; Davey, 2016, 37). This vessel is unambiguously a large round ship; however, the excavations to the present time have not revealed details of the hull or its construction. Without evidence of the hull structure, it is not possible to determine if this was fitted with more than one mast, similarly it is not possible to determine the means of construction of the hull. Evidence for a further increase in the size of the largest wrecks in the general population of merchant ships from the 5th century BC through to the 2nd century AD can be seen in Table 2.1. It is not proposed to examine all of these; rather, in the following I will highlight particular features of vessels relevant to the discussions in Chapters 5 and 6. In this regard, one of the earliest vessels of relevance is the Ma'agan-Michael wreck of ca.400 BC. This vessel was found around 35 km south of Haifa and was approximately 13.5 metres in length. A number of authors record details of the construction of the vessel by a mix of stitching and mortice and tenon joints (Kahanov and Pomey, 2004, 6; McGrail, 2004, 135-136; Steffy, 2017, 40-42). All note that the stitching was primarily used in the ends of the hull, it is possible then that this was representative of a transition in the means of vessel construction. McGrail records that the wine glass profile of this vessel would have enhanced the strength of the hull and reduced leeway, the same comment presumably applies to the earlier Gela 2 vessel. Although this vessel was found in the eastern Mediterranean, off what is now Israel, Kahanov and Pomey (2004) locate this ship within the Greek shipbuilding tradition.

The later Kyrenia ship from the late 4th century BC was a 14-metre vessel constructed using frames and pegged mortice and tenon joints (Katzev, 1981, 318; Steffy, 1985, 43-45; McGrail, 2004, 149-151; Pomey, 2004, 29-30). None of these authors discuss why a vessel of this size might have been constructed by mortice and tenon joints throughout its hull, rather than having at least some of its timbers stitched. In the context of a process of vessel development, I consider this point to be worthy of review given the large number of wrecks of similar size, or indeed larger, built to this point which were constructed using a combination of joint types. I will discuss this issue in more detail in section 6.3.2. Figure 4.34 shows the hull timbers and joints from the Kyrenia ship, Steffy (1985, 81) records that the average length of the tenons were around 8 cm, these having a variation between 4 and 10 cm. These joints then are broadly similar to those used in the Mazarron 1 wreck, but they are significantly shorter than those used in the Uluburun hull. Steffy (2017, 46-49) records that 'these tenons, at least on the Kyrenia ship, were more than mere seam connectors…these slips of wood also acted as small internal frames.' Steffy goes on to record that 'the Kyrenia ship's planking shell was its primary structure; more than half the hull's strength was vested in this skin' (48). Later; however, Steffy appears to qualify this when he notes that: 'It seems unlikely that the shipwright went beyond the bottom planking before installing floor timbers. It would have been advantageous to use the added rigidity they supplied before setting the heavy wales above' (49).

Steffy appears to be very definite in making these statements; however, in doing so he makes no comparison with the joints on either the Dashur or Uluburun hulls. A comparison between all of these vessels might explain how two such widely varying forms of mortice and tenon could both act as efficient internal frames. It might also have been useful to have Steffy's observations on the role of frames in the Kyrenia ship if the joints also served this purpose. This might also raise the question as to what Steffy meant by the term strength in regard to the hull of the vessel. On its own this term provides little information, Steffy failing to state whether this refers to compressive strength, tensile strength or tortional strength. Steffy also fails to provide a record of how this was either estimated or measured. The final statement on the role of the floors perhaps provides a more balanced picture of the role of the internal timbers in providing rigidity to the hull. Steffy's comments predate the work of Tejedor (2018) on the Mazarron 1 wreck. On this vessel frames along with mortice and tenons of similar length were used; however, in this case Tejedor (2018) makes no suggestion that these latter features acted as internal frames.

The wine glass hull form of both the Ma'agan-Michael and the Kyrenia ships, the latter shown in Figure 4.35, are composed of a combination of convex and concave curves. The combination of the deep section of the hull as this extends down to the external keel results in the lower hull acting as an extended beam, so providing additional longitudinal stiffening to the vessel. At the same time, in providing additional depth to the hull, this assists in preventing the vessel making excessive leeway. The final compound form of the curves would, at least in part, have been determined, or maintained, by the shape of the frames. Steffy notes the relative independence of the shell from the support of frames through its construction; however, he does not discuss the role these may have played in the use of the vessel at sea. Both Steffy (1985, 83; 2017, 56-58, Fig 3-42) and McGrail (2004. 151) note that the wreck of the Kyrenia ship provides additional evidence of the practice of sheathing a vessel in lead below the waterline.

The Marsala shipwrecks from the late 3rd early 2nd century BC are galleys, as such, they are anomalies in the series discussed up to this point. These vessels were Punic in origin and were originally described as a single war galley; however, later re-interpretation of the wreck site suggests the finds comprise the remains of two merchant galleys (Averdung and Pedersen, 2012). Perhaps the most significant features of these wrecks relate to the construction of Marsala 1 using mortice and tenon joints, along with its use of an extended forefoot. The form of this latter feature was used to conduct model tests on how a bow having this configuration may have allowed a vessel to run up onto a beach. The data presented in Averdung and Pedersen (2012, 129-131) confirmed this was the case. As galleys were largely limited to coastal voyages, and frequently came into the beach to rest the crews, this feature would clearly provide advantages to the vessels in use. From this it might not be unreasonable to assume that this function may have been a contributory factor in the introduction of this feature on vessels of this type, and may have contributed to its long-continued use.

The later Madrague de Giens wreck from the mid-1st century BC is described as carrying '400 tons of cargo' (Parker, 1992, 249; Pomey, 2015, 80). On this basis it is widely regarded as an early example of a large Roman sailing ship. The hull of this is recorded as having been constructed using a double skin of timbers joined by mortice and tenon joints (Pomey 2004, 30; McGrail, 2004, 155-158; Steffy, 2017, 62). A cross section of the hull of this vessel, shown in Figure 4.36, is similar to the Kyrenia ship; however, the shape is fuller with more breadth in the lower hull. This vessel is used by Pomey (2020) to make a case that as hull forms became fuller, with more internal framing and floors, there was less emphasis on a wine glass shape and an external keel. Pomey (2020, 46) suggests that this change resulted from the external keel being a point of structural weakness in a hull of this size and shape. It is also possible that it may have been the result of learning that the vertical sides of a deeper hull acted in much the same way as both a structural and external keel, and that a fuller flat-bottomed hull was simpler to construct and provided greater cargo capacity. Pomey (2015, 79-80) records how he based his reconstruction of the hull on that of a vessel shown in a mosaic from Themetra. This vessel has a similar hull form to the merchant galleys shown in Figures 3.8 through to 3.10. Pomey (2020, 36) notes that the reconstructed hull form would 'make the ship very stable at all sailing trims.' Pomey in this comment does not address the problems that might arise from the use of this extended forefoot. These problems were highlighted in section 3.2 where they were referenced to those experienced by Severin (1985, 168-170). It is perhaps relevant that there is no evidence that sailing ships of any size through to the end of the 19th century employed this hull form, and that the iconographic evidence of later large Roman sailing ships in Figures 4.32 and 4.33 show vessels with steep cutaway bows. Taken together this might suggest that this hull feature may not have been connected with the performance of the vessel under sail. I will present an alternative explanation for these differences in section 6.3.4. In these discussions I use the hull shape of this vessel as an example of how learning relating to the construction and use of large galleys may have influenced the development of some early large sailing ships.

There is one final piece of evidence that is relevant to the case that will be presented in the remainder of this thesis. This comes from the Les Laurons B wreck from the late 2nd century AD, a proposed reconstruction of which is shown in Figure 4.38 (Gassend et al, 1984, 84). This 13.3 metre vessel was found in the Gulf de Fos off the coast of Marseille. This wreck was found with evidence suggesting the use of shrouds as shown in the reconstruction. The evidence from this wreck then suggests that by this date even small sailing ships had this form of standing rigging.

4.3.4 Summary

The following summarises the key points of section 4.3. These will be used to support the discussions around the final form of maritime technical development in the period that will be presented in section 6.3.

1. There is widespread evidence for an increase in the size of the largest sailing ships through this period, this is accompanied by evidence for an increase in the numbers of intermediate size vessels.
2. The hull forms used for sailing ships takes on a variety of shapes, some of these might be later adaptations of the wine glass shape apparent in the smaller sailing ships in use by the middle of the period.
3. There was no significant change in the shell first method of construction; however, shorter mortice and tenon joints, in conjunction with hulls supported by frames, appear to become widespread as a means of hull construction.
4. There is evidence that merchant galleys not only continued in use but showed the same increase in size as noted for the sailing ships of the period.
5. There is evidence suggesting that some early large sailing vessels may have shared hull characteristics with large merchant galleys of the period. If this was the case then there are clear implications in regard to both vessel use and learning in the period.

6. Iconographic and textural evidence shows the use of more complex sailing rigs on multiple masts. From the iconography this development appears to be common to both merchant galleys and sailing ships.

4.4 Conclusions

This chapter has focused on the presentation of three lines of evidence each of which presents individual findings but all of which are in broad agreement on the following major outcomes:

1. Hybrid rowed and sailed round ships probably came to dominate trade between 1500 and 1000 BC. In this period the sail type changed from a boom-supported sail to a loose-footed form controlled by brails. There is no evidence for the development of true sailing ships or any vessels with an external keel in this period. Similarly, there is no evidence that any of these round ships exceeded an upper size of around 16 metres.
2. In the period 1000 to 500 BC sailing ships came into use but the development of these was accompanied by the widespread use of larger merchant galleys. The hull forms of the early sailing ships were similar in shape to those of the hybrid rowed and sailed ships of the Late Bronze Age. There is no evidence that the development of sailing ships was linked to an increase in the size of round ships, and it was only in the final century of this period that there is evidence for this vessel type exceeding 16 metres in length. Most excavated wrecks of the period from the central or western Mediterranean preserve hulls which are either wholly, or partly, constructed by stitching the timbers together. The only exception to this general pattern may be traced to the influence of a Carthaginian trading system in Spain. The iconography of the period suggests all vessels used a rig with a single loose-footed sail.
3. Following 500 BC the hull form of sailing ships underwent a change to a wine glass shape that would enhance sailing performance. At the same time the size of both sailing ships and merchant galleys increased significantly. This size increase was accompanied by an increase in the complexity of the sailing rigs in use, although these still used brail controlled loose-footed sails. The range of sizes

shown in the archaeological evidence suggest that the use of large ships was supported by a hierarchy of smaller vessels that spanned a wide range of sizes.

4. The continued use of a large number of small vessels, along with merchant galleys, suggest that many seafaring practices were similar to those of the Bronze Age and Archaic period. This might suggest that maritime trade was still predominantly coastal in nature.

5. Throughout the period there was a change in the manner in which round ships were constructed. The evidence from the earliest wrecks shows two means of construction: the first had a rigid shell supported by long mortice and tenon joints, the second a flexible stitched shell supported by frames. However, by the end of the period most vessels larger than 16 metres used short mortice and tenon joints in a shell supported by frames.

5.0 Vessel capabilities and limitations

The content of my thesis to this point has highlighted what I consider to be the gaps, and misunderstandings, in the presentation and use of the evidence. I have linked these gaps, and misunderstandings, to the lack of a robust taxonomy of vessel types based on their use and capability, coupled with a lack of a model for a development process for vessels based on the nature of learning in the ancient world. Chapters 2 and 3 highlight these shortcomings and provide a taxonomy, and a framework of learning and development, that might bridge these gaps and misunderstandings. The previous chapter has completed this process by presenting a review of the current evidence regarding vessel types and sizes in the period. The purpose of this chapter is to outline some of the capabilities and limitations of the major vessel types in use through the period 1500 BC to AD 200, and to answer the following questions:

- Why is there no evidence for round ships greater than 15 or 16 metres before the 6th century BC when substantially larger vessels appear more common following this time?
- What was the motivation to construct merchant galleys, and why do the literary and iconographic records provide evidence for their use for such an extended period?
- Why did it take so long for the use of large sailing ships to appear in any line of evidence when large merchant galleys were clearly fulfilling a trading role?
- What were the motivations for the development of the foresail, and what vessel types may have been the first to use this?

Before starting on an examination of these questions it is worth recalling the point made at the beginning of Chapter 2. A hybrid vessel, dependent upon both sails and oars, must be capable of being both sailed and rowed when the conditions either allow or demand. The question is where is that limit for the various designs of this vessel type? An understanding of this will underlie much of the discussion in the first two sections. To briefly summarise the evidence presented to this point. Apart from early paddled and rowed craft, there is no evidence for a vessel with a hull with the characteristics of anything other than a hybrid rowed and sailed ship in the archaeological record before the 7th century BC wreck of the Mazarron 1. The form of the external keel and mast step of this vessel represent the most significant features required in a sailing ship. However, the hull shape of this vessel was similar to that of the Bronze Age Uluburun ship. This suggests that the vessel was probably not optimised for performance as a sailing ship. The evidence then suggests the probability of a long period of use of hybrid rowed and sailed vessels. This suggestion is supported by the textual evidence from Homer regarding 20-oared merchant vessels, along with that from Parker (1992) and the shipwreck data base in [http://oxrep.classics.ox.ac.uk/databases/shipwrecksdatabase.html] 1/1/2022, summarised in Table 2.1. Together these show that currently there are no physical remains of round ships that exceeded 15 or 16 metres in length in the period leading up to the date of the Mazarron 1 wreck. A summary of the contents of this chapter is presented in Table 5.2.

5.1 Hybrid rowed and sailed vessels

5.1.1 The size limitation of hybrid rowed and sailed round ships

To determine the possible reasons for the maximum size of around 16 metres for hybrid rowed and sailed round ships it is necessary to step outside of archaeology. To achieve this, I will examine this issue using some basic principles of structural engineering and mathematics. For this purpose, the most appropriate tool is the Square Cube Law. The impact of this law on the scaling up of similarly shaped objects was explained by Galileo in *The Discourses on two New Sciences* first published in 1638. This law states that for any regularly shaped object, if all of the dimensions are increased equally, the surface area and the volume, and hence the capacity and mass, increase in fixed ratios. A simple example of this shows that if all the linear dimensions of a solid cube were to be doubled, its surface area would increase by four, while its volume and mass would increase by eight. The application of this technique to a hybrid vessel such as the Uluburun ship shows that, if all of its dimensions were doubled, its volume, and hence its cargo capacity, would increase by around eight.

There is an obvious problem in scaling up the size of a hybrid rowed and sailed vessel in this manner, as the following example will show. If Homer's 20-oared merchantman can be taken as an example, then based on the number of oarsmen, this might be broadly similar in size to the Uluburun vessel. If this was doubled in size the resulting vessel could probably fit between 40 and 50 oarsmen in a single bank along the sides. However, if the ship retained the same round ship proportions, then its cargo might increase from the 20 to 30 tons estimated for the Uluburun vessel, to between 160 and 240 tons. This in turn would impact on the load on the oarsmen. In the smaller vessel each oarsman would be pulling the product of 20 to 30 tons divided by 20 rowers, or between 1 and 1.5 tons. In the larger vessel; however, the 40 or 50 oarsmen might be expected to pull between 160 and 240 tons. Assuming this to be divided by a maximum of 50 rowers the increase in the size of the vessel would result in each pulling a load of between 3 and 5 tons. It hardly needs saying, but if oarsmen could consistently pull loads between 3 and 5 tons then the smaller vessel, of between 20 and 30-tons capacity, might only require between 4 and 6 oarsmen. This is considerably fewer than the 20 oarsmen which is a figure referenced in contemporary texts, and suggested by much of the iconography of the period.

In addition to this obvious drawback the surface area of the vessel would have increased by four. If it is assumed that the same percentage of this was below the waterline then this would also increase by four. It is the surface area of the hull in contact with the water that provides much of the frictional resistance that the rowers are attempting to overcome in propelling the vessel. It is also the surface area on which any adverse current and wave action takes effect. In the case of this larger vessel this surface area would also increase relative to each oarsman. The same issue would also relate to the problem of windage, that is, the impact of the wind on the hull of the vessel above the waterline. The larger sized round ship would stand higher out of the water. This in turn would result in the vessel encountering more windage as its size increased. As a result, when rowed, the oarsmen would also have to overcome this greater load. The result overall would be a vessel with greater deadweight loads on each oarsman making it harder to row, along with higher dynamic loads making it harder to control. This does not appear to be a logical outcome for the process of invention and innovation based on learning in iterative steps outlined in Chapter 3. Most applications of this model are based on the assumption that each step would bring a marginal improvement in performance, this improvement providing the motivation to continue the process. This would hardly be the case if for each step up in size the ship became increasingly hard to row and control.

On the basis of the case presented it seems probable that there was an optimum size and tonnage for a hybrid rowed and sailed round ship. The application of the square cube law suggests that this size limit was probably determined by the load that a rowing crew might have been expected to pull for a shift at sea. The consistent literary and iconographic references to vessels with crews of around 20 oarsmen is recorded in Chapter 4. Coupled with this is the evidence from the shipwrecks shown in Table 2.1 indicating a maximum size of vessel of around 16 metres from the Late Bronze Age to the Archaic period. Taken together these might suggest that for hybrid rowed and sailed ships the maximum load that each oarsman could pull for a working shift was probably between 1 and 1.5 tons. I contend that it was this combination of factors that limited hybrid rowed and sailed round ships to a maximum length of around 16 metres. These discussions are clearly speculative, there are no records that explain why vessels of this kind were limited to these sizes. However, it is difficult to escape the conclusion that empirical learning of the time had informed shipwrights and merchants of the negative effect of attempting to increase the length of hybrid rowed and sailed round ships much beyond 16 metres.

5.1.2 The merchant Galley

A possible route to the genesis of the merchant galley is outlined in Wedde (1996), in this Wedde consistently links the development of this vessel type to higher speeds. In this section I propose an alternative motivation for the development of this vessel type, that of increased size and cargo capacity. The following will review both of these possible motivations, the case for speed proposed by Wedde will be examined first. As with the case for the round ship outlined above it is appreciated that the following is conjecture, this; however, has been based on an examination of the relevant evidence.

Some of the problems associated with Wedde's 1996 paper have been discussed in section 3.2. In this it was noted how this paper contained the implication that early galleys appeared to share characteristics with the more complex vessels of the Late Archaic or Classical periods. In this earlier section I discussed the implication in the case made by Wedde that these early galleys may have formed part of a process of directed development aimed at producing these later, faster, galleys. On this basis perhaps the most fundamental questions posed in this case are: what are the range of speeds proposed for these vessel types, and what may have provided the motivation for this speed?

Coates, (1987 fig 2) presents estimates of what he considers to be the maximum continuous speed in knots of a number of galley types, these are shown in Table 5.1. Coates is not specific on the types of vessels; however, the bireme and trireme types might be considered to be war galleys, and the single bank triaconter and pentaconter might be assumed to have either been trading or raiding vessels. If correct, these figures show that a single bank pentaconter, that might be considered to be the standard merchant galley of the Archaic period, was only slightly faster than a triaconter. Although both of these vessel types might be considered to have been used as early war galleys, if Coates is correct in his estimates, both could only manage a consistent speed somewhere between a brisk walking pace and a slow jog. Neither then might be considered to be really fast. Again, assuming Coate's estimates are correct, the most significant increase in speed in galleys arose with the multibank forms equipped with rams. There is evidence from the palace of Sennacherib that this type was in use in the late 8th century. The speeds of these; however, were still only in the range of a fast jog. As a comparison to these speeds Katzev (1987, 250) shows that on the first voyage of the Kyrenia II the vessel achieved an average speed under sail of 2.95 knots for a 414 nautical mile voyage. This was achieved in a range of wind and weather conditions, on three days, presumably when the wind was most advantageous, the vessel averaged over 4 knots. Katzev (1987, 252) goes on to state that on the return journey in winds of 25 knots Kyrenia II reached speeds of 12 knots, and for one 24-hour period sailed 138 miles at an average speed of 5.75 knots. These figures suggest that, in favourable winds, a small round ship under sail could probably match the performance of all but the fastest galley when rowed.

What has to be understood in regard to the speeds shown for galleys is that the energy required was supplied by the oarsmen, while on the other hand the energy used by a ship under sail is provided by the wind. Energy in the context of a moving object is expressed in the equation $E=1/2mv^2$, where *E* is energy, *m* is mass and *v* is velocity. It can be seen then that when the speed is doubled the energy required increases by four. It is clear then that, where the oarsmen might also be the combat crew, there was a clear advantage in avoiding the prolonged use of high speed before combat began. This might suggest that the best tactics when using a galley would lie in sailing up to an opponent, alternatively, any pirate using this type of vessel, could lie in wait and ambush a vessel from a sheltered location. The result of both scenarios being a short final chase under oars before combat began. In both cases the short-range sprint speed under oars would be the most important. This might be supported by an observation in Vegetius (*IV.45,* trans. Milner, 2001) explaining how, and why, ambushes are set in naval warfare. In this he states that: 'Just as in land warfare, descents are made upon sailors who are unsuspecting, and ambushes are laid about suitable narrows between islands.' Going on to note the advantage to be gained: 'If enemy sailors are weary from lengthy rowing.' In these passages Vegetius is clearly emphasising the advantage of using short bursts of high speed to take advantage of tired crews.

At sea it seems probable that on a downwind course a galley could sail at least as fast as the Kyrenia II. The comment of Plutarch (*Life of Pericles, 26.4*), discussed in section 4.2.2, that the *samaina* was a swift sailer, perhaps reinforces this by commenting on the speed under sail rather than oars when describing this vessel type. This might be confirmed by the later records of Medieval and Renaissance galleys making voyages under sail whenever possible. However, the generally narrow beam of these vessels, and their low freeboard, meant that they were more inclined to roll than round ships. This feature accounts for the greater danger of swamping in these vessels if they attempted courses with the wind on the beam (Guilmartin, 2003, 73; Pryor, 2004, 208-209; Dotson, 2004, 219-220; Higgins, 2012,26). In a general comment on the operation of galleys Severin (1985, 80-81) observed in regard to the Argo 'that moving a 20 oared galley into a headwind by oars was a futile exercise in nine cases out of 10.' These factors suggest that when used to attack other ships galleys probably drew most advantage from their oars in surprise attacks, or in conditions of relative calm when the speed of sailing ships was limited. It seems clear that for a galley to successfully attack a ship under sail particular conditions would need to be met; and where an escape route existed to open water, where high waves and stronger winds might be expected, a ship under sail had every chance of escaping.

This might raise the questions, what was the purpose of these early galleys, and what are meant by the terms combat and piracy in the Bronze Age and the Archaic period? The *Odyssey* (*IX*) records the raids against towns and flocks carried out by Odysseus on his return from Troy. This might suggest the primary objective of much pirate activity in the Bronze Age, and possibly down to the 6th century BC, may have been the raiding of shore targets and those locations where ships came in to rest their crews and shelter from the weather. If a pirate is viewed as a merchant whose basis of trade is violence, rather than in the exchange of goods, then, as merchants, pirates would probably be looking for the maximum assurance of a financial return on a voyage at the lowest risk of loss. In this respect a shore target, or an ambush site similar to that described by Vegetius, would be desirable as it is static. A target such as this can be reliably reconnoitred, an assessment of its vulnerability and wealth can be made, and an attack more easily planned. If this interpretation is correct, then it might have been advantageous to a pirate to have a large vessel. A vessel of this type would carry more attackers and provide the space needed to carry off slaves, or any other goods gained in the encounter. This might suggest vessels intended for this use shared design objectives with merchant galleys in having a focus on cargo capacity rather than pure speed. None of this is to suggest that any opportunity for a vessel of this kind to take a slower merchant ship would not be exploited. However, it is probable that, when used for this purpose, the large rowing crew in a single bank pentaconter galley would afford it the sprint speed to successfully attack a potentially heavily laden merchant ship.

The observations made in this short section are intended more to highlight the uncertainty that may exist regarding some aspects of the use of galleys at the time of their development. I appreciate that the case I have presented is conjecture regarding the tactics that may have been employed by pirates of the period. However, there is no evidence that a similar analysis of tactics has been made to support the case for speed as a design objective in early galleys. What might be said with certainty is that it is probably a mistake to link the performance and design characteristics found in later galley types with a requirement for these in earlier vessels. Clearly as vessel types became more differentiated, with more specialist forms arising, some would almost certainly have been more optimised for speed than others. However, the impact of these differences in any combat situation has to be judged in combination with the circumstances under which the combat may have taken place. That speed was almost certainly not a universal determinant may be appreciated by the later development of large polyremes (Casson, 1971, 97-123; Morrison and Coates, 1996; Morrison, 2004, 66-77; Murray, 2012).

Rather than speed the following case examines how the development of merchant galleys may have been based on a need for the cargo capacity of a larger vessel. The following discussion will highlight the problems that arise in attempting to combine an increase in the speed of a rowed vessel with an increase in the cargo capacity. These problems might account for the lack of reference to the rowing speed in the primary sources which discuss the use of merchant galleys in the Greek Archaic and Classical periods. The problem of increasing the size of the hybrid rowed and sailed round ship has been discussed above in section 5.1.1. If; however, a vessel of the size and type of the Uluburun ship were to be increased in length alone then the cargo capacity would increase in proportion to the length. Most of any increase in the length in this case would probably be taken up by an increase of the length of the vessel at its maximum width. In the case that the length was doubled in this fashion then the cargo capacity would probably increase to slightly more than double that of the original round ship. This might lift the original cargo capacity of between 20 and 30 tons to a capacity between 50 and 75 tons. The same increase in length of the vessel at its maximum width would also allow the rowing crew to increase to between 40 and 50. The result would be that the load on each oarsman would probably be around the same as that of the smaller vessel. However, the resulting vessel would have the proportions more closely associated with a galley. Due to the manner in which this increase in size was achieved the wetted surface area of this would also only double, meaning that there would be little net increase in load on the rowers. Also, the fact that only the length had been increased, rather than the height, would mean that there was no significant increase in windage. It is perhaps worth recording that, with the similarity in the load on the oarsmen, it is difficult to make a reasoned case that loaded galleys built to these proportions would have been substantially faster under oars than a loaded round ship.

At this point it is worth recalling the comments by Usher (1954, 68-69) relating to the slow rate of learning in the ancient world, and the comments of Unger (1994, 7) regarding the conservatism of those building and operating ships. Changes from a vessel with the form of a round ship to a galley would appear to align with these observations. The resulting changes in vessel form and size may also accord with the point made in section 3.1 regarding the potential difficulties of making large scale changes to vessels constructed shell first. It might easily be imagined that the process proposed above occurred as a series of iterative developments, in each of these the length of the vessel was increased in a series of small steps, each of these being intended to make a small increase in the capacity of a known vessel type. The result being that the form moved away from one associated with a round ship to one associated with a merchant galley. The upper limit to this increase in size would probably be a function of the longitudinal stiffness of the larger vessel. It was noted in Chapter 4 that early Egyptian sea going vessels had long hulls and required a hogging truss to provide this stiffness. Morrison and Coates (1986, 170-172) discuss the use of an undergirdle, the hypozoma, in Athenian triremes of the 5th century BC to provide the same function. These latter vessels; however, probably gained an advantage in speed and manoeuvrability in combat by retaining a lightweight hull. A hull of this type could probably be easily supported in this manner. In addition, these vessels tended to be stored out of the water in sheds when not required. Any tightening of the hypozoma then could probably be managed when the vessel was unloaded, and possibly out of use. This was not the case with merchant galleys which were likely to have been in service on a more regular basis. It is also probable that while at sea these vessels carried heavier cargoes, and operated in a wider range of weather conditions. These factors would have resulted in merchant galleys having additional stress on the hull while having less opportunity to tighten a hypozoma. In this context it seems probable that, as the hybrid vessel type increased in length toward the form of a merchant galley, some means of stiffening the hull would be required.

The evidence presented in Chapter 4 shows that when merchant galleys are recorded in the archaeological record the hulls of these may have been constructed either by stitching, or by shorter mortice and tenon joints. Both of these methods of construction would have resulted in a flexible shell. In these cases, to provide the necessary stiffness, it is probable that frames and some form of structural keel would be necessary. As noted in the previous chapter the only maritime keels known from the Bronze Age are those of the Uluburun and Zambratija vessels, shown in Figures 2.11a and 4.20. However, these keels are still wider than they are deep, this orientation would not substantially increase the stiffness of the hull. In fact, by adding to its width the shipbuilders may have added unnecessary weight to the keel, this in turn would increase the tendency for the keel to bend under its own weight. This suggests that if Bronze Age shipwrights were attempting to stiffen the vessel, they did not understand the basic principles of a structural keel acting as a beam. What seems probable is that some time through the process of extending the length of these vessels this form of keel would have been modified to provide a true structural keel.

There is a further line of evidence related to oar mechanics that supports the advantages of the development of the galley form over that of a larger rowed round ship. 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 at its entry to the water (Guilmartin, 2003, 84-85; Bondioli et al, 2004, 181; Shaw, 2004, 167). An oar is more efficient in use when this angle is low. In any hybrid vessel the volume below deck might be expected to be reserved for cargo. If this is correct, then it would be desirable to keep the rowing crew at the level of the main deck. Scaling up a round ship would result in an increase in freeboard which would require the crew to operate further from the waterline. This would increase the angle of the oar on entry to the water. On the other hand, any development that extended the length toward a galley form would retain the low freeboard of the smaller round ship, this would maintain the efficient angle for the entry of the oar. The low freeboard of this vessel type came with associated disadvantages which restricted the nature of the voyages they could undertake (Dotson, 2004, 220; Higgins, 2012, 26). As discussed earlier, any attempt to hold courses with the wind or sea on the beam risked the vessel rolling excessively and being swamped. The result was that galleys were largely confined to coastal voyages, (Guilmartin, 2003, 73; Pryor, 2004, 208-209; Higgins, 2012, 2). On this basis it might be expected that the resultant trade routes would comprise largely coastal rather than offshore passages. The implication of this on the development of seafaring will be discussed in Chapter 7.

In regard to the load on an oar crew it is interesting to note the size of these on the later Venetian galleys. Casson (1971, 123-124) and Higgins (2012, 20) both note that at the beginning of the 15th century vessels with cargo capacities of 140-200 tons required an oar crew of 170. This suggests that this cargo weight, in combination with that of the hull of the vessel, would result in the load on each oarsman being similar to that calculated in section 5.1.1. Higgins (2012, 29) might be seen to add further support to this in observing that: 'By 1481, the galley's size increased so much that the Senate put a restriction of 210 deadweight tons maximum on the great galleys … due to the enlarged size, the galleys were unable to be maneuvered by oars.' The conclusion that might be taken from this is that it is not unreasonable to assume that the capabilities of the oar crew to propel the vessel would place limits on both the size, and the form, of hybrid rowed and sailed ships. The continued reference to 50-oared vessels through the Archaic period suggests that this may have represented an upper limit on the vessel type at this time. If, as noted in this section, later larger galleys were normally sailed whenever possible, it might be the case that any further increase in size would require an increase in the capability of the sailing rig. This issue will be examined in more detail in section 6.3.3.

A further point that is of relevance to vessel development overall is that, if merchant galleys were the largest vessels in use for a considerable period, and performed services of strategic importance to cities and states, it is probably not unreasonable to assume that large sailing ships did not exist. On this basis it might be expected that this vessel type would not only provide the focus for innovations in shipbuilding, but may have determined the main form of seafaring and navigation on which later developments were based. The implications of these links will be examined more fully in Chapter 7.

5.1.3 Conclusions

The foregoing has shown a link between the archaeological evidence relating to the size and type of hybrid rowed and sailed vessels, and the engineering requirements of vessels of this type. These suggest that:

1. It is unlikely that hybrid rowed and sailed round ships could be safely operated if they were much larger than 16 metres in length.
2. The motivation for the development of the merchant galley appears to have been related to the development of larger hybrid rowed and sailed vessels.
3. The maximum cargo load that an oarsman could manage through a working shift on a hybrid vessel of any kind appears to have been around 1.5 tons.
4. The consistent load on the oarsmen as hybrid merchant vessels developed probably meant that the speed under oars of fully laden round ships and galleys were broadly similar, and that both types were faster when sailed in optimum conditions.
5. There is no evidence that the early development of merchant galleys was related to the speed of the vessel when rowed. The vessels could probably make their maximum speed under sail.
6. The development of the pentaconter merchant galley in the Archaic period was probably dependent upon the development of a structural keel.
7. All hybrid rowed and sailed vessels were best suited to, and largely restricted to, coastal voyages. This requirement being a function both of their design and the needs of the rowing crew.

The implications of these findings might be that the merchant galley resulted from a process of innovation from an earlier more general vessel type. It is possible that one of the most significant earlier forms that may have influenced this development was the hybrid rowed and sailed round ship. It is also clear that the development of this vessel type is unlikely to have resulted in a change in seafaring skills and techniques, or of the trade routes in use.

5.2 Limitations, and increases, in the size of sailing ships.

In earlier sections I discussed how vessels with the characteristics of true sailing ships appear in the record from the 7th century BC, and that merchant galleys with larger capacities than 16 metre round ships had almost certainly been in use for centuries before this time. In this section I attempt to answer the question of why sailing ships substantially larger than 16 metres do not appear in the archaeological record until the 5th century BC. Pomey (2020) makes a link between the widespread adoption of mortice and tenon joints in ship construction as a possible contributory factor in this. Rather than focussing on vessel construction, as Pomey appears to have done, the approach I will take in the following focusses on factors associated with the operation of these large sailing ships.

The 5th century BC wreck found at Alonnesos is the earliest example of a wreck of a large sailing round ship. This was around 25 metres in length with a capacity of around 125 tons. This vessel demonstrates unambiguously that by this date sailing round ships were no longer restricted to 16 metres in length (Hadjidak, 2009; Polzer, 2009, 88-90; Davey, 2016, 37). The question posed by the dating of this vessel is why did it take so long for larger sailing vessels to be built and operated? If the motivation for the use of merchant galleys proposed earlier in this chapter is correct, then there was clearly a role for larger vessels. The textural evidence from Herodotus (*Histories I.163 and IV.153*) for the use of 50-oared galleys clearly demonstrates this. What should be appreciated is that a large sailing ship is not simply a small ship with all of the features increased in size. It is a more complex mechanism requiring additional equipment to become practical in an operational sense. If the model of iterative learning summarised in Figure 3.1 is accepted, then all of the subsidiary developments that make up the contributing development paths would have to have been in place before larger vessels could be operated successfully. The range of additional features required to operate large sailing ships is complex, some of these, along with others relating to social and economic motivations will be outlined in the following, and more fully discussed in Chapter 7. In the following discussions I will focus on the same issue that I raised earlier in relation to hybrid vessels; how could a large sailing ship be provided with sufficient power for both propulsion and manoeuvrability?

I suggest that the reason for the long period of time when 16-metre sailing vessels were the largest in use relates to the balance between the size of the vessel and the size and weight of their sails and yards. It is clear that as sailing vessels increased in size the weight of any single sail, along with the associated equipment that had to be raised and handled aloft at sea, also increased. It is my contention that sailing vessels of around 16 metres were the maximum size in which the sailing rig could be managed relatively easily by a small crew without complex lifting equipment. It seems probable that part of the motivation to change from a hybrid rowed and sailed round ship, to the use of a sailing round ship, would be to reduce the size of the crew. This would ease the logistical implications of feeding and watering a large number of men, in doing so, this would increase the length of individual voyages a vessel might undertake. This in turn would reduce the operating costs of a vessel while increasing the flexibility of this in use. It might be assumed that the increase in the size of the yard and sail possibly required in a merchant galley could be easily managed by the large rowing crew. However, in the case of a sailing ship, in any attempt to increase the size of the vessel, a balance would be required between the size of the crew needed to safely manage the ship, with the size of crew needed to manage the larger sailing rig. A consequence of this would be that, any attempt to continue to increase the size of a vessel while maintaining a small crew would ultimately require lifting equipment. I contend that the appearance of larger sailing ships was determined by the timing of the development of this lifting equipment.

5.2.1 The use of lifting equipment on sailing ships

It is possible to test the logic of this assertion by examining the case of two representative vessels used in contemporary experimental archaeology. The historic context and form of these vessels differ; however, the relevant factors of size and the use of a single square-rigged sail are consistent, they should then serve as analogues in this comparison. If we take a round ship of around 16 metres and equip it as a sailing ship, we have a vessel with a form close to that of the Kyrenia ship from the Hellenistic period. Reconstructions of this have demonstrated that without significant lifting devices a crew of four can handle the sails and operate the vessel, (Katzev, 1987). Figure 5.1 shows this reconstruction at sea, this is a useful indicator of the scale and nature of the hull along with the sail and standing rigging. However, once the size of a sailing round ship is increased the size and weight of the sails and yards also increases, as does the wind load on the sail and mast.

It is the combination of these loads that has to be considered in the context of the ability of a crew to safely operate vessels significantly larger than 16 metres when sailing in open waters. There are no reconstructions of larger vessels from the period in question that might allow a direct comparison to be made. An indication of the requirements that result from the increase in size can; however, be gained by an examination of the reports of the operation of the reconstructed Bremen cog. I appreciate that this vessel was built within a different ship building tradition. As a result, the structure of the hull, and its resulting shape, will differ to that of vessels from the Mediterranean in the time period examined in this thesis. Rather than the details of its construction, it is the size and the type of the sailing rig, and the record of its operation, that is particularly relevant in this discussion. Hoffman and Hoffman (2009) record three reconstructions of this vessel. These are between 22.5 and 24 metres long. Due to the three versions of this being built with different thicknesses of timber, and with slightly different hull forms, the loaded weights vary from 75 to 120 tons. These cogs are all larger than the reconstructed Kyrenia ship, while being broadly representative of the Alonnesos wreck (Hadjidaki, 2009). As noted above the hull of this has not been excavated, as a result, there is no indication of the number of masts fitted in this vessel. It is assumed here that even if the Alonnesos vessel had been fitted with a small foresail its primary propulsion would have involved the use of a large sail on the main mast.

Figure 5.2 is an example of one of these reconstructed Cogs at sea, this provides a good idea of the scale and nature of the hull along with the sail and standing rigging. A comparison with the Kyrenia ship in Figure 5.1 emphasises the manner in which the size and complexity of the mast and rigging grew with the increase in vessel size. What is of particular relevance in regard to the cog are comments by Hoffmann and Hoffmann (2009, 289) regarding the size of the sailing rig and its handling. In these they state: 'The cog replica was fitted with a mast that stands 24 m above deck; her yard is 14.6 m long and the sail has an area of 199 m^2. 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.' In regard to sailing these reproductions Hoffmann and Hoffmann go on to quote Captain Hans-Joachim Möller. In this they note that Moller was a ship's master with wide experience of sailing square rigged ships. In this regard they state that: 'Möller sails with a crew of not less than 12: to take in the sail against the yard in heavy weather needs one to two men at the sheets and two men at the braces, two at the clew lines and six at the buntlines, one to two at the tiller, and the captain to give orders. The yard with its length of 18 m and weight of three tonnes with the sail is too unmanageable and dangerous to be lowered down onto the deck to take in the sail, so it is kept aloft. The number of crew cannot be reduced with training: their physical strength is needed,' (Hoffmann and Hoffmann, 2009, 290-291).

There are a number of points of relevance in these statements. The first relates to the use of a winch and the problems involved in raising and lowering the yard. The later quote from Möller; however, provides insight into the difficulty of managing the sail and yard in heavy weather even with this assistance. What is of further relevance from this statement are the difficulties reported in operating the cog. These problems occurring even when some of the rigging on these appears to be equipped with compound pulley blocks. These features increase the mechanical efficiency of the crew, in doing so, they allow heavy loads to be managed with smaller numbers of men. The comments of Möller suggest that a large fit crew is required to handle the sail at sea, but that, even with this assistance, some aspects of sail handling are too dangerous to undertake in strong winds. It is important to note that these reconstructed cogs are largely used for day sailing. This suggests that these difficulties were experienced on inshore coastal voyages rather than extended offshore passages

It is apparent from these comments that to safely sail a vessel of the size of the Bremen cog, fitted with a single main drive sail, a range of lifting equipment is required. On this basis it seems reasonable to assume that a similar sized sailing ship in the ancient Mediterranean would have the same requirements. A reasonable question to ask from an operational perspective might be, in the period under review, did vessels lower the yard at sea? Toward the end of the period this might be answered by a passage in Seneca *Epistles* (*77.2,* trans, Gummere, 2014). In this passage Seneca states: 'Suddenly there came into our view to-day the "Alexandrian" ships, …For they alone may keep spread their topsails, which all ships use when out at sea, because nothing sends a ship along so well as its upper canvas; that is where most of the speed is obtained. So, when the breeze has stiffened and becomes stronger than is comfortable, they set their yards lower; for the wind has less force near the surface of the water.' The passage suggests the use of the same technique of lowering the yard when the strength of the wind increased. The implications of the term 'Alexandrian ships' in the age of Seneca might be taken to mean the arrival of grain ships from Egypt. This formation is likely to have included a substantial number of vessels at least as large as the Bremen Cog. If these assumptions are correct, then the sail handling described suggests that these vessels were probably equipped with the same range of lifting equipment.

This might pose the question, when did these technologies first appear in the historical record? Wilson (2010, 342) suggests that: 'There is no evidence for the use of cranes or hoists in architecture before the late sixth century BC'. While this is not proof of absence it is hard to see how winches, or any other kind of lifting equipment, might have achieved widespread use on ships before this date when the same technology appears to have been absent from use in building works onshore. The date recorded by Wilson in this regard is itself interesting. The earliest monumental stone temples in Archaic Greece are commonly considered to have been constructed from the mid-7th century BC in the north east Peloponnese around Corinth (Salmon, 1984, 60; Osborne, 2009, 199). Temples of this size and type are most likely to be the buildings on which lifting equipment would have been beneficial. I suggest a possible motivation for the development of lifting equipment at this time may have been to support the subsequent expansion of monumental architecture and construction by Greek communities. In Chapter 3 I noted how Unger (1994, 7) discussed how learning, innovation and the diffusion of new ideas, moved faster in societies with shared cultures and motivations. On this basis, I suggest that the shared language and culture of Greek city states, along with their competitive natures, might have provided an ideal environment for the rapid transfer and hybridisation of this technology from construction to maritime activity. Wilson (2010, 344) goes onto discuss the invention of the compound pulley, noting in this regard that, the first secure reference to this 'appears in the pseudo-Aristotelian *Mechanics* 18 (ca.270 BC),'but notes that 'Coulton (1974) argues on the basis of weights lifted in archaic and classical-period architecture that the compound pulley may have been known from the late sixth century BC'. However, Wilson goes on to qualify this by suggesting alternative means that might result in the same effects. Cotterell and Kamminga (1992, 90-94) are broadly supportive of these dates for both lines of technical development.

As I discussed above in regard to the first occurrence of an external keel on a vessel these dates only set a time when the devices are known to have existed, they do not disprove their earlier possible invention. However, given the significance of both devices to the construction of monumental architecture, and the manner in which innovation with regard to lifting equipment may have influenced the rapid expansion of the urban building programmes in Archaic Greece, it is difficult to imagine these developments having occurred much before the times suggested by these authors. If the Bremen cog is accepted as analogous to the operation of any square-rigged vessel of the same tonnage equipped with a single drive sail, then I suggest this may be used to estimate a date at which vessels of around this tonnage could be safely operated with crews of comparable sizes. Clearly it may have been possible to operate vessels of this size without lifting equipment; however, this is likely to have had an adverse commercial and logistical impact based on the very much larger crew size required. It is also likely to have entailed a substantial increase in the risk of operating the vessels in a range of weather conditions. The date provided by Wilson (2010) for the appearance of lifting equipment can be seen to have preceded the confirmed appearance of round sailing ships substantially larger than 16 metres in the shipwreck record shown in Table 2.1. It is clear that this does not prove a link any more than it is possible to be specific about the need for this requirement. However, if the development of galleys outlined above is correct there was clearly a motivation to build and use larger vessels at this time. In this context, the relatively sudden increase in the size of sailing ships after such a long period of stasis suggests some fundamental change in technology may have taken place at around this time. At the same time, the coincidence in dates supports the suggestion that the appearance of the winch might be linked to the operation of sailing ships significantly larger than 16 metres. Without this it is difficult to see how a vessel of the size of the Alonnesos vessel, equipped with a single drive sail, could be operated without an excessively large crew. The problem of carrying out the same operation on vessels of 450 tons, rigged in the same fashion, would obviously be orders of magnitude greater.

In terms of the model of learning discussed in Chapter 3, the relatively sudden appearance of lifting equipment in the field of maritime technology is probably best explained by the process of hybridisation discussed by Buckley and Boudot (2017, 20-21). In the model proposed by Usher (1954, 69, Fig 8), and shown in Figure 3.1, the development of lifting equipment might be assumed to have progressed down one of the subsidiary lines separate from those on the mainstream of maritime technology. This subsidiary line itself probably having numerous links to contemporary socio-economic developments. Their application to the field of maritime technology at this time probably being the result of the impact of social factors on technology noted by Edgerton (1999, 112).

The issue of operability in larger vessels does not appear to be the subject of much discussion in the technical literature. This is probably the reason authors such as Aubet (2001, 174) and Cunliffe (2017, 267) discussed the use of 450-ton vessels in the Archaic period and their earlier use in the Bronze Age. It might be expected that if the process of vessel development, and the operational issues around vessel use, had been more fully explored in the technical literature the assumption of this early use of large vessels would have been avoided. The issue of the use of compound pulleys is perhaps more nuanced. If the sail area of a large ship were reduced by use of the brails as the wind rose it may have been possible to keep the loads experienced by the crew handling these to manageable levels. However, the end result might be a vessel that was sailed very conservatively as the wind strengthened. In this case it might be legitimate to pose the question, how logical it would be to expect vessels to continue to be developed incrementally if they had already reached a size where they were unable to operate to their full potential?

There is clearly an alternative means of providing additional sail power to a sailing ship without the use of larger sails and yards. This could be accomplished by providing the vessel with two masts and sails of similar size to those in use on the Kyrenia ship. The first evidence of the conventional foresail on a sailing ship is that in the 5th century BC Tomba della Nave, shown in Figure 4.31. This is around the same time as documentary evidence from Athenian naval inventories record triremes being equipped with two masts (Morrison and Coates, 1986, 176-177). Unfortunately, as noted in section 4.3.1, it is not possible to determine the length of the vessel in the Tomba della Nave. The square cube law shows that small increases in overall vessel size would increase their capacity and weight significantly. The point at which any increase in weight may have required an additional mast and sail to deliver the additional power is unclear. There is clearly a potential problem with this as a process of incremental learning in terms of a round ship. In sailing vessels only a few metres longer than the Kyrenia ship the solution would be far from ideal due to the proximity of the masts. This might result in the mainsail preventing the foresail filling properly on downwind courses. The discussions in Chapter 7 will show how these were probably the most common courses made by sailing ships down to the end of the period covered in this thesis. The real advantage of two sails for this purpose might not be realised until the space between the masts increased; however, this was only likely to be achieved once the vessel was substantially larger. In this context the following line of thought is possibly relevant: If the sail of the Kyrenia ship was around the largest that a small crew could manage, then, two sails of this size would probably not provide sufficient power to a round ship of substantially larger size. Indeed, it is possible that before the separation in the masts became sufficient for the foresail to fill properly on downwind courses, the vessel would have been too large to be powered by two sails that could be managed without a winch. In the context of learning in iterative steps, each of which produced an increase in performance, it is difficult to see this as a path of development leading to larger vessels. Overall, it would appear that any substantial increase in the size of sailing ships would be dependent upon the ability of crews to safely manage larger individual sails. It is my contention that this would have been dependent upon the use of lifting equipment.

5.2.2 Conclusions

In the 6th century BC, when sailing ships up to 16 metres in length were in use, larger merchant galleys were being used on colonising voyages. In the same period these larger galleys are also recorded as being used for long-distance trade. It is clear from this that the motivation existed at this time for the construction and use of larger vessels. The lack of development of sailing ships to fill this niche, and the sudden expansion of these from around the end of the 6th century BC, requires an explanation. I contend that, as was the case with hybrid round ships, the size limitation derived from problems of operability in supplying the necessary power to the vessel. In this case; however, the limitation was the probable result of a lack of the means necessary to deploy, and safely manage, the required area of sail. This meant that whereas the limitation in the size of the hybrid rowed and sailed round ship was absolute in relation to this specific vessel type, the limitation in the size of the sailing ship was open to solution when the appropriate technology became available. I further suggest that this is best explained by a process of hybridisation of an existing technology from a separate field of use. This process providing the means for a rapid change in the development of maritime technology which otherwise comprised a series of small iterative steps. A summary of the main points in the evidence presented to this point are listed below:

1. There is evidence for the use of merchant galleys in the Mediterranean before the first appearance of sailing ships in the 7th century BC. At this time merchant galleys were almost certainly the largest merchant vessels in use.

2. There is no evidence for sailing ships over 16 metres in length for centuries after the introduction of the vessel type, and no evidence that the introduction of sailing ships was linked to an increase in the size of vessels in use.
3. The key invention that enabled sailing ships to increase to the largest sizes achieved in the ancient world probably relate to lifting equipment in the form of winches and compound pulleys. These would allow greater weights of sailing rig to be handled safely by smaller crews. There is no evidence that these technologies were in use at the time of the initial development of sailing ships.
4. The origin of winches and other forms of lifting technology probably lay outside of the field of maritime activity. The introduction of this technology to this area of use, and its apparent rapid impact on vessel size, was probably the result of a mix of technical, social and economic factors.
5. The full potential of sailing ships in the ancient Mediterranean was probably only achieved following their increase in size, and the development of forms with multiple masts and complex sailing rigs.

6.0 Suggested process of vessel development 1500 BC to AD 200.

In this chapter, I combine the evidence and discussions presented previously into a proposed process of vessel development for the period overall. This involved a change in vessel type from those broadly similar to early Egyptian river vessels to large seagoing sailing ships capable of carrying over 1000 tons of cargo. The following discussions are largely conjecture, there is no secure means to prove the cases proposed, this said, these will show that the process of development proposed can be explained by learning based on practical experience. The results of this largely being a function of the diffusion of innovations to existing technology, along with a few key inventions. In addition, I will discuss how the role of society appears likely to have been key to many of the developments described. I have broken the contents down into the development of key features of particular vessel types and sizes, along with their means of propulsion. The following looks at this process in the same time periods used in Chapter 4.

The focus of the early discussion in the following is on the development of vessels in the eastern Mediterranean. The reason for this is that most of the evidence relating to vessel types and construction for the period discussed in section 4.1 comes from this area. For the period covered in section 4.1, the evidence presented from the Aegean and central Mediterranean is intended to serve as a comparison to this, the relevance and impact of this is discussed in more detail in the later sections. These discussions will show how the impact of hybridization of technologies from across the basin contributed to the later development of hulls using short mortice and tenon joints. Once again, I suggest that the overall process is best summarized in the model of learning shown in Figure 3.1 from Usher (1988, 69) and discussed in detail in Chapter 3.

This said, throughout the following I frequently discuss the influences of seafaring and seafarers on vessel development in the period as if they were a single group. This is not to suggest that I do not appreciate that different societies would have individual influences upon these seafarers. The impact of societies on vessel use, and the possible impact of this on vessel development within these societies, is discussed further in Chapter 7. Rather, the discussions in the following examine how, when using similar vessel types for similar purposes, seafarers might face the same range of problems and experience the same risks. On this basis I suggest it is likely that similar iterative developments would have taken place across the Mediterranean to mitigate these issues, and, where societies were part of a larger maritime network, many of these iterative developments would have been borrowed and shared. In the following then, while I hope I have taken due regard to the differences between societies, I have taken the same approach as Pomey (2004, 26) where he noted: ‘In the first place, the builder conceives, in a global fashion, the vessel to be realized according to the demands to which it will be subject, that is, according to the function and usage of the ship.’

6.1 Vessel development 1500 to 1000 BC

The evidence for vessel development I present through this section is summarised in section 4.1.4. This evidence shows that the round ship form of hybrid vessel came into use in the Levantine centres at this time, and that their construction, based on mortice and tenon joints, shared many features with earlier Egyptian vessels. The evidence for ship building in the central Mediterranean and Aegean suggests that a range of hybrid vessels were used in these regions; however, the hulls of these were constructed by stitching the timbers together. The similarities in hull form of the vessels found in these regions, particularly in regard to the lack of any evidence of an external keel, suggests these were probably used for similar forms of seafaring. In conjunction with the shorter hull the most marked change in the period was the introduction of a loose-footed rather than a boom-supported sail. There is no evidence that this change was accompanied by the development of an external keel in the vessels of either area.

6.1.1 The development of the round ship

The earliest physical evidence for a vessel that may have had this form is the Pseira wreck found off Crete, dated to the 18th century BC. The excavations show this vessel to have been around 16 metres in length, this vessel then was of a similar size to later round ships of the Late Bronze Age. The widespread use of vessels of this size might be supported by the numbers of oars in use on the vessels shown in Cretan and Levantine seals shown in Figures 4.1 and 4.2. The lack of any hull remains of the Pseira vessel means that it is not possible to make an accurate determination of its hull form. However, the Kumluca vessel from the 15th century BC provides evidence for the round ship form, although, as noted in section 4.1.3 excavations of this vessel are still ongoing (Oniz, 2019). The 14th century BC Uluburun wreck has similar dimensions and is unambiguously a round ship. The widespread use of this vessel type may be confirmed by the depiction of a ship in the tomb of Kenamun dated to the early 14th century BC, shown in Figure 4.3, which McGrail (2004, 130) discusses as representing an early example of a round ship. The shorter hull form of these vessels is in marked contrast to those in Figure 2.9 showing the vessels used on Hatshepsut's voyage to Punt. The change in hull form suggests that a fundamental change in vessel type may have been underway by this time. Based on the evidence of the cargo, and the crew's possessions, a number of authors suggest a Syrian origin for the Uluburun vessel (McGrail, 2004, 130; Pulak, 2008, 300; Wachsmann, 2019, 4). A similar range of evidence can be used to link the Kumluca wreck to this region. This might suggest that in the Late Bronze Age Egypt was no longer the focal point in the development of maritime technology in the eastern Mediterranean, but rather, at this time the Levantine trading communities were assuming a larger, possibly dominant, role in this regard.

McGrail (2004, 130) notes that the shorter hull of the Kenamun vessel may have contributed to this by providing a stronger, more seaworthy, hull. This is perhaps confirmed by the lack of a hogging truss. From the view given it is difficult to establish the width of the hull. On this basis it is not possible to determine whether this was simply a shorter form of the earlier vessel type or one with a broader beam. This said, if this vessel is representative of the types at Uluburun and Kumluca then it would probably have a length-to-beam ratio of between 3:1 and 4:1. The shorter hull would clearly be less liable to bending than the long hulls of the Egyptian vessels discussed above. It is also relevant to record the use of long pegged mortice and tenon joints in the Uluburun hull. These almost certainly provided greater integrity to the structure of the vessel than would have been possible if unpegged versions of the same type of joint had been used. If these construction details were shared by all of these vessels it might suggest, that not only was the shorter hull form itself more rigid and seaworthy, but, that this means of construction was intended to enhance these qualities (Pulak, 1998, 213; 1999, 623; 2008, 302-303; Steffy, 2017, 37).

These three vessels of the Late Bronze Age were broadly contemporary. The evidence presented in section 4.1.3 suggests that these probably came from the trading communities in the north eastern Mediterranean. The earlier comments by Unger (1994, 7) and Adams (2013, 40-41) suggest that interlinked societies of this type may have shared beneficial technical developments. If this is correct, then it might be expected that the main features relating to the hull form and sailing rig found on the final vessel in the sequence, the Uluburun ship, incorporated any beneficial features in use on earlier vessels. In this case it is worth revisiting the complexity of the joints in the Uluburun hull shown in Figure 4.17 and discussed in section 4.1.3. In this Pulak (1998, 213; 1999, 623) noted that the pegged mortice and tenon joints were long, in some cases penetrating three strakes, and substituted for frames in supporting the hull. In section 4.1.3 it was recorded how Steffy (2017, 33) suggested a similar function and purpose for the long, unpegged, mortice and tenon joints used on the Dashur vessel. It is possible that unpegged joints of this type were also used on the vessels shown in Figures 2.6, 2.7 and 2.9, these were possibly representative of the ships that traded to Byblos from the 3rd millennium BC. This may represent the means by which the pegged form of this joint type first developed, and later came into general use in the Levant in the shipbuilding industry. The stronger pegged joints provided for a stronger hull allowing these vessels to be used in more rigorous sea conditions. Similar joints are in evidence on the smaller Cape Gelidonya wreck (Bass et al, 1967, 450; 2012, 3). The use of this joint on a small vessel might provide further support for the widespread use of this in hull construction in the region.

I suggest that the complexity of the joints used on the Uluburun hull imply a long period of learning, and iterative development, in the local shipbuilding industry. It would not be unreasonable to assume that the aim of each step in this process would have been to construct a shorter and stronger hull, the result of the process overall being a vessel capable of operating in greater safety in a wide variety of sea conditions.

6.1.2 The change from a boom-supported to a loose-footed sail

This period was one in which the loose-footed sail replaced the earlier boom-supported form. I suggest that understanding the background to this change is fundamental to any discussion on vessel development and usage. Vinson (1993) and Wachsmann (2009, 251-253) discuss how the boom-supported sail could probably only be used in a limited range of courses and weathers. As a result, it seems probable that any maritime vessel using this type of sail would have been a hybrid rowed and sailed vessel. As discussed earlier, vessels of this type were likely to have been dependent upon a rowing crew at some time through the course of a voyage. In this respect it is relevant to recall the lack of an external keel on the Uluburun vessel, along with the limitations that Pulak considers this would have imposed on the ship in regard to sailing (Pulak, 1998, 210-211; 1999, 618-619; 2008, 302; 2012, 13). In the eastern Mediterranean there is a lack of evidence of loose footed sails on seagoing vessels until their appearance in the 12th century BC mortuary temple of Medinet Habu. This might suggest that the Uluburun vessel was also equipped with a boom-supported sail. As discussed in section 4.1.3 Wachsmann shows a hypothetical reconstruction of the vessel with this feature, shown here in Figure 4.18. This is where the variation in keels shown in Figures 2.11a-2.11d, and discussed in the case studies in section 2.1.2, are of relevance in placing the Uluburun vessel in any taxonomy of vessel types, and any sequence of vessel development. The short form, discussed by Pulak (1998, 210-211; 1999, 618-619; 2008, 302; 2012, 13) and shown in Figure 2.11a, clearly implies that any vessel in which it was fitted was not a true sailing ship. The implications of this form of keel, and the possible motivation for the introduction of an external keel, are discussed in the following section.

The concluding discussion in section 6.1.1 suggested that a process of iterative development in the seafaring communities of the Levant through this period resulted in the use of a more seaworthy vessel type. If this is correct, it might be expected this would have allowed vessels to stay at sea in conditions where stronger, more changeable, winds might be experienced. In these conditions the ability to manage, and particularly to shorten, the sail is of critical importance. The relative inflexibility of the boom-supported sail in terms of handling at sea might impede any attempts to respond to rapid changes in the weather (Vinson, 1993, 145; Wachsmann, 2009, 248). This would result in the crews being exposed to higher risk in operating the vessel in these conditions. To extend the safe use of these more seaworthy vessels it might be expected that there would be a motivation to develop a more easily handled sail type. This might be seen as the result of the process of learning described by Edgerton (1999, 123) in which use leads to invention and innovation. In this case it is possible to see a process where the boom-supported sail might be changed for the loose-footed type while using a vessel with the same hull form. In these circumstances seafarers would be exercising the same seafaring skills in making the same type of voyages as were made with the earlier sail type. The motivation for this change being to make these voyages safely in a wider range of more changeable weathers, and in doing so increase the time a vessel might have stayed at sea. Vinson (1993, 143) and Wachsmann (2009, 252) note that a possible intermediate form of rig shown in Figure 4.4 may have developed around the date of the loss of the Uluburun vessel. The end point of this development can be seen in the vessels in the 12th century BC temple at Medinet Habu shown in Figures 4.6a and b (Nelson, 1943, figs 1 and 4). All of the vessels in this relief are shown with loose-footed sails. On this basis, it is probably reasonable to assume that by this time this had become the standard rig in use in seafaring in the eastern Mediterranean.

6.1.3 The nature of keels in Bronze Age vessels

The following discussions focus on maritime vessels and their requirements, for this reason they omit reference to Egyptian river vessels which were less likely to require a keel. At the present time there are only two Bronze Age wrecks from the Mediterranean that show substantial remains of a keel timber, the Uluburun ship shown in Figure 2.11a and the Zambratija vessel in Figure 4.20. In both cases this timber takes the form of a thick plank. As noted, Pulak (1998, 210-211; 1999, 618-619; 2008, 302; 2012, 13) is clear that a keel of this type would not contribute to the operation of a sailing ship. This poses the question: if this was not intended to enhance the sailing abilities of the vessel, what was its purpose? An alternative role might be to provide longitudinal stiffness to the hull, the lack of this feature necessitating the use of a hogging truss in the longer Egyptian vessels of the period. To determine its effectiveness in this regard it is necessary to examine the shape, and the orientation, of this timber as a means to provide stiffness to the hull. For a simple beam, as found in a rectangular section keel, this is the product of the cube of the depth of the beam, [https://www.doitpoms.ac.uk/tlplib/beam_bending] 27/01/2022. The implication of this is that if the depth of a beam is increased ten-fold then its longitudinal stiffness might increase a thousand-fold. When longitudinal stiffness is required in a beam then, rather than the width, it is the depth of the beam that should be increased.

What is clear from Figures 2.11a and 4.20 is that in both cases the long side of the keel is horizontal. Simply by rotating the same timber through ninety degrees the keel would have provided significantly more rigidity to the hull. The fact that the builders did not do this suggests either, a lack of understanding of this principle, or that this additional stiffness was not required. In the case of the Uluburun vessel, I suggest it is probable that any necessary stiffness was achieved through a combination of the shorter length of the vessel and the integrity of the pegged joints used to construct the hull. I have proposed that the Kenamun, the Kumluca and Uluburun vessels all came from interlinked communities. If this is correct it might be assumed that learning and innovation across these progressed in iterative steps to the Uluburun vessel which was the final vessel in this sequence. On this basis, I suggest that the hull form and keel of the Uluburun vessel was either common to the earlier two vessels noted, or represented an optimisation of learning from these, and that neither of these had an external keel.

This leaves open the question of when the external keel suggested by the forms in Figures 2.11b, c and d and discussed in section 2.1.2, may have come in to use. I propose that the process of learning and development outlined may provide an insight into this. If the purpose of an external keel is to prevent a vessel from making excessive leeway when making courses with the wind on the beam, it might be assumed that a vessel fitted with an external keel would also be equipped with a sail that would allow these courses to be safely steered. From the discussions to this point this would suggest that an external keel would not be required for use with a boom-supported sail, but would rather be found in combination with the use of a loose-footed sail. The question that might be posed is: which of the two, the loose-footed sail or the external keel, was developed first.

It is possible that the external keel may have developed before the loose-footed sail. However, in this case the question would centre on the motivation for this development. In a vessel that was equipped with a boom-supported sail; that is, one that only allowed vessels to safely make courses close to downwind, there is no obvious purpose to be served in equipping a hull with an external keel. It might even be a disadvantage to a vessel that was manoeuvred under oars and drawn up on the beach at the end of each day. It is possible that it was introduced to stiffen the hull; however, if the vessels shown in the temple at Medinet Habu were the largest examples of seagoing ships in use in the 12th century BC then they were probably no larger than the Uluburun vessel. The evidence presented shows that this vessel did not require this feature. If learning progressed in the manner described in section 3.1, then it is unclear how the introduction of the external keel would have pre-dated the introduction of a loose-footed sail.

It could be proposed that the development of the external keel may have accompanied that of the loose-footed sail. The aim being to develop a vessel able to sail with the wind on the beam without making substantial leeway. In this regard it is important to take note of the comments of Vinson (1993, 145) and Wachsmann (2009, 248) regarding the limitations of the boom supported sail. The implications of these suggest that at the start of this period, when the boom supported sail was in use, sailing with the wind on the beam was unlikely to have been a common form of seafaring. To suggest the later simultaneous development of both loose footed sail and external keel were aimed at developing this form of seafaring would suggest a teleological process of learning. The assumption underlying this process would be that the long-term objective was understood and worked toward by the simultaneous modification of a number of features. This model also suggests a theoretical understanding of the problem of preventing leeway when sailing in this manner, before the form of seafaring was common practice. It also suggests this change was accompanied by planned changes in the nature of seafaring, sailing to windward not being possible with a boom supported sail. As noted earlier in Chapter 3 the range of assumptions implied in this process does not fit easily into the model of learning by practical experience described by Philon in Belopoeica 50.14-29 (Schiefsky, 2015). Further, as discussed in section 3.1, it does not accord with the one proposed by Usher (1954), Basalla (1989), Greene (2010) and Adams (2013) regarding those followed in the ancient world. Similarly, it does not accord with those found in craft industries today described by Ingold (2013), Buckley and Boudot (2017) and Marchand (2020). It is also relevant to note that this model would not accord with the idea suggested by Edgerton (1999, 123) that use led to innovation, but rather posits the opposite, that innovation might have led to use. Perhaps more importantly it does not take into account the issue of risk as discussed by McGrail (1989, 850) and Unger (1994, 7) and outlined earlier in section 3.1.

On the basis of these conclusions, I suggest that the external keel developed some time after the introduction of the loose-footed sail. As the earliest evidence for the use of the loose-footed sail in maritime applications dates to the early 12th century BC mortuary temple of Rameses III at Medinet Habu, I contend that it is not possible to safely assume that the external keel was in use before this time.

6.1.4 Possible societal impacts on vessel development

The evidence I presented through section 4.1 shows that in the eastern Mediterranean in the period 1500 to 1000 BC technical development leading to the round ship vessel type occurred in the cities of the Levant rather than Egypt. This is despite the widespread evidence of the wealth and power of the Egyptian state, and the evidence of trade between the two regions (Marcus, 2007; Cline, 2007; Kelder, Cole and Cline, 2018). I suggest that in this context it is probable that the differing natures of the two societies, and the role of trade within these, may have been of importance.

In this period, it appears to have been largely the elite in Egypt that benefited from trade in a variety of products from Byblos, Ugarit and the other cities of the Levant (Marcus, 2007, 137). However, for these cities the role of trade was clearly different. By the Late Bronze Age these had become reliant on trade and its associated manufacturing and processing industries for their prosperity and security. This latter factor possibly being of particular importance in their location in the border region between competing military powers. This development may be reflected in the mixed nature of the cargo of the Uluburun vessel as discussed by Bass (1986, 275-296), Pulak (1988, 6-33; 2012, 3-9) and Bass et al (1989). The way in which this mixed cargo may reflect the role of the mercantile elite in the Levant at this time is discussed by Sherratt and Sherratt (1997, 83-84) and Monroe (2010). Monroe (2010, 29) suggesting ‘the relationship between palace and merchant in this setting is likely to have been less patrimonial and more symbiotic than is implied by conventional paradigms of authority and control’. This symbiotic relationship between the state and merchants is one that might have motivated the development and prosperity of the trades and crafts across the communities of the region. Where these communities were themselves linked by close commercial and cultural ties it might be expected that these influences would be common across the region.

The scope of this extended trading hierarchy in the northeast Mediterranean is perhaps exemplified by the Cape Gelidonya wreck dated to around 1200 BC. This vessel of around 10 metres is described in Bass et al (1967, 450) and Bass (2012, 3) as carrying a cargo of copper ingots, tin and a selection of complete and broken bronze tools and ornaments. On this basis it is widely assumed that the Cape Gelidonya wreck was used by small scale itinerant traders and metal workers (Bass et al 1967, 52-115; Bass, 2012, 3-4; Sherratt and Sherratt 1997, 87-88; Monroe, 2015, 34; Sherratt, 2016, 295). This wreck then illustrates how trading and economic activity was not restricted to those in direct contact with the ruling elite, but rather extended to those of considerably lower social status. This latter group were perhaps more closely associated with the shipwrights and seafarers who built and operated many of the vessels from these communities. Unger (1994, 7) in his description of the maritime communities in Medieval Europe describes a situation in which technical development accelerated due to the exchange of ideas in culturally similar, interlinked, economically dynamic communities. I suggest that a similar situation may have existed in the societies of the Levant in the Late Bronze Age, and that this resulted in a similar optimisation of a common means of vessel construction suitable for use in more challenging conditions.

6.1.5 Summary

The period 1500 to 1000 BC saw the development in the northeast Mediterranean of a more seaworthy vessel in the form of a short round ship constructed using long pegged mortice and tenon joints. The hull of these vessels appears to have had a simple concave shape with no evidence for the use of either a structural or an external keel. At some time following the introduction of this hull form the type of sail in use changed from the boom-supported square sail to a loose-footed form. On the basis of the model of learning proposed I suggest that this change in sail type was probably motivated by safety issues associated with incremental developments in an existing form of seafaring. The result of these changes being the development of a hybrid vessel type that could operate in greater safety, on largely coastal voyages, in a wider range of weathers. I contend that within a system of learning in iterative steps the need for an external keel was only likely to have arisen following this change in sail type. This lack of an external keel would have impeded any learning and development in seafaring techniques leading to the use of true sailing ships as defined by Tilley (1994, 309). On this basis, the model of learning suggested by Edgerton (1999, 123) suggests that this was not an objective of either shipwrights or seafarers. The implications of the continued use of hybrid rowed and sailed vessels at this time, in conjunction with the conclusions of section 5.1.1 regarding the limitations on the size of hybrid rowed and sailed round ships, confirm my earlier observation that vessels of 450 tons did not exist in this period.

The form of construction discussed to this point was not the only one in use in the Mediterranean in this period. As I discussed in section 4.1.3, the vessel from the early 19th century BC from Mitrou on the Euboean Gulf (Van de Moortel, 2009, 20-21), and the Zambratija vessel from the northern Adriatic possibly dating from as late as the 10th century BC (Pomey and Boetto, 2019), suggests a long history of the use of stitching in hull construction in the Aegean and central Mediterranean. There is iconographic evidence for the range of vessels in use from the area, but the shortage of shipwreck evidence, along with the lack of textual records, means there is no indication of either their size or cargo capacity. By the end of the period the evidence from the 12th century BC mortuary temple at Medinet Habu (Nelson, 1943, 41-47) suggests that seafarers from the area were probably using the same type of sail, in vessels with similar hull forms, to those in use in the eastern Mediterranean.

6.2 Vessel development 1000 to 500 BC

The contents of this section are based on the summary conclusions I presented in section 4.2.4. These show that the period was marked by the widespread adoption of vessels with hulls comprising flexible shells supported by internal frames. The hulls of these vessels were constructed by either stitching or short mortice and tenon joints. The evidence presented to this point suggests it is possible that this change might be explained by a hybridization of the construction techniques in use across the Mediterranean basin. The possible social, economic and political background to this will form a significant part of the following discussions. Much of my discussion in this section will focus on the manner in which the change in form of mortice and tenon joints contributed to this development. To appreciate the significance of this it is necessary to picture the problem that might result from attempting to build a vessel of the size of the Alonnesos wreck (Hadjidaki, 2009; Polzer, 2009, 88-90; Davey, 2016, 37) in the same manner as the Uluburun hull; that is, by using long mortice and tenon joints but no frames. The same problems can also be envisaged in any 450-ton vessel that might be proposed to have been constructed in the Late Bronze Age.

Along with these changes in the type of mortice and tenon joints there is evidence for the adoption of both structural and external keels in vessels, along with the appearance of both merchant galleys and true sailing ships. There is a tendency in much of the current literature to view these latter two vessel types independently. I contend that this approach misses a key point in terms of learning and vessel development. These two distinct vessel types were almost certainly built by the same craftsmen, and the seafaring communities and traders of the period were probably familiar with both. To examine the development of each as separate issues then is artificial; for this reason, in the remainder of this chapter the crossover of technology will be a focus of my discussions.

6.2.1 The change in hull construction techniques

I have discussed the nature of the joints used on the Bronze Age Uluburun and Dashur hulls in some detail in section 4.1.3. In these discussions I recorded how the nature of the joints used on these vessels resulted in the shell being a self-supporting, relatively rigid, structure that did not require the use of frames (Pulak 1999, 626). The remains of the Uluburun vessel were incomplete; however, some idea of its form can be gained from Figure 2.11a, this shows that the planks of the lower hull joined the keel at a low angle. This suggests the hull had a gentle concave form close to the simple curve form shown in the early Norse examples in Figure 3.3. The evidence of the Zambratija wreck from the Adriatic (Pomey and Boetto, 2019), shown in Figure 4.20, was of stitched construction and had a similar simple curved hull form. Pulak (1998, 210-211; 1999, 618-619; 2008, 302; 2012, 13) links the keel and the hull form of the Uluburun vessel with limitations regarding its use. If Pulak is correct, then it seems probable that this observation would also be relevant to the Zambratija vessel. The evidence then might suggest that, in the Late Bronze Age, the same technical constraints probably applied to seafaring across the central and eastern Mediterranean.

The earliest excavated wrecks of this period are Mazarron 1 and Jules Verne 9. As discussed in section 4.2.3, the means of construction of these two vessels differed; Mazarron 1 was built using short mortice and tenon joints, while the hull of Jules

Verne 9 was stitched. The point made in section 4.2.3 was that these two vessels were the products of distinct shipbuilding traditions. The former appears to have incorporated Punic influences, possibly resulting from Carthaginian colonization (Tejedor, 2018, 319-320; Pomey and Boetto, 2019, 6). However, the latter vessel was constructed in a Greek colony, and as such, this probably represents a continuation of a tradition of stitching in hull construction from earlier Aegean societies (Pomey and Poveda, 2018). The joints used on the Mazarron I vessel can be seen to have marked a change from the long mortice and tenons used on the Uluburun hull. The result of this was that, in hulls where these shorter forms were used, the vessels lacked inherent rigidity. As a result, they required frames, to provide the necessary stiffening to the hull in construction, and, to resist loadings on the vessel when at sea. The use of both means to fasten hull timbers in vessels through to the end of this period suggests that neither provided an overwhelming technical advantage in vessels of the size in use. In section 4.2.3 I reviewed some of the points raised by McGrail (2004, 145-148), Polzer (2012) and Pomey (2020) regarding the reasons why stitched hulls were ultimately displaced by those using mortice and tenon joints, I will return to this issue in the following discussions. However, there are more fundamental questions that might be asked that were not addressed by these authors. Why, and at what point, was the method of hull construction based on long mortice and tenon joints used on the Uluburun vessel superseded in this period, and by what process did this occur? This is important in the light of the comment made in the introduction to this section regarding the improbability that later large vessels could have been built using this earlier technique. The limited extent of the archaeological evidence means that these questions cannot be answered definitively. However, I suggest, that it might be examined using the processes and models of learning outlined in Chapter 3; the conclusions presented in the following then are conjectural, but the process by which these were reached is clear for discussion and challenge.

The material presented to this point shows that, while the evidence shows a change in the means of construction, the hull shape of the Mazarron I wreck was still broadly similar to that of the Uluburun and Zambratija vessels. This suggests that the motivation for the change in joint type was not linked to a fundamental change in vessel usage. This might be supported by the evidence presented in section 4.2.2 in regard to the *Odyssey* (*9.322–23*). In these discussions it was noted that the version of Homer that forms the basis of modern translations possibly drew on evidence and seafaring practices in use as late as the 6th century BC (Willcock, 2004, 348-351; Dickinson, 2017, 9-10; Sherratt, 2017, 36-37). In this respect the key line of evidence is that the passage refers to a merchantman as a hybrid vessel. So, if this change in joint type was not linked to use, this poses the question of how, why and when, this fundamental change occurred?

To resolve this, it is necessary to revisit the evidence from the Uluburun shipwreck and note once again the extremely long mortice and tenon joints. The comments by Pulak (1998, 211-213; 1999, 626-629) regarding their possible combined purpose, as both hull fastenings and internal frames intended to increase the stiffness of the hull, are of particular relevance in this respect. The complexity of these is apparent from Figure 4.14. As I discussed in section 4.1.3, it is likely that this form of hull construction constituted the end point of a long process of learning and development in which the joints had come to serve these multiple roles. I suggest that this would have posed problems for any independent path of development in hull construction that might ultimately lead to a flexible hull. The use of such long mortice and tenon joints would both stiffen the hull and fix the profile to the shallow concave curve as shown in Figure 2.11a. Frames would serve no purpose in a rigid hull built in this manner. On the basis of a process of iterative learning then frames are unlikely to have arisen as a product of the craft tradition that built the Uluburun vessel. Similarly, it is unlikely that shipbuilders familiar with the Uluburun hull would revert to shorter mortice and tenon joints without some means to stiffen the hull, and without frames this alternative would not be available. Furthermore, all the evidence presented in Chapters 2 and 4 suggest that the vessels in use throughout much of this period had similar hull shapes and required an oar crew. As such, there was no apparent change in use that might result in invention and innovation contributing to a change in the means of construction used on the Uluburun hull, as suggested by the comments of Edgerton (1999, 123).

The possibility exists that the change in the means of construction, to the use of shorter mortice and tenon joints, to build a more flexible hull, could have been developed simultaneously with the introduction of frames. However, this process would suggest that an end point of long-term development was foreseen and multiple paths of change directed to achieve this. This assumption might also carry with it the belief that seafarers of the time were envisaging a future in which their method of seafaring would also undergo significant change. This would presumably be accompanied by one that suggests they also had a vision of the hull form required to achieve this, along with the optimum means of its construction. This suggests a teleological process of learning and development, rather than one based on empirical learning comprising a series of iterative steps, as outlined in Chapter 3. Similarly, they do not fit easily in to one in which ship building was a craft industry in which skills, techniques and vessel design, were passed down by practical experience. Further to this, it is perhaps necessary to recall Unger's (1994, 7) comment on risk and conservatism in shipbuilding and seafaring. If this were to be applied to this period, a change of this magnitude might be regarded as a high-risk option; moreover, the similarity in the hull forms suggest that this risk would have been accompanied by no apparent immediate benefits in terms of its use.

6.2.2 The possible societal impacts on vessel development

The evidence presented in section 4.1.3 shows that the Zambratija wreck from the central Mediterranean, dated between the last quarter of the 12th and the last quarter of the 10th centuries BC, was of stitched construction and the hull of the vessel used frames (Pomey and Boetto, 2019, Figure 3). I propose that the answer to the question; how did flexible hulls using mortice and tenon joints develop? may lie in finding a way to hybridise the ship-building tradition that built this stitched vessel, with that responsible for the Uluburun ship. There are a number of ways in which this may have taken place. It may have been the result of traders to the central Mediterranean in the Late Bronze Age bringing knowledge of alternative hull types to shipwrights at home. However, later instances of the mix of Arab and Chinese traders from the late 1st millennium AD did not produce similar widespread changes in the fundamentals of domestic ship construction techniques. Neither did the widespread global reach of European explorers, colonisers and traders, from the period following the Middle Ages. The evidence in Phillips (1994, 91-114) and McGrail (2004, 71-77, 223-248, 360-390) supports a continuity in the forms of vessel construction in these societies through these periods. These cases suggest that where strong domestic traditions in shipbuilding existed, in societies at broadly similar levels of technical and economic developments, these appear to have retained their own methods of construction even when alternative methods became known. It seems unlikely then that the change in the form of hull construction around the close of the Late Bronze Age was the result of exchange along earlier trade routes, or an increase in the intensity of trade. My most fundamental objection to this hypothesis can be linked to learning and motivation. In the vessel sizes in use at this time, a hybrid rowed and sailed vessel with frames in a stitched shell offers no clear advantages in regard to seafaring over a similar vessel constructed by means of long pegged mortice and tenon joints. On the basis of usage then there would been no motivation for craftsmen to change long standing practices. In these cases, it is likely that inertia in the relevant craft industries regarding a particular technology might be strong, and resistant to change.

However, the Late Bronze Age was marked by the collapse of the regional trading system in the eastern Mediterranean along with many of the palace-based societies of the Levant (Aubet, 2001, 23). A widely discussed hypothesis associates this collapse with the immigration of groups commonly referred to as the Sea People. This process is widely considered to have involved the movement of a considerable number of people from the Aegean and perhaps central and western Mediterranean (Markoe, 2000, 23-25; Bell, 2006, 12-17; Cunliffe, 2011, 236-245; Knapp, 2013, 447-454; Broodbank, 2014, 460-472). The scale of the resulting changes are the subject of the book *1177BC: The Year Civilization Collapsed* by Cline (2014). Cline concluded this work by comparing the process to Renfrew's definition of 'a systems collapse', a process described as involving the decline and collapse of administrative, political and economic power and cohesion in the societies of the region (Cline, 2014, 167). The Zambratija wreck dates to around this period and, as discussed earlier, was constructed by stitching and used frames to support the resulting flexible hull. There are few comparable wrecks from the same area from this period. However, as noted in section 4.1.3 Van de Moortel (2009, 20-21) discusses the incomplete remains of a smaller Greek vessel of the early 19th century BC that she suggests was also constructed in this manner. Polzer (2009, 29-30) discusses evidence from central Mediterranean sites suggesting the use of stitching in hull construction dated from the 3rd millennium BC. On this basis I have assumed that stitching had a long history of use in the central Mediterranean, and that the Zambratija wreck might be taken as a model type for vessels from this area at the close of the Late Bronze Age. If this is correct, then it is not unreasonable to assume that the immigrant population to the Levant in the Late Bronze Age used vessels constructed in a manner similar to that of the Zambratija wreck.

Following the incursion of the Sea Peoples the distribution of settlers, and the nature and method of their settlement, varied across the region. Markoe (2000, 23-24) and Bell (2006, 15-16) note the absence of widespread archaeological evidence for their presence in what later became the Phoenician cities. Bell noted that the impact of migration was stronger in the southern Levant in the areas associated with the Philistines (Bell, 2006, 15-16; 2016, 92). Knapp and Manning (2016, 99) discuss events in the Levant at this time noting 'the end of a long-standing high-culture era of interregional connectivity followed by major reorientations, change, and decline.' They go on to note that while some cities were totally destroyed, other areas appear to have experienced little disruption, concluding with the suggestion that: 'All this signals a more peaceful process involving the hybridization of different cultures.' Aubet (2001, 23-29) makes much the same point regarding social and political decline and a deterioration in trade. These conditions are perhaps best summarized in the earlier reference by Cline (2014, 167) where he refers to 'a system collapse.' The situation that may have faced local shipwrights then was potentially one in which local seafarers were operating when trade probably produced lower profits. At the same time, an immigrant population was using, and probably building, an alternative vessel design. Moreover, because this did not involve the same complex carpentry, this design was probably faster and cheaper to build while also being capable of making the same voyages as those constructed using the more complex local technique. This combination of factors may have provided the means and motivation for the local shipwrights to modify their construction technique. The objective of the change being to build a similar vessel at a lower cost with less skilled labour. Given the familiarity of the local shipbuilding industry with mortice and tenon joints, it might be expected that these vessels would be constructed using more easily constructed joints of the same type. However, a vessel constructed in this manner would have a less rigid hull that required frames to provide the necessary stiffness. The presence of a non-indigenous shipbuilding industry working in the same area, that probably built vessels similar to that found at Zambratija, may have allowed the transfer of learning regarding frames. The underlying process then would be one of hybridisation, the product being a hull form that contained two previously independent lines of maritime development.

Early examples of the more flexible hulls may well have resulted in more leaks along the seams, this in turn may have required caulking to be used. With a contemporary shipbuilding tradition based on stitching operating in the same area it would not be surprising if this technique was copied to solve this issue. This might result in the development of a hull type similar to the Mazarron 1 wreck. If this speculation is correct, this might suggest that the developments in hull form that I propose were fundamental to the development of later large sailing ships occurred in the Levant after the Late Bronze Age/Iron Age transition. It might also suggest that these were the result of a set of unique social, economic and political developments, and that these were themselves unrelated to any immediate change in the size, or the use, of the vessels produced.

6.2.3 The implications of the change in hull construction

Kahanov and Pomey (2004, 20-25) provide a good record of the change in hull construction of the shipwrecks that span the Late Archaic to early Classical periods. In addition, Pomey (2020, 46) discusses the early use of pegged mortice and tenon joints in the Phoenician ship-building tradition, he goes on to discuss the manner in which this later fed back into the wider Mediterranean region. I contend that, by starting their discussions at the mid-point in the overall development process, these papers fail to acknowledge the probable significance of the earlier combining of frames with shorter mortice and tenon joints. Pomey (2020, 46) goes on to state in regard to the later change to the dominant use of mortice and tenon joints that: ‘This evolution led to the building of larger ships with greater tonnage…’. There is no doubt that this link is sound in a general sense; however, Pomey omits any discussion on the equipment needed for the safe operation of these large vessels. A further point that might be questioned in this statement is the cause-and-effect relationship that it might imply. It is perhaps relevant to record in this regard that the use of both stitching and mortice and tenon joints is recorded on the Gela, Giglio and Pabuc Burnu vessels. All of these were larger than the earlier Mazarron 1 vessel which appears to have been built using mortice and tenons throughout, the stitching in this vessel relating to the caulking rather than the construction of the shell (Panvini, 2001; Bound, 2001, 170; Polzer, 2007, 28; 2009, 73-78; Davey, 2016, 37; Tejedor, 2018, 304). In regard to these later larger vessels, it is frequently observed that the use of mortice and tenons were to provide temporary support to the timbers while they were stitched, rather than to provide structural support to the final hull. The Gela, Giglio and Pabuc Burnu vessels are all linked to societies in the central Mediterranean, all then may represent examples of the long-standing tradition of stitched hulls. At the same time all might be seen as examples of a process of hybridization of technologies between the shipbuilding communities of the Aegean and the central Mediterranean and those of the eastern Mediterranean. It is clear from the evidence of these wrecks that in the 7th and 6th centuries BC there was no unambiguous link between vessel size and the nature of the joints in use. McGrail (2004, 73) discusses later Portuguese records of stitched Arab vessels between 100 and 250 tons in use in the 15th century. Similarly, Severin (2018) and Staples (2019) record the construction and voyage of a stitched reconstruction of an Arab trading vessel that was 26.5 metres in length. It is clear from these examples that stitched vessels significantly larger than the transition vessels listed above can be built and operated successfully. On this basis I suggest that there was no single technical motivation for a change in the means of hull construction for vessels in the Late Archaic or early Classical periods.

Polzer (2012, 27-28) discusses this change in the nature of hull construction and concludes that this may have been the result of multiple factors. It is clear the change to mortice and tenon construction facilitated the later building and operation of large vessels, much as the earlier switch to a flexible frame-supported hull form had. On the basis of the learning process discussed in Chapter 3 I suggest it would be unsafe to assume that either of these changes were made to facilitate this later development. It appears more probable that the motivation for the widespread change resulted from a combination of contemporary social, economic and cultural factors. Polzer (2012, 27-28) goes on to note one of these in his discussions on the use of this type of joint in triremes. However, he does not extend this to a discussion of the joints used in earlier bireme galleys which may have been crucial in this development. Coates (1985; 1987) spells out a possible iterative learning process by which the trireme may have developed from the earlier bireme form, and, in doing so, suggests the probability of a link of this kind. Morrison and Coates (1986, 202-204) discuss further implications of this, in these discussions they note the use of mortice and tenon joints in triremes in conjunction with a keel, emphasising the advantages of the resulting rigidity and strength in a hull designed for ramming. If these requirements were motivated by the means of combat employed, that is ramming, then it is probable that these features were also required in the bireme pentaconters shown in Figures 4.21 and 4.23. The shorter hulls of these, coupled with the presence of a ram, suggest that this tactic also influenced their design and construction. If these biremes were braced in the manner similar to that of the reconstructed trireme shown in Figure 6.1 (Morrison and Coates, 1986, fig 66) then it seems probable that a combination of mortice and tenon joints, internal frames and a structural keel, were in use on vessels of this type by the late 8th century BC. For this reason, I suggest that many of the developments observed in the later wrecks of small round sailing ships possibly had an origin in, or were at least heavily influenced by, developments in war galleys. I will discuss the possible influence of these vessels on the later widespread adoption of mortice and tenon joints in section 6.3.2.

6.2.4 The development of the sailing ship

In regard to how hybrid round ships developed into sailing ships, there is no clear time line that may be drawn on the basis of the evidence available. In section 4.1.2 I used Homer's *Odyssey* (*9.322-23*) in which he refers to a 20-oared merchantman, along with the comments of Willcock (2004, 348-351), Dickinson (2017, 9-10) and Sherratt (2017, 36-37) who suggest that the contents of the Epics were probably finalized at some time in the 6th century BC, to suggest that hybrid rowed and sailed round ships were familiar features of seafaring in the Archaic period. I appreciate that this suggestion is not proof, what is clear; however, is the lack of any textual or iconographic evidence for sailing vessels for much of this period. Similarly, the long period required for the development of keels and mast steps in Nordic shipbuilding shown in Figure 3.3 is perhaps relevant as a basis of comparison. Taken together, these points suggest that it may have taken most of the period from the end of the Bronze Age to the 7th century BC for vessels to transition to one similar to the Marazzon I wreck.

On the basis of the discussions to this point, I suggest that to look for the development of the external keel, which is a key feature of early sailing ships, it may be necessary to examine the development of merchant galleys. As outlined in section 5.1.2 the size of merchant galleys probably necessitated the development of a structural keel. The shape of a keel of this kind is essentially the same as that of an external keel. The difference being that in the case of the structural keel it is purely the form and orientation of the timber that is essential to it fulfilling its role; on the other hand, in the case of an external keel the same shape of timber is required to extend below the hull. It is not possible without more evidence to be definite about which vessel type was core to this development, or if it occurred in both galley and round ship forms at the same time. However, it is possible to examine this in the context of the motivation for learning and development outlined to this point. These assume that learning took place in a conservative tradition, as suggested by Usher (1954, 68-69), and that seafaring communities might have been expected to have been risk adverse, as suggested by Unger (1994, 7) and McGrail (1989, 850). In regard to ship construction, it might be expected that the result of a combination of these factors would be that learning progressed in a series of small steps where a familiar form was adapted within an established form of seafaring.

The use of structural timbers to provide rigidity to a long hull had been used earlier in the Cheops barge, as I discussed in section 4.1.3. While clearly not proof, this might support the case that a similar feature, intended to serve the same purpose, was introduced at this time. This process could be accomplished by a series of small changes in vessel construction as each generation of vessels increased slightly in length. This process itself might be accomplished without significant change in the nature of seafaring, or increase in risk to the seafarers. This might be seen to align with the earlier comments by Usher (1954, 68-69), Unger (1994, 7) and McGrail (1989, 850) on conservatism and risk. Each step in this process itself would have required additional stiffness in the keel to support the longer hull. Each increase in size of the vessel presumably being intended to increase either its profitability or its utility as a raiding vessel. Once the pentaconter form of this single bank galley entered widespread use it might be expected that, with its increased capacity, it would take the dominant position in trade and colonisation activity recorded by Snodgrass (2006, 221-234). This might in turn result in a feedback loop of development that focussed on optimising the performance of this larger vessel type.

I do not consider it possible to be definitive regarding how, or when, a structural keel that may have arisen by this process might have developed into the external keel. It may have been related to establishing the most efficient means of fixing the hull timbers to the keel. In this regard it may be of relevance to consider the example of the Uluburun hull, Figure 2.11a shows how on this vessel the hull timbers join the keel timber close to the lower face. The keel timber in this vessel; however, does not intrude too far into the hull. As any keel became more substantial, this intrusion would increase, and possibly result in inconvenience in loading the vessel, and bailing the hold. The contrast is particularly marked between this and the keel on the Jules Verne 9 vessel shown in Figure 4.30. In this vessel the hull timbers join the keel at the top, and the keel itself projects below the hull. In this regard it is relevant to note that, unlike the case of the Uluburun vessel, the Jules Verne 9 hull has a keel orientated such that the depth is greater than the width. The orientation of this timber then is similar to that I suggested earlier was required in galleys from at least the late 8th century BC. If this hypothesis is correct, this might represent another example of hybridisation in which maritime technology switched from one application to another. If this suggested process of development is accepted, it seems possible that a small incidental change in how the keel was joined to the hull may have resulted in an observed positive change in performance. These perhaps becoming the starting point of a further line of small steps in learning and development that ultimately resulted in the wine glass hull form shown in Figure 4.35.

6.2.5 Summary

The evidence suggests that through this period seafaring was dominated by hybrid rowed and sailed vessels. I have suggested that the adoption of frames in vessels constructed with mortice and tenon joints was probably unconnected with seafaring issues. Rather, I suggest the adoption of this method of construction was more likely to have been motivated by unique socio-economic factors in play in the eastern Mediterranean at this time. The evidence suggests that the vessels in use were probably limited to largely downwind voyages, many of which would have been coastal in nature. It would be possible to increase the size of these vessels but only by increasing the length. This increase in length would probably have required the introduction of a structural keel to provide the necessary rigidity to the longer hull. This keel could serve this function by being located either inside or outside of the vessel. For galleys there would probably be no requirement for this to be an external keel. The key advantage offered by the external keel is to sailing ships that are attempting to sail courses where the wind is likely to blow the vessel to leeward. There is no evidence of vessels with keels of this kind in the Mediterranean before the 7th century BC Mazarron I wreck (Tejedor, 2018). Kahanov and Pomey (2004, 20) record how this hull form was also found in the later vessels, Grand Ribaud F and Gela 1 which have been dated to the late 6th or early 5th centuries BC. The evidence of these wrecks shows that, at this date, vessels with a rectangular keel still had a hull form similar in shape to that of the Uluburun vessel from the Bronze Age. This might suggest that, at the time of its introduction, only a limited improvement in the windward performance was afforded by the external keel.

If this summary is correct, then it is possible that the motivation for the development of an internal structural keel preceded the requirement for an external keel. This might suggest that the development of a key feature of later sailing ships may have been an indirect result of the development of galleys. The observation by Snodgrass (2006, 223) that vessels of this kind dominated bulk trade and colonisation, and through these activities may have been key to the development of larger maritime states, perhaps emphasises the importance of this vessel type at this time. The result being that the use of these vessels may have been the driving force behind many of the developments in maritime technology in this period.

6.3 Vessel development 500 BC to AD 200.

The contents of this section are based on that of the preceding sections and the summary conclusions presented in section 4.3.4. In this I highlighted how the period was one in which true sailing ships came into widespread use, and the size and complexity of the largest vessels increased significantly. A theme of this thesis to this point has been how, in examining the issue of the size of vessels, any discussion should focus on both their construction and their operation. In addition to this it is perhaps as important to determine why these larger vessels were built. In the following I propose a sequence of technical developments by which large vessels may have arisen, and then outline the possible socio-political factors that may have motivated these developments. In earlier discussions I have suggested two vessel types that may have been involved in this process, the merchant galley and the sailing ship. The following sections examine these two vessel types independently to assess the factors that might have affected the increase in size of each; at the same time, I will be examining these to assess any crossover in the relevant learning and development. The final section examines the possible societal influences and how connectivity, both within and across societies, may have influenced developments in maritime technology.

6.3.1 Why build larger vessels?

The first question to address is, why build large vessels at all? If these were rare, and small and intermediate size vessels were more numerous, and possibly shaped the nature of trade and seafaring, why not simply build more of these as the volume of trade increased? The answer to this probably lies in the link between the square cube law and the economic implications of building and operating ships. The discussion in section 5.1.1 showed that, if the lengths of all the sides of a vessel were to be doubled the volume would increase to eight times the original capacity. Perhaps less obvious is that if the length and width increase by a quarter then the volume nearly doubles. In terms of ship construction then the question might be posed as follows. If the owner of ships similar to the Kyrenia vessel of around 14 metres, and 20-ton capacity, wished to expand his fleet would he be more likely to build two vessels of this size to carry 40 tons, or one of around 18 metres? From the point of view of the costs to both build and operate these vessels, the latter option would appear to be the cheapest solution. The logic of this case may be extended to larger vessels; however, this clearly reaches a limit when the increased size starts to limit the operational flexibility in terms of the ports and harbour facilities that any vessel may access. It is also possible that the difficulty in filling a very large hull with a range of cargoes, and having to unload specific items at any port along a route, would limit the application of these larger vessels to specific forms of trade on particular routes. The layered manner in which the cargo of the Alonnesos ship was loaded is perhaps an example of the possible range of problems (Hadjidaki (1996, 591). Scheidel (2009, 7) makes a further point that, rather than using the largest vessel possible, merchants might seek to reduce the risk of loss of any individual ship by using a number of intermediate size vessels. The full implications of this balance of ship size, and ship numbers, are complex and lie beyond the scope of this thesis. However, it seems probable that once the technical issues discussed in section 5.2 were resolved the balance between the capital and operating costs would have played a large part in determining the range and type of vessels in use.

6.3.2 The widespread adoption of the mortice and tenon joint

In earlier discussions I recorded how Polzer (2012) had commented that the widespread use of mortice and tenon joints was probably the result of a wide range of social and technical issues, and may have been linked to their use on triremes. The following examines how this use of mortice and tenon joints on triremes, and later war galleys, was perhaps of wider relevance than is appreciated. The expansion of naval power by some states in the early Classical period generated the need to build substantial fleets of triremes, and to replace these on a regular basis following losses in combat (Morrison and Coates, 1986; McArthur, 2021). The impact that these large-scale vessel construction programmes may have had on the widespread application of mortice and tenon joints in shipbuilding appears to have been ignored. McArthur (2021) discusses the development of the Athenian shipbuilding industry that accompanied the expansion of its trireme fleet in the 5th and 4th centuries BC. The case he makes is that, at this time, the Athenians had a policy of attracting shipwrights to the city to construct these vessels. He goes on to note that these were kept occupied by instituting an annual quota of triremes to be constructed. McArthur (2021, 484) noting that: 'The shipbuilding tradition that found its legs in the time of Themistokles became instrumental to Athenian military ambitions for much of the Classical period, and shipwrights would remain a fixture in Attica for even longer'. No comparable evidence is presented for other maritime powers that might have been competing with Athens at this time. However, it would be unsurprising if similar measures were not taken in these cities.

If this assumption is correct, then I suggest that the overall effect is likely to have been to familiarise a substantial body of shipwrights in the use of mortice and tenon joints in order to build triremes. This process was almost certainly continued through the later construction of larger polyremes (Casson, 1971, 97-123; Morrison and Coates, 1996; Morrison, 2004, 66-77; Murray, 2012). I suggest that it is possible that these factors contributed to the mortice and tenon joint becoming the default means of vessel construction across the Greek world. If this were the case, then the issues leading to the widespread adoption of mortice and tenon joints might have been broadly similar to those that influenced the earlier change from the long, to the short, form of this joint. In both cases it is possible that socio-political factors, rather than any specific technical requirement of the merchant vessels of the time, may have been the key influences. This is not to dispute that the change facilitated later developments; rather, that the change was not motivated by this requirement.

6.3.3 The increased size and complexity of merchant galleys

In section 4.2.2 I discussed the evidence for the continued use of large hybrid rowed and sailed vessels in colonising voyages, and the references to their use in long-distance trade up to the start of this period (Herodotus, *Histories I.163; IV.153*; Plutarch, *Life of Pericles, 26.4*). In this context Plutarch, who - as discussed earlier - relied heavily on earlier Greek sources, recorded that as late as the 6th century BC the *samaina* was developed to support a form of bulk trade. There is additional evidence in the opening verse of the Periplus of Hanno the Navigator (Schoff, 1912) to suggest the use of pentaconter sized vessels by the Carthaginians for colonising voyages in this period. The period in which these voyages are recorded all predate the earliest confirmed appearance of large sailing ships, as recorded in Table 2.1 and discussed throughout section 4.3. In the roles outlined, these vessels appear to have been employed in activities where sailing ships would have been a viable alternative had they existed. The later exploration of the west coast of Africa by the Portuguese in the 15th and 16th centuries was carried out in Caravels, this type of ship is commonly recorded as having a capacity of between 50 and 100 tons (Phillips, 1994, 91-98). The use of hybrid rowed and sailed vessels by the Carthaginians for these voyages might suggest that sailing vessels of this size did not exist at this time.

The types of voyages that Herodotus, Plutarch, and Schoff describe as using some form of 50 oared ships can probably be regarded as being of strategic, or economic, importance to the communities involved. This might reinforce the point that the types of voyages on which these vessels were used provided the motivation to focus development on enhancing their performance, and further increasing their cargo capacity. Evidence for vessels of this type in use through to the later Roman Empire are provided in Figures 3.8, 3.9 and 3.10. This suggests that the coastal voyages undertaken by large galleys did not prohibit their continued use and development at a time when large sailing ships were becoming more common. This might suggest that the introduction of large sailing ships did not represent a significant change in the nature of maritime trade and trade routes. This issue will be discussed further in sections 7.5.1 and 7.5.2.

In terms of learning it is perhaps relevant at this point to return to the issue of the development of more complex sailing rigs, in particular the artemon sail. Along with the sailing ships shown in Figures 4.32 and 4.33, it is apparent from Figures 3.8, 3.9 and 3.10 that more complex sailing rigs, in particular those involving the use of an artemon sail, were in use on later large merchant galleys. One suggestion for the development of these rigs is that this was linked to attempts to sail to windward (Whitewright, 2011a; 2017). Rather than an origin in sailing ships, I suggest that this development may rather have been linked to the nature of the problems experienced by Severin (1985, 168-170) on the Argo, discussed earlier in section 2.2. This might suggest that complex sailing rigs were first introduced in long galley type vessels fitted with an extended forefoot. The iconography shown in Figures 4.24a-d, and the textual evidence of Herodotus *I.163 and IV.153* show that pentaconter sized vessels were in use through the Archaic period, this precedes any secure iconographic evidence for the use of an artemon sail. If this was the case, then attempts to further increase the size of this vessel type may have resulted in more frequent problems of the kind recorded by Severin on the Argo. This in turn may have initiated a process of minor changes to existing sailing rigs, the purpose of this being to increase the safety of these large vessels when practicing a common form of seafaring. The first steps in this may have resulted in the mast being located closer to the bows of the vessel in an attempt to aid in its handling, as discussed earlier this process might be suggested by the location of the masts in Figures 4.24a-d. However, there are clearly potential dangers in this process which may be suggested in Cariolou (1997, 96-97). In this Cariolou suggests that a number of design features of the Kyrenia ship were optimised for safety in downwind passages. The mast on this vessel is located in the centre of the vessel which suggests its location may also have been linked to this requirement. If a process of innovation linked to the safe use of galleys was underway at this time, the result may have been the development of a sailing rig that comprised a conventional drive sail in the centre of the vessel along with some form of foresail. The results of this process may be reflected in the references to the use of artemon sails in the contents of the Athenian naval inventories from the 5th century BC, Morrison and Coates (1986, 176 – 177). As with the development of the loose-footed sail discussed in section 6.1.4 the motivation for this would have been to increase the safe use of a familiar vessel type, on a familiar type of voyage. This process then might be seen as one in accord with a conservative tradition discussed by Usher (1954, 68-69) and Unger (1994, 7) and aimed at minimising risk as identified by McGrail (1989, 850) and Unger (1994, 7).

It might have been expected that the importance of merchant galleys would decline toward the end of the period due to the widespread use of sailing ships with the range of sizes shown in Table 2.1. However, there are continued depictions of vessels with the hull forms associated with galleys in Roman iconography through to the 2nd century AD, as shown in Figures 3.8 to 3.10. These depictions suggest that where large galleys were used in these later times, they were equipped with the same sailing rigs as the larger sailing ships. It is of relevance in this regard to recall the point made in section 2.0 that, through to the Renaissance, records suggest these vessels were sailed whenever possible. If a similar pattern of use existed in this period it might be expected that galleys at this time would have been fitted with the most efficient sailing rigs. I have suggested to this point that, on the basis of the model of learning presented, galleys may have been the focus of the continued development of these more complex sailing rigs at this time. The observation by Edgerton (1999, 123) relating use to invention and innovation, in conjunction with the key role these vessels appear to have played in trade at the time, suggests both a motivation to improve their safety and increase their cargo capacity. However, it seems probable that despite their increase in size these vessels were sailed in the same manner, and on broadly similar types of voyages, as the earlier hybrid vessels of the Bronze Age. On this basis, they are unlikely to have contributed to the development of new seafaring skills.

6.3.4 The development of large sailing ships

From the evidence shown in Table 2.1 it might be fair to assume that, up to the 6th century BC, routine trade in the Mediterranean was dominated by a mix of hybrid and sailing round ships and that these only rarely exceeded 16 metres in length. Requirements for larger cargo capacity vessels up to this time having been met by merchant galleys. The evidence of the development of larger sailing vessels from some time after the 6th century BC may be seen then as the final stage in the development of vessel types in the period. In section 5.2 I discussed the lifting technologies, and the increase in complexity of the sailing rigs, that provided the means to increase the size of sailing ships. If the process of learning discussed in Chapter 3 is accepted, the development and use of the largest vessel sizes followed this date.

I suggest that before sailing ships were likely to have increased significantly in size it was probable that elements of the hull would change. The case has been made earlier that the form of this shown on both the Mazarron 1 and Jules Verne 9 wrecks are intermediate types in the line of development from earlier hybrid vessels to true sailing ships. The hull forms of the later Gela 2, Ma'agan-Michael and Kyrenia ships exhibit more features of a true sailing ship. In particular, the deeper wine glass shape leading down to the keel. This enhanced the effectiveness of the keel itself, while increasing the stiffness of the hull. This latter feature of the design may have facilitated the later construction and use of larger sailing ships.

The model of learning presented in Chapter 3 suggests that as sailing ships increased in size, shipbuilders would use all relevant practical experience to build them. As I have discussed to this point, this process was likely to involve the hybridisation of any experience gained in the construction and use of larger galleys. These developments would clearly be influenced by the specific experience of the shipwrights involved. Where merchant galleys had been a dominant local form of vessel the features used on this vessel type may have been incorporated into new larger forms of sailing ship. This may have resulted in some lines of development being pursued that were ultimately discontinued as particular features were found to be counterproductive. I suggest that it is possible that this process may be seen in regard to the bow construction of the Madrague de Giens vessel shown in Figure 4.37.

The Madrague de Giens wreck provides the earliest physical evidence of a large Roman trading vessel. Pomey (2020, 36) suggests its distinctive bow feature would 'make the ship very stable at all sailing trims'; however, Pomey presents no evidence to support this assertion. I take a counter view and suggest this was not an optimum form of hull design for a sailing ship. I base this observation on the lack of evidence that any sailing ship through to the end of the 19th century repeated this hull form. It also appears to run counter to the cases presented in Tilley (1993), Roberts (1995) and Palmer (2008). All of these authors note that in sailing vessels the handling is largely the result of the balance of forces between those applied by the sails and the resistance of the hull. Palmer (2008, 93-94) discusses this specific issue in regard to the Kollerup cog. In this instance he notes that the sharp, undercut, forefoot of this vessel would have been helpful in tacking manoeuvres. This forefoot in the case of the Kollerup cog being close to the form of later Roman sailing ships shown in Figures 4.32 and 4.33. Davey (2015) and Whitewright (2017) make the same general point with regard to the benefit derived from the force applied close to the bows of vessels by the artemon and sprit sails. The concluding observations of these authors might be taken to be that, for a sailing ship, it is an advantage to minimise any projection of the bows ahead of the foremost sails. I suggest the later iconography of large Roman sailing ships from the 2nd and 3rd centuries AD, shown in Figures 4.32 and 4.33, is significant in this regard. These vessels probably represent the end point of the development of large Roman sailing ships, as such, both show the sharp, undercut, forefoot recorded by Palmer. This later change is difficult to explain if the observation of Pomey (2020, 36) regarding the beneficial effects of the extended forefoot is correct. In a number of works Pomey (1982, 140-145; 2015, 79) compares the bow form of the Madrague de Giens ship to a later vessel from the Themetra mosaic. I suggest that this comparison is based on a failure to appreciate that the vessel used as the basis of this may have been a merchant galley. The vessel shown in Figure 3.10, also from a 3rd century mosaic from Themetra, shows that merchant galleys with a similar sailing rig were in use at this time.

If a process of development is considered to have been underway at this time, then an explanation for the distinctive form of the bow of Madrague de Giens vessel may be seen to lie in the date of construction, and the model of learning presented to this point. This vessel has been dated to the 1st century BC, this predates by several centuries those shown in Figures 3.8, 4.32 and 4.33, and the vessel from the Themetra mosaic used by Pomey (2015, 79-80). In section 3.1 I discussed the potential problems of making radical changes to the forms of any vessel constructed shell first. If, both this assumption, along with the model of learning I have proposed is sound, it seems likely that shipwrights would be reluctant to make large scale changes when constructing any hull. This might suggest that those responsible for the construction of early large sailing ships, such as the Madrague de Giens vessel, were likely to modify the form of the largest vessels they had experience of building. At the date of construction of this vessel, it is quite possible that for many shipwrights the largest vessels they had built were merchant galleys. Given the model of learning practiced in craft industries in the past, it would not be surprising if shipwrights had used elements of the hull form of this vessel type to serve as a template for the construction of an early large sailing ship. On this basis, it might be expected that the form of the new vessel would be a hybridisation of a broadly similar existing type.

This proposed galley influence might be confirmed if the recorded dimensions of the Madrague de Giens vessel of around 40 metres long and 9 metres wide are correct (Parker, 1992, 250; Pomey, 2020, 34). These suggest a vessel with a length-to-beam ratio of around 4.5:1. This ratio lies outside of the norm for vessels of this type noted by Casson (1971, 189) where he records that 'wooden freighters in all ages have had a general length-to-beam ratio of 3 or 4:1'. These figures for sailing ships might be compared to those suggested by Casson (1971, 166-167) for a *cybaea*; a vessel he described as being a broad galley with a length to beam ratio of around 5:1. If the measurements of the Madrague de Giens vessel are correct, the vessel is slimmer than a typical freighter, but broader than a contemporary large galley. The vessel then might represent an intermediate stage of vessel development in which the dimensions and hull form of a large merchant galley were being adapted to meet the needs of a new vessel type. The implications of this may suggest that in the 1^{st} century BC the construction of large sailing ships may not have been based solely on incremental changes to existing forms of smaller sailing vessels. Rather, a number of their features may have been transferred from existing galley forms, with the result that the vessels were not optimised for sailing performance. The possible implications of this will be reviewed in section 7.5.2.

With the introduction of larger sailing vessels equipped with more complex sailing rigs, the following question might be posed: how did these impact on the nature of seafaring? I contend that the shape of the bow of the Madrague de Giens ship suggests this vessel would have been limited in its ability to tack across the wind. This suggests that it is quite possible that the balance of forces between the sails and the hull form of vessels was not fully understood at this time. This might not be surprising if seafaring had been dominated by smaller sailing ships and larger merchant galleys. These vessels were likely to have been safer when operating on largely downwind courses comprising coastal routes with short inter-island passages.

A final point to consider is the manner in which the efficient operation of these vessels under sail would be dependent upon the forestays, the backstays and the shrouds that together support the mast. To understand the importance of these features it is necessary to understand the nature of the mast as an engineering structure. In this context, a mast is an example of a cantilever beam; that is, a beam which is only supported at one end. In a simple cantilever, when a load is applied to the unsecured end the end at which it is supported must provide the means to withstand this load. A further obvious point being that the beam itself, just above this point of support, must have the strength to resist the bending load applied. In the case of a mast acting as a beam, the load may be regarded as the wind operating on the sail supported high on the mast. The mast being supported by a combination of the mast step and the deck housing. A comparison of the masts of the Kyrenia ship and the Bremen cog shown in Figures 5.1 and 5.2, emphasise how the width of the mast increases with relatively small increases in vessel size. This is a clear indication of the increased load experienced by the mast of a larger sailing ship. In most sailing ships a mast is a particular example of a cantilever beam, this is known as a guyed cantilever. In this the structure is in part supported by lines strung from positions high on the mast, these lines being secured to the deck. When a load is applied to the top of a mast supported in this way, rather than manifest as a single bending load at the base of the mast, a percentage of the load is converted into tensile loads in the rigging which transfers this to the deck. The purpose of the rigging then is to reduce the load on the lower mast. Any vessel that consistently attempts to sail on courses where the wind is on the beam, that is courses in which the wind comes over the side of the vessel, will require standing rigging on either side to support the mast in this manner. This form of standing rigging is known as shrouds. If these are not used then the vessel will have to be sailed very conservatively to reduce the resulting loads. An alternative would be to use masts of extreme thickness in an attempt to provide the necessary strength. However, this latter option leads to masts of greater weight, which further increases the load on the mast at the base, the solution then generates its own problems.

As noted, shrouds are not an absolute requirement. It is possible to use square rigged sailing ships with no shrouds; however, their integrity and safety in strong winds would probably be heavily dependent upon the limited range of courses they steered. Any attempt to sail to windward in strong winds in vessels without shrouds would be likely to involve high risks. It is apparent then that the lack of shrouds is likely to inhibit the development of seafaring skills that might contribute to long-distance offshore sailing in variable winds. The Porto bas-relief shown in Figure 4.33 from the 3rd century AD shows shrouds as part of the standing rigging. The complex form of these suggests they appeared well before this time; however, the lack of evidence of the precursors does not allow a process of development to be assessed. This said, evidence also exists from the Les Laurons B wreck from the late 2nd century AD, shown in Figure 4.38 (Gassend et al, 1984, 84). Their use on a small vessel at this time suggests their possible widespread use by the end of the period covered in this thesis. The implications of the possible late development of shrouds, and their impact on seafaring, will be discussed in Chapter 7.

6.3.5 Possible societal factors impacting vessel development

The interaction of maritime technology and trade routes is the subject of Chapter 7, at the present time; however, it is relevant to revisit the evidence in Table 2.1, Parker (1992) and [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022. The evidence from these suggests that the initial increase in the size of sailing ships appears to have been linked to the Greeks, and possibly the Etruscans, rather than the Phoenicians. I appreciate that this may relate to the incomplete nature of the shipwreck record. However, the evidence as it currently stands appears to run counter to the accounts of Aubet (2001), Cunliffe (2011; 2017) and Abulafia (2011). These authors consider the Phoenicians to have pioneered the widespread use of large sailing ships in this period. These conclusions being based on the assumption that similar vessels had been in use in the area in the Bronze Age (Casson, 1971, 36; Bass, 1974, 23; Wachsmann, 2009, 41).

From the societal viewpoint the development of these larger sailing ships followed a period of economic and demographic growth of independent Greek colonies in the Mediterranean. The independent socio-political structures of these resulted in growth in intra-regional trade, along with competition and conflict between individual cities within a shared cultural tradition. In many respects these paralleled relations between city states in Greece (Graham, 1971; Osborne, 2009, 111-123). This development coincided with the introduction of coinage into the Greek world. It is possible that this may have facilitated the development of commerce in the manner discussed by Morley (2007, 61-62). I suggest that these shared traditions may have facilitated the cross fertilization of ideas noted by Adams (2013, 40-41), and had the same impact as noted by Unger (1994, 7) as occurred in the maritime communities of Medieval Europe. It is possible then that, as much as any individual change in maritime technology, it was the motivation provided by the nature of Greek society, and the number and independent nature of Greek city-states in this period, that propelled widespread innovation in maritime technology within the Greek world.

In regard to Phoenician society in the same period Aubet (2001, 113-114) discusses the 'institutionalization of the colonies.' She goes on to note that while there was a role for independent trade, the mercantile oligarchies of Tyre and Byblos, along with the monarchy, played a dominant role. Markoe (2000, 96) is even more definitive in noting that: 'In the Late Bronze Age and Early Iron Age, Phoenician trade thus appears to have been controlled by the state.' These suggest that the model under which Phoenician colonisation developed appears to have been more closely associated with a command economy. This suggests that there may have been less competition between the individual colonies, this may in turn have stifled technical innovation. Within this social structure it seems likely that development may have been more rigidly controlled from major trading hubs. It is possible then that maritime technology in the Phoenician world was focussed on the requirements of its most significant trade routes. I will discuss these in more detail in section 7.4.1, these discussions will show that many of these focussed on delivering strategic goods from trading emporia to the host cities in the Levant. Interestingly, for a society renowned for commercial activity, the introduction and widespread use of coinage appears to have been a later development in Phoenician states (Aubet, 2001, 141-142).

If the opinion expressed by Aubet and Marcus regarding the institutional nature of Phoenician society and trade are correct, there were likely to have been significant societal differences between Greek and Phoenician colonies. The greater centralised control suggested in the case of the Phoenicians seems likely to have reduced the potential for the same level of independence, and competition, between colonies and emporia as existed between the Greek equivalents. In this case, the positive societal factors relating to technical development noted by Unger (1994, 7) and Adams (2013, 40-41) may have been less likely to apply. Overall, I suggest that it is possible that the reputation of the Phoenicians was based on their ability as seafarers in a technical environment dominated by hybrid rowed and sailed ships. The discussions in sections 6.2.1 and 6.2.2 confirms the contribution of the Levantine cities to the development of flexible hulls based on a combination of frames and mortice and tenon construction. However, as noted earlier, the significance of this change appears not to have been emphasised in currently published works. The evidence suggests they also influenced the development of sailing technology as demonstrated in the Mazarron 1 vessel. However, there is no evidence for any Phoenician involvement in the development of maritime technology relating to large sailing ships. I appreciate that these observations may be subject to change as fresh archaeological discoveries are made across the Mediterranean.

The evidence presented to this point suggests that many features of later Roman sailing ships may have been based on technologies that were derivative of earlier Greek or Etruscan usage. If this is correct, then many changes in this period were probably less the result of invention and innovation; rather, they might be seen to be the result of the diffusion of existing ideas and technologies. In his discussion on diffusion Rogers (1995, 35) notes that: 'Diffusion is the process by which an innovation is communicated through certain channels over time among members of a social system.' In this context, it is probably not unreasonable to assume that communication in any social system was linked to connectivity and integration within society. In the Roman Empire this issue is indirectly addressed by Bowman and Wilson (2009, 16-17) in their discussion on Rome as an integrated economy. In these discussions they noted that 'the gradual transformation of the Hellenistic kingdoms, north Africa, and western Europe into a Roman empire inevitably involves greater economic integration than had existed earlier.' They later go on to link growth and development in the empire with the spread of institutional, linguistic, cultural, economic and religious phenomena. Scheidel (2009, 1) makes a similar point regarding the scale and scope of integration and connectivity in the Roman world, stating in this regard that 'imperial state formation was the single most important ultimate determinant of the scale, structure, and productivity of maritime commerce in the Roman period.' If Roger's assertion linking diffusion, innovation and communication is accepted, then the comments of Bowman and Wilson, and Scheidel, might suggest that the size of the Roman Empire, and its greater coherence and power, provided the means by which maritime technologies of earlier Greek and Etruscan societies became more widespread. At the same time, this period of enhanced communication, and integration, probably reduced the chance that any advantageous change was lost to the wider process of technical development. The Roman Empire then probably provided an ideal environment for societies across the basin to fully exploit the earlier learning of the Greeks, Etruscans and Phoenicians.

6.3.6 Summary

There is clear evidence in this period for the widespread use of sailing ships and merchant galleys, and for an increase in the size of both vessel types. The current evidence suggests that the introduction of lifting technology to maritime use that probably led to the use of larger sailing ships, and the evidence for the development of more complex sailing rigs, is specific to this period. The continued use of a range of vessels for trade, in conjunction with the massive expansion of naval power by a number of states at this time, suggests that a complex mix of influences may have contributed to any single invention or innovation. In particular, this might be the case for the widespread adoption of mortice and tenon joints, and the introduction of complex sailing rigs. These factors perhaps emphasise how to fully understand the process of learning and development in relation to maritime technology it is necessary to examine this in the context of a wide range of potential influences.

6.4 Conclusions

To this point I have presented a system of taxonomy for describing vessel types, and a process by which maritime technical development may be explained by a model of learning appropriate to the ancient world. These have been used to present a proposed sequence of development based on the currently available evidence. The main conclusions reached to this point are presented in Table 6.1. These can be summarised either as part of the suggested process of development or through a review of the evidence itself.

The first of these were discussed in some detail in Chapters 2 and 3, and in summary suggest that:

1. Any model for a process of development needs to be based on a system of taxonomy of vessel types that is itself based on vessel usage.

2. A process of development based on a model of learning can provide a viable means to examine changes in maritime technology.

The use of this taxonomy and the learning model suggested, along with the totality of the evidence presented to this stage, have been used to support the process of development presented in this chapter. As noted in the introduction to this chapter many of the conclusions presented are based on conjecture. There is no clear textual evidence from the period covered by this thesis explaining how the development process worked, and the iconographic and archaeological evidence leaves many gaps in the record. I contend; however, that the use of some engineering principles, and a recognised model of learning, provides a solid basis for this conjecture. The methodology used, and the conclusions reached to this stage, can only be improved by challenge. Hopefully, any challenge will take note of the caution in Rogers (1937, 29) to test technical issues against both engineering and operational realities, and be based in turn on a clearly stated model of learning and a process of development. The need to integrate these factors across the full range of inputs to assess the development of vessel types and their features is hopefully apparent from the discussions presented. The invitation to challenge notwithstanding, the conclusions presented in this section will be used as the basis of the examination of seafaring and trade routes in the following chapter.

7.0 Learning in relation to the use of maritime technology

The purpose of this chapter is to examine how the conclusions reached to this point regarding learning and development, and the limitations and capabilities of the differing vessel types, are reflected in vessel use. In this regard the link Edgerton (1999, 123) makes between use and invention and innovation will again underlie much of the following discussion.

7.1 Introduction, risks and limitations in seafaring

The discussions in sections 5.1.1 and 5.1.2 showed that the maximum length of any hybrid rowed and sailed round ship would probably be around 16 metres, and that the only means to achieve larger sizes for a vessel of this type was to adopt the galley form. The evidence presented to this point shows this latter vessel type to have been the largest in use until the development of large sailing ships sometime after the mid-5th century BC. Similarly, I have discussed at a number of points how the voyages undertaken by merchant galleys were limited by their lack of seaworthiness to coastal voyages with short offshore legs (Guilmartin, 2003, 73; Pryor, 2004, 208-209; Dotson, 2004, 219-220; Higgins, 2012, 26). The use of these hybrid vessels will form the basis of much of the following discussions on learning relating to seafaring and vessel use. In section 5.2 I examined some of the technical issues that underlay the introduction of sailing ships substantially larger than 16 metres. The content of this chapter will expand on this to show a direct link between vessel size and the risks experienced on long distance offshore voyages.

In section 2.2 I discussed how Taylor (1951, 64) and McGrail (1991, 311) had used the same translation of Homer's *Odyssey,* and how this had led to confusion regarding the route of the voyage being described. In this chapter I examine in some detail the risks involved in the route that both of these authors appear to propose. I use this to support my contention that the offshore voyage described by McGrail, and possibly implied by Taylor, did not form a routine part of seafaring at any time from the Bronze

Age to the Roman era. To substantiate this, I will review the limitations of the vessel types for which there is evidence in the archaeological record, and present an appreciation of how risk may have influenced learning in regard to seafaring when using these. I do not dispute the extent of the trade carried out by the Cypriot and Phoenician seafarers in the Bronze Age and Archaic periods; rather, I contend that the routes proposed by many authors are based on a failure to fully assess the nature of both the technology available, and the risks associated with its use.

Before proceeding it is appropriate to revisit some of the evidence that will form the basis of the cases presented in this chapter. The evidence of the early 14th century BC Kenamun vessel, shown in Figure 4.3, shows this to have a boom-supported sail. Both Vinson (1993), and Wachsmann (2009, 248-251), discuss the limitations resulting from the use of this sailing rig for any courses other than those close to downwind. I contend that the observations of Roberts (1995, 308), Gifford and Gifford (1996), Pulak (1998, 210-211), Wachsmann (2009, 253), McGrail (2010, 103), Whitewright (2011a, 5; 2011b, 92-93) and Davey (2015, 31) regarding the importance of the hull form on sailing performance are of particular relevance to discussions on vessel use. In this regard the evidence of the hull form of the Uluburun and Zambratija vessels, discussed in section 4.1.3, shows these to have had a simple concave form, and to have lacked an external keel. This lack of an external keel resulted in Pulak (1998, 210-211) differentiating the Uluburun vessel from 'much later sailing ships.'

In Chapter 6 I presented a process of learning and development that suggested the external keel only appeared following the introduction of the loose-footed sail. The earliest confirmed evidence for the use of this type of sail is found on the reliefs in the mortuary temple at Medinet Habu from the early 12th century BC. Mazarron I is the earliest evidence of a vessel with an external keel and dates to the 7th century BC; this small vessel was found in Spain and has been associated with Punic activity in the region (Tejedor, 2018). The hull form of this was similar to that of the Uluburun vessel and lacked the more efficient wine glass shape of the later Kyrenia and Ma'agan-Michael vessels discussed in section 4.3.3. As a result, this vessel probably could not have matched the limited capabilities of these later sailing ships as discussed by Katzev (1987), Cariolou (1997), Safadi and Sturt (2019) and Gal et al

(2021a;2021b;2022;2023). The textual and iconographic evidence is dominated by hybrid rowed and sailed vessels down to the 6th century BC. This might suggest that they played a significant part in seafaring to around this date. The limited performance under oars of a 20-oared reconstruction vessel of this type might be judged from Severin, where he records how; a 20-oared vessel had a rowing speed of 3-4 knots in calm conditions, but that 'a scarcely perceptible breeze blowing against the prow of the boat, cut down her speed alarmingly', and then goes on to note 'that moving a 20 oared galley into a headwind by oars was a futile exercise in nine cases out of 10' (Severin, 1985, 80-81).

The records by Katzev (1987), Cariolou (1997) and Gal et al (2021a;2021b;2022;2023) on the voyages of the reconstructed Kyrenia ship and Ma'agan Mikhael II are instructive in many respects. However, these have to be considered in the appropriate historic context. These vessels were sailing ships with a wine glass hull form, and the earliest evidence of a vessel with this hull form is the Gela 2 from the third quarter of the 5th century BC (Kahanov and Pomey, 2004, 18). The accounts of the performance of these vessels cannot be used as analogues for the performance, and use, of earlier vessels that lacked these features. In regard to these later vessels, the accounts of Katzev and Cariolou show the Kyrenia ship to have been capable of making a voyage from Greece to Cyprus by a series of inter-island passages, and a similar return journey from Cyprus to Greece. The longest individual passage involved a voyage of 178 miles and is recorded as having taken 65 hours (Katzev, 1987, 248). However, the account of the voyages show most daily passages were considerably shorter.

The reports of these voyages contain a number of relevant points relating to risk that should be considered. Cariolou (1997, 91) records that the vessel was equipped with 'one marine VHF radio with another reserve radio, fourteen life jackets, one life raft capable of holding ten people and two parachute flares.' On both voyages the vessel was towed for around 30% of the distance covered. On some occasions this was due to the vessel being becalmed, on other occasions it was as a result of gear failure. These voyages then were carried out in a more sophisticated vessel than those available to sailors through much of the ancient world, and the crew was provided with a greater assurance of safe recovery in the event of a problem occurring. The relevance of these points in regard to the willingness of seafarers to undertake voyages of this kind are not discussed by Safadi and Sturt (2019), and Gal et al (2021a;2021b;2022;2023) in their proposed reconstructions of extended offshore passages. It is my contention that the lack of these support packages in the past may have resulted in ancient seafarers making more conservative operational decisions regarding the length of individual passages undertaken, or the weather conditions willingly faced.

In regard to this latter issue, Cariolou (1997, 93) observed that: 'Tacking was found to be difficult but possible. We successfully tacked twice without using oars in winds between 2-4 Beaufort. Tacking in winds above 4 Beaufort proved difficult and very dangerous for the integrity of the sail, and therefore was not practiced.' To put these figures into context, a mean wind speed of force 2 is 5 knots and is described as a light breeze, whereas a mean wind speed of force 4 is 13 knots and is described as a moderate breeze Beaufort wind force scale - Met Office 20/3/2022. The same problems were reported by Gal et al (2021b, 4; 2023, 8-9) where they record how the limited windward ability of Ma'agan Mikhael II disappeared completely over the same range of windspeeds. The difficulties in tacking, or making progress to windward, in these vessels in relatively benign conditions would clearly have impacted on their ability to undertake extended offshore voyages in variable winds. These difficulties perhaps provide context for the speculations of Fabre (2004, 89) regarding the use of a steering oar in Egyptian vessels to reliably balance the loads of a sail, and in doing so allow vessels of the period to sail courses to windward. The nature of the problems resulting from the failure of the rudder when at sea, described by Katzev (1987, 253) and Cariolou (1997, 94) in regard to the Kyrenia ship, and Severin (1985, 168-170) in regard to the Argo, suggest that, while Fabre's idea may have been possible it was unlikely to have been a reliable technique regularly employed by seafarers.

Gilmer (1987, 207-208) discusses the issue of equipping a reconstruction vessel to meet current legal requirements for use, and how this may detract from their use as accurate representations of the voyages made by ancient vessels. These qualifications might be accompanied by considering the motivational factors at play. For the purposes of research, sailors of modern reconstructions might be expected to have a focus on testing the operational limits of the vessels they had built, and were sailing. This issue is discussed by Whitewright (2011, 8-9). In these discussions Whitewright suggests that because the crew of a reconstruction vessel were 'actively trying to achieve the best performance' they might provide 'an optimal yardstick' for assessing voyages in the ancient world. It is my contention that this misses the issue of risk in determining the nature of seafaring. For reasons of safety, sailors in the ancient world, particularly if they were tired toward the end of a long voyage, or indeed a long sailing season, might be less inclined to pursue the same objectives. There are further relevant comments by Crumlin-Pedersen (2004,) and Whitewright (2010) regarding the impact of sea conditions on the windward performance of reconstruction sailing vessels. Both of these authors note that in most cases the best windward performances were achieved in calm seas with only small waves. However, trading vessels undertaking long offshore voyages cannot pick all of the conditions they might face. For this reason, the performances of reconstruction vessels should be examined in depth to assess their relevance to trading voyages in the ancient world.

Safadi and Sturt (2019) and Gal et al (2021a;2021b;2022;2023) provide comprehensive accounts of the possible windward ability of ancient sailing ships. The latter going on to provide a comprehensive guide to the difference between the true and apparent wind. A similar understanding, and perhaps one with a more operational focus, may be gained from accounts of the vessels in use at the end of the 18th century AD. At this time, it is reliably recorded that the best heading a square-rigged sailing ship could achieve was 2 points, or around 22 degrees, into the wind (Steel, 1794, 280). Willis (2003) notes the same figure, and goes on to detail the operational problems encountered in naval vessels of the 18th century in attempting windward courses. Willis discusses the variation in windward performance for these vessels, recording how only the most seaworthy ships, with the most able crews, were able to make the heading of 2 points recorded by Steel. Willis concludes by noting 'it would be reasonable to say that most ships, most of the time, made about one point (11 VA°) of leeway' (Willis, 2003, 35). This would mean that in a realistic range of weather conditions even the best vessels of this late period might only make a true course of 1 point to windward, and many might be unable to make a windward course at all. This might support the opinion of Pryor (1988, 35) in saying 'early medieval round ships conceded as much ground to leeway as they gained through their ability to point into the wind.' Pryor going on to note that 'any lee shore was a master's nightmare.' Pryor here is describing the risk of a sailing ship being blown on to the shore because the vessel cannot make progress against the wind. In these circumstances the caution of Severin (1985, 80-81) regarding the performance of a 20 oared galley under oars is relevant. It is possible that on a weather shore, that is one where the wind blows offshore, a hybrid vessel that lacked the ability to sail to windward would be unable to sail back to the beach when a consistent offshore wind was blowing. In these circumstances it is possible a vessel could be blown beyond the ability of the oar crew to bring it back to the beach against the prevailing wind. For a hybrid vessel then, both weather and lee shores might be seen to present a range of problems that were linked to the limited capabilities of this particular vessel type. This issue will be revisited throughout the following discussions.

Through the remainder of this chapter, I will use the evidence of the technology in use to present a model of the development of Mediterranean seafaring based on learning. Throughout this, the risks involved in the use of the vessels of the period will form a fundamental part of the examination of the possible seafaring techniques employed on the voyages undertaken. I appreciate the conclusions I reach in the following are conjectural; however, these will be based on the evidence of vessel types and the process of learning presented to this point.

Before undertaking a review of seafaring though, it is necessary to first outline the environment in which this seafaring took place; an outline of this forms the content of the following section.

7.2 The Mediterranean Environment

For vessels of the period the general pattern of regional winds in the Mediterranean was perhaps the most relevant environmental factor. The broad pattern of these winds, along with the generally counterclockwise current, are shown in Map 7.1 (Pryor, 2004, Figure 2). This broad pattern is confirmed by the more detailed studies of wind directions and wind stresses discussed by May (1982) in a study covering 1.2 million ship-based observations made between 1937 and 1973. This pattern has been confirmed by Zecchetto and Biasio (2006) in a study based on NASA Quik-SCAT satellite data, and de Paula Gomez-Delgado et al. (2019) in a study of ship's logs extending back to the mid-19th century. It is appreciated that while these regional winds predominate there are areas in which local winds might be of more significance. In this regard the variations in the winds off the coast of the Levant recorded in *The Sailing Directions for the Eastern Mediterranean 2017* are of particular relevance to the later discussions in this chapter. Similarly, there are times when seasonal winds blow in other areas, where relevant this variability will be discussed in the following sections. Katrantsiotis et al (2019, 36-37) discuss how the aridification trend which resulted in the establishment of the current regional weather patterns across the basin started around 5500 years ago. Pryor (2004, 208) makes the point that over the last 2500 years the seafaring cultures of the Mediterranean have recorded the same regional winds. On this basis it seems secure to use wind data from the recent past to model that for the period from 1500 BC. The wind patterns shown in map 7.1 are the winds that predominate in the summer, although the information in May (1982), Zecchetto and Biasio (2006) and de Paula Gomez-Delgado (2019) suggest that much of the same pattern holds through the year.

None of this should be taken to suggest that the climate in the region has been consistent through this period. Recent work on climate modelling in the Mediterranean basin shows the temperature variations experienced since the end of the last Ice Age. Perhaps the most comprehensive of these are the meta-analyses by Finne et al (2019) and Marriner et al (2022), the former being based on a range of sources of evidence, and the latter on seabed cores alone. The main conclusions from these appear to be the variability in both climate and climate change across the basin, these variations including a number of periods that were significantly cooler than today. Of particular significance in this regard is Marriner et al. (2022, 7) who notes that 'several sites from Syria, Israel and the Nile Delta show a transition to cooler and more arid conditions at ~1200 BCE.'

In *The Ancient Sailing Season* Beresford (2013) discusses the seasonal variations in the weather experienced across the basin. Beresford (2013, 65-69) also discusses the variation across specific regions of the basin, in this regard he noted that the Gulf of Lyons and the Aegean Sea were susceptible to winter storms, while areas of the eastern Mediterranean appear to have experienced more benign weather conditions throughout the year. Beresford concludes from this that sailing may have been more seasonal in some areas than was the case in others, but that, overall, the sea was never closed to trade. However, the focus of this work is the period from Classical Greece to the Roman era when large sailing ships were in use (Beresford, 2013, 6). Beresford (2013, 157) goes on to record that the short sailing season proposed by Hesiod was 'because the focus of the poet's calendar is on galleys.' Beresford then is implying a link between the vessel type in use and the earlier shorter sailing season recorded by Hesiod. For the later Roman period (5th century AD) Beresford records how Vegetius's *Epitome of Military Science* was more concerned with military seafaring than trade. However, in this work Vegetius records: 'But after the birthday, so to speak, of navigation which is celebrated with annual games and public spectacles in many cities, it is still perilous to venture upon the sea …not that the activities of merchants cease…when the enterprising are in a hurry for their private profits' (Vegetius *IV.39, trans,* Milner, 2001). The qualification that Vegetius makes in the final phrase perhaps emphasising how individual merchants may have balanced risk and profit. A footnote records the birthday Vegetius is referring to was the festival of Navigium Isidis. This was a festival to Isis in her role as patron of sailors and was held on the 5th March. I suggest that it seems more likely that a festival of this significance would have marked the restart of seafaring in a general sense, rather than these celebrations being specific to military activity. It is perhaps relevant that the period in which Vegetius was writing is recorded as being one of generally cooler weather, this followed what is referred to as the Warm Roman Period that extended to around AD 300 (Ljungqvist, 2020, 341-343). On this basis, if Vegetius was writing with reference to the sailing seasons of his time, it is possible that these may be shorter than those of previous centuries. This possible variation notwithstanding, Beresford presents examples of voyages undertaken in the winter. The record of these voyages might confirm that in some areas of the Mediterranean seafaring may have been less seasonal than many ancient sources suggest. Tammuz (2005, 151-152) also discusses a narrow range of offshore winter voyages in the eastern Mediterranean based on trade with Egypt, these then were in a region that Beresford notes to have had less severe winter weather. Tammuz (2005, 156) goes on to note how these offshore voyages may have been safer than coastal voyages in winter.

Perhaps the most significant feature of the wind pattern in the Mediterranean basin discussed to this point lies in its lack of a circulatory system. Thus, for much of the year when carrying out direct offshore voyages from the eastern to the central Mediterranean, and in many cases voyages from south to north, a vessel would have been required to attempt to make a voyage against the prevailing regional winds, or to wait for an infrequent favourable change in the wind. In this respect the Mediterranean is different to both the Indian and Atlantic oceans over which trade winds drove sailing ships in later periods. The nature of these problems is rarely discussed in scholarly works on trade routes and seafaring (Sherratt and Sherratt, 1993; Aubet, 2001; Broodbank, 2010; 2014; Abulafia, 2011; Cunliffe, 2011; 2017). These problems will form a substantial part of the points I will discuss in the following sections relating to risk and seafaring. The later discussions will show how these might have shaped and formed the trade routes discussed throughout this chapter.

In addition to understanding the pattern of regional winds, it is also necessary to consider the shape of the basin itself. Map 7.2 shows how this may be divided into three distinct regions. There appears to be little consensus on where the borders of these regions may lie. Cazzella and Recchia (2009, Fig 1) show the central Mediterranean as comprising Italy, Sicily, Sardinia and Corsica, and the western coast of the Adriatic. Vagnetti (2009) in a work entitled *Western Mediterranean* use the terms central and western Mediterranean without any specific boundaries between the two being spelt out. The divisions I show in Map 7.2 broadly reflect the division between the eastern and central Mediterranean shown in Cazzella and Recchia.

For any long-distance offshore voyages from the eastern to the Central Mediterranean some of the most significant risks are encountered around the southern Peloponnese. Strabo (*VIII.6.20*, trans, Jones and Sterrett, 2015) observed in regard to this: ‘And just as in early times the Strait of Sicily was not easy to navigate, so also the high seas, and particularly the sea beyond Maleae, were not, on account of the contrary winds; and hence the proverb, "But when you double Maleae, forget your home."' Pliny (IV.10, trans, Rackham, 2015) is less specific about Cape Malea but made the same general point when he said that: 'The circuit of the Morea is a long and dangerous voyage for vessels prohibited by their size from being carried across the isthmus on trolleys.' Further references to the problems associated with this region have been recorded by a number of other sources, both ancient and modern (Homer*, Od, 3.285-300, 4.515-520 and 9.80-85*; Torr, 1891, 57; McDonald, 1986, 192; Drijvers, 1992, 75-76; Morton, 2001, 81-85; Pettigrew, 2011, 552; *Sailing Directions Eastern Mediterranean, 2017*, 191-192). With the exception of Homer, most of these sources discuss problems experienced by shipping when many vessels were large sailing ships. It might be expected then that they would experience fewer problems than the small round ships, or merchant galleys, in use up to the 6th century BC. The difficulties involved in the use of this route by the vessels of the Bronze Age, and the impact this may have had on learning, will be the subject of much of the following section.

When seafarers lacked a secure means of offshore navigation, and might have relied on some form of peripli up to the Roman era, navigation by landmarks was likely to be one of the main techniques employed. In this case it is necessary to understand how visibility in the Mediterranean may have impacted on the choice of routes. A map proposing to show this is used by McGrail (2004, Fig 4.2), Cunliffe (2011, Fig 2.12), Broodbank (2014, 8-9) and Horden and Purcell (2014, Map 9), the map itself being based on earlier work by Schüle (1970, Fig 1). Horden and Purcell (2014, 126) use this map to support the comment that: 'There are only relatively restricted zones where in the clearest weather, sailors will find themselves out of sight of land … the map shows how relatively restricted these are … much of the Mediterranean basin is linked quite easily by lines of sight.' This might imply that navigation by the use of landmarks was relatively easy across much of the basin. Davis (2009, 47) examines this issue in more detail, commenting that: 'The major problem with Schüle's map is the misleading premise that optimal or even favorable conditions of visibility exist, or can exist, in the Mediterranean. Determining the geographic range is simply a starting point.' Davis (2009, 45-49) uses data from the Naval Weather Service Detachment. 1970. *Summary* *of Synoptic Meteorological Observations: Mediterranean Marine Areas*. Vols. 7-9 to examine changes in visibility resulting from varying meteorological conditions across the Mediterranean. He concludes that visibility due to dust or haze might be less than 10 nautical miles one day in three or four over many regions, and one day in two in specific local areas. The contrast between this distance and that of Schüle is clear from Davis (2009, Figure 2.18) shown here as Map 7.3. Regarding those periods of clear weather, it is perhaps relevant to note that Davis (2009, 48) states that: 'Visibility during these times can be crystal clear, but not for more than a day or two before inclement weather arrives'. On this basis it might be reasonable to assume that on other days the visibility may still be less than that proposed by Schule. This case made by Davis for the impact of reduced visibility, and the dependence on landmarks for navigation, is cited by Leidwanger (2020, 28-29) to support the case he makes for the nature of much of Roman seafaring. It is clear from Davis' comments that, for a significant period of the year, the use of landmarks is not a secure form of navigation when a ship might be significantly more than 10 miles offshore. In the case where the use of landmarks was the basis for navigation then, it might not be surprising if many major routes were close to the shore. Clearly, attempting to use landmarks to navigate at night introduces a further range of potential problems. These practical limitations on the visibility in the Mediterranean will underlie the discussions in the following sections.

Map 7.2 shows that in many areas the northern shoreline and its coastal waters have more islands than the southern or eastern shores. Associated with these features the northern shore also tends to have a high relief with more cliffs and bays. This results in a shoreline that offers the possibility of many inter-island passages of varying length, and many safe beaches with deep water close inshore. The southern shore on the other hand has more extensive areas of shallow water extending further offshore, and fewer well defined natural harbours. In the following discussions I will review the advantages that might result from these features, and discuss how these may have related to the vessel type in use.

7.3 Risk and Seafaring 1500 to 1000 BC

The initial focus in this section is on maritime activity in the eastern Mediterranean, this will then be followed by a review of voyages and trade between this area and the central Mediterranean. The material I presented in section 4.1 shows no evidence for the use of true sailing ships as described by Tilley (1994, 309) as detailed in section 2.0: rather, the evidence points to the vessels in use at this time being hybrid rowed and sailed ships. The case made in section 4.1.3 based on Pulak's description of the Uluburun vessel will form the basis of much of the discussion in the following. The case presented in section 5.1.1 explained why round ships of this type were probably limited to around 16 metres in length. The iconography presented in section 4.1.2 shows no evidence for the use of a loose footed sail before the early 12th century BC, this is five centuries earlier than the first archaeological evidence of the use of an external keel. In section 4.2.4 I discussed how Mazarron I, the first vessel known to have an external keel, had a hull shape similar to that of the Uluburun vessel; this vessel then was almost certainly unable to match even the limited abilities of the Kyrenia and Ma'agan vessels in making progress to windward, or in resisting making leeway.

In addition to the problems resulting from these general limitations of the vessels in use, the following discussions describe two of the major risks involved in the use of vessels of this size when attempting to make extended offshore voyages, these stem from the impact of the environment on the crew, and the stability of the vessel itself. In respect to the former Cariolou (1997, 96) records the following in regard to the Kyrenia II: 'Sailing a replica of a 2,500-year-old sailing vessel is a hard exercise…being wet, cold, without sleep and completely exposed to the elements on an almost continuous basis.' The voyage that Cariolou is discussing was between Cyprus and Greece between the 7th and the 27th of April, the conditions described clearly being based on the temperatures experienced today. Coincidentally the Kyrenia ship was around the same size as the Uluburun vessel, the largest known Bronze Age round ship. It might be expected then that the same physical conditions would have been experienced by the crews of Bronze Age vessels. As I discussed in the previous section, in the period 1500 to 1000 BC the Mediterranean basin experienced a range of temperature variations. Of possible relevance to the offshore voyage from the Levant to Crete discussed by McGrail (1991, 311) is the observation in Kaniewski et al (2020, 6) where he states that: 'Several cold periods were recorded in Cyprus during the last 6,000 years … and 3.2 ka BP.' The variation over the whole basin through the Holocene is discussed by Finne et al (2019), these show that in some instances significant variation occurred within adjacent sites within regions. On the basis of this data, it is not possible to be precise regarding the temperatures experienced by a crew in the Bronze Age. What is clear; however, is that any attempt to use the less capable vessels of the Bronze Age, such as that found at Uluburun, on longer offshore voyages is likely to have exposed its crew to cold and wet conditions for longer periods. These factors raise the issue of the possible effects of hypothermia experienced when undertaking a voyage of the kind described by McGrail.

The effects of hypothermia can range somewhere on a spectrum from mild to severe depending upon the temperature experienced, and the length of exposure. The following definition, symptoms, causes and mitigations for mild hypothermia are from The Maritime Human Resource Institute, Japan Department of Technology and Research [*http://www.maritime-forum.jp/Guidelines for Control Hypothermia at Sea (2017).html]* (accessed on 4/11/21). This shows that mild hypothermia occurs when the core body temperature falls to between 35 and 32°C, normal body temperature ranging between 36 and 37°C. The symptoms for this are recorded as overpowering exhaustion, an inability to move as desired, impaired cognition and judgement and an inability to stand. In maritime environments these are most likely to be the result of either falling into the sea or working in a cold environment on deck. The mitigations include changing out of wet clothing, moving to a warm place and raising the body temperature. The combination of these factors is unlikely to have enhanced the efficiency of the crew of a hybrid vessel of the period, it not being unreasonable to assume that this efficiency would have been heavily dependent on the crew's physical strength, and the co-ordination of their activities. The range of mitigations are simple; however, as suggested by Cariolou (1997, 96) these were unlikely to have been practical on any small open vessel at sea.

Table 7.2 is from *http://www.maritime-forum.jp/Guidelines for Control Hypothermia at Sea (2017).html* (accessed on 24/11/21) and records the time taken for the onset of hypothermia under different temperature regimes. The discussion on hypothermia and the contents of Table 7.2 should be compared to the data presented in Table 7.3. This shows the range of present-day sea water temperatures from a range of locations around the Mediterranean and is based on the daily satellite readings provided by the NOAA World Water Temperature and (seatemperature.org) accessed on 1/2/2022. The data from Tables 7.1, 7.2 and 7.3, shows that, early in the year, when the easterly winds off the coast of the Levant, recorded in *The Sailing Directions for the Eastern Mediterranean 2017*, might support the offshore route from the Levant to Crete proposed by McGrial (1991, 311), the current sea water temperatures in the area of Tyre are low enough to impact the performance, and potentially the survival, of a crew. Clearly, if the cooler temperatures suggested by Marriner et al (2022, 7) and Kaniewski et al (2020, 6) were reflected in the seawater temperatures of the time then this problem may have extended later into the year.

A further problem relating to vessel size might be identified in regard to vessel stability; the following passage from Steel (1794, 284-285) was addressed to naval officers in the late 18th century: 'When sailing in smooth water, the greater the stability the better; but if a vessel with a heavy cargo, stowed low in her bottom, be sent out into a rough tempestuous sea, where every wave will throw her from her equilibrium, she will return with such violence as to endanger her masts; and should she be dismasted, her roll will then be with still greater force, possibly to the destruction of her hull. Was the cargo in this laboursome vessel to be removed higher up towards the centre of motion, so as to lessen her stability, she would be found considerably easier; her roll would be by such deliberate motions, as to lessen the danger to her masts and hull.' What is relevant here is that in smooth calm waters it is an advantage to stow heavy weights low in the vessel. This might reflect the learning gained from sailing close to shore or in rivers and estuaries. However, in offshore conditions, where larger waves might be expected, a vessel loaded in this manner will roll with sufficient violence to potentially damage the structure of the ship. In regard to the Kyrenia II Cariolou (1997, 92) made much the same point when he noted that 'the return or recovery to the vertical plane of the mast after wave induced inclination was very quick.' In this passage he noted how the limited cargo may have contributed to this motion, this presumably being located low in the hold. The loading of the Uluburun vessel is examined by Lin (2003, 211-214). Lin's conclusions suggest that the construction of the vessel, and possibly the loading, may have been aimed at achieving a high degree of static stability. If this pattern of loading is correct, then it would appear that the Uluburun vessel may have been liable to the range of problems outlined by Steel. It seems probable then that, as was the case with the impact of hypothermia, the small vessel size in use at this time may have contributed to an elevated level of risk in offshore seafaring. In the latter case the use of larger ships may have provided the space to distribute the cargo in a safe fashion. In the case of stability; however, this learning appears to be counter-intuitive, and, as a result, would probably not be picked up through experience gained from sailing on coastal voyages in small vessels. I suggest that the combined effect of these factors may have been that seafarers were disinclined to risk sailing small heavily laden vessels in conditions where rough weather might be expected.

7.3.1 Seafaring and voyages 1500 to 1000 BC

It is clear from the evidence that through the course of this period a system of maritime trade had been established that linked Egypt, the Levant and Mycenaean Greece and Crete, with Sicily, southern Italy and Sardinia (Vagnetti and Schiavo, 1989; Alberti 2005, 2006; Cline, 2007; Marcus, 2007; Blake, 2008; Graziadio and Gugliemino, 2008; Vagnetti, 2009; Cazzella and Recchia 2009; Cline, 2011; Lo Schiavo, 2013; Sestieri, 2013; Russel, 2017; Kelder, Cole and Cline 2018; Sabatini and Lo Schiavo, 2020; Lo Schiavo, 2021; Kanta, 2021; Sabatini and Alberti, 2021; Fischer, 2021; Pearce, 2021). If the seafaring that enabled this system of trade developed through a process of learning in iterative steps, then the nature of earlier seafaring would be critical to understanding how the relevant skills developed through this period. The mix and complexity of the types of voyage that may have been undertaken is summarized in Figure 7.1 from Leidwanger (2020, Fig 3.2). Leidwanger presented this in the context of Roman seafaring; however, I suggest that the same mix was probably true for the period overall. The element missing from this is the manner in which vessel size and capability may have contributed to biasing any of the facets of mobility shown. This issue underlies the central themes of this thesis, and has formed the basis of the discussions to this point in this chapter. The conclusions I have drawn from these will be used to support the cases made in the following sections.

The evidence points to a long history of coastal seafaring from the spread of Mesolithic and Neolithic cultures around the Mediterranean basin (Colledge et al, 2004, 42; Broodbank, 2006, 214-217). These authors suggest that seafarers of this period used a range of paddled craft to make coastal and short inter-island voyages along the northern shore of the basin. The same pattern of short-range inter-island voyages by the long boat trading communities of the Early and Middle Bronze Age Aegean are recorded by Broodbank (2008; 2014), Alberti (2012) and Papadatos and Tompkins (2013). If learning relating to seafaring and navigation was based on a combination of experience, and the available maritime technology, it is not unreasonable to suppose that these Early Bronze Age seafarers were applying learning from their Neolithic predecessors. Similarly, it is not unreasonable to assume that the later trading cultures of the eastern Mediterranean based in Crete, the Levantine cities and Egypt, that developed early hybrid rowed and sailed vessels, exploited the learning derived from the Early Bronze Age seafarers. The shortcomings of these vessels associated with their use on extended voyages where a range of changeable weather conditions might be experienced have been discussed in earlier sections of this thesis. On this basis, it appears unlikely that the introduction of hybrid rowed and sailed vessels was either, initiated by, or associated with, a sudden change in the nature of seafaring. Rather, it seems more likely that at their introduction the seafarers operating these vessels used the same long-established coastal forms of seafaring as their predecessors dating back to the Neolithic. The development of the hybrid vessel type probably being motivated by the need for the larger cargo capacity that this afforded. This increase in capacity being required to meet the demand generated by the expansion of maritime trade brought about by growth in social hierarchies in the societies of the region (Betancourt, 2008, 209-229; Wright, 2008, 230-257; Broodbank, 2014, 344-444). For these reasons it is proposed to begin the examination of seafaring in this period with a review of how this may have been carried out using coastal voyages. The proposed counterclockwise system of largely coastal voyages that will form the basis of the review from this point are shown in Map 7.4 from Pulak (2008, fig 97).

Safadi and Sturt (2019) and Gal et al. (2021a) review some of the seafaring techniques that may have been used on a route similar to this. Both base their assessment using vessels from the 4th century BC. In both cases these vessels were equipped with a loose footed sail and a sophisticated wine glass hull form. These features would facilitate sailing to windward, and both would minimize leeway when sailing headings other than downwind. As discussed to this point, there is no evidence that vessels with these capabilities were in use in the Bronze Age. I have no doubt that the method of seafaring described in the papers by Safadi and Sturt and Gal et al. was the one practised, and that the techniques described applied to these voyages; however, I contend that the performances achieved by the vessels they discuss probably cannot be used as an accurate basis of comparison for sailing performance in the Bronze Age. The iconographic and textual evidence suggests that at the start of the period seafaring was carried out in hybrid rowed and sailed vessels with a boom supported sail, the archaeological evidence from the Uluburun wreck showing no evidence for an external keel. A vessel equipped in this way would be limited to making a range of courses close to downwind. It might similarly be supposed that the rowing crew would be capable of making progress in cases where there was no wind, but only limited progress when the wind was unfavourable; the extent of the progress in the latter case being dependent on the strength and direction of the wind (Severin, 1985, 80-81). Vessels of this type then would be capable of exploiting the wind on downwind passages while making coastal voyages similar to those described by Safadi and Sturt (2019) and Gal et al. (2021a), and to those that had been in use by earlier seafarers. The long-standing evidence of Egyptian trade with the Levant (Marcus, 2007) provide evidence that the hybrid vessels of the time were capable of making a return voyage along the coast of the eastern Mediterranean. A more problematic route; however, would be one that ran east to west from the Levant to Crete, the Aegean, and ultimately to the central Mediterranean.

A direct offshore voyage following this route was discussed in section 2.2. The earlier discussions in this chapter show that a voyage of this nature would have had to have been made against the predominant wind. This factor, in combination with the extended length of the voyage, suggests that in vessels of the size in use at this time this route would have represented a high risk to seafarers. The route along this coast had presumably been in use from earlier periods and was exposed to the same regional wind, and the same seawater temperatures, as the offshore route. It is also worthy of note that the predominant regional wind on this coast is offshore; as discussed earlier this might itself be a hazard in the case where vessels lacked the ability to sail to windward. However, it is possible to make this voyage at lower risk by taking advantage of the diurnal offshore and onshore breezes discussed by Safadi and Sturt (2019) and Gal et al (2021a). As voyages of this type are dependent upon local heating generated by the sun, the winds generated might be expected to be stronger in the summer than winter; this might itself strengthen the case for a summer sailing season for hybrid rowed and sailed vessels that were largely dependent upon this pattern of winds for their safe operation. Winds of this kind would allow seafarers to sail a number of short-range, effectively downwind courses, going out from shore on an offshore breeze in the morning and returning to the beach on an onshore breeze in the afternoon. The distances over which these local winds might override regional winds depends upon local conditions, Morton (2001, 52) noting that these may extend up to 25 km offshore. The desire to remain within this distance while sailing west along the north coast of the eastern basin might be reinforced by the effect of the regional current. The *Sailing Directions en-route eastern Mediterranean* (2017, 75) notes that: ‘The current on the S coast of Turkey, unless affected by gales, generally sets W… Some distance from the land the current is weak, but close in to the coast its rate is occasionally considerable.’ This pattern of seafaring would mirror that proposed by Pulak (2008, 297-300) in regard to the proposed use of the Uluburun ship, and accords with the limitations imposed on that vessel by the nature of its keel (Pulak, 1998, 210-211; 2008, 302).

Daily voyages of this kind would not require a vessel to possess the ability to make progress to windward. Similarly, it would not require complex navigational techniques, and the limitations regarding visibility would be less relevant as the vessel would never be far from shore. At the same time, this form of seafaring would allow the crew to rest onshore overnight, cook a meal, warm themselves at a fire and dry their clothes. Taken together these factors would mitigate many of the effects of mild hypothermia generated by working a small vessel in cold wet conditions. Perhaps as important from the point of view of learning, this might have further focussed the development of seafaring and navigational skills on optimising the means to safely use a sail on coastal voyages. Within the model of learning proposed it is difficult to understand what might have motivated any attempt to undertake more risky offshore voyages to windward at this time. This is not to suggest that a voyage along the coast would have been free of risk, the Uluburun wreck provides proof of the dangers. However, the fact that such a valuable vessel appears to have been taking a coastal route in the 14th century BC raises questions as to what vessels may have attempted the direct east to west offshore route. In this context it is worth considering the observations by Katzev (1987, 55) relating to the finds on the later Kyrenia wreck which was similar in size to the Uluburun vessel. In relation to these Katzev suggests that the presence of only one lamp, but no hearth, may indicate that 'the captain and crew cooked their meals and spent their nights on land.' On this basis Katzev hypothesises that the Kyrenia ship was largely working coastal passages. This might suggest that the risks experienced on extended offshore voyages when using vessels of the size of the Kyrenia ship continued to shape seafaring practices down to later periods.

In terms of learning from seafaring practices, and the impact of these on vessel development, it is also perhaps worth considering the nature of the coastal features along this northern route. The generally rocky nature of the northern shore provided limited opportunities to safely beach a vessel. It is possible then that safety issues would have required the use of an oar crew to avoid the hazards found around the safe anchorages on this coast. Once this became routine this may have continued following the introduction of true sailing ships; a parallel to this might be found in the common practice today where modern sailboats often use a motor as a convenient means to come in to a mooring or anchorage. The risks associated with attempting similar tasks in a vessel in which the sailing capability was compromised by a poor sail design, and a less efficient hull form, would presumably be higher than those faced in a modern sailboat. This might in turn have made seafarers unwilling to face these risks without a backup means of propulsion in the form of an oar crew. It is possible that this continued presence and use of an oar crew may in turn have further focussed sailing on coastal voyages due to the logistical requirements associated with feeding and watering these men. As ships increased in size, and, as discussed in sections 5.1.1 and 5.1.2, their propulsion by oars became more problematic, it seems probable that the larger ports, and common anchorages, may have provided rowed vessels to provide this service, much as modern tugs do in ports today. This provision may have provided the means for these larger vessels to continue to make this range of coastal voyages while using a crew optimized for offshore sailing.

On the basis of the discussions to this point, I contend that one of the key risks on the east to west offshore route in the eastern Mediterranean in this period related to vessel size. The risks identified could only be reduced following the introduction of larger vessels. These would probably have had a deck and stood higher out of the water, this in turn would have provided a drier working environment, along with provision for sheltered accommodation and a galley to provide warmth. The larger size would also provide the space for a larger crew to work the vessel in watches, thus providing for fresh crewmen throughout a 24-hour working day. In this case the point raised by Cariolou (1997, 96) about the crew being ‘without sleep’ would be less relevant. These larger vessels would also have allowed for a more rational loading of cargo, this in turn would minimise any tendency to violent motion in heavy seas. As I discussed in section 5.1.1, the problem with this proposal at this time, is the inability to construct hybrid rowed and sailed round ships much larger than 16 metres. I suggest then that due to the poor sailing ability of the small hybrid vessels of the Bronze Age, and the risks involved in their use on extended offshore passages, any learning would largely have been based on the experience gained on coastal voyages. Longer offshore voyages are likely to have been limited to downwind passages toward large target landfalls, or restricted to regions where known downwind shelters existed in the case of need. An example of this is in the passage from Crete to north Africa shown on Map 7.4; voyages of this kind are recorded in Homer and were discussed in section 2.2.

These discussions relate to seafaring in the eastern Mediterranean, to make a direct east to west voyage in to the central Mediterranean it is necessary to consider additional local features particular to this area. Perhaps the most relevant of these relate to the problems experienced in rounding the southern Peloponnese, as these are recorded in texts from antiquity down to the present day (Strabo *VIII.6.20*; Pliny IV.10; Homer*, Od, 3.285-300, 4.515-520 and 9.80-85*; Torr, 1891, 57; McDonald, 1986, 192; Drijvers, 1992, 75-76; Morton, 2001, 81-85; Pettigrew, 2011, 552; *Sailing Directions Eastern Mediterranean, 2017*, 191-192). It is apparent from these that in many cases the risks described were encountered in periods when vessels were larger and more sophisticated than those of the Bronze Age, and the seafaring skills more advanced. The extent of the dangers experienced in the seas around the southern Peloponnese might be appreciated from the construction of the Diolkos in the late 7th or early 6th century BC. Both McDonald (1986, 192) and Drijvers (1992, 75-76) discuss how this was constructed specifically to allow seafarers of this later period to avoid the risks arising from the passage around the southern Peloponnese. If learning progressed in small steps based on earlier experience, and the seafarers of the Bronze Age were largely restricted to coastal voyages, then it seems possible that later seafarers who used the Diolkos to make this isthmus route were exploiting practices based on portage that dated to this period.

I appreciate that toward the end of this period the loose footed sail came into widespread use; for the reasons I outlined in sections 6.1.2 and 6.1.3 I do not think that this would have resulted in the immediate introduction of an external keel. Similarly, given the probable long-standing practice of coastal voyages in hybrid rowed and sailed vessels up to the introduction of the loose footed sail, and the iterative nature of learning proposed in section 3.1, I do not think this would have heralded a sudden change in the nature of seafaring in small vessels. I think that the elevated environmental risks associated with sailing around the southern Peloponnese, along with the lack of evidence that the relevance of latitude was understood as an aid to navigation at this time, suggest that the offshore passage from Crete to southern Italy was unlikely to have been used as the basis of a trade route. On the basis of both the maritime technology available, and the basis of learning discussed to this point, I think it more likely that voyages between the eastern and central Mediterranean at this time would have been largely coastal in nature.

7.3.2 Summary

I appreciate that the emphasis on the use of coastal routes suggested in this discussion is speculative. This speculation; however, is based on the model of learning discussed in Chapter 3 that suggests an iterative process of development based on use, and the appreciation of risks involved in the use of small vessels for extended offshore voyages. These limitations are perhaps supported by the evidence of the finds on the Kyrenia ship (Katzev, 1987, 55), and the limitations revealed in the sailing trials of both this vessel and the Ma'agan Mikhael vessel (Gal et al., 2021a). The evidence presented show that hybrid rowed and sailed round ships of this size dominated trade for much of the following period, this makes the risks identified with their use particularly pertinent to the discussions relating to learning throughout this chapter. I contend then that any proposal for direct offshore routes across the eastern Mediterranean, or from the eastern to the central Mediterranean, in the Bronze Age are speculative. The discussions to this point show that these voyages cannot be supported by any substantial evidence relating either to vessel type, or to a model of learning that might show how the necessary seafaring skills developed. I suggest then that these assumptions should be set aside until the appropriate evidence is produced.

7.4 Risk, Seafaring and trade routes 1000 to 500 BC

The evidence in section 4.2 shows that a range of hybrid rowed and sailed vessels dominated through the early part of this period, as a consequence many of the risks attendant upon their use would have been similar to those experienced by Late Bronze Age seafarers. There is evidence for the use of sailing ships by the early 7th century BC; however, it was not until the late 6th century BC that these had increased beyond 16 metres (Parker, 1992; [http://oxrep.classics.ox.ac.uk/databases/shipwrecks database.html] 1/1/2022. On this basis it might be expected that early in this period seafarers would undertake similar coastal voyages to those taken by their Bronze Age predecessors. Through the same period there is iconographic evidence for the development of merchant galleys, and textual evidence suggesting their use in trade and colonisation (Herodotus *I.163; IV.153*). In section 5.1.2 I suggested that the motivation for the development of the merchant galley was to increase the size of hybrid vessels. In the course of this I recorded how, due to structural characteristics, vessels of this kind were largely restricted to coastal and inter-island voyages (Guilmartin, 2003, 73; Pryor, 2004, 208-209; Higgins, 2012). In the following, I will use the model of learning outlined in Chapter 3 as the basis of an examination of how these factors probably influenced the development of seafaring. I will go on to present a model for the trading voyages undertaken in this period that is based on the capabilities of the vessels in use.

The evidence presented in Chapter 4 suggests that the Phoenicians and the Greeks were key to the development of seafaring and maritime technology in the Mediterranean in this period. Their impact on seafaring and trade routes will be reviewed separately in the following two sections.

7.4.1 Phoenician seafaring and trade routes

Some authors directly attribute Phoenician seafaring and navigational skills, along with their use of extended offshore trade routes, to learning acquired from earlier Cypriot seafarers. On the other hand, in some cases this link is implied rather than stated (Sherratt and Sherratt, 1993, 364; Cunliffe, 2011, 274-277; Broodbank, 2014, 444, 491). A selection of recent papers that discuss Phoenician seafaring suggest the use of a similar pattern of trade routes. I will briefly review these before moving on to a discussion based on the work presented to this point. Puckett (2012, 80-81) discusses Phoenician ship construction, the use of the brailed sail, and the possible use of an external keel. He goes on to discuss some of the possible navigation methods used by Phoenician seafarers in establishing a number of offshore trade routes, shown here in Map 7.5. Gal et al. (2022, 31-36) discuss a number of offshore routes used by Phoenician seafarers that are broadly similar to those shown by Puckett. In the methodology supporting their case the authors state that: ‘The characteristics of the simulated ship were derived from the experimental sailings of the Ma ‘agan Mikhael II replica ship as described in the published method for direct sailing passages’ (Gal et al.

2022, 4). In proposing the voyages outlined in these cases Gal et al., on the same page of this paper, go on to state that: ‘For the current study, an additional bias for marginally better upwind capability was defined, to allow the simulated ship to make good a course of 78° to the true wind in all sea conditions.’ The problem I see with the resulting trade routes proposed lies in the use of the Ma ‘agan Mikhael as the basis for modelling, and the manner in which a positive bias was applied to the windward ability of the vessel.

In the case presented Gal et al. are discussing a 4th century BC sailing ship with a sophisticated wine glass hull form. The discussions in sections 4.2 and 4.3; however, show there is currently no evidence for the use of sailing ships by the Phoenicians, and none for the use of this hull form before the Gela 2 wreck of the 5th century BC (Kahanov and Pomey, 2004, 18). It is probable then that the sailing qualities of the vessel they use as the base case exceeded those of any ship used by the Phoenicians in the period in which they established their network of trading centres. Neither Puckett nor Gal et al. discuss the environmental risks that the crews may have experienced when attempting the offshore routes proposed in vessels of the size and type available to them, nor the risks to the stability of the vessel. On this basis, I do not consider that either Puckett or Gal et al. have fully taken account of the practical limitations of the vessels of the period in the trade routes they propose.

In the following I examine Phoenician seafaring in the context of learning and the evidence presented to this point. On this basis, I contend that the evidence presented, and the conclusions reached, in the previous section show there is no secure evidence that seafarers in the Bronze Age ever used long distance offshore seafaring to make passages to windward. On this basis, the pattern shown in Map 7.4 seems to be the most rational starting point for learning in this period. If correct, this suggests there is no evidence that the Phoenicians learnt skills that would have enabled them to make long distance passages to windward from earlier seafaring practices in the region. However, there is evidence, possibly from as early as the 10th century BC, for contact between the Phoenicians and Huelva in a metal rich province of Atlantic Spain (Bell, 2016, 99-100). This poses a number of questions: how did the Phoenicians make these early voyages, where did they learn of the possible value of the trade at this destination, and how did early Phoenician seafarers penetrate the difficult waters of the Straights of Gibraltar discussed in *Sailing Directions enroute Western Mediterranean* (2004, 3)?

To answer these questions, it might be worth considering the following observation by Arnaud (2014, 66): 'There are many reasons to doubt whether ancient mariners ever had a coherent vision of the Mediterranean. The main one is that that the mariners' experience consisted mainly in the life-long repetition of a limited number of routes to an even more restricted number of destinations.' This might suggest that the Phoenicians learnt of the route, the destination, and the potential value of this trade from others familiar with the local regions between Spain and the Levant. Given the length of the voyage, and the probable risks, it might also suggest they probably knew this with some certainty before they set out. A possible source for much of this may have been both Cypriot seafarers and members of the immigrant population in the Levant, descendants of the 'Sea People', some of whom may have come from Sardinia. Members of this latter group are likely to have had knowledge of the source of the valuable cargoes moving around the trading system of the western Mediterranean suggested by Lo Schiavo (2013, 668-672) and Lull et al (2013, 614). From the point of view of learning, it is not unreasonable to assume that the Phoenicians reached Spain by combining the knowledge of the Cypriots to access the Central Mediterranean with that of Sardinians familiar with voyages in the western Mediterranean. Access to the southern Atlantic coast of Spain through the Straits of Gibraltar seems most likely to have been gained by learning from the local cultures in southern Mediterranean Spain. The evidence presented to this point suggests that when these first voyages to the west took place Phoenician seafarers were using hybrid rowed and sailed vessels similar to those of Bronze Age seafarers. The use of this vessel type is likely to have resulted in voyages comprising a mix of coastal and relatively short inter-island passages as I described in section 7.3.1. Long offshore voyages were only likely to have taken place where the landfall was large, and the voyage was largely downwind.

However, once the presence of these valuable sources of metals had been established the issue would come down to which route to use to transport these back to the Levant. This would be of particular concern to the Phoenicians as the profits of this provided the means to trade for food products, and to pay tribute to more powerful neighbours (Aubet, 2001, 26-69; Master, 2003; Faust and Weiss, 2005; Faust, 2011; Cunliffe, 2011, 275; Monroe, 2018). In section 6.3.5 I noted some of the characteristics of Phoenician society discussed by Aubet (2001, 113-114) and Markoe (2000, 96) both of whom emphasised the role of the state in Phoenician trade. The importance of this trade to the cities, and the role of traders in what may have been a centralised approach to trade, suggests that low-risk voyages are most likely to have been employed to provide maximum assurance that these strategic cargos would be delivered safely. The main operational risks faced by the Phoenician seafarers of the period were probably those of loss due to weather, shipwreck, or piracy.

As discussed in section 7.3.1 many of the risks arising from weather can be linked to vessel size and type. Evidence of the vessels used by the Phoenicians in the 8th century BC when this trade was well established is provided by the vessel types shown in Figures 4.21 and 4.22, and the 16-metre round ships found off Ashkelon (Ballard, 2002) which I discussed in section 4.2.3. In this I noted how the exact vessel type found by Ballard has not been determined by excavation. However, in section 2.1 it was discussed how a source of the same period (*Od. 9.322–2,3*) describes a vessel with 20 oars which was clearly a hybrid vessel of around the same length. The risks relating to exposure and stability in using a vessel of this size for extended offshore voyages have been discussed in section 7.3.1. The evidence of later vessel types in use by Carthaginians is provided in Schoff (1912, v1). This suggests that even toward the end of this period 50-oared vessels were in use by the Carthaginians when undertaking colonising voyages. If Schoff's translation is a reliable source on the vessel type in use at this time, then it suggests that for much of the period Phoenicians were using hybrid vessels which may have had many of the same limitations as those in use in the Bronze Age.

This raises the question, where was the major strategic trading route from the Levant to Spain located? Early development of this may have followed the route used by earlier Cypriot traders based on coastal and short inter-island passages. With hybrid vessels this would have required stops at intermediate locations to rest and feed the crews, and, given the value of the cargo carried, these would need to be secure from any threat. However, the combination of the expansion of the population of Greece in this period (Scheidel, 2004, 747), the consolidation of Spartan power in the Peloponnese (Morris, 2005, 14), and the later spread of Greek colonisation in Sicily and southern Italy through the Archaic period, probably resulted in an increasing number of favourable anchorages being settled by Greeks. As a result, the security of this route is likely to have become less reliable. An alternative route was proposed by Negbi (1992), this is shown in Map 7.6. This map also shows the location of some of the more significant Phoenician trading emporia across the Mediterranean founded around the same period (Carter1965; Chamorro, 1987; Negbi, 1992; Treumann-Watkin, 1992; Yon and Childs, 1997; Aubet,2001, 96; Hunt,2009; Monroe,2018, 242). The location of many of these emporia probably related to local Phoenician trade; however, if the point made in section 6.3.5 by Aubet (2001, 113-114) regarding the 'institutionalization of the colonies' is correct, this may suggest their locations may have been influenced by the need to provide a chain of secure harbours for a long-distance system of trade based on coastal voyages. Negbi does not propose a route west from Sardinia to Spain. However, the earlier development of Phoenician trade with Huelva in the 10^{th} century BC suggests that they had already established inter-island routes in this area. Once again however, it seems probable that these were based on earlier routes developed by the local cultures using Late Bronze Age vessels.

Negbi does not discuss vessel types as a contributory factor in selecting this route; however, it can be seen as a low-risk option based on the learning and development of seafaring skills that might accrue from the long use of hybrid rowed and sailed vessels. The largely coastal route would reduce the risk of loss due to the effects of weather. At the same time this would minimise any potential impact of exhaustion and hypothermia the crew might experience on the voyage by allowing for frequent stops onshore. It would also achieve the maximum distance between Phoenician trade and any potential Greek piracy in the Central Mediterranean. The hazards discussed in section 7.1 relating to the shallow waters along this lee shore should be considered in the context of the vessels undertaking the voyages. The balance of risk of hybrid vessels navigating both a weather and lee shore have been discussed earlier. In relation to the shallow waters along this coast the observations of Averdung and Pedersen (2012, 129-130) discussed in section 4.1.1 are perhaps relevant. These noted how the extended forefoot found on the wreck of the 3rd century BC Carthaginian Marsala galley may have reduced the problems that resulted from grounding when operating in shallow waters.

The limited cargo capacity of hybrid vessels, coupled with the volume and the importance of the trade to the Phoenician cities of the Levant, probably meant these travelled in convoys. This would have provided enhanced security, and ensured that each season delivered the required volume of cargo. The problems of keeping such a convoy together were probably a major concern to Phoenician seafarers. If these were to attempt the extended offshore route between the eastern and central Mediterranean this would involve sailing at night. This night time sailing would have occurred in an area where unfavourable winds might have been expected. In this case the same variations in vessel performance experienced by 18th century vessels discussed in section 7.1 (Willis, 2003) would have been experienced by the Phoenicians. If this were the case, it seems probable that a convoy would either have to adopt the course followed by the least seaworthy ships, or face the risk of the vessels scattering across the open seas with little chance of regrouping. Neither of these is likely to have been a desirable outcome for the efficient delivery of the strategic goods these convoys would be carrying. In the alternative route along the southern shore these convoys of hybrid vessels would probably have travelled at slow speeds, and stopped overnight at suitable anchorages. This form of voyage would reduce the risk of the convoy becoming scattered. The use of oars probably providing additional assurance regarding manoeuvrability in shallow waters with their associated reefs and sandbanks. These factors would probably allow the vessels to have avoided many of the navigational hazards, and if a grounding should occur it seems unlikely that it would result in significant damage to the slow-moving vessel. It seems probable that in a convoy, any stranded ship could also be lightened by partially unloading its cargo on to others, the combined oar power of a number of vessels could probably serve to pull any vessel free. Overall then the risks of the voyage would have been manageable. They would certainly have been lower than those faced by later deep hulled sailing ships that may have sailed this route. They would almost certainly have been considerably less than those faced by hybrid vessels attempting an offshore voyage around the southern Peloponnese.

The continued use of this route by the Cyrenaeans in the 5th century BC is recorded by Thucydides (*7.50*, trans, Smith, 2015) where he notes in regard to reinforcements for Gylippus that 'the Cyrenaeans had given them two triremes and pilots for their voyage; as they sailed along the shore of Libya…and sailing thence along the coast to Neapolis, an emporium of the Carthaginians, from which place the distance to Sicily is shortest.' The availability of pilots suggests that the Greeks at this time made frequent use of this coastal route. The Greek colony of Cyrene was founded in 630 BC, later than the probable establishment of the route proposed by Negbi. The colony itself was located at around the point where Map 7.5 shows the southwesterly route from Crete making landfall in North Africa. It may be of relevance that Herodotus (*IV. 151*, trans, Godley, 2015) notes in regard to the founding that colonists were guided to the location by 'a fisher of murex', itself an occupation that might imply a link to Phoenician trading activity. If this was the case, it may be that the Greek colony of Cyrene was established in an area in which seaborne activity was dominated by the Phoenicians. It is possible that the long-standing presence of Phoenician vessels in the area would have lessened any security threat that may have originated from this particular Greek colony.

7.4.2 Greek seafaring and trade routes in the central Mediterranean

The evidence summarised in 7.4 shows that in the Archaic, when Greek colonisation in the central Mediterranean began, the Greeks were using the same hybrid rowed and sailed vessels as the Phoenicians. On this basis there is no reason to assume the nature of their seafaring differed in any way either to that of the Phoenicians or to the earlier seafarers of the Bronze Age. However, the background to the founding and location of Greek colonies differed substantially from that of their Phoenician counterparts. In the case of the Greeks, the process appears to have been the result of individual groups from independent city states, most of which had a primarily agricultural economy, establishing a large number of independent, largely agricultural, colonies (White, 1961; Graham, 1983, 4-5; De Angelis, 2000, 111-112; Boardman, 2001, 36-37; Scheidel, 2003, 131; Morris, 2005, 6; Osborne, 2009, 111). The result was a large number of small independent colonies scattered across the Central Mediterranean, all of which were linked through the sharing of a common Greek language and culture. As was the case with many of the mother cities, all of these were to a greater or lesser degree in competition with each other for resources or status. Most of these colonies could be connected by coastal voyages similar to those used by the earlier Sardinian, Mycenaean and Cypriot traders in the region. As a result, there was no requirement to develop new forms of seafaring to establish these colonies, or to change the nature of the trade links that connected them. As with earlier seafarers the trade with the Greek cities of the Aegean may have taken routes around the southern Peloponnese, or been carried out by portage across the Isthmus at Corinth. I have discussed the risks faced in the use of this latter route by seafarers in the Late Bronze Age in section 7.2.2. By the close of this period there is evidence in the form of the Diolkos that the cross-isthmus route was exploited by the Corinthians to profit from this passing trade (McDonald, 1986, 192; Drijvers, 1992, 75-76; Salmon, 1997, 37; Morton, 2001, 81-85; Pettigrew, 2011, 552).

It is my contention that in terms of the development of maritime technology and seafaring the construction of the Diolkos represents a case study in terms of learning, risk management and the vessel type in use. Similarly, I suggest that the learning from this case study is relevant to seafaring in the Late Bronze Age. Drijvers (1992, 75-76) and Pettigrew (2011, 561-565) discuss how the maximum size of the merchant vessels that might have used the Diolkos was smaller than the larger ships of the Classical period. I suggest that this misses the issue summarised in Edgerton’s comments on how use, and the past and present, shaped invention and innovation (Edgerton, 1999, 123-124). In this case the Diolkos might be seen to have been constructed to handle the vessels in use up to the time it was built in the period around the late 7th or early 6th century BC (Pettigrew, 2011, 558). Based on my discussions in section 7.3.1 this seems unlikely to have been the first use of the Isthmus for this purpose. I contend that the paving of the Diolkos should be seen as an innovation intended to optimise a long-standing system of portage for small vessels, and that the practice had probably extended back to the Bronze Age. The case that should be considered is the capital investment required for the construction of the Diolkos. If this was seen as a valuable use of resources in the 7th century BC it might be assumed that these would only be spent if the result was likely to result in profit for the city. This in turn might suggest that the risk of the alternative offshore passage was seen to have been very real, and that as a result the Diolkos would be in frequent use. This perhaps repeats the earlier question posed, how much risk would earlier Bronze Age seafarers have been exposed to in attempting the alternative offshore passage when using similar sized, but probably less sophisticated, vessels?

The effects of differing demographic growth within the Greek trading network resulted in some cities increasing in size relative to others. This in turn led to the formation of a hierarchy of trading centres both in Greece and in the central Mediterranean. The end point of this was that the more successful colonies such as Syracuse assumed greater regional economic and military power. Scheidel (2003; 2004) and Morris (2004; 2005) discuss demographic growth in Greek cities toward the close of this period; they go on to make the link between this and an increase in the trade in raw materials required by these larger urban centres. In section 5.2.1 I discussed the possible links between the growth in the size of these cities, the construction of monumental architecture, the introduction of lifting technology, and the possible role of this in the development of larger sailing ships. If this was the route by which sailing vessels increased in size the immediate impact of these developments on the nature of seafaring appears to have been minimal. Snodgrass (2006, 223) records that for most of this period merchant galleys carried the bulk trade of these communities. As I have discussed to this point, a number of authors have written extensively on the use of these vessels and all record how the voyages made by these were largely coastal, with short offshore and inter-island passages (Guilmartin, 2003, 73; Pryor, 2004, 208-209; Dotson, 2004, 219-220; Higgins, 2012, 26). This might imply that any increase in the volume of trade between Greek centres in this period was largely carried out by the same types of voyages that were in use in the Bronze Age.

As areas in which learning relating to seafaring may have taken place the Central Mediterranean and the Aegean comprise a potential mix of coastal and offshore inter-island voyages of varying length. As I discussed in section 2.2 there is reference in the Epics that voyages of this kind were in use in the Bronze Age. This area then would have provided a relatively safe environment in which the seafarers of the late Archaic period could have begun to exploit and learn of the enhanced capabilities offered by larger sailing ships, and merchant galleys with more complex sailing rigs. It is possible to see this leading to an iterative process of undertaking progressively longer inter-island voyages, which, as a result of their greater length, were likely to encounter more variable weather. In regard to learning, the advantage offered by these voyages being the number of potential stop overs they provided if changing weather conditions demanded any voyage be cut short. The result of this may have been the development of a relatively low risk learning process, in this the larger and more sophisticated vessels coming in to use may have sailed longer individual passages on trade networks comprising a long-established system of local routes.

7.4.3 Summary

The evidence presented in section 4.2 shows there is archaeological evidence for the introduction of the external keel on small vessels, this is accompanied by the development of larger sailing ships toward the end of the period. However, the iconographic and textual evidence suggests that for much of this period the same range of hybrid rowed and sailed vessels were in use by both Greeks and Phoenicians. The structural and operational limitations of these would mean that they were most suitable for the same short duration voyages in sheltered coastal waters as their Bronze Age precursors. There is no direct evidence for the use of alternative means of seafaring involving the development and use of long-distance offshore routes at this time. If invention and innovation in terms of seafaring resulted from use, then this long history of the use of hybrid rowed and sailed vessels in the region is likely to have inhibited the early development of alternative seafaring skills and techniques. I suggest that the case made for long distance offshore voyages by the Phoenicians is largely based on a faulty interpretation of the capabilities of Cypriot seafaring, the unfounded assumption that sailing ships were in use from the 2nd millennium, and the use of an ambiguous translation of a single Ugarit text to justify the existence and use of vessels of 450 tons in the Late Bronze Age. The evidence I have presented suggests that none of these assumptions are correct. I appreciate that the route based largely on coastal voyages that I have proposed for Phoenician trade is similarly speculative. However, the case is based on a model of learning regarding how seafaring skills may have developed in conjunction with the vessel types for which evidence exists from the period. The voyages and routes identified also take account of the seafaring risks identified in the use of reconstructed vessels for which evidence exists at the time, and a consideration of the security risks that resulted from piracy.

The same cases for long distance voyages are rarely raised in regard to the Greeks; however, the appearance of the Giglio and Grand Ribaud wrecks discussed in section 4.2.3 might suggest the use of larger sailing ships by either the Greeks or Etruscans toward the close of the period. However, if the dates presented by Kahanov and Pomey (2007, 20-25) are correct the vessels in use through to the end of this period still had the same rounded hull profile of the Uluburun vessel. From the earlier discussions on the risks relating to stability, and the health and safety of the crew, an increase in size over the apparent limit of 16 metres might be seen as a prerequisite for the development of long-distance offshore seafaring. The continued use of merchant galleys through this period, and their later expansion in size, might support the continuation of this 16-metre size limit for round ships at this time. The model of learning discussed in Chapter 3, and the considerations of risk raised by McGrail (1989, 850) and Unger (1994, 7), suggest that any expansion in the use of sailing ships to achieve long distance offshore voyages was likely to have required a strong motivation, and have followed an extended process of iterative learning. It is difficult to find evidence of either of these from the iconographic, textual or archaeological sources of the period.

7.5 Risk, Seafaring and trade routes 500 BC to AD 200.

The evidence I have presented in Chapters 4, 5 and 6 shows that through this period both sailing ships and merchant galleys became substantially larger, and the sailing rigs in use became more complex. The discussions to this point in this chapter show there is no evidence that seafarers prior to this period were sailing to windward to make long distance offshore voyages. On this basis then, it cannot be assumed that learning relating to these skills was passed on to seafarers of this period. The discussions in this section will show how the sailing ships that came into use in this period were large enough to provide a safer working environment for larger crews. This increase in the size of vessels allowed the crew to work in watches, this in turn would have provided the rested hands required to work the vessel both day and night on longer voyages. These larger vessel sizes would also be capable of making these longer offshore voyages in greater safety from the point of view of stability. The limitations of the sailing ships of the 18th and 19th centuries discussed in section 7.1 suggest that vessels of this period would still have experienced difficulties, and perhaps elevated risks, in making windward courses.

These risks are perhaps best summarised in the idiom 'sailing close to the wind', meaning behaviour that is dangerous or only just acceptable https://dictionary.cambridge.org/ 01/12/2021. This phrase relates to ships attempting to achieve over optimistic windward performance. The entry of this into common use when sophisticated sailing ships dominated trade suggests a pervasive and widely understood problem. It is not unreasonable to assume that this would also have been understood in the ancient world. The impact of the resulting problems and risks are summarised by Adams (1904, 19) in a work on commercial geography, which was written at a time when sailing ships still constituted a substantial part of the merchant marine. In this he observes that: 'Winds affect the speed of even modern steam ships, and the routes of sailing ships are shaped by them.' The implication of this statement by Adams being that at this late date trade routes were largely downwind and followed the trade winds. The necessity of making some passages against prevailing winds in the Mediterranean are likely to have resulted in a range of problems not faced by later sailors who used these trade winds. In terms of the core subjects of this thesis, i.e. learning and vessel development, it is important to appreciate that these problems would have been faced using less sophisticated technology than that used by seafarers in the ships referred to by Adams.

This is not to deny that sailors in the ancient world may have been attempting courses to windward, or even possibly tacking across the wind. Some evidence for voyages undertaken in unfavourable winds is recorded by Casson (1971, 290-291), Whitewright (2011, 9) and Leidwanger (2020, 59-62). However, all of these discuss the problem of establishing the exact meaning of the term unfavourable wind. The problem being that even if the direction of the wind is known, the degree to which it is unfavourable would largely depend upon wind strength. This perhaps reflects the observation by Cariolou (1997, 93) when he related wind strength to the tacking ability of the Kyrenia II, and those of Gal et al. (2022a) regarding the performance of the reconstruction of the Ma'agan Mikhael vessel. Cariolou (1997, 97) goes on to note how some features of the design of the Kyrenia II appeared to have been optimised for assurance and security on downwind courses. I suggest this may show how learning and practices, in regard to the priorities in Hellenistic seafaring, were reflected in maritime technology and vessel construction. The conclusions that might be drawn from this being that windward performance was only attempted as a routine measure in the most benign weather conditions.

7.5.1 Greek and Roman seafaring and voyages 500 BC to AD 200.

It is not possible to cover this subject in detail in a work of this scope, much less the associated subject of Greek and Roman trade. Rather, the objective of the following is to examine how the developing maritime technologies I have discussed to this point were reflected in the seafaring practices recorded, or implied, in some texts of the period, and in some recent scholarship. What is clear is that the period was marked by a shift in the demographics of Greek and Roman urban centres, the populations of the largest of these increasing significantly through the period (Scheidel, 2003; 2004; Morris, 2004; 2005). The largest of these are noted by Morris (2005, 10-22) as requiring the import of basic requirements from wider catchment areas. It seems probable that this expansion in city size, and more particularly the increased size of the states in the Mediterranean at this time, was almost certainly the primary motivation to increase the size of vessels.

Before beginning an examination of Greek or Roman seafaring it is worth understanding the range of vessel types and sizes in use in the period overall. These vessels are the subject of discussion and record by Houston (1988, 558-559), Parker (1992), Nantet (2020; 75-90) and Leidwanger (2020, 47-53) these discussions emphasising the mix of vessel types in use, and how these operated on a wide range of voyages frequently while carrying a mixed range of cargos. As discussed in section 7.3.1, the mix and complexity of the facets that might impact mobility, and by extension the voyages undertaken, are summarized in Figure 7.1 from Leidwanger (2020, Fig 3.2). It is perhaps worth reiterating with reference to this chart that Greek and Roman seafaring had access to the largest vessels in the period, this might imply they also had access to the greatest mobility, and as a result undertook the longest voyages.

The excavation of the Alonnesos shipwreck provides evidence for the nature of the final voyage undertaken, and the goods carried, by one of the early large vessels of the period. Hadjidaki (1996, 591) notes that a major part of this cargo comprised around 4000 amphorae from Mende and Peparethus, each of which was loaded in a particular layer in the hold. Along with these amphorae were a range of black glaze pottery of either an Athenian or a southern Italian source. This suggests that the vessel picked up distinct cargoes from a number of ports on a local inter-island voyage around the Aegean. It might appear then that, rather than exploiting new forms of trade, this vessel was used to carry larger cargoes on a local trade route that had possibly been used for generations. It seems probable then that the final voyage of this vessel could largely have been accomplished by using a range of long-established seafaring skills and practices.

The evidence presented in Table 4.1 suggests that vessels of this size were also used to transport bulk goods. The nature of the voyages used to support this bulk trade might be implied by a comment in Demosthenes (*56. 10-11,* trans, Murray, 2006) where he discusses the diversion of a grain shipment in the following terms, ‘when the ships from Sicily had arrived, and the prices of grain here were falling, and their ship had reached Egypt, the defendant straightaway sent a man to Rhodes to inform his partner Parmeniscus of the state of things here, well knowing that his ship would be forced to touch at Rhodes.' Xenophon's *Oeconomicus* (*20.27-8*, trans, Henderson et al 2015) appears to confirm this form of trade when he speaks of merchants in the following manner: 'So deep is their love of grain…when they need money, they don't unload the grain just anywhere, but they carry it to the place where they hear that grain is most valued and the people prize it most highly, and deliver it to them there.' The trade described by Demosthenes and Xenophon would only be possible if ships were stopping at intermediate ports where agents were able to redirect them as required. This suggests that at this time at least some bulk cargos of strategic significance were carried on voyages that involved local stopovers. This might imply a possible link to an earlier form of down the line trade. I suggest then that in this period while the size of the ships may have increased, and the volume of trade may have expanded, these voyages imply a use that was unlikely to have required the learning of innovative seafaring or navigational techniques. Clearly, some voyages involving the transport of these cargos may have been based on the use of direct routes, although the phrase 'his ship would be forced to touch at Rhodes' in Demosthenes (*56. 10-11,* trans, Murray, 2006) may, if the translation is accurate, imply these stopovers were necessary for some vessels used in the grain trade at this time. It might appear then that, even where maritime technology provided the means to make a direct voyage, many of the routes used allowed stopovers to be made. The frequency with which these stopovers occurred being linked to the motivations of the individuals that controlled the ships.

The discussions by Houston (1988, 558-559) regarding the range of vessels used by Roman seafarers might reflect the same range of motivations. As discussed in section 4.3.2, these are based in part on the contents of Livy's Lex Claudius (*21.63*), on Suetonius' *Claudius* (*18-19*) and the Gaius *Institutes* (*1.32c*). The point that Houston appears to be making is that merchants were possibly using the range of small and intermediate vessels outlined by Nantet (2020; 75-90) to integrate local and strategic trade on long-distance voyages. In this respect it is perhaps worth considering a point raised by Scheidel in regard to the 10,000 modii vessel discussed in Gaius's *Institutes 1.32c*. The construction of vessels of this size was noted as being worthy of reward; however, Scheidel (2009, 14) notes that 10,000 modii equates to a capacity of around 68 tons. It might appear from this that the construction of mid-sized vessels was being encouraged and that these may have formed the backbone of Roman trade in the Imperial period. This might suggest that many of the patterns of trade, including the grain trade, may have been based on the use of vessels of this size. There is a further possible link between port usage and these Roman edicts on vessel size in Arnaud (2015, 68). In this work Arnaud discusses the close interest of emperors in the network of ports involved in the supply of grain to Rome. This might suggest that the interest of the Roman state in vessel size may in part have been based on the problems of logistics at these ports, and the congestion that might develop outside them. The legislation then may not have been related to the need for large ships to meet the requirements of the grain trade, but rather to the logistics at ports relating to handling large numbers of small ships.

Arnaud (2018, Fig 3.1) shows the range of Roman trade routes in use across the Mediterranean, this is shown in Map 7.7. If this map is compared to Map 7.1, it can be seen that most of the offshore routes are downwind toward large target destinations. The limited number of those that might appear to run against the predominant wind directions are noted by Arnaud (2018, 16.12) to be limited to specific times of the year. This qualification appears to apply to the direct south to north routes shown from north Africa to Greece and Italy. Pryor (2004, 211) records the seasonal Ghibli, a southerly wind, that probably provided the means to make these voyages downwind at the times when Arnaud proposes their use. In the same passage Arnaud (2018, 16.12) goes on to note the common use of the counter-clockwise coastal route for the return voyage. Davis (2009, 76-81) discusses Roman trade routes in the eastern and central Mediterranean in his thesis on navigation techniques in the period. Davis (2009, 78) records the lack of any guide to precise routes sailed by Roman seafarers, and how these might best be described as comprising wide corridors within which a bundle of different routes may have existed. The choice of any individual route, on any individual voyage, depended presumably on the weather conditions experienced and the nature of the cargo. Davis describes the counter-clockwise route from Alexandria to Rome as one that started out broadly following the eastern and northern shores of the Mediterranean. Davis (2009, 78-79) links this route to earlier Bronze Age seafaring, going on to note how along the northern shore ‘ships used alternating sea and land breezes to effect the difficult passage westward along the Cilician, Pamphylian and Lycian coasts toward Rhodes.' Later, Davis (2009, 219-220) emphasises the use of coastal landmarks for navigation on this route, and goes on to discuss how some of the grain ships made stop overs to trade and refresh food and water. From Rhodes, Davis describes the routes and problems that seafarers in the Roman period might face in making a course to Italy, in doing so noting that: 'This long, east-west corridor required several weeks of difficult sailing and seamanship and involved both coastal and open-sea navigation' (Davis, 2009, 80). In this Davis outlines the nature of the routine problems experienced in sailing around the southern Peloponnese. In doing so, he indirectly reinforces the extent of the problems that might have been faced in making this passage when using the smaller, less sophisticated, vessels of earlier periods. Later Davis (2009, 207-208) notes how Roman ships might attempt to make two round trips a year from Alexandria to Rome. On the first of these, a vessel might be able to take advantage of favourable winds to make one of the shorter direct voyages as shown by Arnaud (2018), shown here in Map 7.7. However, Davis goes on to record the issues that vessels faced attempting the same voyage later in the season.

Both Davis (2009, 207-208) and Arnaud (2018) reference the relevance of the seasonal weather in planning the return voyage, and how a late departure from Alexandria might result in the ship being held at an intermediate port to overwinter. Many of these issues are raised in the accounts of Paul's voyage to Rome recorded in *Acts 27–28 (NIV Bible)*. The first part of this journey was in a ship of Adramyttium, a port in north west Turkey, 'that was about to set sail to the ports along the coast of Asia' (*Acts 27.2*). The second part describes a passage in 'an Alexandrian ship bound for Italy' (*Acts 27.6*). This vessel is recorded as carrying 276 passengers and crew, who, prior to a later shipwreck 'lightened the ship by throwing the grain into the sea' (*Acts 27.37*). After this ship was wrecked in Malta the third voyage was undertaken in a ship that had wintered in Malta on a voyage to Rome. This vessel stopped off in Syracuse, Rhegium and Puteoli, before making Rome (*Acts 28.11-14*). It is clear from these accounts that the first part of the voyage was planned to take advantage of a system of interconnected coastal voyages, the first vessel not being bound for Rome; however, the centurion in charge was clearly planning on picking up a vessel en-route to Rome at some point along the coast. The third vessel appears to have continued this form of short haul inter-island and coastal seafaring on the final leg of the voyage to Rome.

Of equal interest is the account of the second voyage and the events preceding Paul's shipwreck recorded in *Acts 27.8-12.* This records a dispute over the optimum port in which to over winter. In leaving a temporary anchorage and attempting to sail to the port of Phoenix in Crete the ship was caught in a storm. At this time, the passage states that the ship was 'caught and could not be turned head-on into the wind.' This description is of particular interest as, even though the manoeuvre was unsuccessful, the comment suggests the crew thought the vessel capable of making this heading. This poses the following question; why was this ship making a coastal voyage to make an east to west passage when it apparently had the ability to make a more direct voyage by sailing too windward? It seems probable that the answer to this may be explained by, the limited abilities of even the more efficient later sailing ships to reliably make progress to windward as recorded by Steel (1794, 280), Pryor (1988, 35) and Willis (2003, 35), and the manner in which the windward performance of even the most efficient of these deteriorated as the wind strength increased (Katzev, 1987; Cariolou, 1997; Safadi and Sturt, 2019; Gal et al., 2021a;2021b;2022;2023).

The fact that at this time the centurion taking Paul to Rome relied on finding a vessel making a coastal voyage might confirm Davis's suggestion that it was not unusual for grain ships to stop over on the voyage to Rome. The account is not clear how many passengers made up the total number of people on this vessel at the time of its loss. However, it was clearly common practice for these vessels to carry passengers, and, if a substantial number of these had boarded in Egypt, this might provide the reason for the route chosen. Feeding this number of people would be easier on a coastal voyage where they could arrange their own food at ports along the way. Also, if this was the case, and the voyage described in *Acts 27-28* was planned to include stopovers, it seems probable that the vessel was also involved in trading along the route. The dominance of small and intermediate sized vessels in the Roman merchant fleet discussed by Houston (1988), along with the continued use and development of merchant galleys suggested in Cicero *Verrem 2.5.44,* and shown in Figures 3.8, 3.9 and 3.10, might suggest this may have been the normal pattern of seafaring at this time.

The hull form of the Madrague de Giens vessel discussed in sections 4.3.3 and 6.3.4 may suggest that in the 1st century BC large sailing vessels were not optimized for extended voyages to windward. This might suggest a pattern of learning in which where passages were direct, they were likely to be downwind, and where they were indirect, they took advantage of favourable coastal features and the associated opportunities for intermediate stop overs.

7.5.2 Summary

It is difficult to summarise all of the issues discussed relating to this period. However, if the process of development leading to the construction of the Madrague de Giens ship identified in section 6.3.4 is correct, then it would appear that windward performance may not have been a design feature of large sailing ships up to the 1st century BC. This might confirm the earlier comment by Whitewright (2011a, 5-6) included in section 3.2: 'Quite simply, windward performance was not as important as other factors.' If correct, taken together these would clearly impact on learning relating to seafaring and the nature of the trade routes in use. The evidence from textual sources, iconography and shipwrecks for this period shows how learning from Greek shipbuilding provided the means to increase vessel size and complexity. However, the range of vessel types shown in Roman iconography and the evidence of texts such as the voyage of Paul in *Acts 27–28* suggest that, even late in this period, long voyages to destinations upwind of the departure point are likely to have comprised a route that allowed for stopovers at intermediate ports. Clearly, in the case of favourable weather many of the anti-clockwise voyages from Alexandria to Rome would likely be made by the most direct means possible.

The way trade winds shaped maritime routes at a later time, when superior technology was probably employed, was spelt out by Adams (1904, 19). On this basis it seems unlikely that seafarers in the Greek or Roman periods were attempting long distance voyages against the regional pattern of prevailing winds. I appreciate that for short periods of time local seasonal winds may have overcome this predominant regional pattern, and in doing so provided the means for seafarers to make voyages that for most of the year would probably not have been possible. However, given the limited time over which seasonal winds might blow, and the mix of vessel types and sizes involved in much of the maritime trade of the period, it seems probable that where direct voyages were planned, a careful seafarer would ensure that most passages included the potential of an intermediate safe haven should the need arise. This might suggest that on the basis of learning and development much of any improvement in windward performance through this period was incidental. There is certainly no evidence to suggest that learning and development was focussed on producing any improvement in this type of seafaring. It would appear from the account of Paul's voyage that seafarers of this time were aware of the technique of heading into the wind; however, the inability of the vessel to make this heading in bad weather might confirm the limitations in this regard. It might appear then that even when Rome dominated the Mediterranean, and its seafarers were operating the largest vessels in the ancient world, many routine features of seafaring were similar to those that I suggest to have been in use in the Bronze Age.

7.6 Conclusions

My purpose in this chapter on vessel use has been to attempt to resolve the anomalies identified in the forms of seafaring used through the period overall. In doing so it is of fundamental importance to understand the difference between the possible and probable, and the role of motivation in decision making. In this regard it is important to appreciate that my focus has been on merchant vessels and trade. On this basis I have assumed that voyages would be conducted taking risk and profit, be that economic military or socio-political profit, into account. My contention throughout the discussions has been that for much of the period the resulting form of seafaring predominantly comprised coastal and short inter-island passages. Where longer offshore voyages were attempted the limitations of the vessels in use meant that these were likely to have been downwind. I accept that the duration and complexity of these offshore passages certainly increased through the period overall; however, this was dependent upon the incremental development of maritime technology, and the nature of the environment and the societies in which these vessels were used. The uptake of these longer voyages being a function of the rate of learning regarding seafaring techniques, and the motivation to undertake the potentially riskier voyages.

None of the points raised should be thought to indicate that I preclude the possibility of using small hybrid vessels to make long offshore voyages. I am aware that at a later date in Europe the Norse cultures of Norway settled many of the Islands of the north Atlantic largely by the use of offshore voyages. I am similarly aware that these voyages were made using a range of hybrid rowed and sailed vessels that shared many of the characteristics with those I have discussed. However, voyages of this kind need to be understood in the context of the physical and social environments in which they took place. Perhaps most important is that of the environment; many of the north Atlantic islands settled could only be reached by offshore voyages as no coastal options existed. The socio-political environment was also clearly relevant. An account of this may be found in the *Heimskringla,* a 13th century AD history of the Kings of Norway by Snorri Sturlason. *Harald Harfager's saga,* (*V.20, trans,* https://www.gutenberg.org 1/11/22 starts by stating that: 'After the battle King Harald met no opposition in Norway, for all his opponents and greatest enemies were cut off. But some and they were a great multitude, fled out of the country…In the discontent that King Harald seized on the lands of Norway, the out-countries of Iceland and the Farey Isles were discovered and peopled. The Northmen had also great resort to Hjaltland (Shetland Isles).' This is a later written account of an oral historic tradition dating to the 9th century AD. On this basis its accuracy in regard to historic detail might be open to question; however, Sturlason was an Icelandic poet and historian who transcribed what was understood at the time to have been the events leading up to the settlement of the Island. The motivation for fleeing from Norway and undertaking a dangerous voyage is clear. These voyages then were undertaken out of necessity, rather than choice, and they were undertaken in the only vessel type available. The saga suggests that the risk of remaining probably outweighed the risk of attempting the voyage; however, in both cases these were probably high. It might be assumed that learning would accrue to the successful colonists from the continued use of the routes once the islands had been settled. The case for voyages of this type then is substantially different to those examined for merchants in the ancient Mediterranean.

I suggest that a failure to appreciate the risks and motivations at work in any society can result in a fundamental misunderstanding of the means by which types of seafaring arose, and learning progressed. Through this chapter I have noted the significance of the increase in vessel size from the 5th century BC through to the Roman era, and the means these larger vessels offered to make longer offshore voyages in greater safety. However, discussions in this chapter have highlighted the apparent continued limitation of these vessels to make progress to windward in any but the most favourable conditions. Overall, this suggests that while longer voyages were almost certainly more common in this period, these longer voyages were still likely to have been downwind.

This perhaps answers the most fundamental question that I contend underlies much of the discussion to this point: how probable is it that early Bronze Age seafarers in hybrid rowed and sailed vessels would have made long distance offshore voyages against the prevailing winds? The obvious answer to this is that they did not make these voyages, but rather, would have adopted an alternative low risk coastal route. Any learning regarding seafaring and navigational techniques that the Phoenicians may have gained from these earlier seafarers would be constrained by these earlier practices. The currently available evidence suggests that the Phoenicians also used hybrid rowed and sailed vessels, and that these were similar in many respects to those used by Bronze Age seafarers. This vessel usage supports my case that they probably exploited the same range of inter-island and coastal routes, and made only short offshore downwind voyages.

I contend that the evidence confirming the longevity of this means of seafaring can most easily be understood in the context of the nature of learning in the ancient world. The iterative form of this both in the craft industries of today and in the ancient world have been discussed at length in Chapter 3 (Philon *Belopoeica 50.14-29*; Usher, 1954; Coates,1987; Edgerton, 1999; Ingold, 2013; Buckley and Boudot, 2017; Adams, 2013; Olaberria, 2014; Marchand, 2020). In all cases these suggest that learning in these environments progresses in small steps, to solve immediate problems. There is no evidence to suggest the alternative teleological approach to learning was ever adopted, or indeed, in the absence of a secure theoretical base on which to locate this, was ever realistic in the ancient world. Throughout these discussions I have frequently returned to the case made by Edgerton (1999, 123) of use leading to invention and innovation. I have used this as I think it links the two main themes involved in the methodology I have employed, taxonomy and learning. In this sense use will clearly depend upon vessel type, and invention and innovation relate to learning in terms of both technical development and use. I contend that this methodology for determining developments in these fields is more secure than others presented in the case studies in Chapters 2 and 3. I cannot offer absolute proofs that the conclusions presented are correct, and I welcome challenge to these. However, I contend that any challenge should be presented on the basis of an equally viable model of learning and development, and provide a similar analysis across the scope of evidence presented.

8.0 Conclusions

It is not my purpose in this section to repeat in detail the conclusions of the preceding chapters. Rather, I propose to revisit the aim and objectives set out in the Introduction to this thesis, and assess the extent to which the discussion has met these in the case presented. Along with this, I suggest an approach to the presentation of research relating to maritime archaeology that might alleviate the problems I have identified. The case studies presented in Chapter 2 show how many of the proposed voyages through the period cannot be supported by the current archaeological evidence regarding vessel types in use. More to the point, the predominant vessel type in use through much of the period is rarely discussed in relation to its limitations in size, performance and seafaring. The case studies in Chapter 3 show that where maritime technical development is discussed, these discussions do not reference the learning which must underlie this process. The resulting problems experienced by scholars from outside of this specialist field have formed the core discussions in much of this thesis. I suggest the system of taxonomy, and the means by which this may be linked to the model of learning suggested in this thesis, provides the means to alleviate these problems. As I have noted throughout, challenge of this system and model can only strengthen the general case that a structure for the presentation of evidence is required.

It is possible that a solution to the problems arising from these issues may be found outside of the field of maritime archaeology. I outlined in the introduction that I have come to this field following a multi-disciplinary career in engineering. This has provided me with some basic tools and techniques to examine the practicality of any vessel design, and proposed use. I appreciate the singular nature of my background; however, I believe the cases presented in Chapters 2 and 3 suggest that anyone working in the field should be aware of the general caution raised by Rogers (1937, 29) that: ‘A bad design now must have been a bad design 2500 years ago.’ I appreciate that to achieve this assumes an individual to have sufficient awareness of engineering principles to understand what constitutes a bad design. Hopefully the discussion on development will have shown that this is itself a combination of the specific time period one is examining, and the relevance of this within a process of development. In this case, an example of bad design might be to assume the use of a 450-ton vessel in the Late Bronze Age, when on the other hand, the evidence shows that a vessel of this size might be considered quite normal in the Roman era. This caution being equally appropriate to the context of use, as it is to the context of design; clearly a reconstruction vessel that is unsafe when operated in the safety regime of today would probably have been even less safe 3500 years ago.

From my earlier career in engineering there is further experience relating to departmental organisation that I think is relevant to these discussions. In this career I worked as a drilling engineer; in this role my work depended upon the input of a range of other departments, subsurface teams of geologists and geophysicists, completion engineers, and production and facilities engineers. Early in my career communication between these teams was normally at formal meetings, these meetings largely being called to resolve specific issues. Needless to say, there were a large number of expensive problems that arose from this structure, some of these we identified before a well was drilled, many unfortunately we did not. The cost of these failures was high, both from an economic and reputational standpoint. The situation was largely resolved when the organisation of the departments was changed to one based on multi-disciplinary teams. In these the input of the widest range of experience and expertise was shared at the early planning stages, and daily communication maintained from that point as plans progressed. I would not claim that the approach removed all failures from the project planning process; however, where these occurred, they were largely due to events that fell outside of the scope of any rational planning process.

I do not know the process by which the works discussed in this thesis were prepared for publication. Similarly, I do not know the extent to which any multi-disciplinary peer review process was undertaken through any pre-publication reviews. The following suggestions reflect what appears to be lacking from the content of these works. Ships of any era probably represent some of the most complex engineering structures of contemporary industries. To fully analyse their construction, and particularly their use, they need to be viewed in this context. To achieve this means any analysis should probably involve some technical input to ensure that the conclusions reached are both sound in the context of the period, and practical in application, in this latter case perhaps by fully examining accounts of relevant reconstructed vessels. I am not suggesting that every university department should have multi-disciplinary teams composed of these specialists. However, I suggest a way should be found to conduct either formal or informal multi-disciplinary peer reviews of works covering this range of topics before publication, the intent being, to ensure the contents presented, and the conclusions reached, are robust.

This thesis has highlighted the lack of a clear taxonomy relating to vessel types, and how this lack has provided the route by which respected scholars from outside of the field have made unsafe assumptions regarding vessel use. The extent to which these misunderstandings are represented in mainstream publications has been discussed in the case studies in Chapters 2 and 3. The manner in which these have the potential to shape the understanding of the current generation of students regarding seafaring and trade in the ancient Mediterranean is clear. The case that Rogers makes regarding the strength of the written word from authoritative sources is perhaps relevant in this regard. The case of the 450-ton ship of Ugarit might almost be a case study of this issue. This reference is now found in published material from major works on maritime archaeology and Bronze Age seafaring, to specialist works on the Phoenicians, to more general textbooks covering trade across the entire period. It might be expected that any of these might be used for reference at undergraduate level. The discussions presented in this thesis; however, shows the lack of secure evidence regarding the vessel capacity in the primary source used, and the lack of evidence for either the vessel type, or the enabling technology required to manage a vessel of this size at sea. The manner in which this might be addressed is clearly complex and fortunately lies outside the scope of this thesis.

It is also clear that authors writing about the development and use of the vessels might benefit from working in a wider more multi-disciplinary environment in regard to risk. I contend that the failure to discuss this, or even to appreciate how risk might change with vessel size and design, underlies many of the problems identified. The potential impact of many of the issues relating to risk are recorded indirectly in the voyages of reconstruction vessels. In many cases; however, these accounts are presented in the form of an assessment of the operating envelope of the vessel. The focus of some of these appears to be to explain what a vessel may have achieved in the past, if it was, sailed in the same manner and exposed to the same conditions as those experienced in the voyage of the reconstruction vessel. For the reasons outlined in Chapter 7; however, the vessel's safety equipment, environmental factors, and the motivations for the voyages, have to be considered when proposing vessel usage. The comment by McGrail (1989, 850) in section 3.1 is worth repeating in this regard: 'The aim of a Ship's master ancient or modern is the safe and timely arrival of his ship at the next destination. One of the principal concerns of a Bronze Age master was thus the safety of his ship.'

If risk may be assumed to be of relevance to vessel use, and risk is directly related to the size and design of the vessels as discussed throughout Chapter 7, then this brings these conclusions back to the original point relating to the aim of this thesis. The need for a taxonomy of vessel types based on propulsion and usage, along with a model for a process of development explaining changes in vessel types. I contend that the lack of this at the present time means that much of the specialist literature on maritime archaeology does not provide the information required by historians and social archaeologists to build secure models of vessel use. I cannot prove the accuracy of the system of taxonomy and the model of learning I have suggested. What I hope I have achieved is to demonstrate the requirement for a system and model that will accommodate all of the lines of evidence. In doing so I hope to have generated sufficient interest to open up the subject for debate and further development.

9.0 Bibliography

Abbreviations used follow the format of the *American Journal of Archaeology*

https://www.ajaonline.org/submissions/abbreviations.

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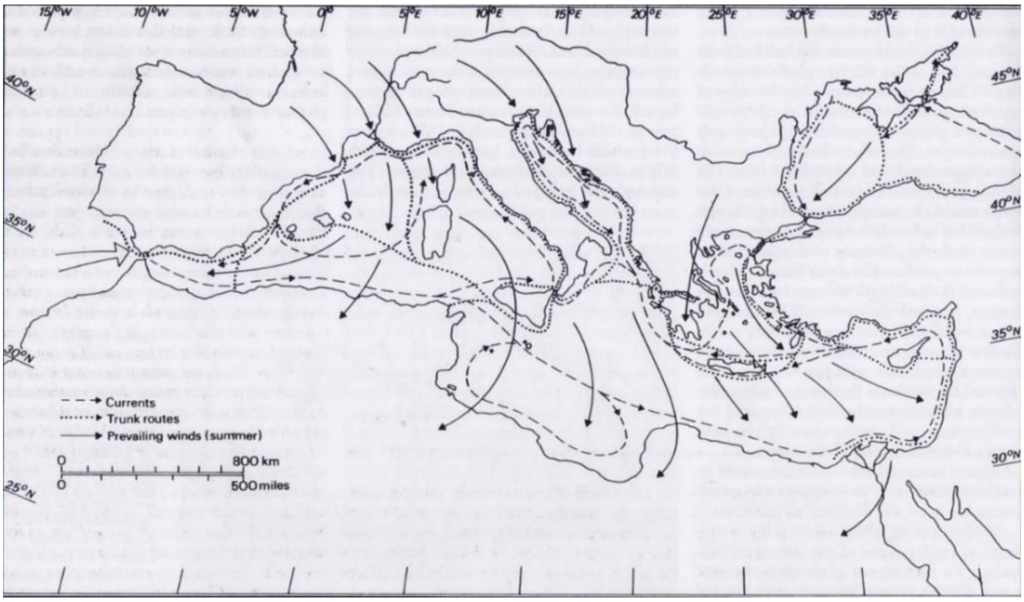
10 Maps, Tables and Figures

Maps

Tables

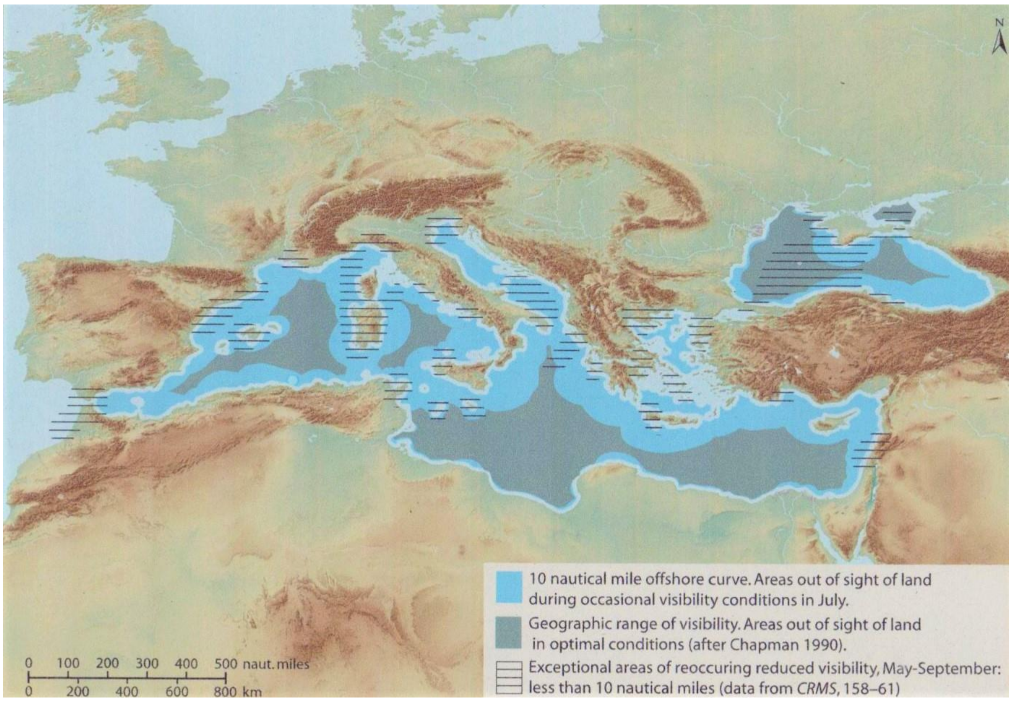
Figures

Maps

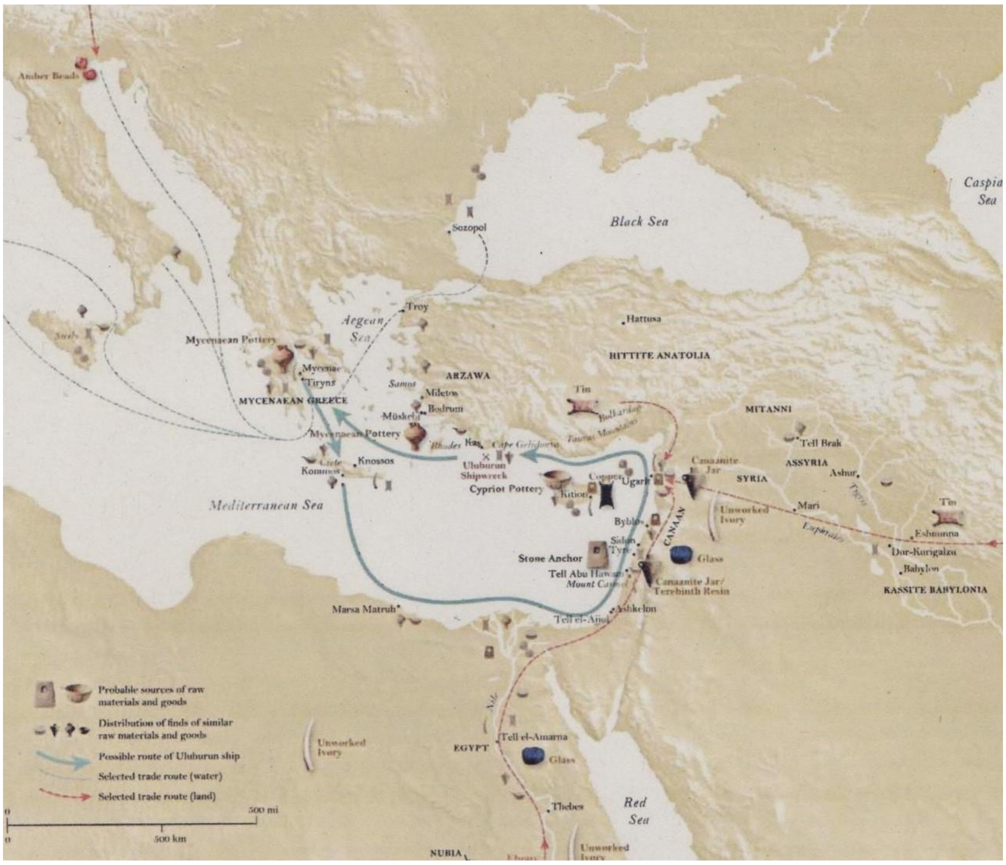


Map 7.1 Showing the predominant direction of summer winds and the prevailing currents across the Mediterranean basin, source Pryor, 1992, fig 2.

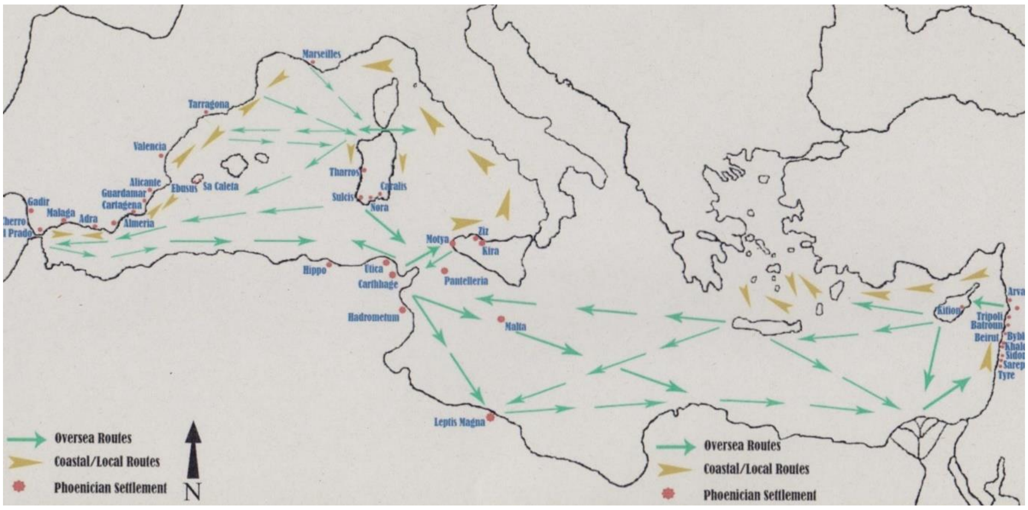
Map 7.2 The three regions of the Mediterranean basin after, Cazzella and Recchia 2009, Fig 1, Vagnetti (2009, Fig 66.1), and Lo Schiavo (2013).



Map 7.3 Showing actual conditions of visibility in the Mediterranean during summer months, source Davis, 2009, fig 2.18

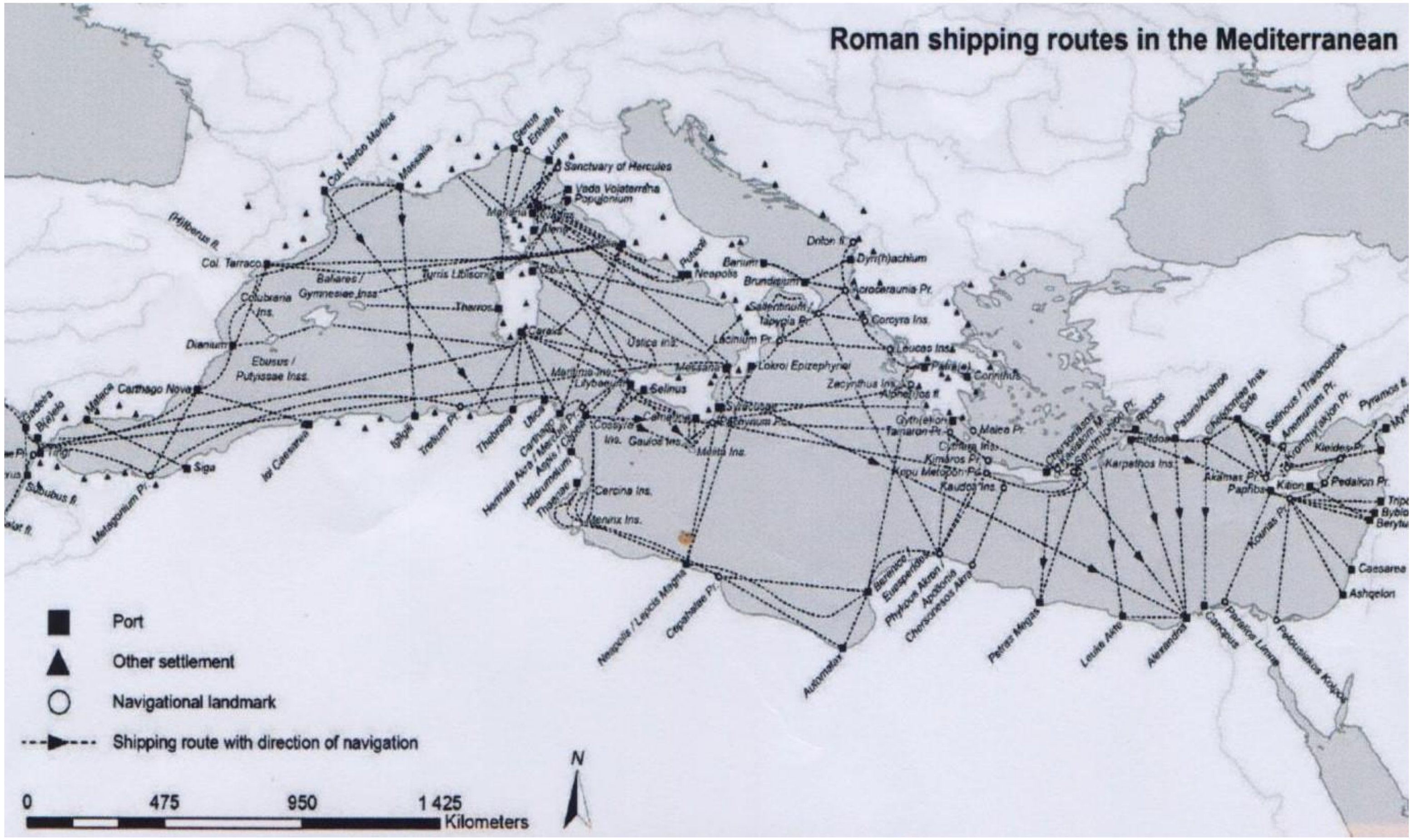


Map 7.4 Showing proposed trade routes in the eastern Mediterranean, source Pulak, 2008, fig 97



Map .7.5 Proposed Phoenician trade routes, source Puckett, 2012, fig 17

Map 7.6 Showing a proposed system of coastal trading links that may have linked the Phoenician colonies in the Mediterranean, source Negbi, 1992, Figure 3



Map 7.7 Showing Arnaud’s interpretation of the range of Roman trade routes, source Arnaud, 2018, fig 3.1

Tables

Table 2.1 Data base of shipwrecks used, sources as shown.

Date	Location	Assumed origin	Description				References
			Hull	Cargo	Length mtrs	tonnage	
1800-1700 BC	Pseria, Crete	Crete	None found	Amphora.	10 - 15	??	Eti Bonn-Muller (2009) by the Archaeological Institute of America archive. archaeology.org/1001/etc/minoan_shipwreck.html Knapp, B. A.(2012). A Minoan Shipwreck off Laconia', ENALIA, .https://www.kommosconservancy.org/a-lakonian-minoan-shipwreck/
1500-1400 BC	Kumluca disrict, Turkey	??	None found	Copper ingots	+/- 14	??	Hakan Öniz (2019) A new Bronze Age shipwreck with ingots in the west of Antalya—preliminary results, Palestine Exploration Quarterly, 151:1, 3-14.
1400 - 1300 BC	Uluburn Turkey.	Levant	Timbers and internal plank keel	Copper and tin ingots, ceramics, glass, resins, mixed small objects.	+/- 15	+/- 25	Bass (1986: 1989) Pulak (1988; 1998; 2012)
+/- 1200 BC	Cape Gelidonya, Turkey	Levant	Timber fragments	Copper ingots, bronze scrap, metal working tools.	+/- 9 metres	??	Bass, (2012).
+/- 1100 BC	Zambratija	Ilyria	Timbers, frames and plank keel	None	+/- 9 metres	???	Pomey and Boetto (2019)
750 - 700 BC	Ashkelon, Isreal	Phoenician	None found	+/- 400 Amphora.	+/- 15	+/- 25	2 wrecks found Balland et al. (2002)
750 - 700 BC	Ashkelon, Isreal	Phoenician	None found	+/- 400 Amphora.	+/- 15	+/- 25	
625 - 575 BC	Mazarron 1, Spain	Phoenician	Timbers, external keel, anchors for a mast step.	No cargo	+/- 9	4	Tejedor (2018)
600 - 580 BC	Giglio, Italy	Greek	Fragmentary, Bows and one other section found.	Ingot, amphora, fine ceramics, mixed products	Possibly greater than 20m	??	Polzer, Bound 1985, 1991
570 - 560 BC	Pabuç Burnu Turkey	Greek	Timber fragments	260 Amphora	13 - 15	??	Polzer. https://www.persee.fr/doc/anatv_1013-9559_(2010_act_20_1_1130)
525 - 510 BC	Jules Verne 7, France	Greek	Hull and keel	Abandoned, no cargo	+/- 16	15	Pomey and Poveda (2018)
510 490 BC	Grand Ribaud France	Greek or Etruscan	Partially exposed, timbers and keelson, possibly wine glass form	Amphora and ceramics	Variously estimated between 20 and 30 metres	30-38	Polzer. Long, (2001), Pomey and Rival (2002).
500-480 BC	Gela 1, Sicily	Greek	Timbers, external keel. keelson, mast step	Ballast, ceramics, amphora	+/- 18	??	Panvini.(2001). The Archaic Greek ship at Gela.Assessorato dei beni culturali e ambientali e della pubblica istruzione.
450 -425 BC	Gela 2, Sicily	Greek	Fragmentary, timbers, wine glass form	Ballast, ceramics, amphora	Estimated at +/- 18	??	Polzer, Bennini (2001)
425 - 400 BC	Alonnesis, Sporades	Greek	Not exposed	+/- 4200 Amphora, along with ceramics	+/- 25	Minimum of 125 based on wt of loaded amphora	Hadjidaki Underwater Excavations of a Late Fifth Century Merchant Ship at Alonnesos, Greece : the 1991-1993 Seasons. In: Bulletin de correspondance hellénique. Volume 120, livraison 2, (1996. pp. 561-593)
425 - 400 BC	Porticello Italy	Greek	Timber fragments	Amphora, pieces of bronze sculture	+/- 20	??	Jones Eiseman. The Porticello Shipwreck.AINA Newsletter, Spring, (1975. Vol2. No 1).
400 BC	Ma'agan Mikhae Isreal	Ionian Greek	Wine glass form, mast step and external keel.	No cargo	13 - 14	20 - 25	Kahanov & Pomey The Greek sewn shipbuilding tradition and the Ma'agan Mikhael ship: A comparison with Mediterranean parallels from teh sixth to the fourth centuries BC. The Mariner's Mirror, (90:1, 6-28)
+/- 300 BC	Kyrenia, Cyprus	Greek	Wine glass form, external keel, mast step.	+/- 400 Amphora	+/- 15	25 - 30	Katzev.(1981). Steffy. (1985)
70 BC	Madrague des Giens, France	Roman	Wine glass form, mast step and external keel.	Amphora.	+/- 35	+/- 550 displacement	Bonino A Further Proposal for the Hull Lines of the Madrague de Giens Ship (c.70 BC). The International Journal of Nautical Archaeology (2018 47.2: 443–459)

Table 3.1 Summary of the evidence relating to learning

Location in text	Subject	Source	Particular significance
Craft industries in the ancient and modern world			
Section 3.1	Separation of craft and theory in the ancient world	Aristotle *Metaphysics 1.12*	The passage the difference between the artisans and masters performed their tasks noting the latter to have been superior in wisdom because they understand the theory.
		Aristotle *Politics 1.V.9-11*	This passage examines the social position of the artisan and makes clear it is inferior to the master, and more comparable to a slave.
Section 3.1 Fig 3.2		McClelland and Dorn (2006)	These two authors compare the difference in how theory and practice are applied technical development and perhaps indirectly reflect the issues raised in the two works of Aristotle noted.
Section 3.1	Nature of learning in craft industries in the ancient world	Philon of Byzantium In Belopoeica 50.14-29	Explanation of the process of development in craft based industries of the Hellenistic world was by trial and error practical methods rather than reliance on a system based on theory.
Section 3.1	Present day learning in craft industries	Marchand (2020)	Discusses how learning in boat building in the craft industries of the Middle East is by a process of practical experience rather than theory.
		Ingold (2013)	Ingold presents a clear explanation of the different approaches taken by the theorist and the practical craftsman with regard to learning.
Modern writing on learning and development with regard to technology			
Section 3.1 Fig 3.1	Cummulative sysnthesis a model of learning	Usher (1954)	Provides a model that shows a process of learning by small iterative steps. This model underlies the case made throughout this thesis.
Section 3.1	Hybridization in learning	Buckley and Boudot (2017)	Outline how learning might involve the transfer ideas in a process of hybridization, this might illustrate how the model proposed by Usher is a very simple form or reality
Section 3.1	Impact of society on learning	Edgerton (1999)	Makes the observation that the link is banal but possibly for this reason rarely merits attention.
		Unger (1994)	Observes how an increased rate of learning in maritime technology occurred in Medieval Europe due to the interchange of ideas across a trading system.
			Taken together both suggest the need to incorporate social elements in to any use of Usher's model of development
Section 3.1	Rate of learning	Usher (1954, pp68-69)	Discusses the conservatism of ancient societies and the extended use of practices sanctioned by tradition.
		McClellan and Dorn (2006, p427).	Provide evidence for the rapid increase in the desmination of knowledge through the publication of scientific journals and abstracts from the 18th century
Section 3.1 Fig 3.3		McGrail (2004, p209).	Provides evidence for the timing, scale and nature of change in Norse vessels in the period from fourth to the nineth centuries AD
Section 2.1 Fig 2.13	The relative stability of the largest vessel size in use in the pre industrial period, and the hierarch of vessel sizes that might be expected to be present when these large vessels were in use.	Lloyd's Register Of Ships Online Archive & Library /Lloyd's Register of Shipping 1764	Lloyds register of 1764 shows that the largest vessel to use London in that year was no larger than those in use in the Roman Empire in the early centuries of the Christian era. The later information relating to the Preussen shows how rapidly the size of vessels increased in an industrrial society.
Section 3.1		www.bruzelius.info/Nautica/Ships/Fivemast_ships/Preusssen(1902).	
Section 3.2	Motivation and sequence of learning	Edgerton (1999, p124)	Notes that inventive activity is shaped by the past and present not the future.
		Edgerton (1999, p123)	Notes that use drives invention and innovation rather than invention and innovation driving use
Key principles and innovations in the understanding of vessel development			
Section 5.1.1	Square cube law	Galileo *The Discourses on two New Sciences* 1638	First explanation of the relatiolnships that underly the square cube law. The impact of this on the ability of hybrid rowed and sailed round ships to increase over 16 metres in length in fundamental to the case presented in Chapter 5.
Section 5.2.1	Development of lifting equipment	Wilson (2010, p342)	Earliest record of the use of lifting equipment in construction activity

Table 4.1 Summary of the evidence of vessel types and sizes from pre 1500 BC to 1000 BC

	Location in text	Subject	Source	Particular significance
Pre 15th century	Section 4.1.3	Abydos boat graves	O'Connor (1991)	Incomplete remains of vessels, the timbers that were found show the vessels to have been of stitched construction.
	Section 2.1 Fig 2.5	Portrayal of a vessel in the tomb of Kaem'onkh	McGrail (2004, Fig 2.15)	This is an issue of taxonomy. The images is described by source as a sailing ship but the line of crewment suggests a rowing crew and that this is probably a hybrid rowed and sailed vessel
	Section 2.1 Fig 2.6	Portrayal of a vessels in the tomb of Ipi at Saqqara	McGrail (2004, Fig 2.18)	The image shows an early use of a boom supported sail
	Section 2.1 Fig 2.7	Portrayal of a vessel in the tomb of Sahure at Abusir	McGrail (2004, Fig 2.3)	Evidence from 5th dynasty of Egyptian hull type used up to 1500 BC. Use of a hogging truss to support the hull.
	Section 4.1.1 Fig 4.1	Vessel shown on a seal from Tell El Dab'a	Porada (1984, p486)	Evidence of possible alternative hull types on vessels shown in the Levant to those shown in Egyptian iconography
	Section 4.1.3. Fig 4.15	Remains of the cheops barge	Lipke (1984)	Earliest remains of the hull of a whole vessel. Stitched hull construction but the hull has a number of timbers described as central and longitudinal girders by Lipke who quotes heavily from Hag Ahmed Youssef Moustafa who led the reconstruction.The orientation of these timbers is similar to that expected in a modern structural beam, or a structural keel in a ship. The probable failure of this feature to transfer to maritime hulls, as evidenced by the use of hogging trusses on later vessels, and the use of a less efficient form of keel on the later Uluburun hull, suggests that learning and development in the period was discontinuous.
	Section 4.1.3	Mitrou boat remains	Moortel (2009, pp20-21)	Remains of an incomplete vessel between 5.5 and 6 metres in length, evidence that the hull timbers were stitched together.
	Section 4.1.3	Pseira shipwreck	Hadjidaki-Marder (2021)	First wreck of vessel around 16 metres in length, no hull remains but the debris mound was sufficient to provide a good estimate of the vessel size.
	Section 4.1.3. Fig 4.16	The remains of the Dashur boat	Steffy (2017, p33)	Use of mortice and tenon joints used to fix the hull timbers, joints up to 24 cm in length, the hull shows no indication that frames were used in this.. Steffy comments how these long mortice and tenons would have acted in place of these as a form of internal frames to stiffen the hull.
	Section 4.1.1. Fig 4.2	Vessels on early Minoan and Middle Minoan seals	Moortel (2015, p266)	Evidence of possible alternative hull types on vessels shown in the Crete to those shown in Egyptian iconography
	Section 4.1.1 Fig 4.8	Vessel from on a sherd from Iolkos	Morrison and Williams (2008, pp9-10) Vermeule (1964)	Early indication of the development of one form of galley type vessel in use in Mycenaean Greece
	Section 4.1.1 Fig 4.8	Vessel on a sherd from Tragana tholos	Morrison and Williams (2008, pp9-10) Vermeule (1964)	Early indication of the development of an alternative form of galley type vessel in use in Mycenaean Greece
	Section 4.1.1 Fig 4.8	Vessel on a stirrup jar from Asine	Morrison and Williams (2008, pp9-10) Vermeule (1964)	Early indication of the development of a further form of galley type vessel in use in Mycenaean Greece
15 th century BC	Section 2.1 Fig 2.9	Portrayal of the vessels used on Hatshepsut's voyage to Punt	Wachsmann (2009, Fig 2.11) Landstrom (2022, Fig 380)	Hull design and hogging truss similar to that shown in the vessel in the tomb of Sahure at Abusir suggests this was needed to stiffen the long hull shown. Landstrom's suggests that the vessel was fitted with an external keel. There is however no evidence that this was the case and the limitations on the courses the vessel could sail as a result of the sailing rig shown suggests the vessel may not have required this.
	Section 2.1 Fig 2.2	Portrayal of Hatshepsut's obelisk barge		Provides evidence of ability of shipwrights of the period to build large vessels for river use. This might suggest that the absence of large maritime vessels was either the result of a lack of motivation based on the trade of the time, or related the problems of operating a large maritime vessel with the technology of the day.
	Section 4.1.3	Kumluca shipwreck	Oniz (2019)	Earliest Late Bronze Age wreck. The debris pile suggests this is a round ship but excavation incomplete at the time of writing. It is currently unknown if there are substantial hull remains.
14 th century BC	Section 4.1.1. Fig 4.3	Portrayal of the vessel in the Kenamun tomb	Artzy (1987, p80) McGrail (2004, p130)	First clear iconographic evidence of a round ship. Vessel shown is fitted with a boom supported sail but does not show evidence of a hogging truss. The dress of the crew suggests the vessel may have had an origin in the Levant.
	Section 2.1 Figs 2.11a - d Section 4.1.3. Fig 4.17	The Uluburun shipwreck	Pulak (1998:1999;2012)	First Late Bronze Age vessel with substantial hull remains. The keel took the form of a thick plank with minimal extension below the hull. Pulak (1998, pp210-211) differentiates the hull of this from later true sailing ships. The failure to adopt the same keel form as shown in the Cheops barge suggests either that this learning had been lost, or that the this form of keel was simply not required in a vessel of this size. The discussion shows the hull used pegged mortice and tenon joints up to 28-30 cm in length. No evidence of frames were found fitted in hull.
	Section 4.1.1. Fig 4.5	Portrayal of the vessel from a tomb at Hermopolis	Fabre (2004, pp117-118)	This image is incomplete, but on the basis of a reconstruction the suggestion is made by Fabre that the illustration may show a sail handling technique associated with windward performance.
	Section 2.1 Figs 2.3, 2.4	Portrayal of the vessel in the tomb of Huy	Casson (1971, fig 16) www.metmuseum.org.	This is an issue of taxonomy. The source describes this vessel as a sailing ship but the prescence of oars on the complete image from the Metropolitan Museum shows this to be hybrid rowed and sailed vessel.
	Section 4.1.1. Fig 4.4	Portrayal of the vessel in the tomb of Neferhotep	Vinson (1993, Fig 8)	Indications of the possible development of a loose footed sail
13 th century BC	Section 4.1.1	Ugarit text RS 20.212	Nougayrol (1960) Astour (1965, pp254-255) Casson (1971, p36) Hoftijzer and Soldt (1994, p341) Monroe, (2007; 2009; pp82 -84; 2016, p15)	Widely quoted, but unsubstantiated, reference to large sailing ship. The text provides an inconclusive statement on vessel capacity based on an undefined measure. In an early work Nougayrol infers a size for this measure and from this calculates a vessel size. This vessel size is then accepted in a work by Casson to be representative of large vessels in use at the time. Casson as a widely accepted early authority in the field, is then used by other authors as a source that vessels of this size existed at this time. There is no evidence for this assertion, and no evidence that sailing ships of any kind existed at this time. Where the evidence in later periods show that large vessels were in use, these are accompanied by a hierarchy of more numerouse smaller vessels covering a wide range of sizes, there is no evidence that these existed at this time.
	section 4.1.2	Ugarit text KTU 4.40	Hoftijzer and Soldt (1994, p337)	Late Bronze Age text from Ugarit which records crews of around 20 men in vessels at this time. There is broad agreement between this and the figures for Homers broad beamed merchantmen, the iconography of the Battle of the Delta, and the size of the Uluburun vessel.
	Section 4.1.2	Pylos texts AN 610 and AN 724	Chadwick (1976); Palaima (1991); Vitas (2012)	Provide translations and interpretations on the number of oarsmen called up for duty, and the nature of the service and social obligations of the oarsmen.
	Section 4.1.1. Fig 4.9	Vessel in wall paintings from hall 64 Pylos	(Brecoulaki et al, 2015	Provide evidence of the hull forms in use in small vessels in Mycenaean Greece
	Section 4.1.3	Cape Gelidonya shipwreck	Bass (1967; 1991; 2012)	A small vessel around 10 metres in length which from the evidence of the cargo suggests was based in either Cyprus or the Levant. It was constructed by pegged mortice and tenon joints. The use of these on a small vessel might suggest their widespread use in vessels from the north east Mediterranean at this time.
	Section 4.1.1. Fig 4.7	Sherds with portrayal of the Kynos ship	Dakoronia (1987, p122)	Evidence of alternative galley type in Mycenaean Greece
12 th century BC	Section 4.1.1. Fig 4.6a and 4.6b	Portrayal of the vessels involved in the Battle of the Delta	Nelson (1943, pp41-47)	First evidence for the use of loose footed sails. Based on the numbers of oarsmen in the largest vessels the length of these were likely to have been around 17 metres.
11 th century BC	Section 4.1.3. Fig 4.20	The remains of the Zambratija vessel	Pomey and Boetto (2019)	Small vessel around 9 metres in length found in the north east Adriatic. The hull lacked an external keel and the timbers were joined by stitching.

Table 4.2 Summary of the evidence of vessel types and sizes from 1000 BC to 500 BC

	Location in text	Subject	Source	Particular significance
11 th century BC				
10 th century BC				
8 th century BC	Section 4.2.3	Two wrecks found off Ashkelon	Ballard et al (2002)	Wrecks found in an isolated location offshore in deep water. Both orientated with bows to the west suggesting they may have been driven offshore and swamped in strong eaterly winds. The cargo suggests both sailed around the same time from Phoenician ports. The debris pile suggests vessels around the size of the Uluburn vessel. Possible indirect evidence for the lack of larger vessels and the continued use of coastal voyages.
	Section 4.2.1. Fig 4.21	Vessels on Sennacherib relief	Layard rrepresentation	Early repesentations of bireme galleys. Two vessel types shown, one with a ram, one without, the vessels shown with a ram have a mast and sail, the others do not. Those without a ram are frequently described as merchant galleys but the bireme form suggests this might not be the case. The only vessels shown with a mast are those with a ram. The scene shown was probably created to enhance the status of the Assyrian ruler who commissioned it and the scene shown is unlikely to be an accurate representation of the range of vessels types and their use by the Phoenicians at this time.
	Section 4.2.1. Fig 4.22	Phoenician vessels in relief from Khorsabad	McGrail (2004, Fig 4.29)	Vessels shown have similarities to those in LBA, High bow and stern timbers rowed from one level, none are fitted with a mast. These may be more representative of the smaller vessels in use in Phoenician cities at this time.
	Section 4.2.2 Section 5.1.2	General comments in Homer	Homer Od 8.145 Homer Od II.420-421	Reference in Homer to the Phoenicians as traders. Reference to a vessel making sail but the crew were sitting on the benches implying the use of a hybrid rowed and sailed vessel of some kind.
	Section 4.2.1. Fig 4.23	Phoenician warship from Kuyundjik	https://www.britishmuseum.org. 20/11/21	Representation of a bireme galley fitted with a ram. Confirms the use of the bireme form by this time and implies that development of the vessel type was directed toward speed and agility.
7th century BC	Section 4.2.3. Figs 4.26, 27, and 28	Mazaron 1	Tejedor (2018)	Small vessel around 9 metres in lenght from Spain, the hull was constructed using short mortice and tenon joints between 6 and 8 cm long, the more flexible hull was fitted wiht frames. This implies a change in manner of construction from that of the Uluburun vessel and that a signficant development in maritime technology had occured in the period between the two vessels. The constuction suggests a Phoenician / Carthaginian influence. Of more equal importance the vessel is the earliest in the Mediterranean to have an external keel and a mast step implying its suitability for use as a sailing ship.
6 th century BC	Section 4.2.3	Giglio	Polzer (2009)	Vessel +/- 20 metres in length, the hull remains are fragmentary and it is not possible to be certain about the true size. Bound (2001) suggests from the stitching the vessel may have been Etruscan.
	Section 4.2.3	Pabuc Burnu	Polzer (2007)	Early evidence of mix of mortice and tenon and stitched joints in what appears to be a Greek vessel. The mortice and tenons appear to have been used to provide temporary fixing for the timbers prior to their stitching.
	Section 4.2.1. Fig 4.25	Sailing merchantman on a black figure kylix	https://www.bmimages.com/. 20/11/21	First evidence in art for what appears to be a sailing ship as opposed to a small inshore vessel as suggested by the Mazarron 1 wreck.
	Section 4.2.2	Reported use of 50 oared vessels for trade and colonization	Herodotus *I.164* Herototus IV.153	Reported use of 50 oared vessels in long distance trade. Given the time separation of Herodotus from the events t is uncertain if these were pentaconters. The text however is specific that these were not sailing ships. Once again Herodotus refers to 50 oared vessels for a colonizing voyage. Once again it is possible that this was convention but it suggests the use of some kind of hybrid vessel for this purpose.
	Section 4.2.1. Figs 24a-d	Series of four Archaic galleys	Morrison and Williams (2008, plates 13, 17c, 17e & 21e.	Evidence for the general use of an extended forefoot on the hull of galleys at this time and that masts were possibly located forward of midships.
	Section 4.2.3	Jules Verne 9	Pomey and Poveda (2018)	This vessel is associated with the Greek colony at Marseilles and is 10 metres in length. It was constructed by stitching. The hull is fitted with frames and an external keel. Taken with the cummulartive evidence of vessels from LBA it might suggest a long tradition of the use of stitched hull construction in the Aegean, the central and western Mediterranean.
	Sections 2.2 and 4.2.2 Section 2.2	Voyage of Hanno the navigator v. 1 Voyage of Hanno the navigator v. 8	Schoff (1912)	The first verse discusses the use of 50 oared ships for a colonizing voyage by the Carthaginians at this time. These may not have been pentaconters but it does suggest the use of hybrid vessels. Verse eight notes how the location of a new colony was founded, there is no reference to the use of latitude.rather the location is determined by reference to the days spent on the voyage.
	Section 4.2.3	Grand Ribaud F	Polzer (2009)	Large vessel variously estimated to be beween 20 and 30 metres in length. Due to this uncertainty it is not possible to be certain about the vessel type.

Date BC	Quantity		Given to	Given by
	Medimni	Tons		
1st half 3rd century	500	20	Delos	Dealer of Byzantium
c 300 BC	2,355	95	Ephesus	Rodian dealer
179	2,800	115	Delos	Massinissa
end 4th century	3,000	120	Samos	Dealer of Torone
330	4,000	165	Athens	Two dealers from Heraclia
325/4	3,000	120	Athens	Cypriot dealer
324/3	3,000	120	Athens	Dionysius of Heraclia
320/319	3,000	120	Athens	Dealer from Hellespont
320/319	4,000	165	Athens	lost
208/7	8,000	330	Athens	An Aetolian

Table 4.3 Range of Greek vessel sizes based on grain and oil donations, source Casson, 1971, pp183-184

Table 4.4 Summary of the evidence of vessel types and sizes from 500 BC to 200 AD

	Location in text	Subject	Source	Particular significance
5 th century BC	Section 4.3.3	Wreck of the vessel at Gela	Panvini (2001)	Greek sailing ship using both stitching and mortic and tenon joints, the wreck can be dated to beween 490 and 480 BC from some red-figure askoi. The hull has a keel and mast step and there is evidence of lead sheathing.
	Section 3.2 Section 4.3.2	Record of development of the 'modern galley' Record of the size of a large vessel at this time	Thucydides *1.13.4* Thucydides VII.25.5	Provides a definition for what constituted a modern galley at this time, and an estimated date for the earliest sea battle between Greek cities. Thucydides in this passage refers to vessels of 10,000 talent burden this is around 250 tons suggesting the use of large sailing ships by this time.
	Section 4.3.3	The Alonnesos Sporades wreck	Hadjidaki (2009)	First physical evidence of a round ship substantially larger than 16 metres. Based on the cargo it would appear to be around 125 tons, the hull has yet to be excavated.
	Section 4.3.1 Fig 4.31	Vessel from the Tomba della Nave	Steingraber (2006)	Iconography from a tomb dated to around 450 BC showing evidence for the first use of a vessel with two masts and sails. From the reconstruction of the fresco it would appear that the foresail is mounted on a vertical mast and appears to be drive sail. It is not possible to determine the length of the vessel.
4 th century BC	Section 4.3.3	The wreck of Ma'agan-Michael vessel	Kahanov and Pomey (2004)	The hull was constructed by a mix of stitching and mortice and tenon joints, the wreck provides the first evidence of the use of a wine glass hull form with an external keel.
	Section 4.3.1	Table of Greek vessel sizes	Casson (1971, pp183-184))	Information based on donations of cargos of grain and oil to city states by wealthy merchants suggest that vessels of over 100 tons were in common use at the time.
	Section 4.3.3 Figs 4.34 and 4.35	Wreck of the Kyrenia ship	Katzev (1981)	Nearly complete hull remains of a vessel constructed with short mortice and tenon joints with an average length of 8 cm but varying between 4 and 10 cm. The hull was secured by internal frames and had a wine glass form, once again there was evidence for the use of lead sheathing on the hull.
	Section 4.3.2	Roman vessel size	Lex Claudius in Livy *21.63*	Records the restriction in vessel size that a senator might own. Houston (1988, p559) suggests the small size of this, +/- 15 tons, suggests much Roman maritime trade at this time was carried out in small vessels.
	Section 4.3.2	Record of ship sizes in the Thasos port regulations	Casson (1971, pp171-172)	Records how different parts of the harbour were restricted to vessels of particular size. The inner harbour being restricted to vessels of over 130 tons and the outer harbour restricted to those over 80 tons.
2 nd century BC				
1st century BC	Section 4.3.2	Size of a Cybaea, a type of large galley	Cicero in Verrem (2.4.17, 2.5.44, 50, 59)	Suggests the use of a merchant galley, 'the likes of a trireme.'
1 st century AD	Section 4.2.2 Section 4.3.2	Use of merchant galleys in the grain trade Sailing rig in use in Hellenistic vessels	Plutarch *Life of Pericles 26.4* Plutarch *Marcellus 14.8*	Plutarch in this passage is writing about events in the sixth century BC and refers to the development of a particular type of pentaconter for use in the grain trade. It is possible he is writing with hindsight rather than accurately describing events of the time. However if he is writing with an understanding of contemporary vessels this might imply the continued use of large galleys for bulk trade at this time. Plutarch in this passage is referring to the use of vessels with three masts by the Greeks in events occuring the third century BC, this may be projection of large vessels of his time rather than an accurate portrayal of history.
	Section 4.3.3 Figs 4.36 and 4.37	The Madrague des Giens wreck	Pomey, 1982	Early example of a large Roman vessel estimated capacity of around 450 tons. The reconstructed hull form shown by Pomey (1982) is unlike that shown in later Roman iconography showing sailing ships but rather suggests it is related to earlier galley designs. It is difficult to imagine a galley of 450 tons in operation at any time. This may then represent a transition vessel in which craftsmen were adapting earlier vessel forms to new means of seafaring. The vessel then may be of significance in confirming the iterative nature of learninga and development at this time.
2nd century AD	Section 4.3;2	Vessels in Ropman grain trade	Suetonius Claudius 18-19	Records the attempts by the Roman state in provide incentives for merchants to provide shipping for the grain trade.
	Section 4.3.2	Vessels in Ropman grain trade	Gaius Institutes	Refers to an edict of Claudius and the incentives offered to merchants who built a vessel of not less than 10,000 bushels of grain and carried corn for the state 6 years.
	Section 3.2 Fig 3.8	Two Roman vessels on a mosaic from Ostia. Both having multiple sails but distinctly different hull forms, one suggesting a galley.	(Friedman, 2011, fig 3.7.20)	The portrayal of two distinct hull forms in vessels with large and complex sailing rigs suggest that this form of rig was not specific to true sailing ships but was probably in use in merchant galleys at this time. It raises the question of what vessel type may have been the source of this type of sailing rig when considered in the context of Edgertons comment on use leading to invention and innovation.
	Section 3.1	Lucian The Ship, or The wishers	Harmon et al (2015)	Provides the dimensions of a large Roman merchant ship that came in to Athens on the way back to Rome from Egypt. When this is compared to the information from Lloyds register from 1784 it is noticable that vessel sizes showed little sign of increase over this extended period of time. This might confirm both Usher's comments on conservatism in technology in the ancient world, but also note how much development in maritime technology was dependent upon developments outside of this field.
	Section 4.3.3 Fig 4.38	Les Laurons B	Gassend et al, 1984	Small vessel around 13 metres in length the reconstruction of the hull has elements suggesting that shrouds were in use.
Post 2nd century AD	Section 4.3.1 Fig 4.33	The Porto Bas relief	Torlonia Museum Rome	Scene from the port of Ostia showing a large Roman merchantman fitted with two masts and a top sail, the main mast have a complex set of shrouds.
	Section 3.2 Fig 3.10	Roman oared ship from Themetra	Morrison and Coates, 1986, fig 32	Late representation of the use of a merchant galley fitted with an artemon sail
	Section 4.3.1 Fig 4.32	Roman sarcophagus from Ostia with three ships	Ny-Carlsberg Glyptothek Copenhagen	Scene shows three vessels two with square sails and one with a fore and aft rig.
	Section 2.1.2 Fig 2.8	Roman merchant galley from Villa del Casale.	Friedman 2011, Fig 3.8.21	Late representation of the use of a merchant galley fitted with an artemon sail. In this case however Friedman describes the vessel as a sailing ship.
	Section 3.2 Fig 3.9	Roman merchant galley from Tebessa	Casson (1971, Fig 140)	Late representation of the use of a merchant galley fitted with an artemon sail

	Triaconter	Single bank Pentaconter	Bireme pentaconter	Trireme
Maximum continuous speed in knots	4	4.5	5.5	7.5

Table 5.1 A comparison projected speeds of a number of galley types, after Coates, 1987 Figure 2

<table>
<tr><th colspan="7">Table 6.1 summary of vessel development</th></tr>
<tr><th rowspan="2">Time period</th><th colspan="2">Hybrid rowed and sailed vessls</th><th rowspan="2">Sailing ships</th><th rowspan="2">Sailing rigs</th><th rowspan="2">Structural and external keels</th><th rowspan="2">Hull construction</th></tr>
<tr><th>Round ships</th><th>Merchant galleys</th></tr>
<tr><td>1500 - 1000 BC</td><td>The boom supported sail of the Kenamun vessel in Figure 4.3 suggests this was a hybrid rowed and sailed vessel.

The keel of the Uluburun hull suggests this was not a sailing ship, (Pulak, 1998).

The shipwreck evidence from Parker (1992) suggests a maximum size of round ship of around 16 metres.

The application of the square cube law as outlined in Section 5.1.1 suggests this may have been the maximum possible size for this type of vesse.</td><td>There is no evidence for the use of merchant galleys in this period.</td><td>There is no evidence for the use of true sailing ships in this period.</td><td>There is evidence for the use of a single boom supported sail on both Egyptian and Levantine vessels for much of this period.

There is evidence for the use of a single loose footed sail on the vessels in the temple of Medinet Habu from the 12th century BC</td><td>There is evidence for the early use of beams that served the same purpose as a structural keel on the Cheops barge. There is no further evidence for the use of this feature on any vessels following this. The indirect evidence from the use of hogging trusses on Egyptian vessels, and the keel plank used on the Uluburun hull, suggests that learing relating to this feature may have been lost.</td><td>There is evidence for the use of long mortice and tenon joints in vessels from both Egyptian and Levantine sources.The hulls of these vessels lacked frames.

There is evidence of sewn hulls with frames from Greece and the central Mediterraean in this period.</td></tr>
<tr><td rowspan="2">1000 - 500 BC</td><td rowspan="2">In 8th century BC Homer continues to refer to hybrid merchant vessels, OD 9.322 – 23.

Ashkelon wrecks dating to the 8th century BC referenced by Ballard et al (2002) still only 16 metres in length. There is no evidence regarding the hull structure or sailing rig used. As these vessels were contemporary with Homer it is possible they represent the 20 oared merchantmen he refers to but this cannot be confirmed at the present time.</td><td rowspan="2">Evidence of single bank pentaconter type vessels from cermaics dated to 8th century BC, Morrison and Williams (2008)

Herodotus IV.153 makes reference to the use of 50 oared vessels for colonizing voyages from possibly as early as the mid 8th century BC.

Plutarch in the Life of Pericles, 26.4 references the development of the samaina a new type of a more capacious pentaconter.</td><td>Mazaron 1 a 9 metre vessel from the 7th century BC provides first evidence of a vessel with the characteristics of a sailing ship.

At the end of the period a black xx vase provides evidence for the use of a sailing ship</td><td>There is no secure evidence in this period for the use of any sailing rig more complex than a single loose footed sail.</td><td rowspan="2">The appearance of pentaconter merchant galleys, and bireme pentaconter war galleys suggest the development of a structural keel in this period.

The hull of the Mazaron 1 vessel provides evidence for the use of an external keel.</td><td rowspan="2">This period saw the use of short mortice and tenon joints in hulls that used frames to provide support to the shell of the hull.

The nature of learning in the ancient Mediterranean, and the discussion in section xxx implies this was unlikely to have developed without hybridization of the design features of vessels from the eastern and central Mediterranean.</td></tr>
<tr><td colspan="2">Evidence for the development of lifting technology, Wilson (2010). The application of this in sailing ships would allow for the use of larger sailing rigs on larger vessels</td></tr>
<tr><td rowspan="3">500 BC - 200 AD</td><td rowspan="3">There are no specific references suggesting the use of hybrid rowed and sailed round ships in this period.</td><td>Cicero Verrem 2.4.17, 2.5.44, 50, 59 references the use of the cybaea a large merchant galley in the 1st century BC implying a long period of use and development of the vessel type.</td><td>Increasingly large sailing ships come in to use through the period, Parker (1992).</td><td rowspan="2">Evidence for multiple sails in use, the eariest evidence of use on sailing ships is that from the 5th century Tomba della Nave. The Athenian naval records suggest the use of an artemon like sail on triremes also from the 5th century BC.

Plutarch in Marcellus 14.8 notes the use of ships with 3 masts in Syracuse in the 3rd century BC.</td><td colspan="2" rowspan="3">Increasing use of frame supported hulls with constructed with short mortice and tenon joints in this period. The development of the wine glass hull form for smaller sailing ships implies an understanding of the importance of role of the keel as both a structural support, and a means to resist leeway.

The reason for the widespread adoption of mortice and tenon construction in smaller vessels is unlikely to have been linked to any structural requirement. It was more likely to have been the result of a mix of socio economic factors, coupled with the widespread use of the joint type in the rapidly expanding naval construction programmes of the Hellenisic period.</td></tr>
<tr><td colspan="2">The Madrague de Giens, a 450 tons Roman ship of the 1st century BC, can only have been a sailing ship. However its hull form shares many characteristics of a merchant galley. It may represent an early intermediate form in which practices regarding the construction of an established vessel type was being applied to a new form.</td></tr>
<tr><td colspan="3">Widespread iconographic evidence that both sailing ships and merchant galleys were equipped with multiple masts and sails at the close of this period.</td></tr>
</table>

Month	%	Month	%	Month	%
January	31	May	15	September	4
February	27	June	3	October	11
March	24	July	1	November	31
April	22	August	1	December	30

Table 7.1 Frequency of easterly winds in Haifa Bay as a percentage, source, Pryor 1992, Table 1.

Water temperature	Time until losing Consciousness	Estimated time of survival
Below 0C	Within 15 minutes	15 - 45 minutes
0C - 5C	15 - 30 minutes	30 - 90 minutes
5C - 10C	30 - 60 minutes	1 - 3 hours
10C - 15C	**1 - 2 hours**	**1 - 6 hours**
15C - 20C	**2 - 7 hours**	**2 - 40 hours**
20C - 25C	**2 - 12 hours**	**More than 3 hours**

Table 7.2 Showing the impact of exposure to cold water. source _The Maritime Human Resource Institute, Japan Department of Technology and Research [*http://www.maritime-forum.jp/Guidelines for Control Hypothermia at Sea (2017).html]* 24/11/21.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mx	16.6	16.1	16.3	17.6	21.2	24.4	27.8	28.2	26.4	24.5	20.8	18.4
Piraeus	Mn	14.2	14	14.2	13.8	15.8	20.8	23.7	24.4	24.5	20	17.4	14.8
	Av	**15.4**	**15.1**	**15.3**	**15.7**	**18.5**	**22.6**	**25.8**	**26.3**	**25.5**	**22.3**	**19.1**	**16.6**
	Mx	18.1	17.4	17.4	18.5	21.2	24.7	27.1	27.5	26.1	24.9	21.9	19.7
Irakleion	Mn	15.5	15.1	15.5	15.4	17.4	20.9	23.7	24.3	23.9	20.8	18.3	15.9
	Av	**16.8**	**16.3**	**16.5**	**17**	**19.3**	**22.8**	**25.4**	**25.9**	**25**	**22.9**	**20.1**	**17.8**
	Mx	19.6	17.5	17.8	19.1	22.3	25.9	28.6	29.6	28.9	26.5	23.4	20.7
Rhodes	Mn	15.7	15.7	15.8	15.7	18.2	21.6	24.4	26	25	21.3	18.5	16.5
	Av	**17.7**	**16.6**	**16.8**	**17.4**	**20.3**	**23.8**	**26.5**	**27.8**	**27**	**23.9**	**21**	**18.6**
	Mx	19.3	17.7	18.4	19.3	22.9	26.8	29.4	28.9	28	27.1	24.4	21.4
Paphos	Mn	16.1	16.1	16.1	16.5	18.8	22.1	25.1	26.7	25.8	22.5	19.4	17.4
	Av	**17.7**	**16.9**	**17.3**	**17.9**	**20.9**	**24.5**	**27.3**	**27.8**	**26.9**	**24.8**	**21.9**	**19.4**
	Mx	16.5	15.8	16.5	17.6	21.9	25.8	27.6	28.1	27.6	24.9	22.5	19
Siracusa	Mn	14.1	13.8	13.8	14.6	15.8	10	24	24.6	23.4	20.5	18.2	15.4
	Av	**15.3**	**14.8**	**15.2**	**16.1**	**18.9**	**17.9**	**25.8**	**26.4**	**25.5**	**22.7**	**20.4**	**17.2**
	Mx	15.2	14.8	15.4	16.9	21.3	25.3	27.8	27.7	27.5	23.6	19.8	17.2
Taranto	Mn	12.6	13.3	13	14	15.5	19.9	23	23.6	22	18.1	16.4	13.6
	Av	**13.9**	**14.1**	**14.2**	**15.5**	**18.4**	**22.6**	**25.4**	**25.7**	**24.8**	**20.9**	**18.1**	**15.4**
	Mx	15.3	14.5	15.4	16.9	20.9	25.6	26.5	27	26.5	23.8	21.6	18.6
Cagliari	Mn	13.2	12.7	12.8	14	15.7	19	22.2	22.6	21.4	19.5	17.1	14
	Av	**14.3**	**13.6**	**14.1**	**15.5**	**18.3**	**22.3**	**24.4**	**24.8**	**24**	**21.7**	**19.4**	**16.3**
	Mx	14.7	13.3	14.5	16.5	21.9	26.4	26.1	27	25.5	23	20.1	17.9
Livorno	Mn	11.9	12	11.7	13.4	15.5	19.5	22.7	22.6	21.3	17.8	16.2	12.9
	Av	**13.3**	**12.7**	**13.1**	**15**	**18.7**	**23**	**24.4**	**24.8**	**23.4**	**20.4**	**18.2**	**15.4**
	Mx	14.4	13.4	13.9	15.8	20.3	24.4	24.3	25.6	23.8	21.8	19	17.3
Marseille	Mn	12.2	12.2	12.3	13	14.4	17.5	19.6	19.4	20.1	16.9	15.8	12.8
	Av	**13.3**	**12.8**	**13.1**	**14.4**	**17.4**	**21**	**22**	**22.5**	**22**	**19.4**	**17.4**	**15.1**
	Mx	15.8	15.5	16.5	18.4	20.9	24.4	26.2	26.9	26.1	23.9	21.7	18.2
Cartagena	Mn	14.1	13.3	13	14.8	16.5	19.1	22.7	24.4	21.8	19.3	16.3	14.9
	Av	**15**	**14.4**	**14.8**	**16.6**	**18.7**	**21.8**	**24.5**	**25.7**	**24**	**21.6**	**19**	**16.6**
	Mx	20.1	18.3	18.6	20.3	24	26.9	29.5	29.5	28.8	28.2	25.2	21.8
Tyre	Mn	17.2	17	16.8	16.9	19.1	23.2	25.8	27.7	27.4	24.1	20.2	18.6
	Av	**18.7**	**17.7**	**17.7**	**18.6**	**21.6**	**25.1**	**27.7**	**28.6**	**28.1**	**26.2**	**22.7**	**20.2**
	Mx	20	18.1	18.4	20.3	23.6	27	29.1	29.7	29.1	28.2	24.9	21.5
Tripoli	Mn	17	16.9	16.6	16.5	19	23.1	25.9	27.3	27	24.3	20.3	18.3
	Av	**18.5**	**17.5**	**17.5**	**18.4**	**21.3**	**25.1**	**27.5**	**28.5**	**28.1**	**26.3**	**22.6**	**19.9**
	Mx	19.7	18.2	18.2	19.3	22.6	25.7	28.2	28.3	28	27.2	24.3	21.8
Alexandria	Mn	16.8	16.5	16.6	17	18.7	22.1	24.4	26.5	26.1	23.5	20.3	18.4
	Av	**18.3**	**17.4**	**17.4**	**18.2**	**20.7**	**23.9**	**26.3**	**27.4**	**27.1**	**25.4**	**22.3**	**20.1**
	Mx	16.5	15.5	16	17.3	20.4	25.5	26.3	27.3	26.5	24.4	23.1	19.1
Carthage	Mn	14.3	13.6	13.4	14.1	16	19.1	22.7	24.4	23.3	21.1	17.8	15.7
	Av	**15.4**	**14.6**	**14.7**	**15.7**	**18.2**	**22.3**	**24.5**	**25.9**	**24.9**	**22.8**	**20.5**	**17.4**

le 7.3 Present day seawater temperatures at various locations around the Mediterranean, sc

World Water Temperature & (seatemperature.org) 1/2/2022

Table 7.4 Summary of the evidence relating to the environment, seafaring, navigation and risk

Seafaring in the ancient Mediterranean			
Section 2.2	Navigation and seafaring in the Bronze Age	Homer Od 5.250-255 Homer Od 5.270-280	Comparison between the two translations highlights how the use of a less authorative version can lead to errors in establishing the nature of seafaring the the Bronze Age and possibly the Archaic. A passage describing how an easterly course could be steered using the Great Bear as a marker for north.
Section 2.2	Phoenician contribution to navigation by astronomical means	Pliny *Natural History VII*	Use of less than authorative translations, used without regard to the context in which Pliny presents them, may have resulted in inaccurate estimations of the role of the Phoenicians in establishing a viable means of astronomical navigation.
Section 5.1.2	Speed of vessels in ancient Mediterranean	Pliny Natural History IXX. 3-4 Coates (1987, Fig 2) Severin (1985) Katzev (1987) and Cariolou (1997)	This passage provides times for downwind voyages from Rome to Egypt and form the basis of estimates of vessel speeds under optimum conditions Estimates of the continuous speed possible for a range of single and multi bank galleys Accounts of speeds achieved in the Argo a reconstruction 20 oared vessel and the difficulty in making reliable progress in adverse winds Records of speeds achieved on the voyates of the Kyrenia ship
Section 7.1	Cape Maleae and portage at Corinth	Strabo VIII. 6.210 Pliny IV. 10 Homer Od 3.285-300; 4.515-520;9.80-85 Jansen (2002)	All of these ancient sources provides passages that describe the dangers of navigating around the southern Peloponnese and the attraction of making a passage overland at Corinth Discusses the presence of a Mycenaean road system in the north east Peloponnese, Cunliffe (2011, Fig 7.17) shows the layout of these
Accounts of ancient voyages and reconstruction vessels			
Section 4.3.2	Sailing performance of Athenian grain ships	*Dem. Orations 50.20-22*	Demosthenese records two instances in which triremes were required to tow grain ships due to adverse weather conditions. Suggest poor sailing characteristics of the vessels of the time, and the limitations of oarsmen to pull high loads for long periods
Section 5.2.1 Sections 7.0 & 7.2	Kyrenia ship	(Katzev, 1987). Carilou (1997)	Records that a crew of 4 were required to handle the ship at sea. There is no suggestion that in this 16 metre vessel the rigging of this was enhanced by lifting equipment of any kind. Both record the impact of gear failures on the voyages and imply the dependency of the Kyrenia ship on having a safety vessel to tow it when required. Records the safety equipment carried on the vessel. He comments on the difficulties experienced in attempting to tack the vessel in anything other than a gentle breeze. Carilou goes onto state that he doubts the ability of vessels such as the Kyrenia ship to make direct east to west passages in the eastern Mediterranean. Carilou also describes the physical conditions of the crew as being, wet. cold, without sleep, and exposed to the elements.
Section 5.2.1	Bremen Cog	Hoffman and Hoffman (2009)	The authors record that various reconstructions of this vessel varied from 22.5 to 24 metres in length, and capacities from 75 to 120 tons. The vessel required a winch to raise and lower the sail, and was equipped with compound pulleys to reduce the loads on the crew.These fittings might then be seen as essential to the use of vessels of this size, and the date of their introduction key to the introduction of large vessels.The observation by Wilson that evidence of winches only appears in construction activity from the 6th century BC suggests that large vessels requiring these might only have entered use following this time.
Section 7.2	The Argo	Severin (1985, pp80-82)	Discusses the difficulty in rowing a 20 oared vessel against a headwind. Observes that, 'The only safe way to sail a Bronze Age ship is to wait until the weather turns fair.' Overall the evidence for the voyage suggests the difficulty in using vessels of this kind for any form of seafaring other than coastal voyages.
Section 5.1.2	Venentian great galleys	Casson (2004, pp123-124)	Casson provides information on the size of Venetian great galleys and the numbers of oarsment required. There is broad agreement in this that the upper load limit on oarsmen for a working shift may have been around 1.5 tons per oarsman.
Enviornmental conditions			
section 7.1	Late Bronze Age sea water temperatures	Goudeau et a l2014) Drake (2012)	Provides evidence from a number of sources that seawatter temperatures were up to 5 degrees cooler in the LBA/ IA transition compared to those of today.
Section 7.1	Extent of offshore and onshore breezes	Morton (2001_	Discusses how these might have a range of up to 25 km offshore before their effects fade and are overtaken by the pattern of regional winds. This pattern of winds may have provided the means for vessels limited to downwind courses to make progress under sail along the north coast of the Mediterranean by a series of short offshore and onshore courses that brought the vessel back to the beach each night.
Section 7.1	Prevaling current in NE Mediterranean	The *Sailing Directions en-route eastern Mediterranean* ,	Discuss how along the Anatolian coast this current runs to the west and is stronger close to the shore. In conjunction with the pattern of offshore and onshore breezes this current would assist with vessels making at east to west voyage by short, daily, coastal passages.
Section 7.1	Use of trade winds	Adams (1904, p19)	Discusses the importance of trade winds in providing downwind routes for sailing ships in the period in which this vessel type dominated internationa trade to the end of the 19th century.The lack of these in the Mediterranean is clear from the pattern of winds shown in Map xxx (Pryor, xxxxxx)
Section 7.2	Impact of Hypothermia	http://www.maritime-forum.jp/Guidelines for Control Hypothermia at Sea	Discusses the conditions for the onset of various forms of hypothermia, the symptons and mitigations.
Risk			
Section 3.1 & 3.2	Social influences on risk in seafaring	McGrail (1989) Unger (1994, p7)	Comments on how in the Bronze Age a ships master was probably fully aware of risk in seafaring and that safety probably influenced his activities. Discusses how in conservative societies risk might be a dominant factor influencing change in seafaring practices and the methods of ship construction.
Section 7.2	Ship stability	Steel (1794)	Describes how a ship should be loaded to maintain optimum stability at sea, and how this might differ from one intended to operate in calm waters. This is in the form of an instruction to officers and suggest the lesson still needed to be reinforced in the 18th century. Interesting to cross reference to Cariolou (1997, p92) and Pulak (2012, p12). regarding the motion of the Kyrenia ship and the loading of the Uluburun vessel.

Figures

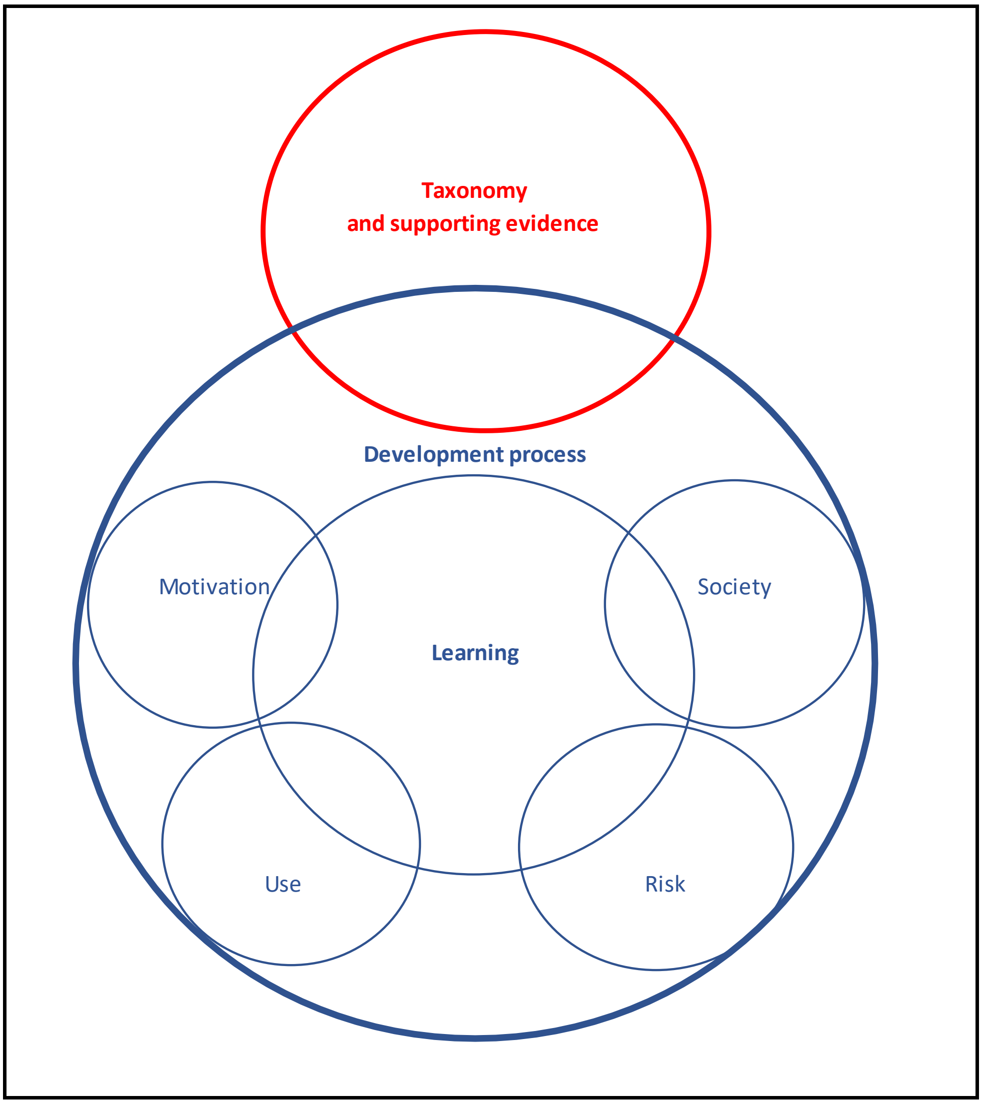


Figure 1.1 A suggested schematic representation of the major factors impacting on maritime technical development.

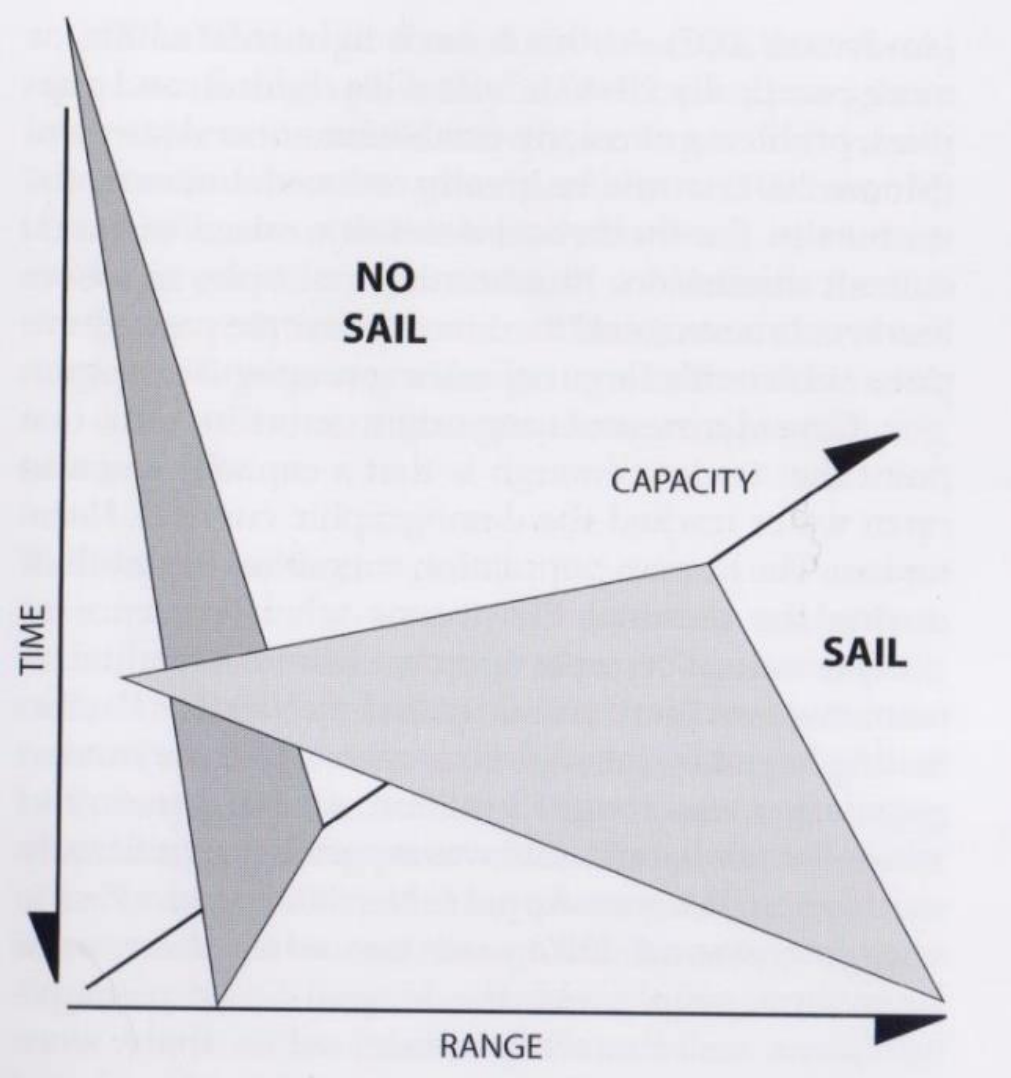


Figure 2.1 Showing Anderson's model of seafaring compared to propulsion, source Anderson, 2010, fig 1.1

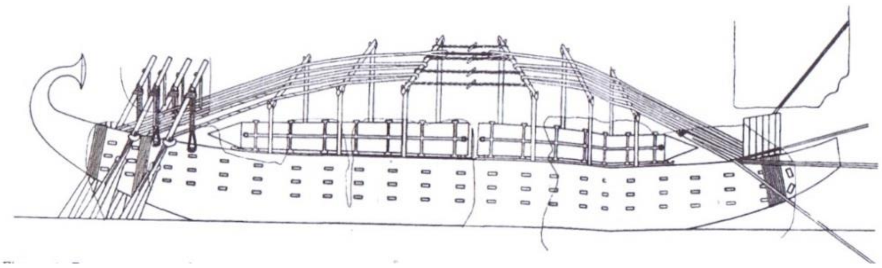


Figure 2.2 Reconstruction of an obelisk barge from the wall of Hatshepsut's temple at Deir el-Bahri c 1500 BC, source McGrail, 2004, fig 14

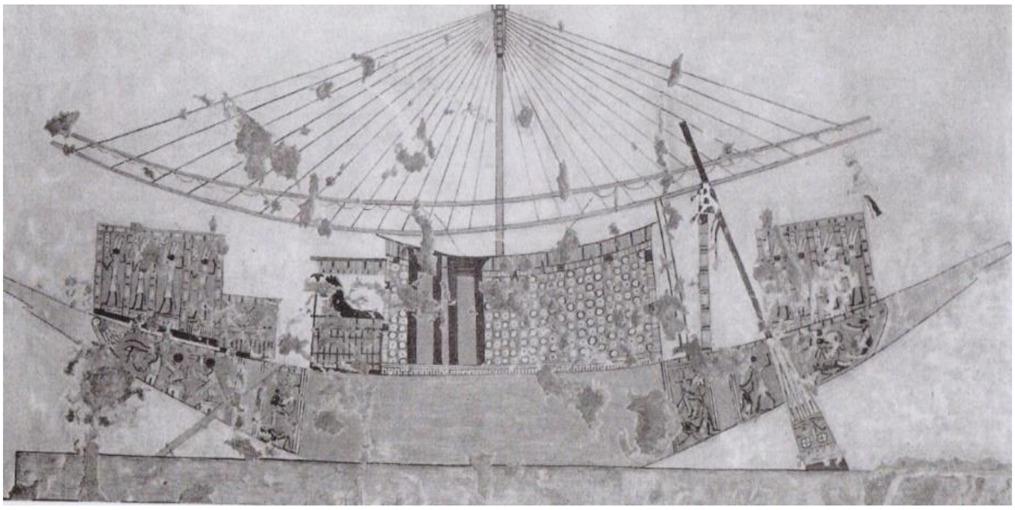


Figure 2.3 Egyptian vessel c.1350 BC from a wall painting from the tomb of Huy labelled as a sailing craft with a broad sail, source Casson, 1971, Fig 16

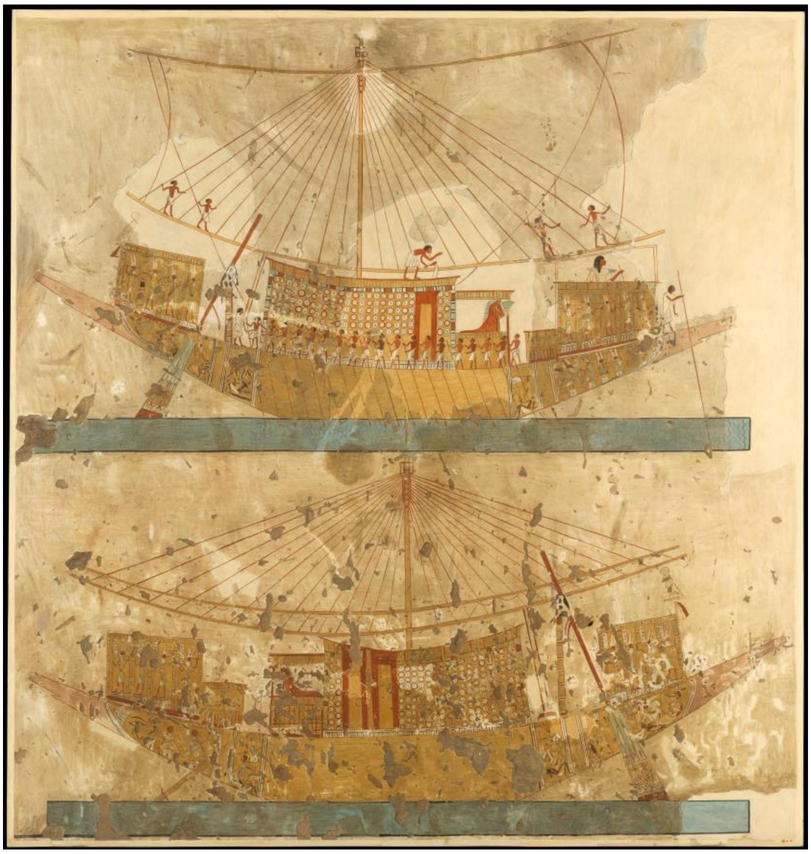


Figure 2.4 Facsimile of a wall painting by Wilkinson of the Viceroy's boat from the 18th Dynasty tomb of Huy, source https://www.metmuseum.org, accessed. 1/3/21

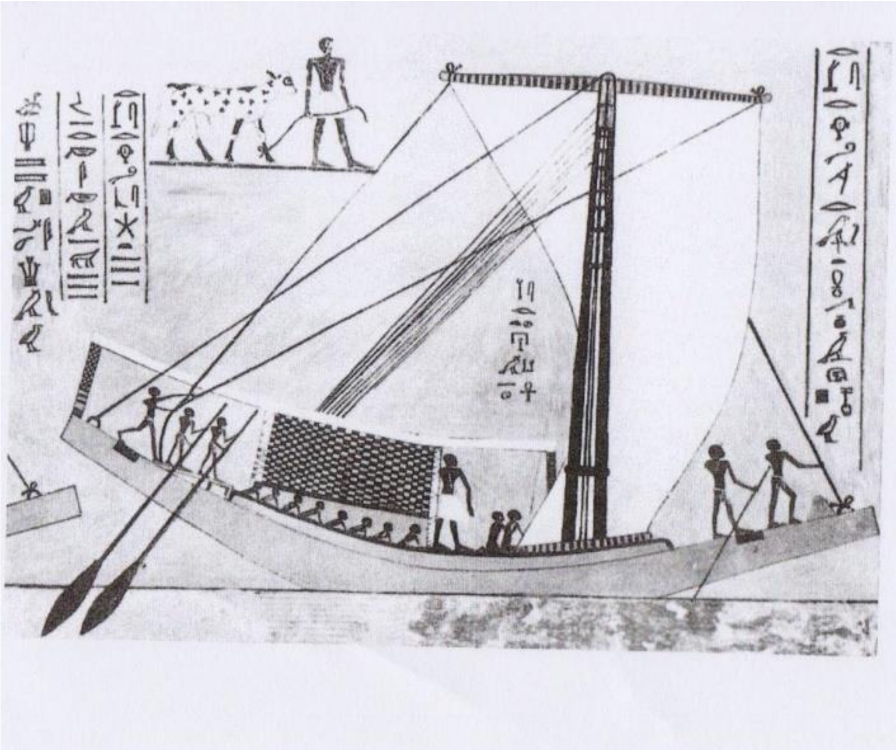


Figure 2.5 Vessel described as a sailing ship on a relief in the tomb of Kaem'onkh at Giza c.2400 – 2300 BC, source McGrail, 2004, Fig 2.15

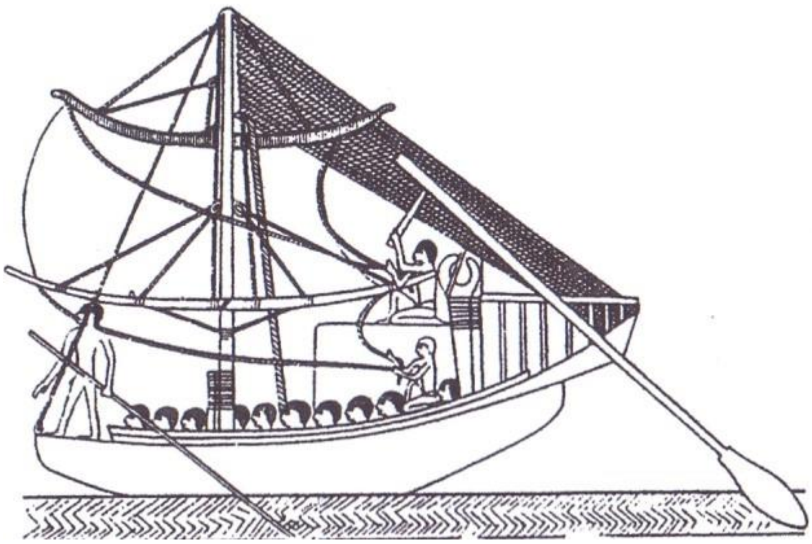


Figure 2.6 A relief from a third millennium BC tomb of Ipi at Saqqara, source McGrail, 2004, Fig 2.18

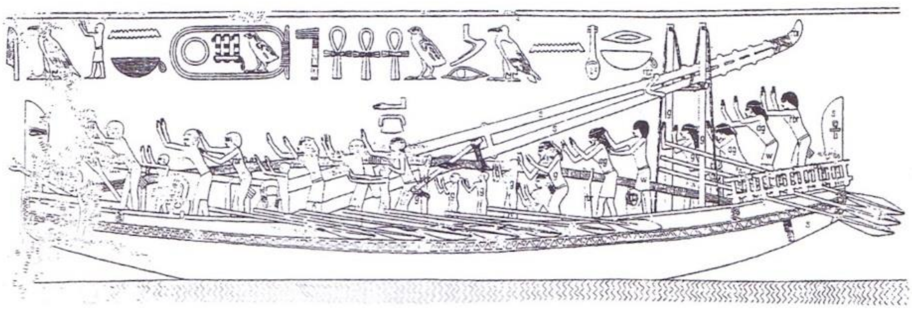


Figure 2.7 Early seagoing vessel from the Fifth dynasty tomb of Sahure at Abusir, source McGrail, 2004, fig 2.3.

Figure 2.8 A Roman vessel described by Friedman as a sailing ship, being used to transport beasts to Italy for use in the arena, from the fourth century AD Villa del Casale in Sicily, source Friedman, 2011, fig 3.8.21.

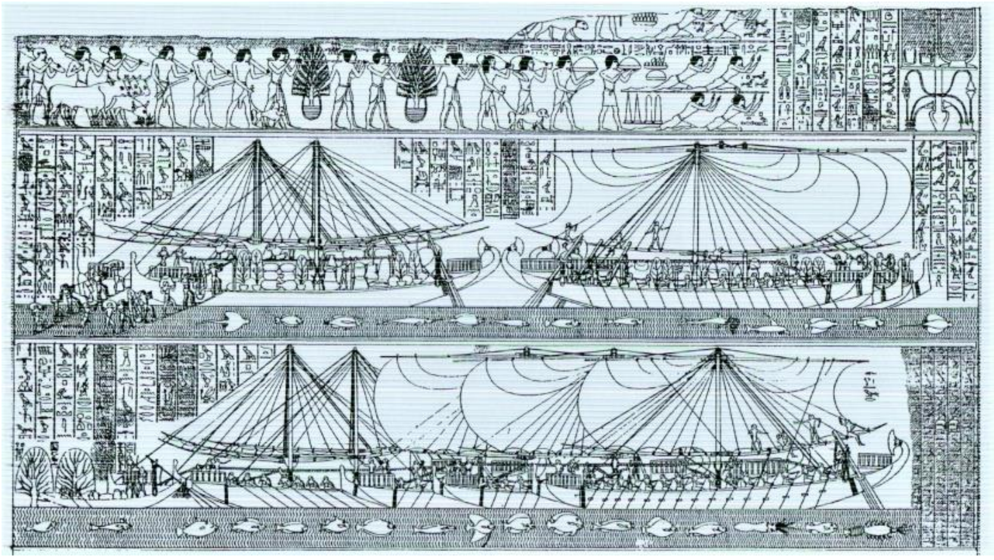


Figure 2.9 Hatshepsut's voyage to Punt from the temple at Deir el-Bahri, source Wachsmann, 2009, fig 2.11

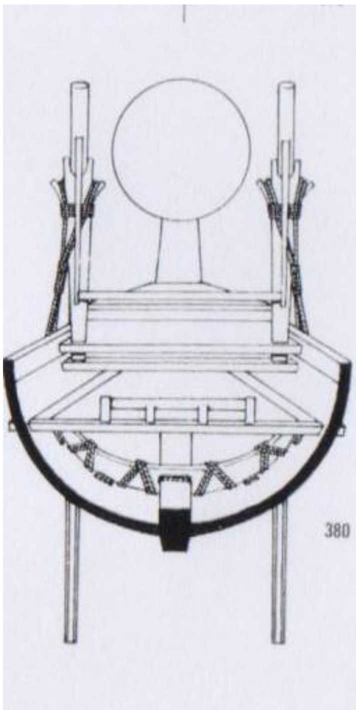


Figure 2.10 A proposed cross section and external keel on Hatshepsut's vessels used on the voyage to Punt, source Landstrom, 2022, figure 380

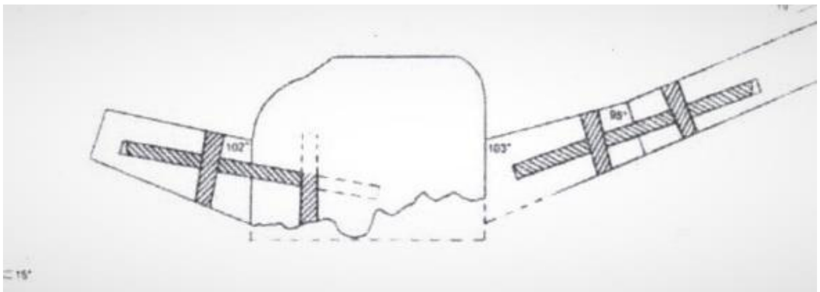


Figure 2.11a The Uluburun keel, source Pulak, 1999, fig 4

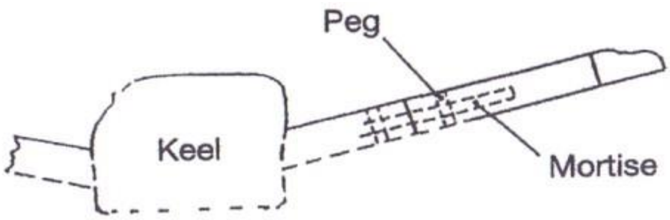


Figure 2.11b Showing the Uluburun keel, source McGrail 2004, fig 4.2

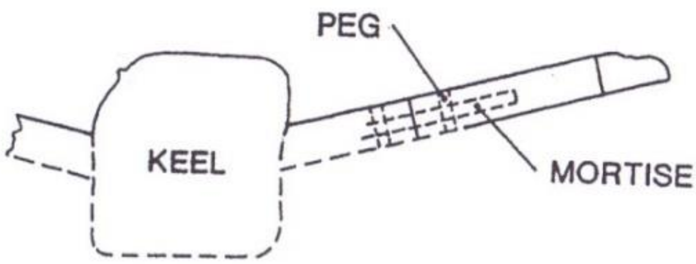


Figure 2.11c The Uluburun keel, source Steffy 2017, fig 3-15

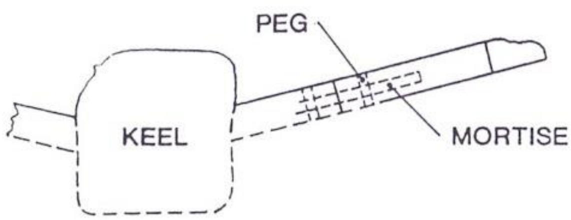


Figure 2.11d The Uluburun keel, source Wachsmann 2009, fig 10.2

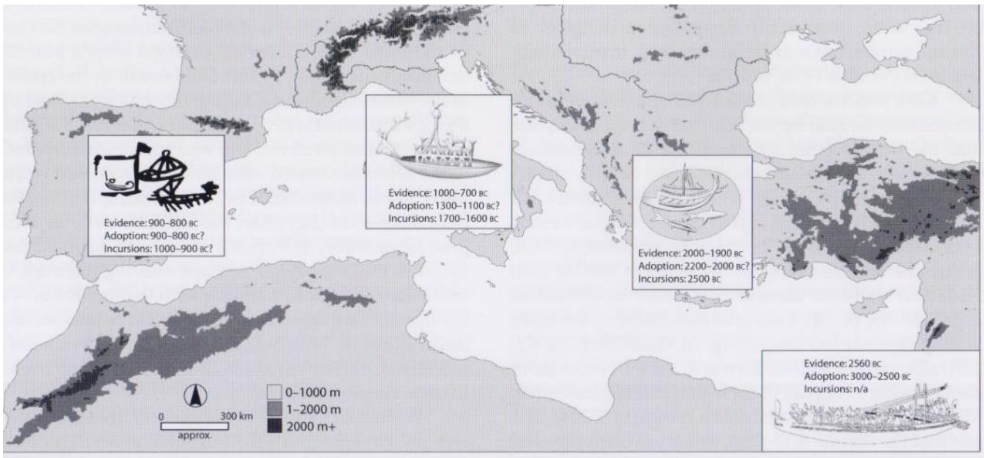


Figure 2.12 Showing vessel types noted by Broodbank to represent the adoption of sailing technology, source Broodbank, 2010, Figure 20.2

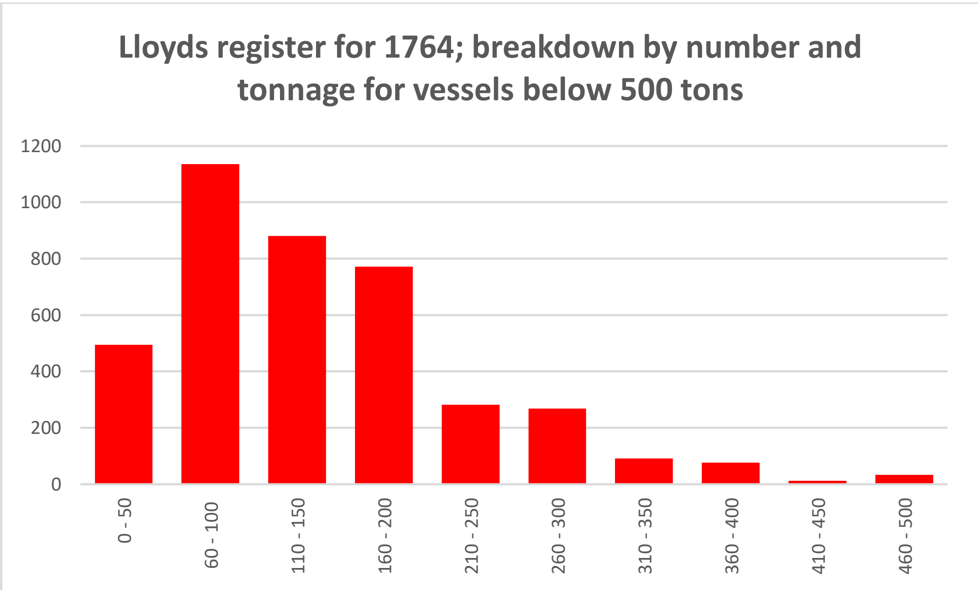


Figure 2.13 Showing data from Lloyds register 1764 of vessel numbers below 500 tons source https://hec.irfoundation.org.uk

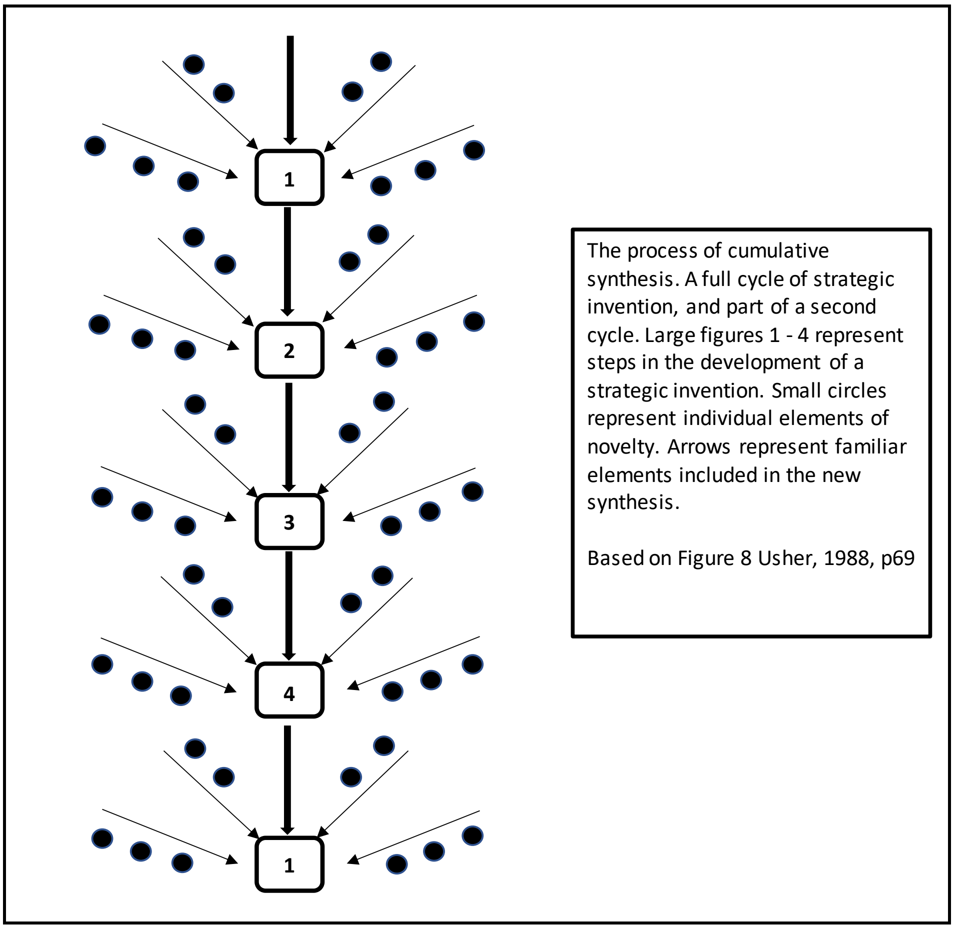


Figure 3.1 Schematic of the process of Cumulative Synthesis, source Usher, 1988, fig 8

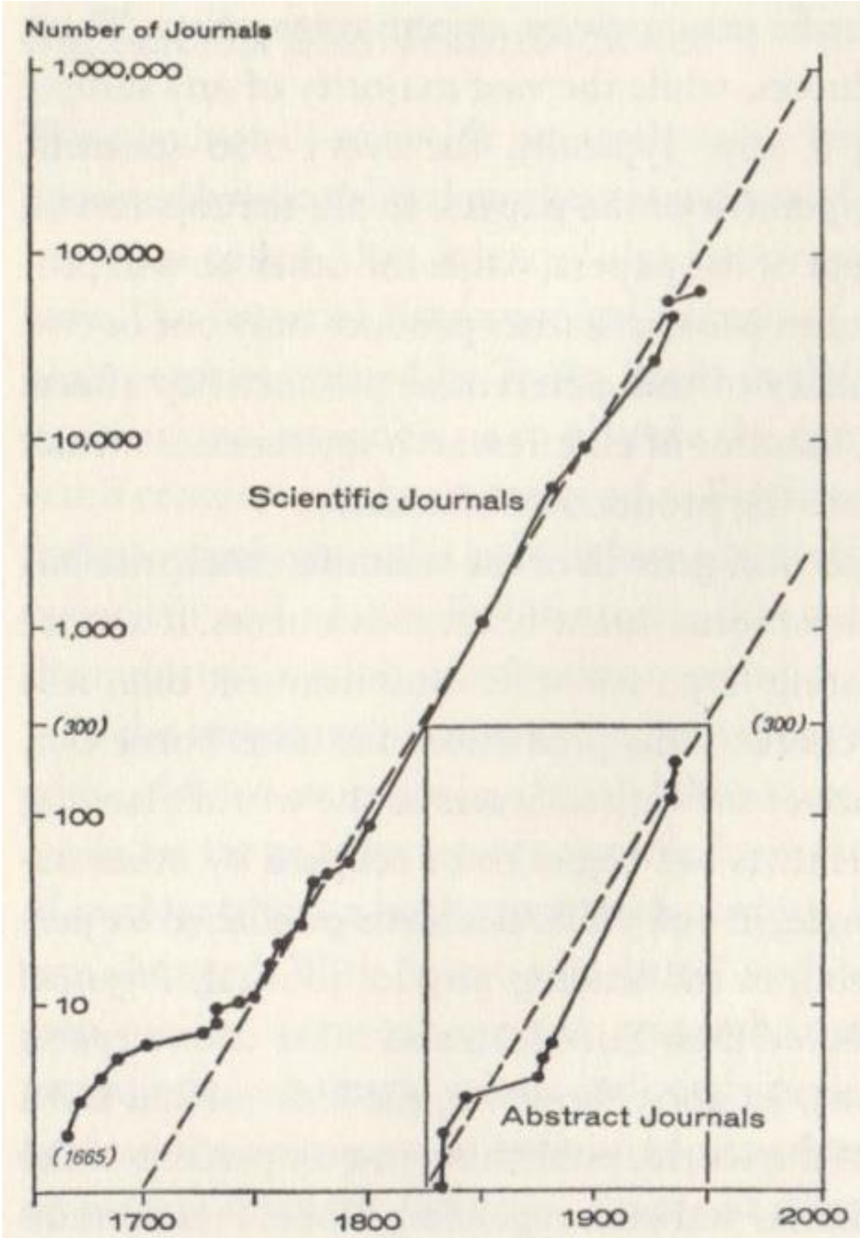


Figure 3.2 Showing the rate at which scientific papers are published in the 20th century, source McClellan and Dorn 2006, fig 20.5

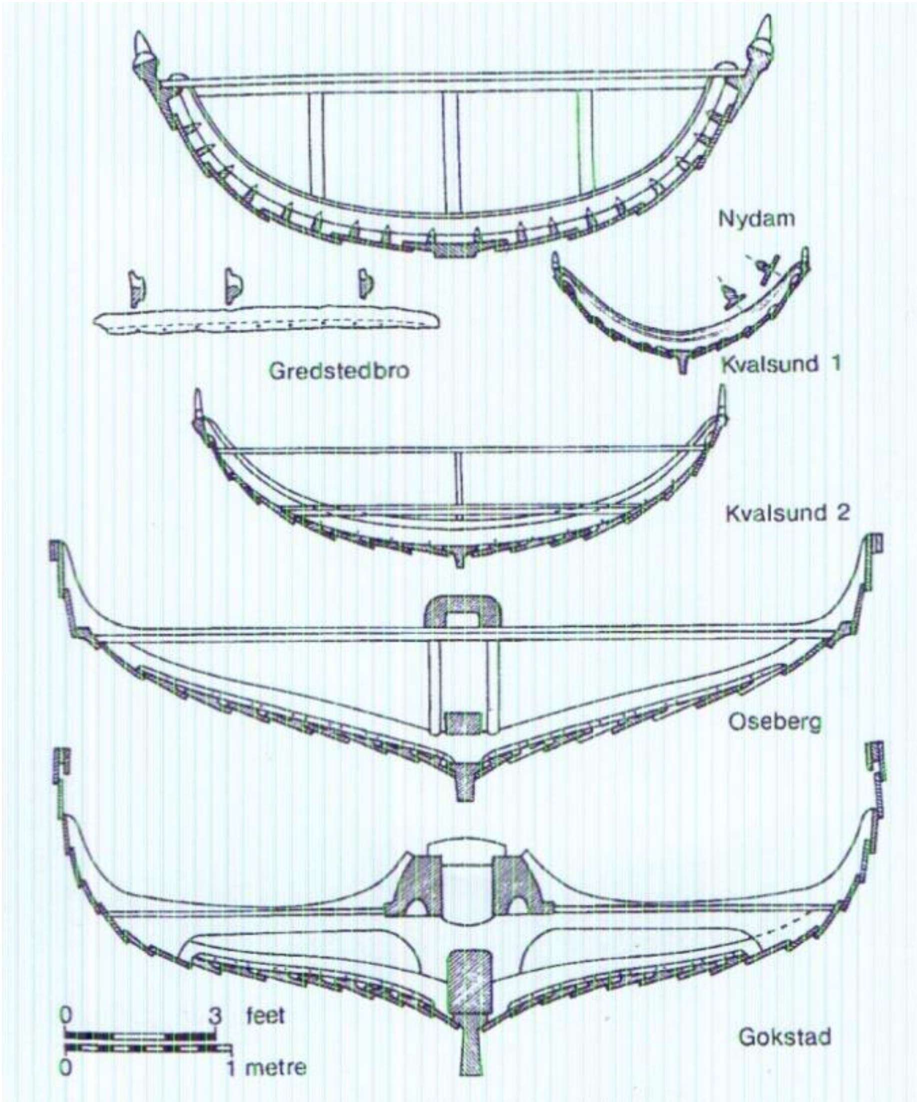


Figure 3.3 Development in hull shapes in Nordic shipbuilding fourth to nineth centuries AD, source McGrail 2004, fig 5.40

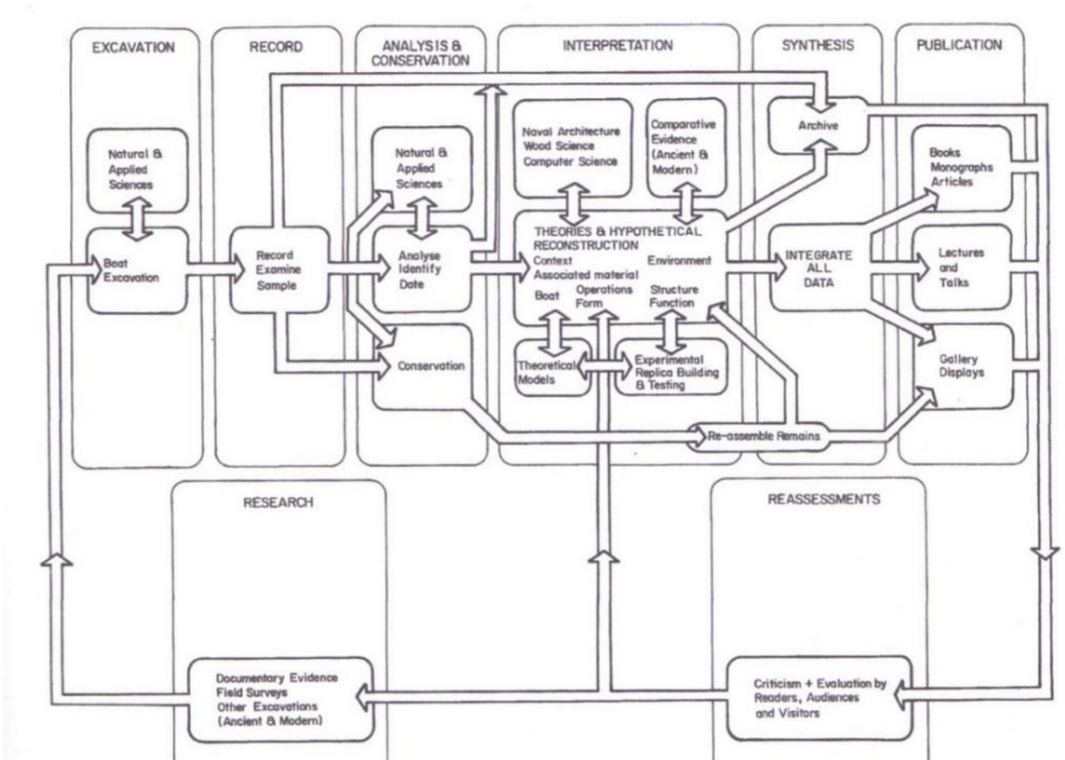


Fig. 1.2. Archaeological research (Institute of Archaeology, Oxford).

Figure 3.4 Flow chart of archaeological research project source McGrail, 2004, fig 1.2

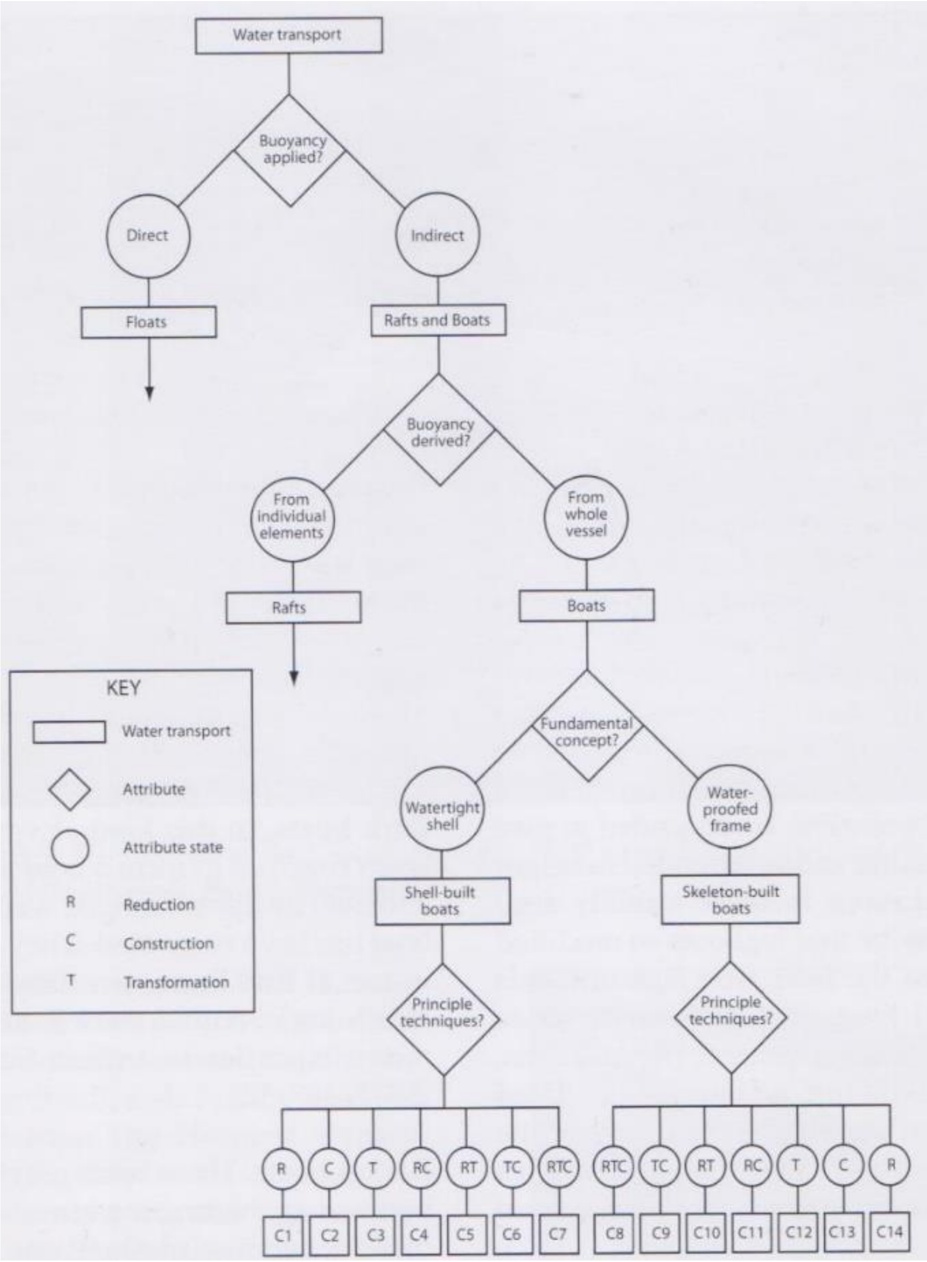


Figure 3.5 Showing a structural classification of water transport-mainly boats (Institute of Archaeology Oxford.) source McGrail, 2010, fig 8.3

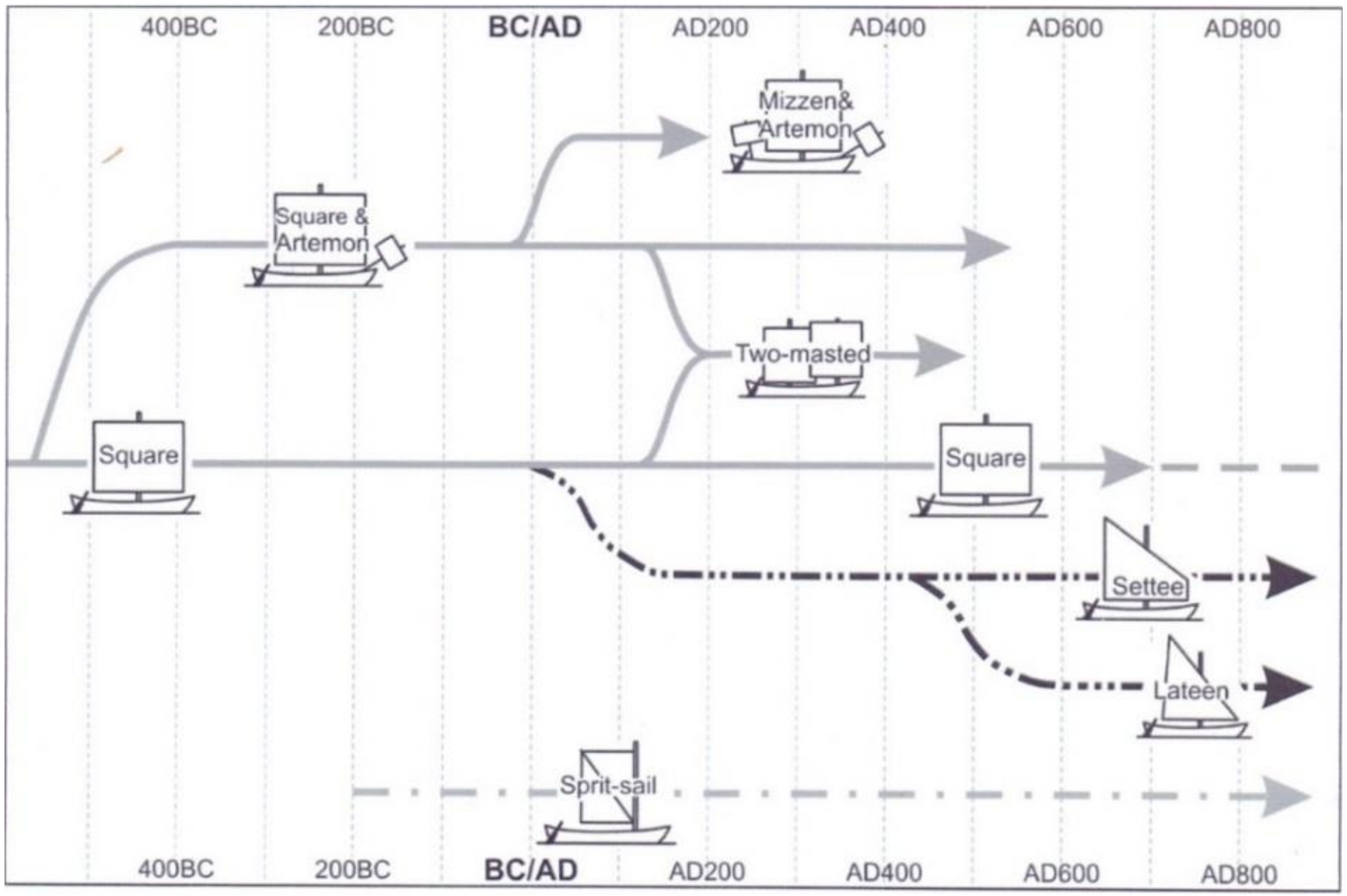


Figure 3.6 Showing proposed development of artemon sail, source Whitewright, 2017, fig 2

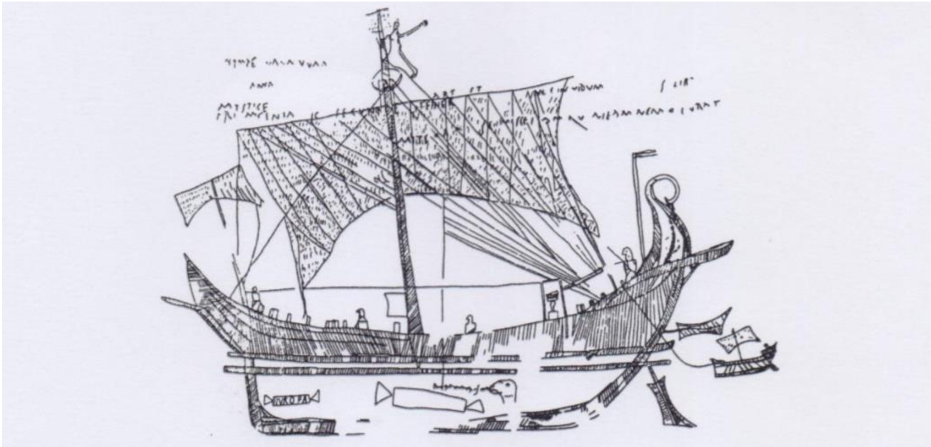
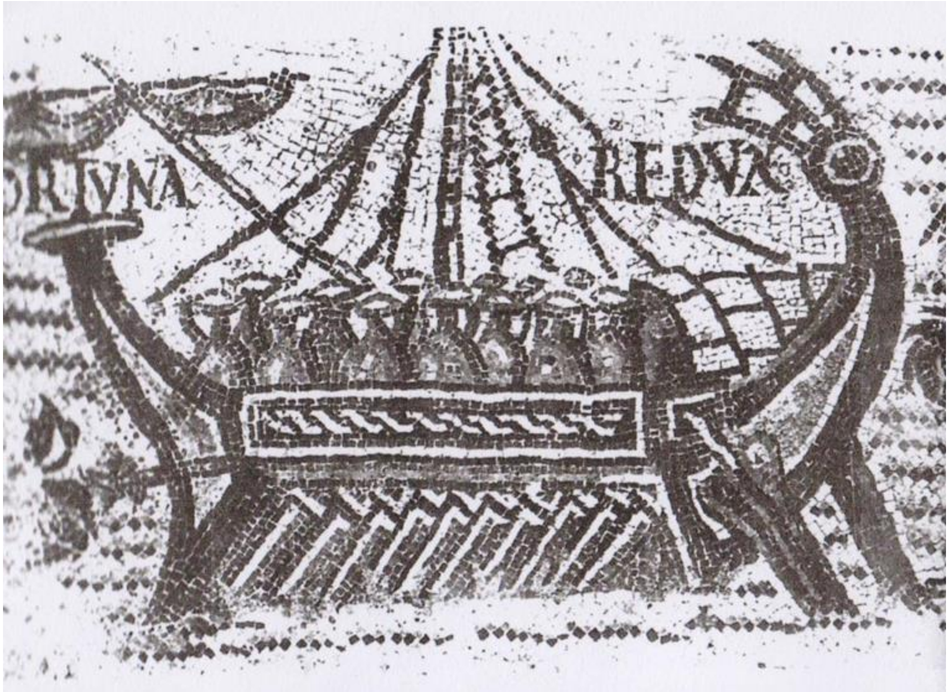


Figure 3.7 Graffiti from Pompeii of a large cargo vessel with an artemon sail, source Davey, 2015, fig 4.

Figure 3.8 Showing a scene with two vessels from the Piazzale della Corporazioni dated to second century AD, source Friedman, 2011, fig 3.7.20



140. Merchant galley loaded with amphorae, 2nd or 3rd A.D.

Figure 3.9 Merchant galley with artemon sail from second or third century AD, from a mosaic found at Tebessa, Algeria. Casson, 1971, Fig 140

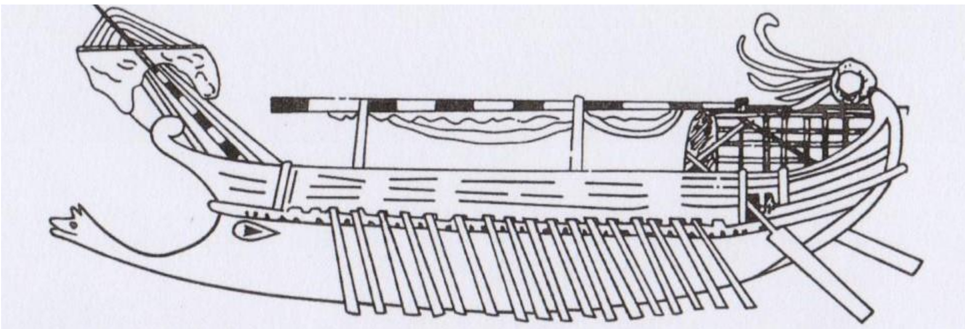


Figure 3.10 Roman oared ship from a mosaic at Themetra AD 225 – 250, source Morrison and Coates, 1986, fig 32.

Figure 4.1 A vessel of the eighteenth-century BC on a cylinder seal from Tell El Dab'a, source Porada 1984, Ill 1

Figure 4.2 Vessels on Early Minoan III (A-B) and Middle Minoan (C-K) seals, source Moortel 2015, Figs 2A and B, and 3A and B

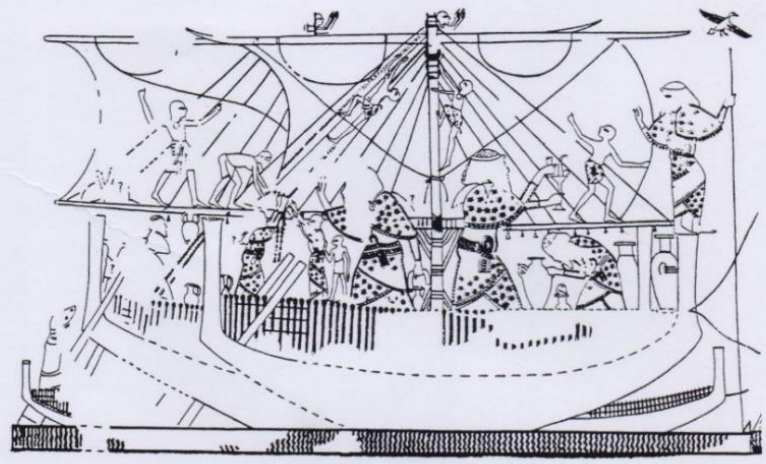


Figure 9. Syrian ship from the tomb of Kenamon, Thebes (from Davies and Faulkner 1947: 40–46, pl. 8).

Figure 4.3 Early fourteenth century BC vessel with a boom supported sail from the tomb of Kenamun, source Artzy, 1987, fig 9

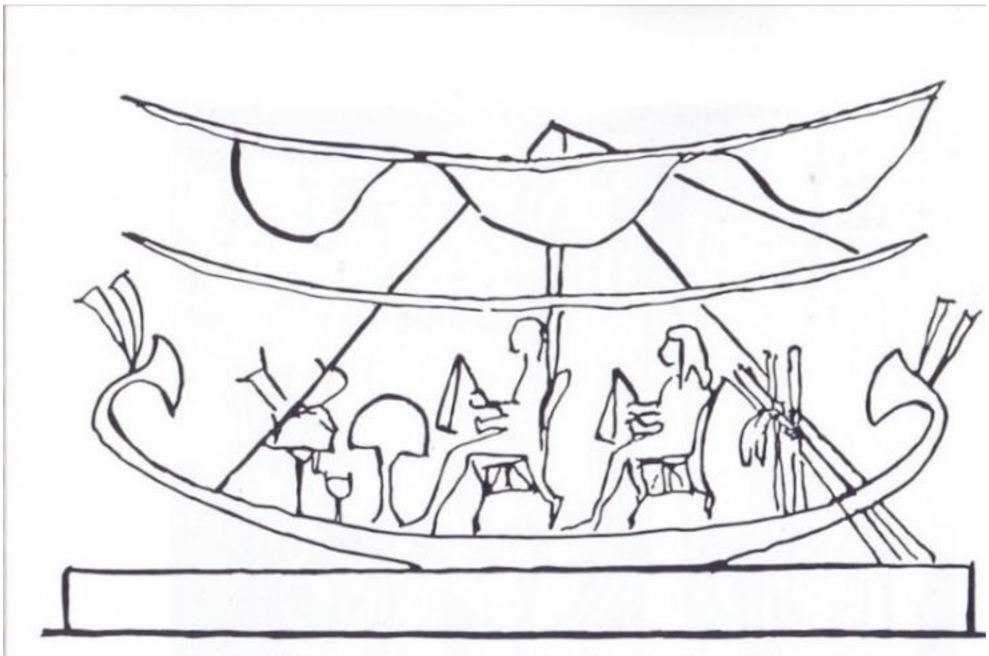


Figure 4.4 Drawing of a Syro-Canaanite ship in the tomb of Neferhotep showing possible early form of brailed sail, source Vinson (1993, fig 8

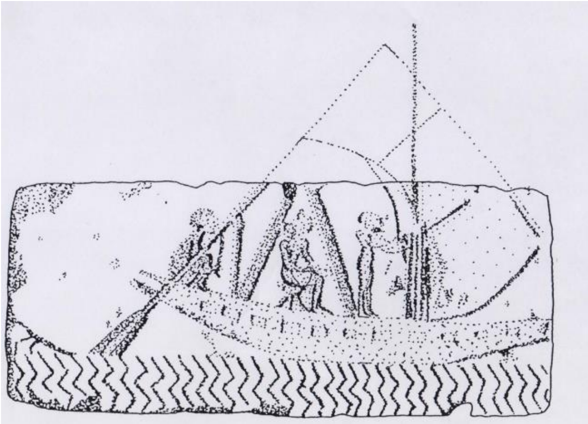


Figure 4.5 Showing a heavily reconstructed talatat from the 18th Dynasty from Hermopolis, collection of Stephane Cattoui, source Fabre, 2004, p118.

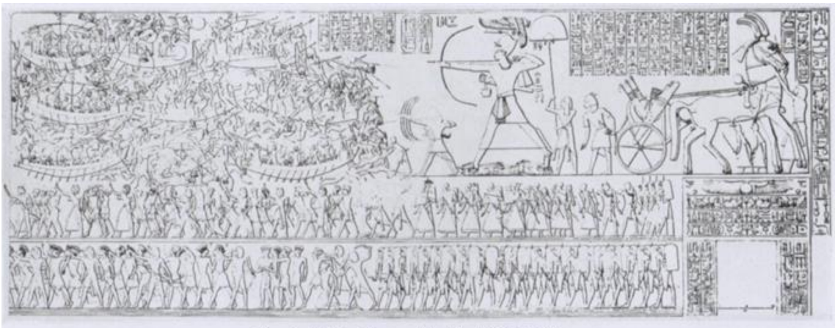


FIG. 1.—Relief of the naval battle at Medinet Habu

Figure 4.6a Showing the Battle of the Delta from the temple of Medinet Habu, source Nelson, 1943, fig 1

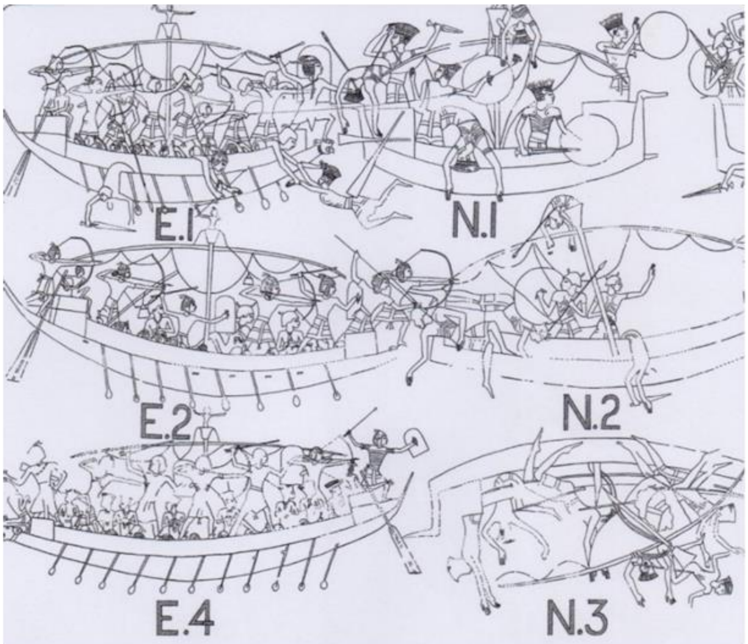


Figure 4.6b Showing detail of the vessels from the Battle of the Delta from the temple of Medinet Habu, source Nelson, 1943, fig 4.

Figure 4.7 Late Helladic depiction of the Kynos ship, source Dakoronia (1987, figs 1, 2 and 3)

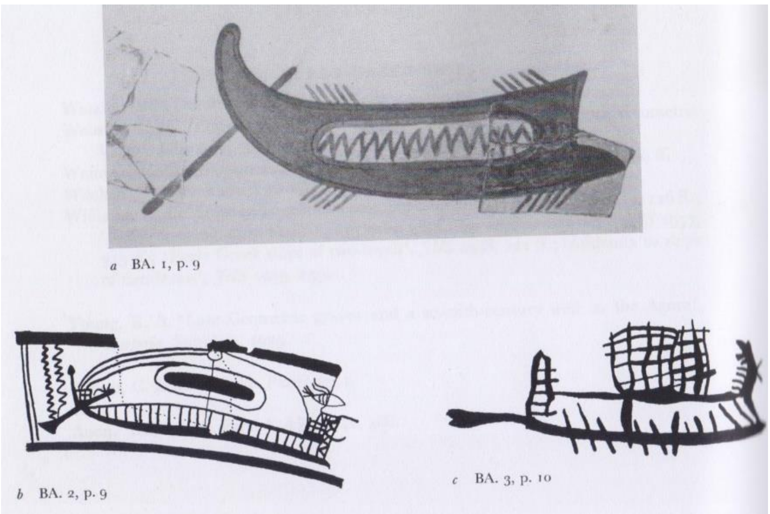


Figure 4.8 Representation of Mycenaean rowed vessel from a vase found in Volos from the Middle Helladic, Morrison and Williams, 2008, Figure BA.1,2 and 3

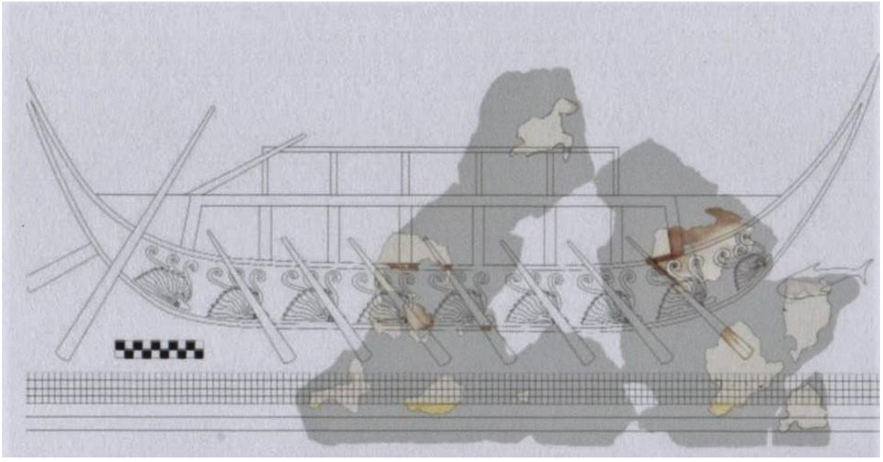


Figure 4.9 Vessel depicted in wall paintings from hall 64 Pylos, source Brecoulaki et al, 2015, fig 9

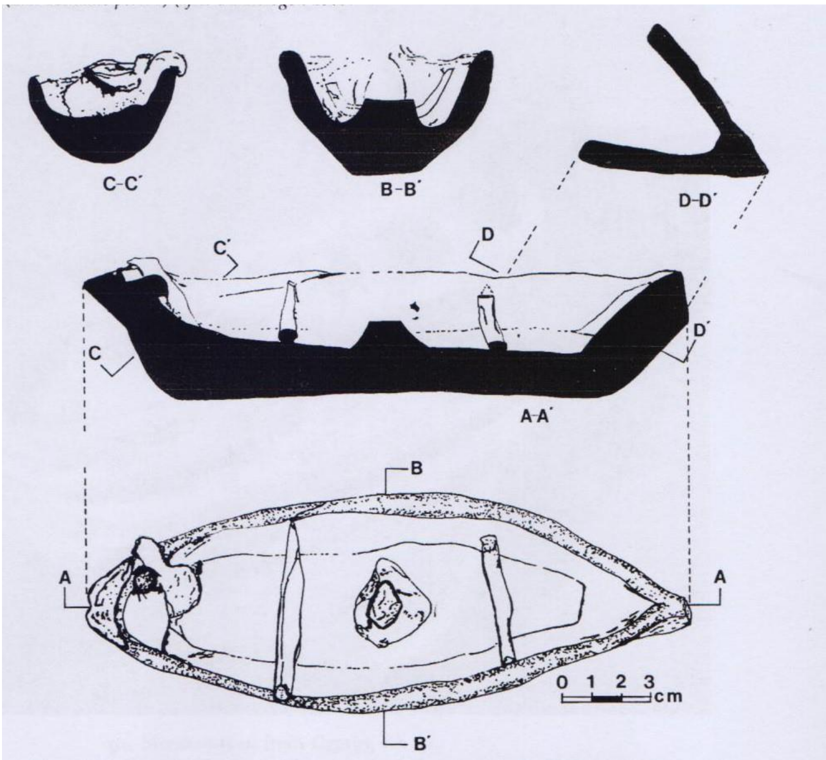


Figure 4.10 Terra-cotta ship model from Argos, late Helladic, Wachsmann, 2009, fig 7.54.

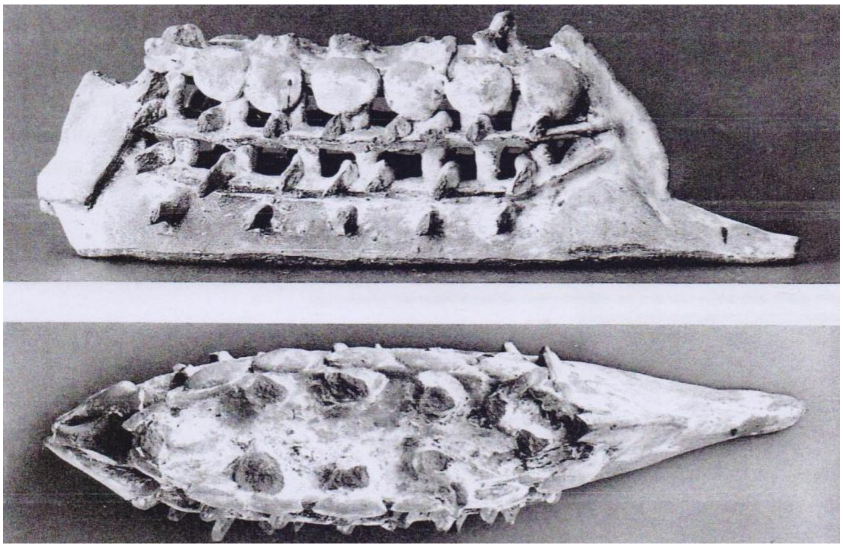


Figure 4.11 Vessel described as a Phoenician trireme of the 4^{th} to 3^{rd} century BC, Casson, 1971 figs 103 - 104

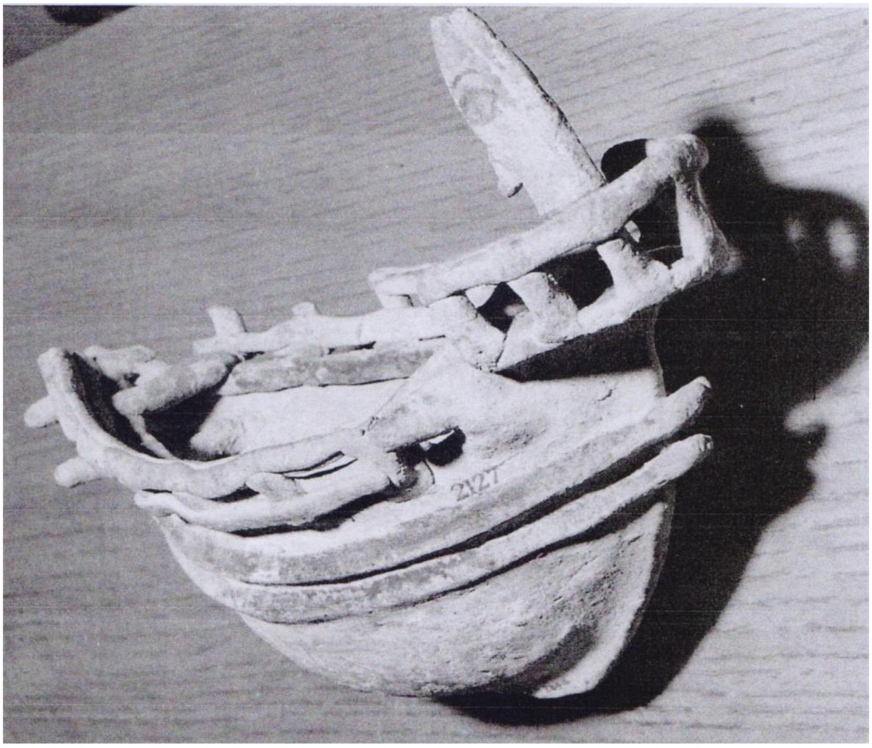


Figure 4.12 Vessel described as a merchantman from Cyprus from the 6^{th} century BC, Casson, 1971, fig 94

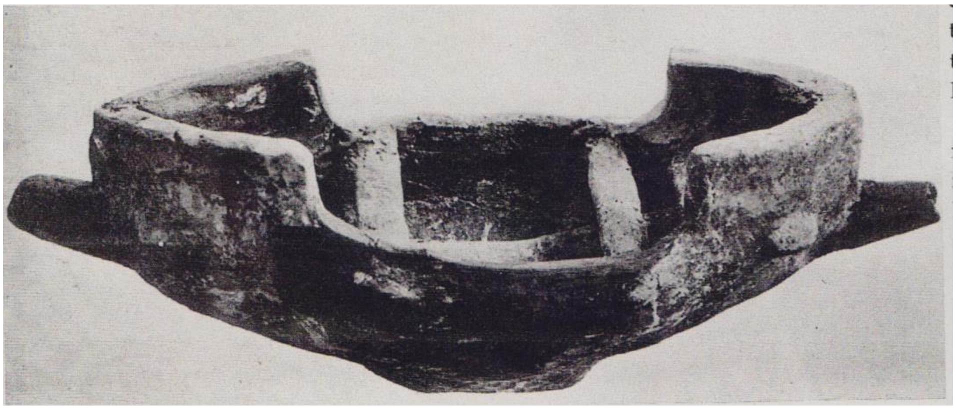


Figure 4.13 Terra-cotta ship model found in the excavations at Byblos. Wachsmann, 2009, fig 3.16

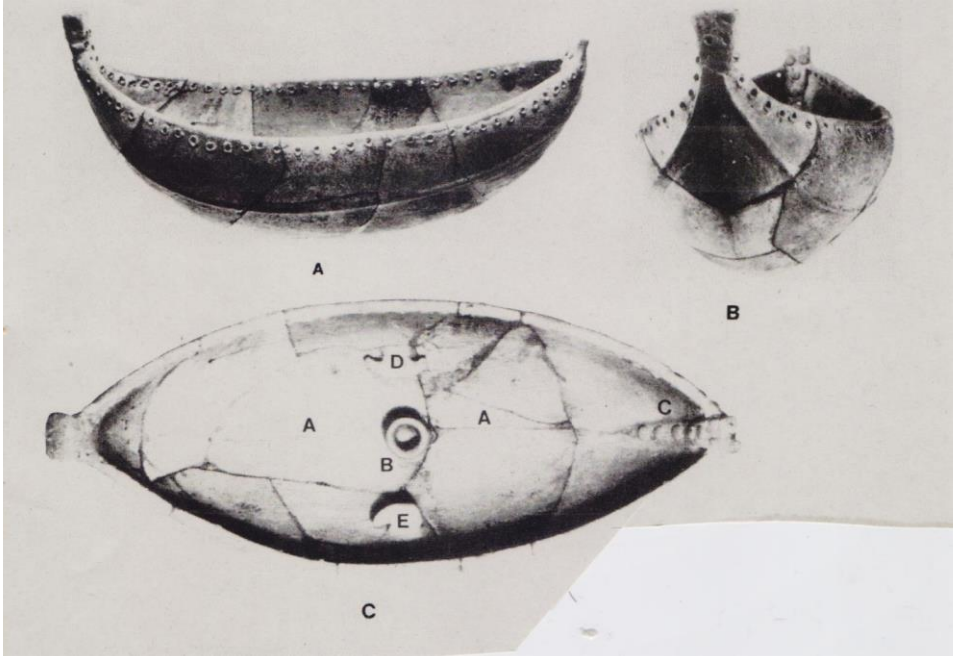


Figure 4.14 Terra-cotta ship model from Tomb 2B at Kazaphani Ayios Andrionikos (Late Cypriot 1-11). Wachsmann, 2009, fig4.5

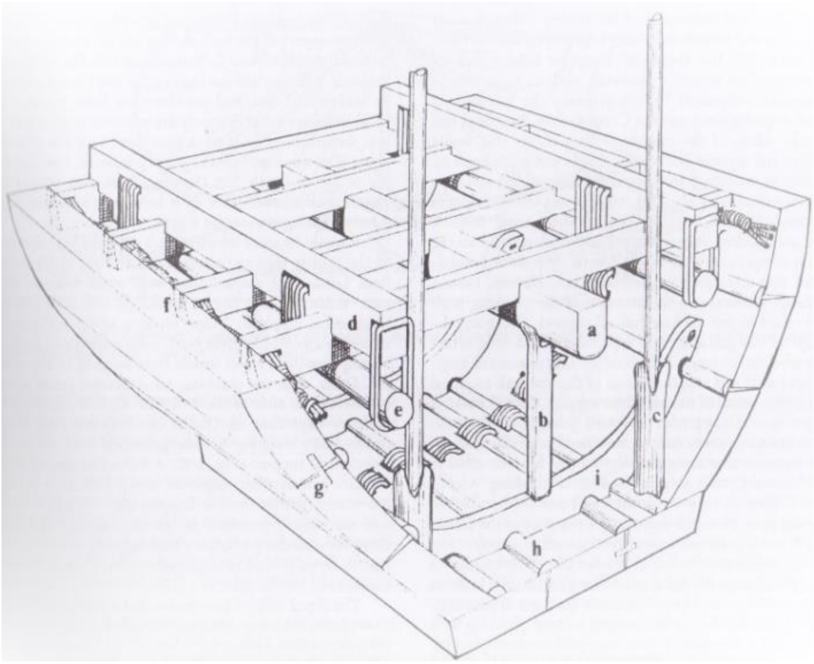


Figure 4.15 Detail of the midships hull construction of Cheop's barge. Lipke, 1984, Fig 11.

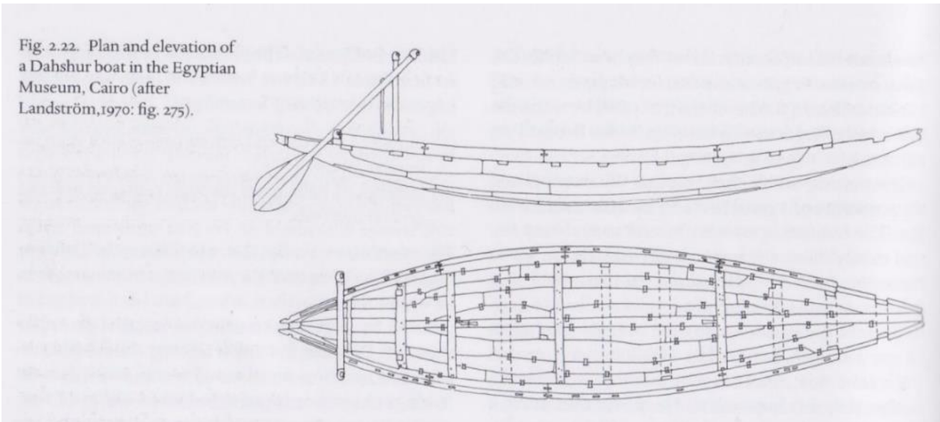


Figure 4.16 The keel and joints on the Dahshur boat. McGrail, 2004, Fig3.6.

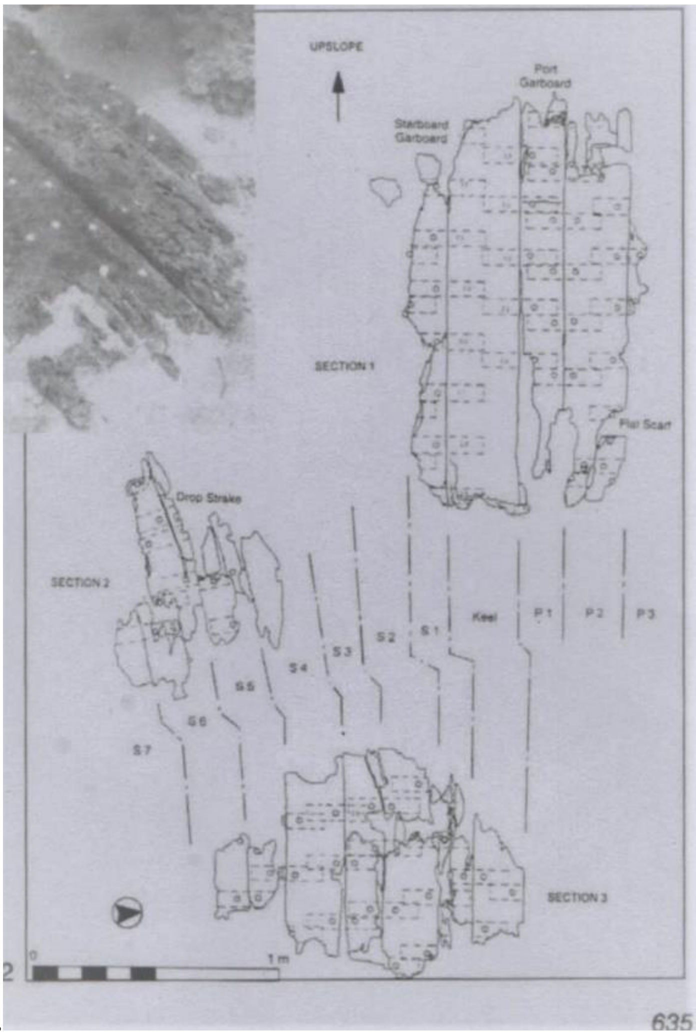


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Figure 4.17 The mortice and tenon joints in the Uluburun hull. Pulak, 1999, Fig2.

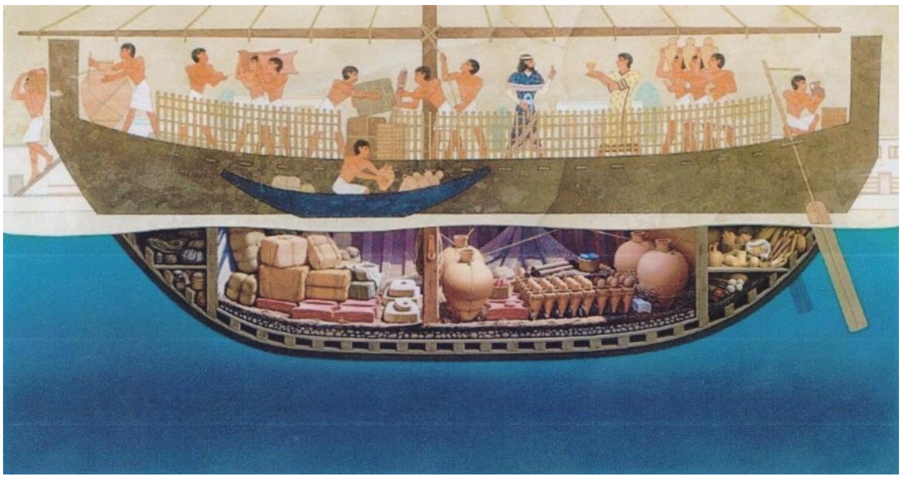

Figure 4.18 Hypothetical reconstruction of the Uluburun vessel, the lower hull is based on the archaeological remains of the ship, the upper hull is based on iconography from the Tomb of Kenamun. Wachsmann, 2019, fi 3.

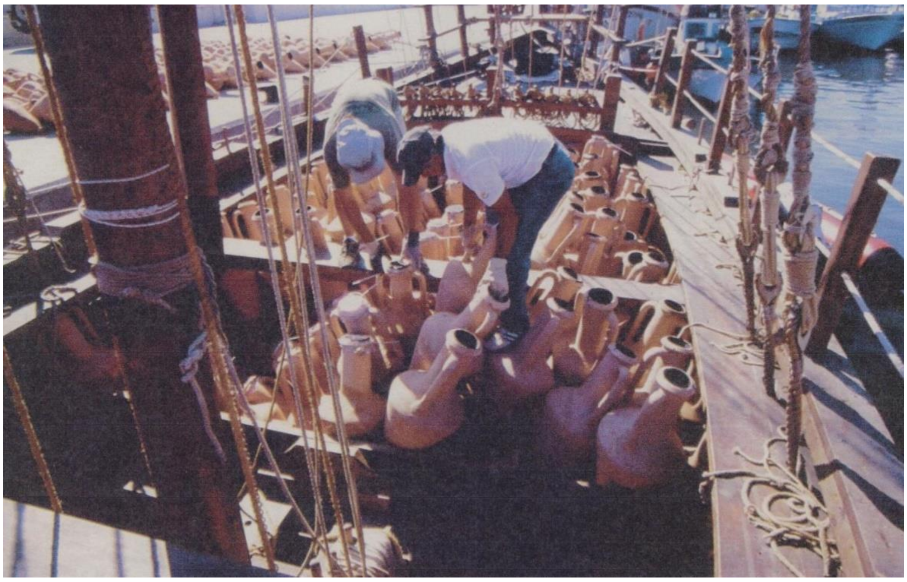

Figure 4.19 View of the open hold of the Kyrenia ship showing the walkways to allow for the crew to work the vessel. Katzev, 2008, 78.

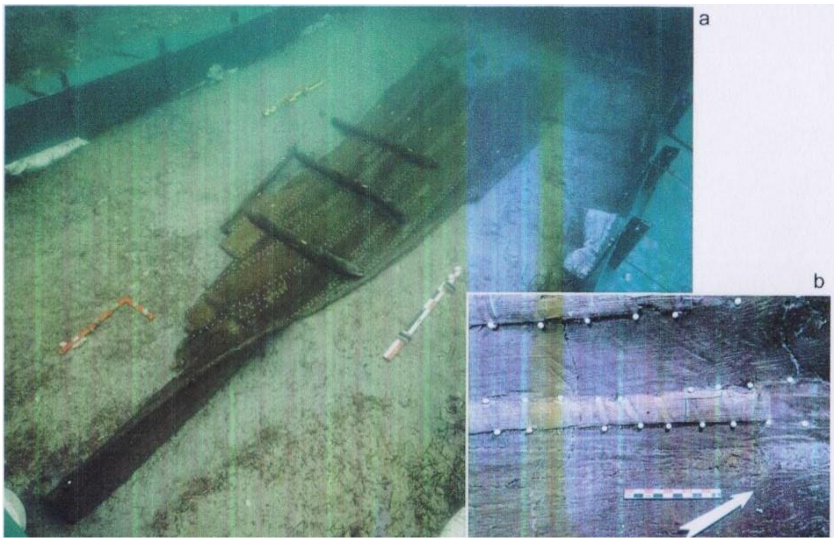

Figure 4.20 The hull remains of the Zambratija vessel. Pomey and Boetto, 2019 Fig 3.

Figure 4.21 Line drawing 2007 6024.352 from the British Museum, showing Phoenician warships and cargo ships taken from a relief in the palace of Sennacherib at Khorsabad by Sir A. H. Layard. drawing | British Museum 20/11/21.

Figure 4.22 Phoenician vessels towing timbers, depicted in the palace of Sargon II at Khorsabad, in the Louvre. McGrail, 2004, Fig 4.29.

Figure 4.23 Phoenician warship on a relief from Kuyundjik ca. 700 BC wall panel relief, Room 9, British Museum.w.1851-0902- wall panel; relief | British Museum 20/11/21

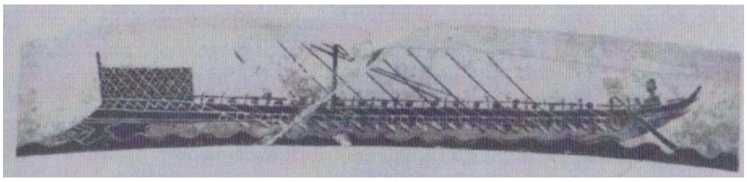

Figure 4.24a Galley from an Attic black Fig dinos by Exekias (550-530 BC) in the Villa Giulla Museum in Rome. Morrison and Williams, 2008, Arch 52, plate 13.

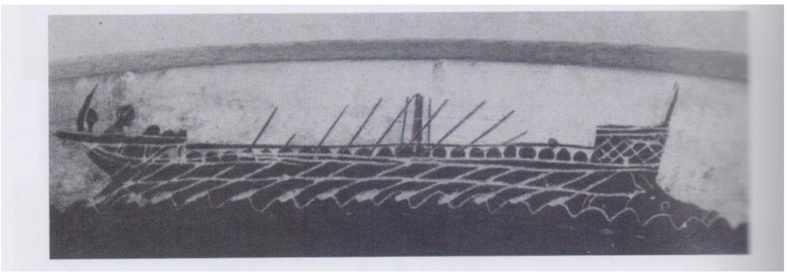

Figure 4.24b Galley from an Attic black Fig dinos (530-510 BC) in the Louvre Paris, source Morrison and Williams, 2008, Arch 67, plate 17c.

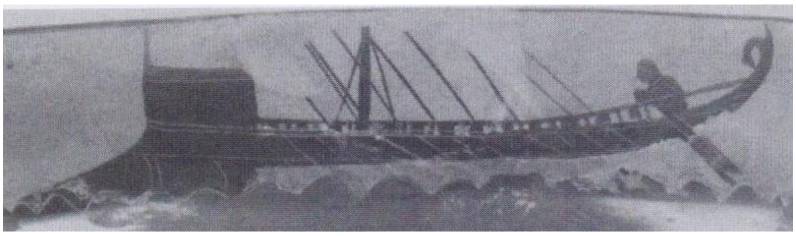

Figure 4.24c Galley from an Attic black Fig band cup (530-510 BC) in the Staatliche Museen, Berlin. Morrison and Williams, 2008, Arch 74, plate 17e.

Figure 4.24d Galley from an Attic red Fig stamnos by the Siren painter (510 BC) from the British Museum. Morrison and Williams, 2008, Arch 94, plate 21e.

Figure 4.25 Early representation of a sailing ship from an Athenian black Fig kylix (520-500 BC) from a tomb in Vulci Italy now in the British Museum. Black-Figd kylix showing merchant vessels, 520-500 BC, Athens - TAKEN DOWN - A BIT ORANGE? | The British Museum Images (bmimages.com) 20/11/21.

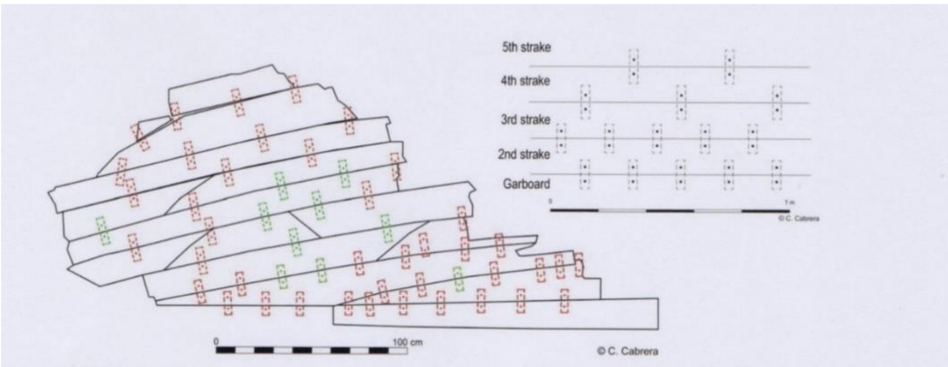

Figure 7. Reconstructed position of the mortise-and-tenon joints of the Mazarrón 1 hull: clearly documented (red) and hypothesized (green), frames are not represented for clarity (scale bar 1m, ©Author); inset: schematic reconstruction of the distribution of tenons: two zones with different arrangements could be identified (scale bar 1m, ©Author).

Figure 4.26 The short mortice and tenon joints used on the Mazarron 1 hull. Tejedor, 2018, Fig7.

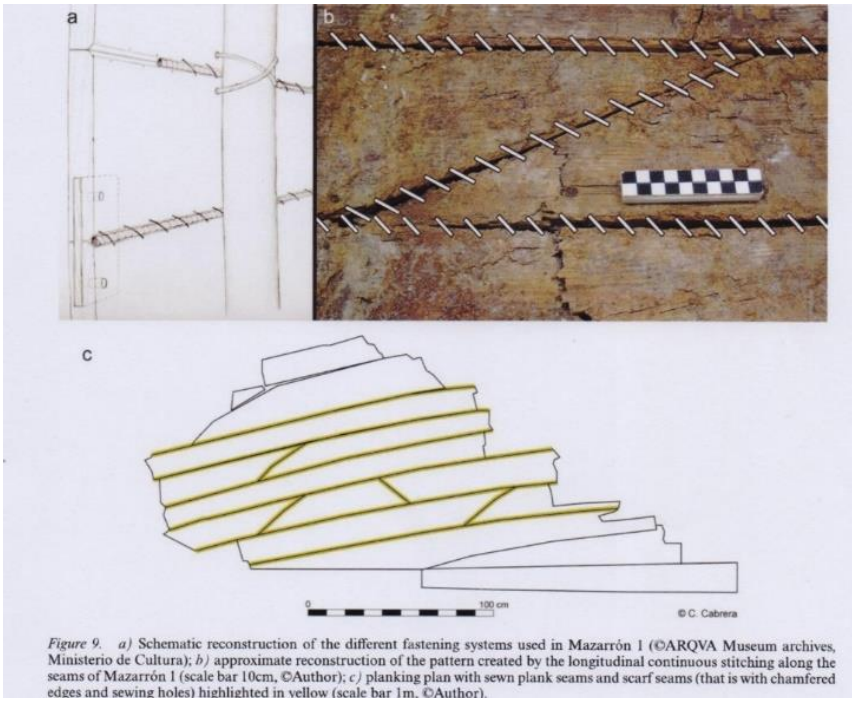

Figure 4.27 Stitching used on the Mazarron 1 hull. Tejedor, 2018, Fig 9.

Figure 4.28 Hull remains of the Mazarron 1 wreck. Tejedor, 2018, Fig 4

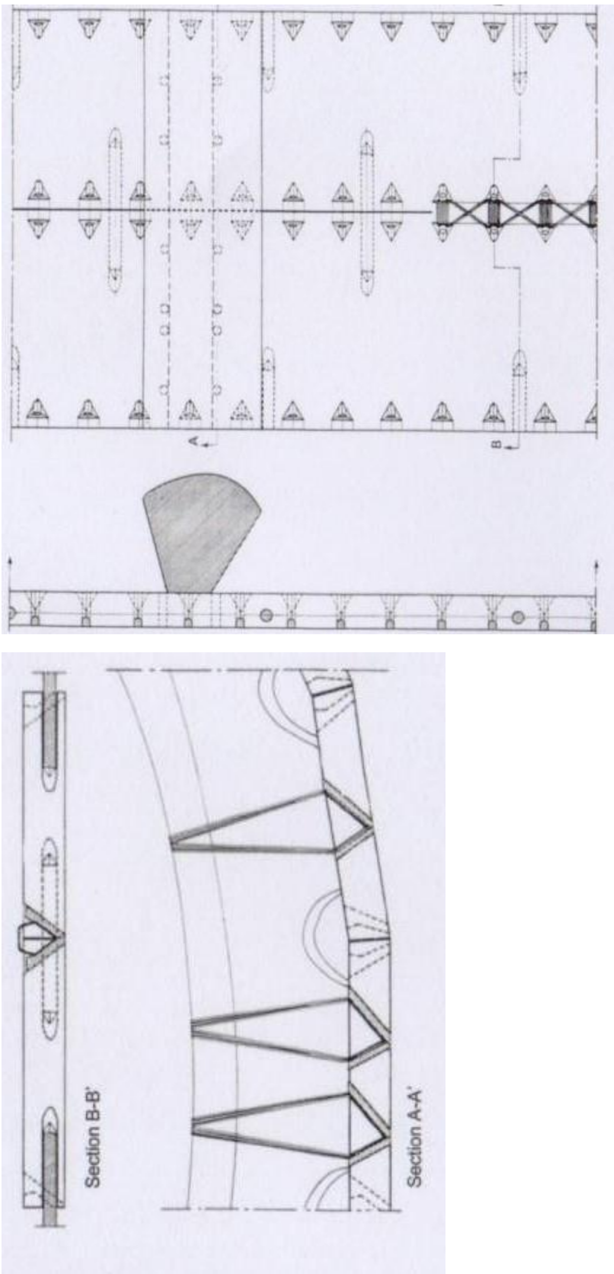

Figure 4.29 The stitched construction of the hull of Jules Verne 9. Pomey and Poveda, 2018, Fig 2.

Figure 4.30 The reconstructed hull of the Jules Verne 9. Pomey and Poveda, 2018, Fig 3.

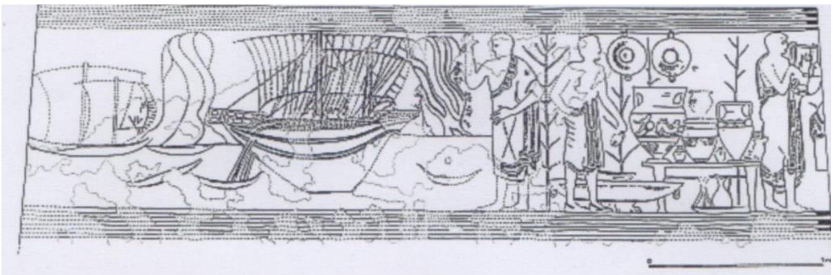

Figure 4.31 Line drawing of the left wall of the Tomba della Nova showing two vessels. Steingraber, 2006, 153.

Figure 4.32 3rd century AD scene of three vessels, the middle one of which has a fore and aft sail, from a sarcophagus found at Ostia, now in the Ny-Carlsberg Glyptothek Copenhagen. Casson, 1971, Fig 147.

Figure 4.33 The Porto Bas relief showing two views of a sailing vessel with triangular topsail and shrouds entering Portus Augusti, ca. AD 200, found on the Porte estate, now in the Torlonia Museum Rome. https://www.fondazionetorlonia.org/bassorilievo-con-veduta-del-portus-augusti/ 25/11/21.

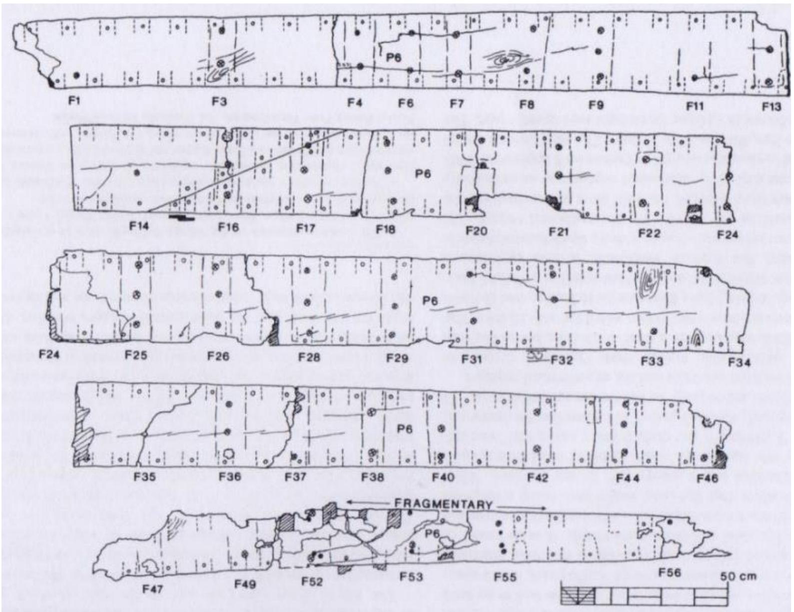

Figure 4.34 The mortice and tenon joints in the Kyrenia hull.

Steffy 1985, Ill 5.

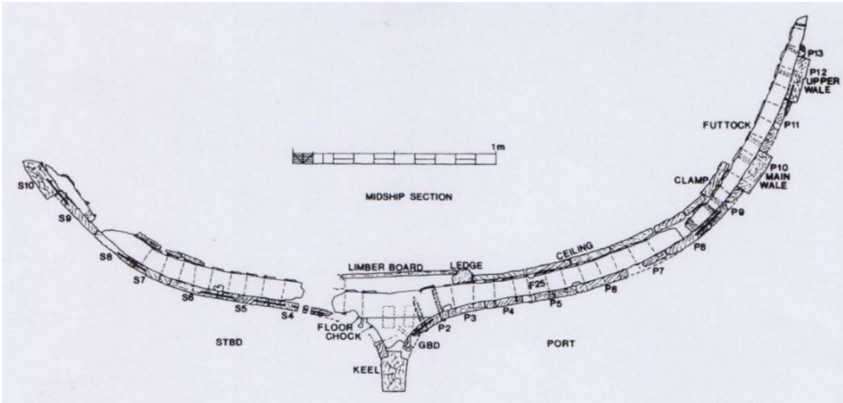

Figure 4.35 The wine glass hull form of Kyrenia ship. Steffy, 1985, Illustration 6.

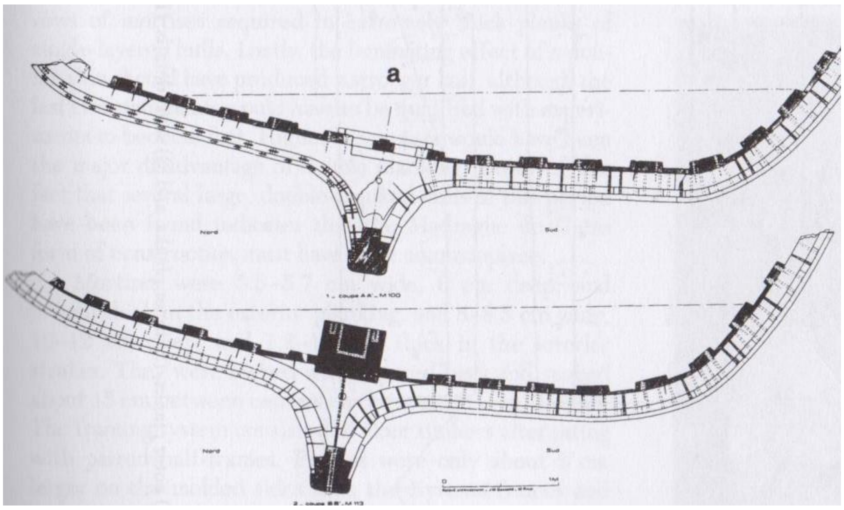

Figure 4.36 The hull form of the Madrague de Giens vessel. Steffy, 2017, Fig 3-49a.

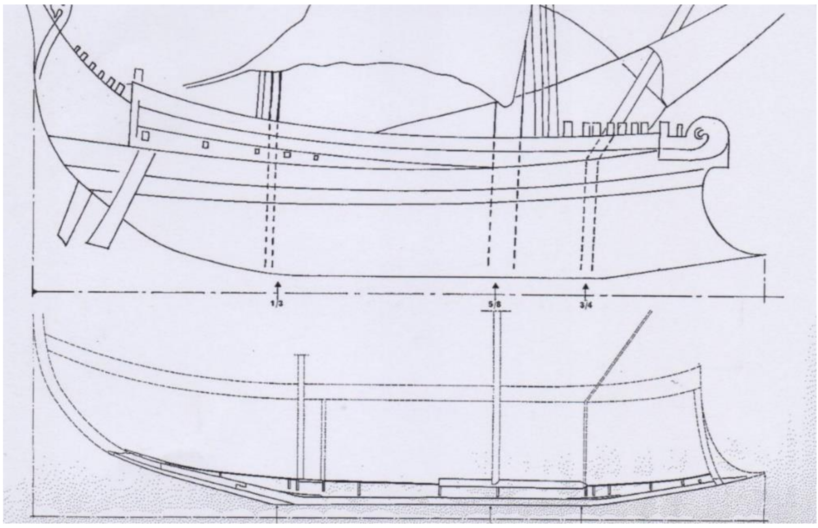

Figure 4.37 The projected bow of the Madrague de Giens vessel. Pomey, 1982, Fig 8.

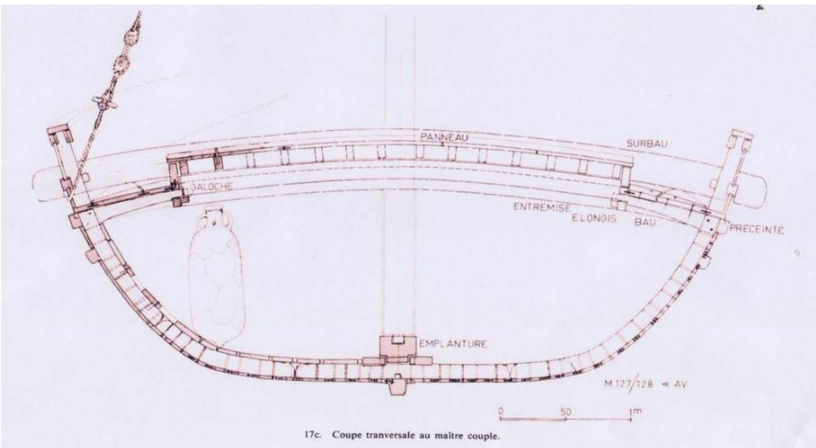

Figure 4.38 A reconstruction of the transverse section of the Les Laurons B wreck. Gassend et al, 1984 Fig17c.

Figure 5.1 The reconstruction of the Kyrenia ship at sea, source Tzalas, 2018, fig 6.

Figure 5.2 A reconstruction of the Bremen Cog. Source https://upload.wikimedia.org/wikipedia/commons/7/7f/Ubena_von_Bremen_Kiel2007_1Ubena_von_Bremen_Kiel2007/ 24/11/21

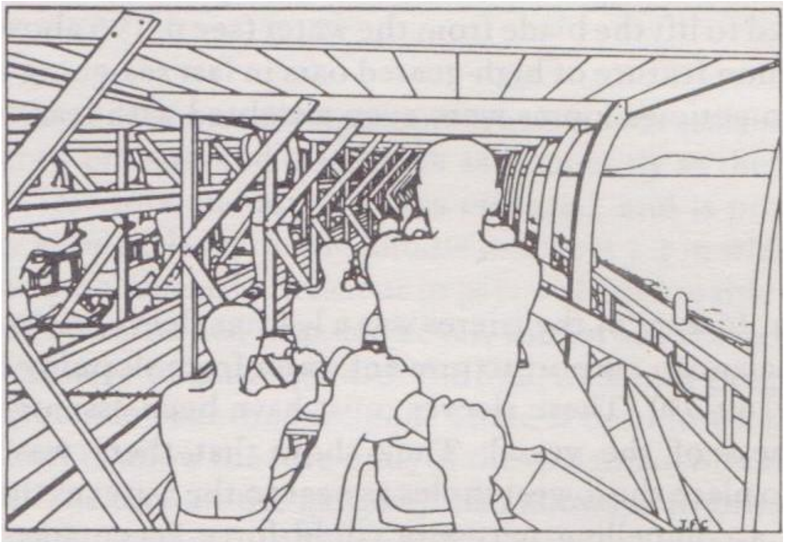

Figure 6.1 Internal view of the Athenian trireme, source Morrison and Coates, 1986, Fig 66

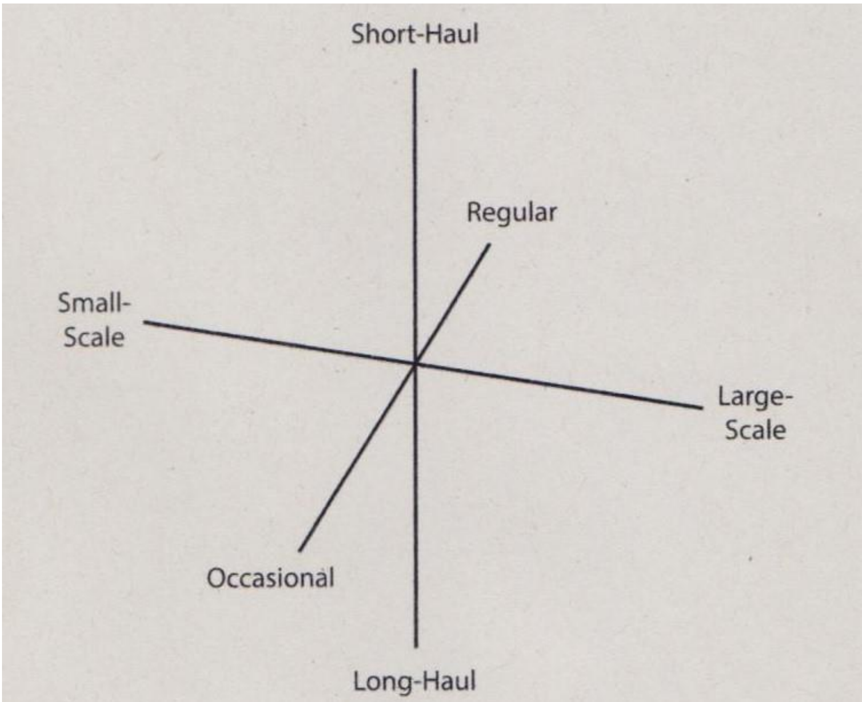

Figure 7.1 Schematic representation of the different facets of maritime mobility, source Leidwanger 2020, fig 3.2