FRAMING THE DEBATE:

A STUDY OF THE DEVELOPMENT OF SHIP FRAMING IN THE MEDITERRANEAN

FROM THE 5TH CENTURY B.C.E. TO THE 9TH CENTURY C.E.

A Thesis

by

KEVIN RIPLEY MARTIN MELIA-TEEVAN

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

Chair of Committee,	Cemalettin Pulak
Committee Members,	Deborah Carlson
	Christoph Konrad
Head of Department,	Cynthia Werner

December 2016

Major Subject: Anthropology

ABSTRACT

This study is a selective compendium of measurements and features relating to framing from Mediterranean shipwrecks dating from the 5th century B.C.E. through the 9th century C.E., with the goal of better understanding the transition from shell-based to frame-based ship construction. With a few notable exceptions, little more than cursory measurements and analyses are published regarding the framing pattern in ancient Mediterranean ships, a system that has been broadly and nondescriptly labeled as "floor timbers alternating with paired half-frames." From its first appearance until the 6th century C.E., the pattern of floor timbers alternating with paired half-frames remains in relative stasis with only a few notable developments. Framing continues to be a non-integrated and secondary form of hull rigidity until the 8th and 9th centuries C.E. when a new system appears – successive and alternating L-shaped floor timbers extended by non-fastened futtocks, or in-line framing. The reasons for the quick adoption of this new system are not entirely clear, but are likely economic in nature. Regardless, the introduction of in-line framing, along with the transition away from strong hull edge-joinery, prompted the obsolescence of the centuries-old arrangement of floor timbers alternating with paired half-frames. While framing systems in ancient Mediterranean ships have received little focused attention in the past, it is clear that the incremental changes between the 4th century B.C.E. and the 9th century C.E. reveal larger patterns in ship construction.

To Mom

While I am glad your long fight is over, I miss you every day.

ACKNOWLEDGEMENTS

I never could have tackled a subject like this without the guidance of Dr. Cemal Pulak. Because he took a chance on a graduate student he barely knew (though he may have not known what he was signing up for at the time), I have reached a goal that seemed lifetimes away when I was 12 years old. While Dr. Pulak may be perpetually busy, I am eternally appreciative that he always had time to discuss my many questions during this long ride. He taught me how to be an academic and a professional, and I will be always grateful to my mentor for his guidance and loyalty. I am incredibly thankful for my other committee members, Dr. Deborah Carlson and Dr. Christoph Konrad, whose contributions were a valuable part of the editing process.

I am also grateful to my father and my two sisters. These years away from them have not been easy for me or my family, but their strength is one of the most important reasons that I have made it this far. Without Stephanie Koenig, the following document would not exist. Along with the countless hours that she spent editing and providing feedback, she kept me grounded and sane. And yes, I am now truly out of reasons to not get a puppy, Steph.

Two others who I would be remiss without mentioning are John Littlefield and Dr. Lilia Campana. These two showed that professionalism begins in graduate school and set the bar that I will continue to chase; I will always be thankful for their friendship.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In 1995, Richard J. Steffy stated that the number of excavated shipwrecks was increasing, but the knowledge about shipbuilders' methods for designing and controlling the shapes of their ships was not.[1] He went on to say, "We have documented a lot of trees… but we still have to find the forest."[2] The factors he believed to have led to this problem are the insufficient recording of hulls and unimaginative avenues of research. One area of weakness he specifically pointed out in ship recording concerns the framing.[3] For instance, he stated that frame spacing should be standardized – measured center-to-center at a number of points along the frames, especially at the keel and the turn of the bilge.[4] Whether it is due to the high costs faced during complete shipwreck excavation, the extreme variability in ship design, the range of hull preservation, the lack of regimented training of nautical archaeologists, the excavation of shipwrecks by non-nautical archaeologists, or the lack of a platform for disseminating raw timber measurements, it seems that Steffy's call for standardized recording has gone unheeded – particularly in regards to framing in ancient Mediterranean shipwrecks. With a few

[1] Steffy 1995, 417.
[2] Steffy 1995, 417.
[3] Steffy 1996, 559.
[4] Center-to-center spacing is the distance between the center of one frame and the center of the next adjacent frame. This is different from room-and-space measurement which is defined as the distance from the moulded edge of one frame to the same spot on the next frame.

notable exceptions, little more than cursory measurements and analyses are published about the framing pattern in ancient Mediterranean ships, a system that has been broadly and nondescriptly labeled as 'floor timbers alternating with paired half-frames.' The transition between shell-based and frame-based construction, as well as its relative chronology, is one of the most intensely contested issues in ancient ship construction.[5] Under the assumption that developments in framing played an important role in this transition, this lack of synthesized information impedes further progress in this area.

The 4th-century B.C.E. shipwreck at Kyrenia is hailed as the classic example of floor timbers alternating with paired half-frames – it is not only the earliest shipwreck to exhibit this framing pattern, but it is also well preserved. Like all ships of shell-based construction, the shape of the Kyrenia shipwreck's hull is dictated by the arrangement of the planking, which primarily is assembled before the framing is installed. After detailed and thorough analysis, it became clear that the frames played no active part in the shaping of the hull.[6] The first indisputable evidence of the installation of a frame prior to the completion of all the planking comes almost 800 years later with the Yassıada 4th-century C.E. wreck – though it is only with the midship frame.[7] However, this transitional ship is still classified as a shell-built vessel, since the shape of the hull is dictated by the plank-first assembly of the hull and not the frames. Many archaeologists have posited their wrecks as the first frame-based ship, but the 11th-century C.E. Serçe Limanı wreck

[5] Basch 1972, 15-6; Hocker 2004, 6-8; Pomey 2004b, 25; Pomey et al. 2012, 235.
[6] Steffy 1994, 57-8.
[7] van Doorninck 1976, 126.

is the earliest example that is widely accepted as one of the earliest ships in which a portion of the hull, particularly amidships, was erected prior to the assembly of the planking.[8]

Conventional scholarly opinion is divided on how and when the development in construction proceeded during the intermediate 1500 years between the Kyrenia and the Serçe Limanı shipwrecks.[9] We can guess that economic reasons were the primary motivation for shipbuilders to alter centuries of shipbuilding tradition, but we do not know when this new tradition began, where it began, how these changes were implemented, and how quickly this diffusion of knowledge occurred. In one of the most recent and comprehensive surveys of ship framing, Pomey et al. addressed some of these issues surrounding the transition from shell-based to frame-based construction.[10] In addition to arguing for an earlier completion of this transition, they also suggest a multi-lineal evolution that occurred in different geographic regions of the Mediterranean at different times. To study this transition, they suggest that several indicators of ship construction should be observed. They highlight the most commonly observed feature – the reduced importance of edge-joinery strength – but argue that there are other identifiable technical characteristics that should be taken into consideration, including the frames and their fastening to the keel and keelson.

---

[8] Steffy 2004, 154-61.
[9] Pomey et al 2012, 236-37; Steffy 1991, 1.
[10] Pomey et al. 2012, 235-314.

Using the criteria defined by Hocker, they reviewed over 30 different shipwrecks to determine the geo-cultural 'roots' of ship construction traditions in the Mediterranean, looking at design, building process, and structural philosophy.[11] In a shell-based vessel, the shape of a hull will be dictated by the assembly of the planks, and therefore design and assembly are inseparable. In contrast, the structure of a frame-based ship must be determined during the design phase, before construction begins and completely separate from the hull's assembly. The structural philosophy of a vessel is the way in which the timbers are intended to distribute the stresses it will encounter. For most shell-based ships, the pegged mortise-and-tenon joinery is the primary source of their strength, whereas a frame-based ship derives its rigidity from the integration of the framing system. Though the archaeological record exhibits evolving features in design and assembly, indicating the development from shell-based to frame-based construction, ultimately the transition in shipbuilding practice in the Mediterranean is marked by a switch in the shipwrights' structural philosophy.

The ships studied by Pomey, with the exception of one, came from the Mediterranean. Pomey et al. believed that the first possible evidence for the transition can be seen in a type that is identified as "western Roman Imperial" tradition, which is marked by flat-bottomed hulls, a gently rounded turn of the bilge, frames bolted to the keel, overlapping half-frames, a long mast step set into two sister keelsons, and the use

[11] Hocker 2004, 6.

of either active or partially active frames.[12] They hypothesized that this type of vessel developed in the western Mediterranean sometime in the 2nd century C.E., based on the earliest archaeological example of this new type, the Saint-Gervais III wreck. Discovered off the coast of southern France, this vessel had a flat-floored main frame and a sharply rounded turn of the bilge, but more importantly, there was evidence found for potentially active frames – 3 tenon pegs were driven from the exterior of the hull and found under a bolted frame.[13] This was contrary to what was seen in the rest of the hull and other classic examples of shell-built vessels, where the tenon pegs were driven from the interior. The insertion of pegs from the exterior has been interpreted as evidence that the frame, already in place, may have been in the way of the builder. The Saint-Gervais III wreck is a prime example of a ship that exhibits some of the indicators of the transition from shell-based to frame-based construction, but does not actually mark the inception of this new shipbuilding tradition. Oddities or changes in the ship's design or assembly are insufficient; there must be evidence of a conceptual change in structural philosophy.

Prior to the advancement of the western Roman Imperial tradition, the only shipbuilding tradition that was recognized by scholars is the Graeco-Roman, or Hellenistic, tradition based on pegged mortise-and-tenon joinery, to which Pomey et al.

[12] A flat-floored vessel is differentiated from a flat-bottomed vessel in the fact that a flat-floored vessel as flat floor timbers and a keel. A flat-bottomed vessel has flat floor timbers but does not have a keel.
[13] An active frame is defined as a frame that determines the shape of the side planking (Basch 1972, 2). Active frames are a necessary component for frame-based construction.

considered the Kyrenia shipwreck to belong. While there is debate as to whether the Graeco-Roman tradition was a natural development of the Greek laced tradition, as Polzer hypothesizes, or an introduced technology, it is indisputably a shell-based tradition.[14] As stated, the basic framing pattern of this ship construction method was floor timbers alternating with paired half-frames, which varied from the western Roman Imperial tradition where the half-frames overlapped the keel axis of the ship. According to Pomey et al., this new development in framing provided more rigidity to the hull.[15] While this is true, it is only seen on two to three frames which makes it difficult to call this feature a new 'development.'

In discussing frame-based construction, Kahanov largely agreed with Pomey et al. and believed that the development took place earlier in the 1st millennium C.E.[16] He also argued that other important changes in construction were taking place alongside the reduction of plank-edge joinery.[17] In that vein, he posited four structural benchmarks as additional indicators: frames nailed to the keel, plank butt joints located at frame stations, the absence of planking edge joinery, and the presence of caulking in all planking seams. But these 'indicators' come with a certain degree of ambiguity; how many frames have to be nailed to the keel in order to indicate a visible transition toward frame-based construction?[18] The larger point that should be made here is that no single

---

[14] Polzer 2010, 33-4; Polzer 2011, 368-69.
[15] Pomey et al. 2012, 298.
[16] Kahanov 2010, 78.
[17] Kahanov 2010, 79.
[18] Kahanov 2010, 79.

construction feature is or ever will be the definitive indicator for this intricate transition. This does not negate the value of studying these particular construction features in shipwrecks; rather, it is only through their rigorous study that scholars will better understand the shift from shell- to frame-based construction.

Kahanov examined factors like frame size and room-and-space, and determined that there is no unequivocal pattern or tendency.[19] His only overriding conclusion was the same one that has been widely accepted about the change from shell- to frame-based construction – it was not a linear transition.[20] This is an undeniable and predictable fact considering both the geographic and chronological range of the evidence and the relatively limited number of wrecks being examined. But this does not imply an absence of directional development in ancient shipbuilding in the Mediterranean.

The reason for this is simple and best described by Steffy.[21] A given vessel will always be a means to an end for those involved in its creation, whatever those ends may be, i.e., to trade or to make war. A shipwright's goal is to build the desired vessel as quickly and as cheaply as possible. Frame-based ship construction is fundamentally more efficient than shell-based construction in terms of both time and resources. Therefore, just like the shift that took place from lacing to pegged mortise-and-tenon joinery in the Greek world, there should be a directional, although non-uniform, transition from shell- to frame-based construction as knowledge was disseminated across the Mediterranean.

---

[19] Kahanov 2010, 81.
[20] Kahanov 2010, 82.
[21] Steffy 1994, 84.

As with biological evolution, this transition in ancient ship construction was the result of thousands of years of ship permutations based on trial and error in which the builders selected between traditional and new, more advantageous features. It is a continuum, not marked by a single cataclysmic event; so the question for nautical archaeologists is not *when* specifically the transition from shell- to frame-based construction begins, but *how* we can discern its presence in the archaeological record. To that end, this study is a selective compendium of measurements and features from 91 Mediterranean shipwrecks dating to the 5th century B.C.E. through the 9th century C.E. that exhibit framing properties relevant to this transition.

CHAPTER II

5th CENTURY B.C.E.

In order to gain better context for the development of framing during the 1st millennium C.E., it is necessary to study the preceding transition from laced to pegged mortise-and-tenon construction in Mediterranean shipbuilding. This transition is the only other major shift in the approach to framing structure, and its well-documented archaeological evidence provides an analog for the transition to frame-based construction. While there are numerous laced traditions from around the world, the lacing tradition seen in the late-5th century B.C.E. Ma'agan Mikhael ship originates from the Aegean and is differentiated from others in the Mediterranean which are based on the use of tetrahedral notches.[22] The pegged mortise-and-tenon tradition dates as far back as the 14th century B.C.E. with the Uluburun shipwreck, but no framing elements were recovered from this wreck.[23] The following section explores the Ma'agan Mikhael wreck, a partially laced vessel dated to 400 B.C.E., when closely spaced and tightly fitting pegged mortise-and-tenon joinery had not yet become the dominant construction technique, at least in the Aegean.

The Ma'agan Mikhael shipwreck was discovered off the coast of Israel, near Haifa.[24] What makes this shipwreck important is that it was built with a combination of

[22] Kahanov 1998, abstract.
[23] Pulak 1999, 213.
[24] Steffy 1994, 40.

lacing and pegged mortise-and-tenon joinery, thus making its construction a transitional one.[25] The ship was assembled with pegged mortise-and-tenon joinery, but at the stem and stern the end of the garboard was laced to the keel. The hood-ends of the planking were laced to a knee which was located between the keel and the endposts. This was done because the extremities of the vessel were the hardest to secure to the endposts due to excessive bending of the planking from near horizontal amidships to almost vertical at the bow and stern ends. The conservative shipwrights, rather than trusting the mortise-and-tenon joints for this process, reinforced the joints by lacing. The hoodends of the strakes near the extremities were laced to the endposts and reinforcement knees, which were buttressed to and provided support for the ends of the keel and the end posts.[26] Over 11 of the original 13.5 m of hull length of the well-preserved vessel survived. The Ma'agan Mikhael ship was fitted with assembled or made-frames, most commonly associated with purely laced ships, like those on the earlier the Bon Porté ship dated to ca. 525 B.C.E.[27] Made-frames were comprised of floor timbers and futtocks that were assembled with the use of scarfs and fastened together with small treenails. After the frame assembly had been completed and shaped to fit to

[25] Dated to the end of the 6th century B.C.E., the Jules-Verne 7 wreck is also a noteworthy transitional vessel. The planking is fastened using pegged mortise-and-tenon joinery in the center of the ship while also using lacing at the bow and stern. It differs from the Ma'agan Mikhael ship in that it does not use alternating floor timbers with paired half-frames. This speaks to the slow and uneven way in which shipbuilders were transitioning to this new method of fastening hulls.

[26] Steffy 1994, 41.

[27] Pomey 1981, 225.

the interior of the existing laced hull, it was installed and fastened to the planking to provide additional reinforcement.

The use of copper nails in attaching framing to the hull on the Ma'agan Mikhael ship is also noteworthy, as it is an early example of the use of metal nails for this purpose. This is a departure from other laced vessels, like the Bon Porté or Jules Verne wrecks (with the exception of Jules Verne 7 which used metal nails), where lacing was the principal method for attaching frames to the hull.[28] Metal fasteners appear as early as the last quarter of the 6th century B.C.E., although they do not become standard until the 4th century B.C.E.[29] Based on the finds at Jules Verne and those of other transitional laced vessels, there is an association between metal fasteners and the transition to pegged mortise-and-tenon construction.

In the Ma'agan Mikhael ship a total of 14 frames survived, made of compass timbers – naturally formed pieces of wood with curvatures that were suitable for use in framing.[30] This allowed the shipbuilder to minimize the amount of work needed to shape the frames; in some cases, the frames still had bark on them. According to the excavators, the frames conformed very closely to the hull planking, usually within 0.002 m, though there were some gaps up to 0.01 m in size.[31] The cross-section of the frames was typical for laced hulls in that they were roughly trapezoidal in shape, with the

[28] Pomey 1995, 478.
[29] Pomey 1996, 430.
[30] Kahanov 2003, 88.
[31] Kahanov 2003, 90.

narrower side positioned to rest on the planking. The frames were widely spread, with a center-to-center spacing of 0.75 m, and were not fastened to the keel; some did not make contact with the keel.[32] The made-frames were attached to the hull with square, double-clenched copper nails that were driven from the outside of the hull with a general, but not absolute, rule of one nail in each strake per frame. According to the excavators, the ship was built with skilled carpentry by experienced and professional shipwrights drawing from a known and well-developed (mostly laced) tradition.[33] What can be learned from the framing of the Ma'agan Mikhael ship? Closer examination shows that the introduction of pegged mortise-and-tenon joinery contemporaneously brought about changes in the framing, particularly in regards to frame spacing, placement of notches on the under face for accommodating lacing seams, and overall shape.

One trend that is clearly evident in the transition from laced to pegged mortise-and-tenon joinery is that the frames become more closely spaced. The average center-to-center spacing for the Ma'agan Mikhael wreck is 0.75 m, already noticeably closer than the spacing observed just a century earlier in wrecks like Jules Verne 7 or Gela 1, which average 0.98 m and 0.84 m, respectively.[34] Just a century later, the Kyrenia ship's framing shows an average center-to-center spacing that has decreased to 0.25 m. The effect of bringing the frames closer together it makes the vessel more rigid. This trend harmonizes well with the transition to pegged mortise-and-tenon joinery, which is a

---

[32] Steffy 1994, 41.
[33] Kahanov 2003, 111.
[34] Kahanov 2003, 120; Pomey 1995, 475-78.

more rigid method of fastening a hull than lacing. Even so, 0.75 m of spacing between frames is still fairly wide if one is attempting to build a more rigid hull, but this is easily explained. The framing system is being adapted to accommodate the more rigid hull construction technique, not the other way around. Therefore, a lag is to be expected between the introduction of pegged mortise-and-tenon joinery and the strengthening of internal framing, affected through frame spacing. The edge fasteners of the hull planking are still the priority, and the frames remain a secondary concern for centuries to come.

The metal-fastened frames of the Ma'agan Mikhael ship are the first to be shaped without notches on their bottom face.[35] Previously, the notches were cut in the under surface of the frames to allow space for the lacing seam; in the Gela 1 shipwreck, the frames were fastened with metal nails but the notches were still cut on the bottom of the frames even though no lacing was used to fastened the planks, a technological hangover that has been attributed to the traditional mindset of shipwrights.[36] The frames of the Ma'agan Mikhael ship are a step further from the lacing tradition – the notched bottoms are in the process of being phased out as this additional task is no longer necessary for the fastening of the frames to the hull.

The trapezoidal cross-sectional shape of the Ma'agan Mikhael ship's frames is typical for Greek laced ships. Frames in laced vessels have a wide and rounded upper face to facilitate the fastening of the frames to the hull with lacing. The large, rounded

[35] Kahanov 2003, 121.
[36] Freschi 1991, 187; Kahanov 2003, 122.

frame face allows for a stronger bind between the planking and the frame by preventing the lashing cordage fibers from tearing on sharp edges. Yet, the same basic shape is visible in the frames of the Ma'agan Mikhael ship, even though these frames are not lashed to the hull but nailed in place with double-clenched copper nails. This provides additional evidence that there is a lag between the transition taking place in hull fastening and framing.

The framing of the Ma'agan Mikhael ship represents a technological hybrid, encompassing traits derived from both laced and pegged mortise-and tenon construction. The made-frames are constructed similarly to those used in laced vessels. The rounded trapezoidal cross-sectional shape is also indicative of traditional laced construction. More importantly, they continue to be used as frames in laced vessels, installed after the completion of the hull and therefore not essential to the formation of the hull shape. In the Ma'agan Mikhael ship, the pegged mortise-and-tenon tradition is in the process of succeeding the older laced tradition, so much so that it is difficult to determine which of the two philosophies is dominant in the ship's construction. In fact, one could argue that there is a dual philosophy – the fastening of the hull planking in Ma'agan Mikhael ship is governed by pegged mortise-and-tenon construction while the frames are very much rooted in the laced tradition.

While decreased frame spacing, notch-free frame bottoms, and pegged mortise-and-tenon planking joinery are all consistent with the construction of a more rigid hull, the additional labor involved in shaping rounded frames is seemingly unnecessary and incompatible. The framing system transitions slowly in response to changes in the hull fastening method, resulting in a technological lag between the two. It may be argued that the shipwrights used built-frames that had already been designed and fashioned for laced boats, but this is unlikely because frames must be individually shaped to fit each pre-built hull. Therefore, it appears that the shipwrights were slow to accept the new adaptations even though it was more time consuming, and continued to employ the frame types with which they were familiar. Within a century, the laced tradition and its associated framing style had been almost completely phased out, with the exception of the northwestern Adriatic basin where the use of lacing in hull construction continued through the Roman Imperial period and later.[37]

[37] Willis and Capulli 2014, 15.

CHAPTER III

4th CENTURY B.C.E.

The shipwreck found near the town of Kyrenia, whose construction dates to the end of the 4th century B.C.E., is one of the most important examples of framing from the Hellenistic world, as it is one of the most thoroughly excavated and recorded, as well as providing the earliest example of floor timbers alternating with paired half-frames.[38] The shipwreck, which was excavated from 1968 to 1969 under the direction of Michael and Susan Katzev, is the cornerstone of our current understanding of this new and enduring framing tradition; indeed, as Steffy observed, "[the Kyrenia ship] had a series of floor timbers that would be improved and remain forever."[39] The ship was built in the shell-based tradition using pegged mortise-and-tenon joinery and was estimated to be 14 m in length with a cargo capacity of 25 tons.[40]

Although the Ma'agan Mikhael and Kyrenia ships present two distinct patterns of hull framing, there is one critical similarity regarding their construction. The framing is being increasingly valued as a source of structural rigidity, as evidenced by the decreased spacing between frames and thus resulting in more frames being installed. However, in both ships the framing remains an ancillary concern in regards to the planking edge-fasteners, at least until the use of potentially active frames in the 6th century C.E. in which

---

[38] Katzev 2005, 75; Steffy 1994, 42.
[39] Steffy 1995, 52
[40] Steffy 1985, 100.

hulls without edge fasteners are found.[41] Both ships use compass timbers in their frames, which are ideal for use in framing because of their natural strength; compass timbers continue to be used in frame timbers whenever feasible or available. The irregular shapes of the three outward faces of the frame timbers and the presence of bark on some floor timbers of the Kyrenia ship suggest that there is minimal labor spent shaping them.[42] The bottom surfaces of the Kyrenia ship's frames roughly conform to the internal hull curvature; any resulting gaps are filled with shims. In the Ma'agan Mikhael ship, the bottoms of the frames closely mirror the inner surface of the hull, but any remaining gaps are not filled in. The shipwrights of each vessel seemingly placed a value in the shaping of the frames, but were not overly concerned with their perfect alignment. Given the high cost of time it would take to find and obtain the proper compass timbers, shipwrights were reducing the amount of work spent on shaping the frames by prioritizing the fitting and shaping of the surface facing the hull. In laced construction, the shipwrights did not have the luxury of ignoring these faces but the introduction of pegged mortise-and-tenon joinery nullified the need for this additional labor. Archaeological evidence from the Kyrenia wreck excavation additionally supports the role of framing as secondary reinforcement in pegged mortise-and-tenon ships. Frame 40, a floor timber, was sawn off to make room for the sump.[43] The removal of a

[41] Several wrecks that did not use edge-fasteners in securing the planking have been discovered in the Tantura Lagoon, Israel, the earliest of which is the Dor 2001/1 wreck, dated to the 6th century CE.
[42] Steffy 1994, 49.
[43] Steffy 1985, 96.

timber with no attempt to reinforce the vulnerable section suggests that any given framing timber can be removed without threatening the overall structural integrity of the hull. This was possible because of the denser spacing of the frames on the Kyrenia ship as compared to Greek laced ships. As the vessels were built using shell-based principles, the shipwrights expected the planking and edge joinery to maintain the vessel's structure, while the framing acted as a supplementary support system – a conceptual holdover from the role of framing in Greek laced hulls.

A total of 41 frame stations were found in the hull, which covered an area measuring 72 m^2.[44] Because the frames were made of tree trunks and large branches, they were neither perfectly straight nor perfectly squared.[45] Similar to those observed in the Ma'agan Mikhael vessel, some of the frames still had bark on them. The Kyrenia ship's frames were shaped to fit onto the planking and not the other way around, reinforcing the fact that it was a shell-built vessel. The placement of some tenons under the frames in the Kyrenia ship suggests that permanent frames could not have been installed before the 6th strake.[46] Whereas the frames in the Ma'agan Mikhael ship were incorporated after the completion of the hull, the frames of the Kyrenia ship were likely installed after the 9th strake was added.[47]

[44] Steffy 1985, 72.
[45] Steffy 1985, 85-6.
[46] Steffy 1994, 48.
[47] Kahanov 2003, 111; Steffy 1994, 43.

There were three different principal framing elements found on the Kyrenia ship – floor timbers, half-frames, and futtocks. There was a fourth framing component called top timbers, which extended from the upper wale to a unknown height.[48] It is difficult to make any definitive statements about the top timbers as they are so poorly preserved on the wreck. The pattern for these different elements was as follows: the floor timber was centered across the keel with both ends, or wrongheads, approximately reaching the turn of the bilge. A pair of futtocks was placed in-line, but not fastened to the wrongheads of the floor timbers. Adjacent to the floor timber, spaced approximately 0.16 m farther along the keel, a pair of half-frames was installed near but not directly touching the keel. Finally, another pair of futtocks was placed at the outer ends of the half-frames in the same manner as on the floor timbers. The pattern then repeats, hence the designation of 'floor timbers alternating with paired half-frames,' as seen in figure 1.[49]

The center-to-center distance between each floor timber and half-frame was 0.25 m over the keel.[50] Subsequently, the center-to-center distance between each floor timber was approximately 0.50 m. The frames were attached to the hull with copper nails driven through treenails from the exterior, which were then double clenched into

[48] Steffy 1985, 84.
[49] This image and all of the subsequent images of ship framing patterns are generalizations as there is variation between all shipwrecks.
[50] Steffy 1994, 51.

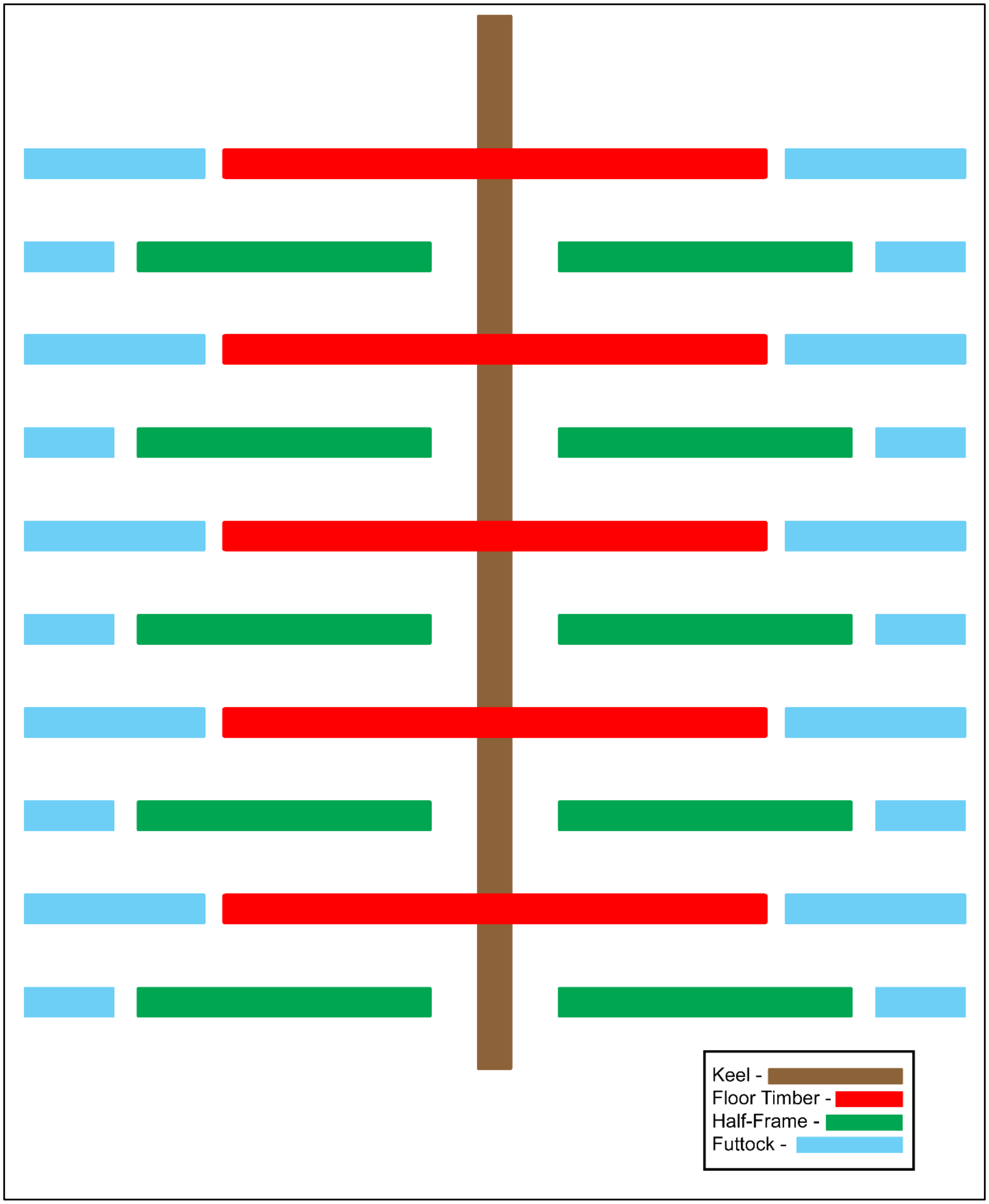

Figure 1. Traditional arrangement of floor timbers alternating with paired half-frames.

the frame itself. The general rule was two nails per frame for each plank that was less than 0.20 m in width, and three nails per frame when the plank was wider. It is estimated that of the more than 3,000 copper nails used in the ship's construction, 75% attached the framing to the planking.[51]

There were a total of 19 floor timbers, with evidence of an additional four. The floor timbers were square in cross-section and averaged 0.09 m per side. The moulded dimension was greater over the keel and narrowed at the outboard end. Due to timber size and the limitations of the wine-glass shaped hull, none of the floor timbers were connected to, or even touched, the keel at the intersection of keel and frame. There was always a small space left between them, into which chocks were inserted and fastened with an unpegged mortise-and tenon joint onto the bottom of the floor timber. These most likely were added to provide internal support for the garboards and into which a copper nail could be driven, thus reinforcing them. This is crucial since the garboards are the weakest link between the keel and the hull in wine-glass shaped hulls.

The paired half-frames were fairly irregularly shaped, although generally they had a square cross-section, averaging 0.085 m per side. The heels, or the ends closest to the keel, of the half-frames rested on one of the first three strakes. Although their overall length varied, the half-frames invariably extended farther up along the hull than the floor timbers. There was little regularity in the spacing between the floor timbers or half-frames and their corresponding futtocks. The half-frames and the futtocks were

[51] Steffy 1994, 49.

fastened to the hull in the same manner as the floor timbers, using double-clenched copper nails. The futtocks were described as shorter, flatter versions of the half-frames.[52] It is likely that many of the futtocks, particularly those paired with half-frames, extended to the sheer strake.[53] Possibly, the positioning of the futtocks and the top timbers had more to do with the structure of the fore and aft decks and the upper hull structure, but this was impossible to determine without more of the upper hull preserved.

What is significant about the framing of the Kyrenia ship? The construction and design in the framing is revolutionized in comparison to that seen in the Ma'agan Mikhael ship. The floor timbers and futtocks are separated, in sharp contrast to the tradition of connected frames and futtocks, as seen in the Ma'agan Mikhael ship's made-frames. Paired half frames are introduced, placed in between floor timbers, which reinforce the turn of the bilge while limiting the need for larger and thus more expensive compass timbers. Paired half-frames present an economical solution – they contribute to the overall rigidity of the hull by keeping the distance between frame stations low with timber that is more easily found than those needed for floor timbers.

The floor timbers have an average center-to-center distance that is 0.25 m closer than the made-frame spacing in the Ma'agan Mikhael ship, adding significantly to the ship's rigidity. Whereas the frames of the Ma'agan Mikhael ship represent a transitional

[52] Steffy 1994, 50.
[53] Steffy 1985, 94.

period in which shipwrights are still using aspects of the laced tradition, the system in the Kyrenia vessel is indicative of a completely new design and system. The Kyrenia ship marks a paradigm shift in Greek shipbuilding tradition in the Mediterranean to one that is dominated by the exclusive use of pegged mortise-and-tenon joinery and the use of floor timbers alternating with paired half-frames. Although there is no archaeological evidence for the emergence of this framing system prior to the Kyrenia ship, the highly developed nature of this system suggests it was an established tradition well before the Kyrenia ship was built. This new and unique framing system of floor timbers alternating with paired half-frames is consistently associated with pegged mortise-and tenon joinery through the 1400-year intermediate period before the introduction of frame-based construction.[54] The Kyrenia ship marks the beginning of an era in Mediterranean shipbuilding dominated by the use of pegged mortise-and-tenon joinery, combined with floor timbers alternating with paired half-frames, and denotes an enduring technological stasis that exists through at least the 5th century C.E., and continues is use for several centuries thereafter with one small change; the use of unpegged mortise-and-tenon joinery.

[54] Beginning in the 8th century CE, several wrecks from Yenikapı excavations have floor timbers alternating with paired half-frames but use coaks instead of mortise-and-tenon as edge joinery.

CHAPTER IV

3rd CENTURY B.C.E.

Examples of ship framing in the 3rd century B.C.E. are relatively sparse, with very few wrecks preserved well enough to permit a detailed study of their framing. While the evidence from this century is fairly limited, there is one outstanding feature: the system of floor timbers alternating with paired half-frames, which appeared in the archaeological record less than a century earlier, is now widely spread and fairly uniform across the Mediterranean. Three wrecks in particular illustrate this fact – two of the wrecks come from the central Mediterranean, one off the coast of Sicily, the other near the Lipari Islands. The third wreck, discovered off the coast France, comes from the western Mediterranean. These vessels illustrate how ubiquitous this new framing system became in a relatively quick period of time.

Roughly half a century after the Kyrenia ship sank, another ship met its perilous fate near modern-day Marsala, Sicily.[55] The excavators initially believed this wreck to be a warship, however, more recent analysis showed that it was more likely to have been a merchant ship due to the reinterpretation of the purported 'ram' as a cut water.[56] Like the Kyrenia ship, it was built shell-first with pegged mortise-and-tenon joinery and floor timbers alternating with paired half-frames. The excavators believed the floor timbers

[55] Frost 1981, 273-75.
[56] Averdung and Pedersen 2012, 127-28.

were added after the planking had reached the waterline – at the 11th strake.[57] The floor timbers were still not fastened to the keel and, in most cases, contrary to those of the Kyrenia ship, there were no chocks used to fill the gaps between the keel and floor timbers. This was because the floor timbers of the Marsala ship were shaped with a chock-like section in one piece, thus negating the need for a separate piece. Scored marks along the frames were preserved across the hull, indicating the floor timbers were being inserted into predetermined positions.[58] According to the excavators, the positions of some of the floor timbers were determined as soon as the keel was laid down.[59] The frames were attached to the hull with the use of iron nails, deviating from the copper nails observed in the Kyrenia ship and after earlier shipwrecks except for Jules Verne 7.[60] Only a single tenon and nail were used to attach the frame to each strake, driven in from the outside and clenched back into the frame. On both the Kyrenia and Marsala ships, the floor timbers are not attached to the keel and the paired half-frames start off of the keel on either of the garboards. The center-to-center spacing between the framing elements has not been published, but based on the scaled drawing provided, the distance ranges from 0.20 to 0.25 m, which is comparable to that of the Kyrenia ship.

The two other ships dating to this century, the Capistello wreck and the Tour Fondu wreck, display the same framing pattern – alternating floor timbers with paired half

[57] Frost 1981, 252.
[58] Frost 1981, 195-97, 249.
[59] Frost 1981, 197, 222-4.
[60] Frost 1981, 249.

frames – but even fewer published details and measurements are available for these two wrecks. These three ships vary in size and presumably in function and origin, yet the framing and plank joinery are similar. Despite the limited number of wrecks from the 3rd century B.C.E., it is evident that little has changed in ship framing since the Kyrenia ship. Ships across the Mediterranean continue to be built using pegged mortise-and-tenon edge joinery between the hull planking, and shipbuilders are almost universally implementing this standardized pattern of floor timbers alternating with paired half-frames. Used first in the eastern Mediterranean, this framing pattern spread to the central and western Mediterranean in less than a century. Comparably, it took over 700 years for the laced tradition of boat building to be replaced by one using pegged mortise-and-tenon edge joinery. With this rapid adaptation of a new style of framing, one observes an unprecedented malleability in a profession usually marked by its conservative adherence to traditional methods of construction. The dominance of this framing system suggests this style was well adapted to the needs of seafarers during that time. The overwhelming economic and functional advantages of both tightly fit pegged mortise-and-tenon joinery combined with the framing system of floor timbers alternating with paired half-frames creates a technological stasis until at least the 5th century C.E.

CHAPTER V

2nd CENTURY B.C.E.

The number of shipwrecks with hull remains, particularly with surviving frame timbers, increases significantly in the 2nd century B.C.E., although not all are well-preserved. The plethora of recorded wrecks from this period provides amount large of comparanda of raw data for the elements of ship framing, revealing greater range and diversity in individual measurements, but ultimately indicating no major changes or developments in the basic pattern or framing components. In total, seven reviewed wrecks are firmly dated to the 2nd century B.C.E.[61] With the exception of the 2nd-century Chrétienne C wreck, all ships exhibit floor timbers alternating with paired half-frames.[62] Shipwrights continue to use compass timbers to maximize the frame strength, and the better-preserved frames of these shipwrecks appear to be fairly well-shaped – indicative of the high quality of craftsmanship, as well as the attention paid to the frames during the building process. However, frames continue to be disconnected from the keel, with only the 2nd-century Pozzino wreck utilizing any fastening between the two – in the form of a copper nail.[63] This shows that the majority of shipwrights have yet to fully integrate

---

[61] The Chrétienne C (Joncheray 1975a, 49-60; 71; 77), Miladou (Dumontier and Joncheray 1991, 134-6; 173-4), Carry-le-Roulet (Long 1988, 26-27), Jeune-Garde B (Carrazé 1977, 301-2), La Rouche Fouras (Joncheray 1976, 110; 112-4; fig. 3. Joncheray and Rochier 1976, 171-3; 180), Pozzino (Riccardi 1996, 397; 394-5, fig. 19), and Punta Scaletta (Lamboglia 1964, 240; fig. 1; fig. 2; 3; 248) shipwrecks are the ones used.
[62] Joncheray 1975a, 49.
[63] Riccardi 1996, 394.

the framing components into the backbone of the ship at this time. The Cavalière wreck, one of the better-preserved shipwrecks, is representative of the enduring framing tradition from the previous century.

The Cavalière wreck was discovered east of Lavandou, France in 1972 and dated to the end of the 2nd century or the beginning of the 1st century B.C.E. based on its associated pottery.[64] The wreck was excavated from 1974 through 1977 under the direction of G. Charlin, J.M. Gassend, and R. Lequément. The ship's estimated dimensions were 12.98 m in length and 4.6 m in breadth, with an estimated tonnage of 21.17.[65] The ship was built using pegged mortise-and-tenon edge joinery and had a slight wine-glass shaped hull with a slack turn of the bilge.

On the wreck, a total of 45 frames were preserved forming a typical pattern of floor timbers alternating with paired half-frames.[66] As with previous wrecks, the floor timbers extended up to the turn of the bilge on either side of the keel, and despite the gentle curvature of the hull, they did not make contact with the top surface of the keel. In contrast with the Kyrenia wreck, chocks were not used to fill this gap, probably because it was significantly smaller. The rest of the framing pattern was consistent with that of the Kyrenia ship and the wrecks from the previous century. There was no fastening between the floor timbers and the keel; each of the paired half-frames began on either the garboard, second, or third strake and extended beyond the turn of the bilge

[64] Charlin et al. 1979, 10, 26.
[65] Charlin et al. 1979, 79-89.
[66] Charlin et al. 1979, 72.

and up the side of the hull to an undetermined point due to lack of preservation. The surviving futtocks varied in their placement – in some cases, the futtocks overlapped with their partnered framing timbers, while others were arranged in line. The sided dimension of the frames ranged from 0.08 to 0.10 m, the moulded dimension varied from 0.20 m over the keel to 0.10 m at the extremities, and the center-to-center spacing of the frames ranged from 0.23 to 0.28 m. Generally, the frames were fastened to the hull with paired treenails. In addition to this, either copper or copper alloy nails were hammered through the garboard strake and into the floor timbers. These served to reinforce the garboard strakes, which were fairly vulnerable in wine-glass shaped hulls.

Aside from the variation in the use of futtocks, there are no significant differences between the framing of the Cavalière and Kyrenia wrecks. The futtocks of the Cavalière wreck were not fastened to their partnered frames, and therefore did not add significantly to the hull's strength, indicating that the frame components were regarded as individual pieces as opposed to being members of an integrated system. The positioning of the futtocks may have been impacted by placement of the upper structures and decks or the shipwrights may simply have thought it unnecessary to standardize their arrangement.

The Cavalière ship's excavators point out a unique feature in the paired half-frames that is not seen in the previous centuries: "Il arrive cependant que les demi-couples ne soient pas parfaitement symétriques et que leur affrontement se situe audelà de l'axe de la quille."[67] It is not specified which half-frame(s) cross over the central axis of the keel, and this feature is not indicated on the site plan of the wreck, making it difficult to interpret. Based on the photograph provided, it is evident that the asymmetrical half-frame in question comes from one of the ship's extremities, judging from the angle of the hull.[68] While asymmetrical frames become increasingly common in later centuries, the irregular frames seen in this wreck are a consequence of the steep hull angles seen at the hull extremities, and are not an indicator of a change or development in the framing design.

The 2nd-century Chrétienne C wreck is the only ship from this century to use a framing pattern that deviates from the typical pattern of floor timbers alternating with paired half-frames. Although discovered in 1953, this shipwreck was not excavated until the early 1970s (1971-1973).[69] The reconstructed length of the ship is 15 to 16 m with a breadth around 5 to 6 m, although only a section 11 m by 3.81 m survived.[70] The vessel had been carrying a cargo of wine in approximately 500 amphorae, giving a total capacity of 13 to 15 tons.[71] The ship was built using pegged mortise-and-tenon edge joinery, with a slight wine-glass shape and a gently rounded turn of the bilge. The 23 frames preserved on the hull exhibited an aberrant framing pattern – successive floor timbers extended by

[67] Charlin et al. 1979, 72.
[68] Charlin et al. 1979, fig. 50.
[69] Joncheray 1975a, 7-8.
[70] Joncheray 1975a, 69-77.
[71] Joncheray 1975a, 77.

overlapping futtocks and an absence of paired half-frames.[72] This phenomenon of successive floor timbers is illustrated in figure 2. The floor timbers extended just before the turn of the bilge and would have made contact with the top surface of the keel had they not been notched underneath to allow the passage of bilge water. The futtocks overlapped the floor timbers but were offset by roughly 0.02 m.[73]

There was also periodic evidence for "courtes membrures," or short frames.[74] Two short frames, evidenced by discoloration on the hull planking, were located in between floor timbers M8 and M9, and between M10 and M11. The sided dimension of the frames averaged 0.08 m and the best preserved floor timber had a moulded dimension that ranged from 0.15 m over the keel to 0.076 m at the preserved extremity. The 0.46 m center-to-center spacing of the floor timbers was notably higher than that seen in the Kyrenia ship, which was only 0.25 m. The floor timbers and futtocks were fastened to the hull with treenails but it was not indicated how the short frames were fastened.

The exclusion of half-frames is a strange feature that, coupled with the wider center-to-center spacing, would weaken the hull structure of this vessel compared to one fitted with a system of floor timbers alternating with paired half-frames. This apparent weakness is difficult to interpret; it is possible that the addition of the two short

[72] Joncheray 1975a, 49-62.
[73] Joncheray 1975a, 49.
[74] Joncheray 1975a, 49.

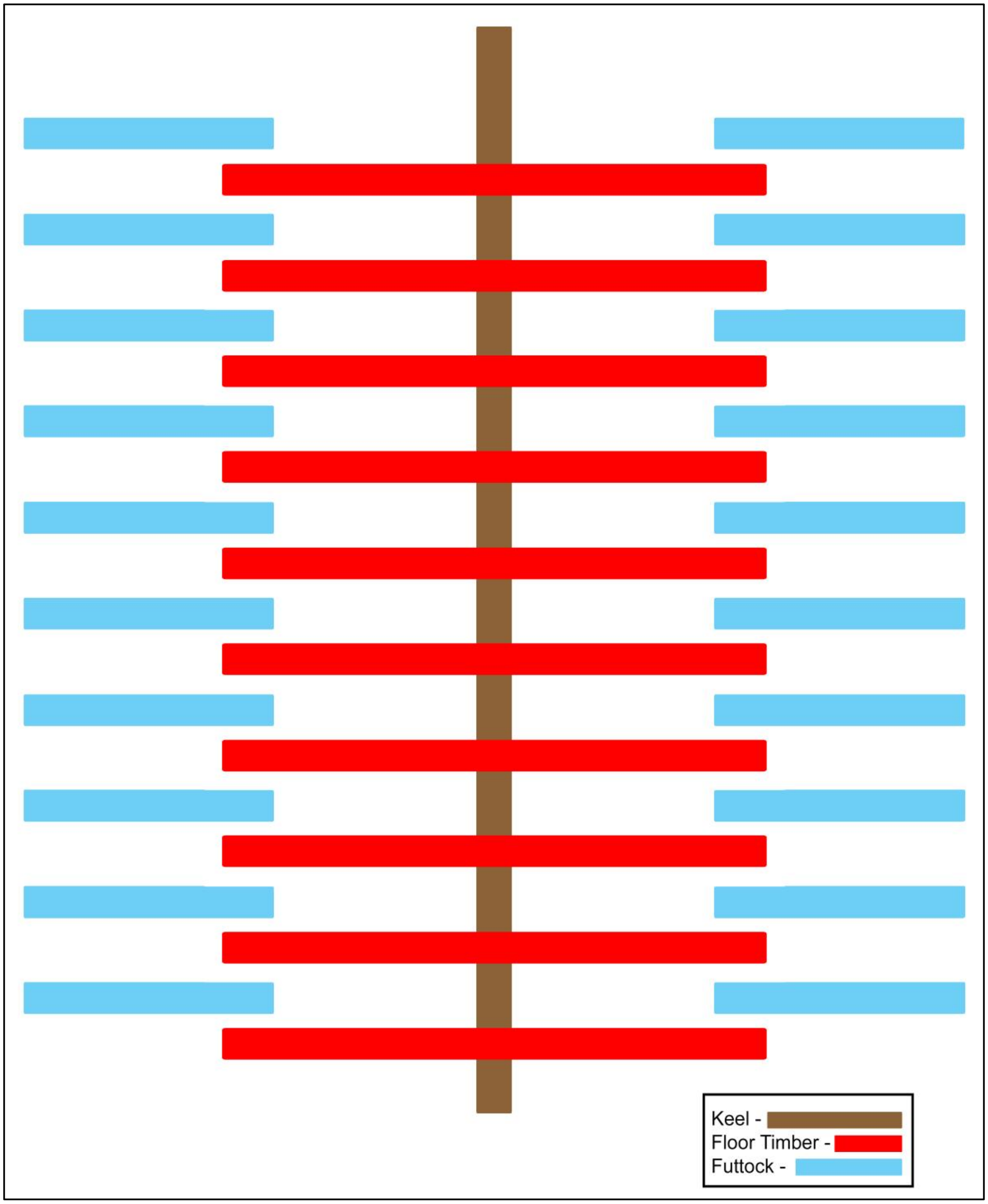

Figure 2. Successive floor timbers without paired half-frames.

frames was an attempt to ameliorate the weakened rigidity of the hull. The odd framing of the Chrétienne C ship makes it one of the more fascinating wrecks from the 2nd century B.C.E., although ultimately it appears to be an exception, rather than the rule. The unusual pattern of the Chrétienne C ship emphasizes that the function of framing is still considered to be a subordinate priority to that of assembling the hull planking with pegged mortise-and-tenon edge joinery.

Overall, the 2nd century B.C.E. is consistent with the previous century: floor timber alternating with paired half-frames continues to be the dominant framing pattern, and futtocks remain a lesser source of additional hull strength. The continuity of this framing pattern speaks not only to the conservative nature of shipbuilders but also to the well-developed and accepted nature of this framing pattern. With this framing system being so recently introduced, one would expect to see more varied applications of its use, rather than the overwhelmingly standardized pattern seen in the archaeological record. The deviation of the Chrétienne C ship from the typical framing pattern is likely due to the increased diversity of available shipwrecks in the 2nd century B.C.E. and, by itself, does not provide sufficient evidence for a new tradition or variation. Instead, it exemplifies the incomplete nature of the archaeological record and our correspondingly limited understanding of ship construction.

CHAPTER VI

1st CENTURY B.C.E.

The 1st century B.C.E. is marked by an increased sophistication in the typical pattern of floor timbers alternating with paired half-frame system. The number of available wrecks continues to increase, with the lengths of ships varying from 18 to 40 m. Eleven of the reviewed shipwrecks for this study are dated to the first century B.C.E.[75] Nearly all of the ships adhere to this dominant framing pattern, although there are variations with the use of successive floor timbers and nails, rather than treenails, for the fastening of frames to the hull.[76] What is most noteworthy about the 1st century B.C.E. is how even large ships can utilize the same, simple pattern of floor timbers alternating with paired half-frames.

A study of ship framing from the 1st century B.C.E. would be remiss without a close examination of one of the most impressive and important shipwrecks from this period, the Madrague de Giens wreck. The decade-long excavation of this shipwreck was

---

[75] The Cavalière (Charlin et al. 1978, 50; 72; 79-80; fig. 33; fig. 34), Albenga (Pallarés 1985, 634. Lamboglia 1953, 203; 206), Cap Benat B (Joncheray 1997, 107; 119), Chrétienne A (Dumas 1964, 157-7; 165; fig. 15a-b), Gernona (Foerster 1980, fig. 1; 245; 252), Grand Congloue B (Benoit 1961, fig. 75; 149-51; 164), Madraque de Giens (Pomey 1978a, 80-3. Pomey 1982, 133; 140. Pomey 2004a, 371-3), Palamos (Laures 1983, 220; 223-4. Laures et al. 1987, 21; 33-35), Dramont A (Santamaria 1973, 133-4; Santamaria 1975, 188, 192-4, fig. 8), and the Planier 3 (Liou 1973, 588-9. Tchernia 1971, 71; 74) shipwrecks are the ones used. The Dramont C shipwreck is dated to the end of the 2nd century B.C.E. and the start of the 1st century B.C.E. (Joncheray 1994, 23-7, 49-51).

[76] The most notable system of fastening comes from the Gerona shipwreck, which was discovered near Cap del Vol, Spain. Floor timbers and paired half-frames are fastened in alternating methods: the first is the use iron nails driven in from the exterior of the hull, while the intervening frames are attached with treenails arranged in pairs with a groove cut in between the treenail holes. It would seem likely that rope would have been used in the groove. (Foerster 1980, 252.

led by André Tchernia and Patrice Pomey with a team from the Centre National de la Recherche Scientifique (CNRS), who dated the wreck to the second quarter of the first century B.C.E.[77] The wreckage, found on the southern coast of France at a depth of 20 m, included 6,000 to 6,500 amphorae, although the vessel's maximum capacity would have been approximately 8,000 – corresponding to 400 tons of cargo, and indicating a very large ship.[78] This led the excavators to conclude that the Madrague de Giens ship was a *myriophoros*, one of the largest categories of cargo carriers from antiquity.[79] The wine-glass shaped hull was estimated to have been 40 m in length and 9 m in beam and, as Steffy points out, was three times the length of the Kyrenia ship with 20 times the cargo capacity.[80] Even though this ship was significantly larger than any of the other previously examined shipwrecks, it was built in accordance with the same shell-based principles and pegged mortise-and-tenon edge joinery of the planking. To allow for the vessel's large size there were several added structural features, including a double rabbeted keel with a double-planked hull, and ceiling stringers to provide additional backing strength.[81] The shipwrights obviously recognized the need for additional reinforcement, but there were no major developments in the framing of the ship.

[77] Tchernia 1978, 75-99; Pomey 1982, 136-46.
[78] Pomey 2004a, 371.
[79] Pomey 1978b, 107.
[80] Steffy 1994, 62.
[81] Steffy 1994, 65.

The excavation of the Madrague de Giens vessel revealed the typical pattern of floor timbers alternating with paired half-frames.[82] The length of the floor timbers ranged between 4.6 to 5.1 m and spanned the bottom of the hull but did not continue into the turn of the bilge on either side. The paired half-frames began on the garboard or second strake, about 0.07 to 0.10 m above the top of the keel, and extended 3 to 4 m along the sides of the hull until the level of the futtocks. In contrast, the floor timbers extended only 2 to 2.5 m between the keel and futtocks. This created an alternating pattern between the joints of the futtocks with the half-frames and the floor timbers.

The average center-to-center spacing of the frames ranged from 0.23 to 0.25 m.[83] The floor timbers varied from 0.09 to 0.19 m in their sided dimension with an average of 0.13 to 0.14 m.[84] The moulded dimension of the floor timbers ranged from 0.57 to 0.60 m over the keel and tapered down to an average of 0.12 to 0.15 m approximately one meter from the keel.[85] The half-frames exhibited similar dimensions over the keel, but thinned to .06 to .10 m at their extremities. The floor timbers and futtocks were in-line but not butt-scarfed to each other; a few centimeters of space was left between them. The frames were fastened to the inner planking with treenails driven in from the exterior, averaging two treenails per strake per frame.[86] The outer layer of planking was fastened

[82] Pomey 1978a, 80-1; Pomey 1982, 140; Pomey 2004a, 372.
[83] Pomey 1978a, 80.
[84] Pomey 1978a, 80-1.
[85] Pomey 1978a, 81.
[86] Pomey 1978a, 81.

to the inner planking and the frames with short iron nails. This weaker fastening method was likely used to avoid wasting time and resources on the sacrificial outer planking layer.

One novel feature found on the Madrague de Giens ship was the bolting of some floor timbers to the keel. Before this excavation, no archaeological evidence existed for the purposeful fastening of floor timbers to the keel to increase the strength of the hull.[87] All of the floor timbers from the Madrague de Giens sat approximately 0.08 to 0.10 m above the keel, with no apparent attempt to reduce for this extra space. Despite this gap, floor timbers 90, 94, 98, 104, 110, and 114 were fastened to the keel with long bolts that had a diameter of approximately 0.03 m. The bolts were driven from the bottom of the keel into the hull and with the end peened over a square nut, which averaged 0.05 to 0.06 m per side. Pomey logically argues that the floor timbers were bolted to the keel to reinforce the hull, and that their presence was not an indicator of active framing.[88] The bolted frames did not make contact with the top of the keel, nor was any other evidence found to suggest that these frames played a role in the shaping of the hull.[89] The extensive study of the hull has not revealed any other potential indicators for active

---

[87] The description of the construction of the *Syracusia*, as described by Athenaeus, has been referenced as the earliest example of metal bolts fastening frames to the keel (Casson 1971, 194; Pomey et al. 2012, 236; Salviat 1990, 301). However, careful examination of the passage in question, including Casson's own interpretation, make it clear that a better interpretation would be a description of driving nails through treenails to fasten frames to the planking (Casson 1971, 194 n. 31). This practice goes back to at least the 4th century B.C.E. with the Kyrenia ship on which frames were fastened to the planking with copper nails driven through treenails and then clenched onto the tops of the frames (Steffy 1985, 84). If this passage is referencing the bolting of frames to the keel (which would have most likely been passing through keel scarfs or keel-to-end post scarfs), then there is a gap of almost 200 years separating the description of the *Syracusia* (3rd century B.C.E.) and the 1st century B.C.E. Madrague de Giens ship, the first archaeological evidence of such a feature.

[88] Pomey 2002, 11-9.

[89] Pomey 2004b, 30.

framing or evidence of the pre-erection of frames prior to raising the hull planking. Most likely, these bolted floor timbers are an attempt by the builders to strengthen the backbone of this large cargo ship.

The Madrague de Giens ship, despite its impressive size and cargo capacity, shows very little innovation in terms of construction or framing. It relies upon mortise-and-tenon joined planking for its primary strength, as evidenced by the meager 0.02 m increase in frame size from those of the Kyrenia ship, whose cargo capacity was less than 30 tons. According to Pomey, the Madrague de Giens ship's framing pattern, futtock placement, and use of independent floor timbers classify it as a typical member of the Hellenistic method of construction.[90] While the Madrague de Giens ship has six floor timbers bolted to the keel, they are still considered independent floor timbers because they do not rest on the keel and therefore do not impart any additional strength to the hull. The shipwrights were more focused on reinforcing the overall hull strength by better integrating the keel to the planking and doubling the hull planking, rather than modifying the framing.

The early 1st century B.C.E. wreck found near the town of Agay, France displayed a unique variation in its framing arrangement. Known as the Chrétienne A wreck, this pegged mortise-and-tenon built ship was estimated to have been 24 to 32 m in length and generally exhibited floor timbers alternating with paired half-frames.[91] There were

---

[90] Pomey 2004a, 372-73.
[91] Dumas 1964, figs. 15a-15b.

a total of 16 preserved frames and a large mast-step; the frames were arranged in pairs but displayed irregular and inconsistent spacing and placement.[92] There were successive floor timbers without paired half-frames placed in between them, but this aberration occurred in only two instances: three frames at the northern end of the wreck and three frames at the southern end of the mast-step. Similarly, the Dramont A wreck, also dating to the 1st century B.C.E., displayed four successive floor timbers in the central portion of the ship, where the mast-step would have been located.[93] The use of successive floor timbers becomes more common throughout time and was meant to reinforce the mast-step. However, this is not a significant deviation in the framing pattern since it was used by shipwrights to reinforce the area of the hull subjected to high stress from the pressure exerted by the mast and sail. The purpose of the successive floor timbers at the northern extremity of the Chrétienne A wreck could not be properly assessed due to their poor preservation and the lack of surrounding hull features.

The traditional pattern of floor timbers alternating with paired half-frames remains unchanged in the 1st century B.C.E., however there is the first archaeological example of the use of bolts to fasten certain floor timbers to the keel. Since an equivalent style of bolting is found on the 11th-century Serçe Limanı ship, it is often associated with the development of frame-based construction. However, the Madrague de Giens wreck predates even the earliest possible candidates for frame-based vessels by 500 to 600

[92] Dumas 1964, 120; Casson 1995, 215.
[93] Santamaria 1975, 194.

years, and is nearly 1100 years younger than the Serçe Limanı ship. This feature of bolting certain frames to the keel developed independently of frame-based construction; it functioned as a supplemental reinforcement to the hull, rather than a precursor to active framing. Even in later centuries, this type of bolting is most commonly associated with keel scarfs, supporting the idea that shipwrights did not consider this to be a viable method for assembling frames, but instead as a way to reinforce critical junctures in a ship's backbone. It is noteworthy that the people who built the Madrague de Giens vessel offset the joints between the futtocks and the floor timbers with those of the futtocks and the half-frames. This illustrates the conceptual purpose of this framing pattern – the combination of floor timbers alternating with paired half-frames does not allow for the creation of long stretches of hull that are not fortified. Though it would not have added significantly more strength, this practice avoids creating a weak line along the ship and continues to be found on other wrecks for some time.

Despite the introduction of a few new features in the 1st century B.C.E., the overall pattern of floor timbers alternating with paired half-frames does not undergo any significant changes. Futtocks remain disconnected from their partnered framing timbers and are placed in a seemingly random manner – suggesting that they continue to play no significant role in the reinforcement of the hull. Ultimately, the 1st century B.C.E. offers no new or valuable indicators of conceptual changes in framing, and retains its status as a secondary method of hull reinforcement.

CHAPTER VII

1st CENTURY C.E.

The turn of the millennium brought with it an increasing number of wrecks with surviving hull components. Wrecks from this century exhibit a remarkable diversity in regards to their size – the largest being the Emperor Gaius' (Caligula) Lake Nemi barges at 71 and 73 m in Italy, while the smallest is the Barthelemy B wreck at 8 to 10 m in France.[94] There are sixteen shipwrecks in total studied from this century.[95] The development in the framing of these ships remain unchanged; the arrangement of floor timbers alternating with paired half-frames is still the dominant form alongside shell-based principles using edge fastened hull planking with pegged mortise-and-tenon joinery. The wreck found near the island of Antirhodos, Egypt best typifies this enduring standardization of framing.[96] However, this century does mark the beginning of frames becoming cruder in shape, as best demonstrated by the Kinneret wreck in Israel,

---

[94] Ucelli 1940, 373-4; Joncheray and Joncheray 2004, 71.

[95] The Antirhodos (Sandrin et al. 2013, 47; 51-2; 57), Barthelemy B (Joncheray and Joncheray 2004a, 26, 37-43, 71), Caesarea (Fitzgerald and Raban 1989, 184-90; Fitzgerald 1995, 33-40, 237, 240), Calanque de L'Ane (Ximénès and Moerman 1994, 110; Ximénès and Moerman 1998, 299-300), Dramont I (Joncheray and Joncheray 1997, 175-84, Joncheray 1998, 150), Herculaneum (Steffy 1985a, 519, 520-1; Steffy 1994, 67-71), La Giraglia (Marlier and Sibella 2002, 161, 164-5, 169, fig. 2), Ladispoli A (Carre 1993, 14-7, 28), Nemi 1 (Ucelli 1950, 153, fig. 153, 157, figs. 158, 159, 379, 382; Bonino 1989, 38-41; Bonino 2001, 106-7), Nemi 2 (Ucelli 1950, 153, fig. 153, 157, figs. 158, 159, 379, 382; Bonino 1989, 41-2; Bonino 2001, 107-8), Sud-Lavezzi II (Liou and Domergue 1990, 121, 122), Napoli A (Giampala et al. 2005, 67-9), Titan (Benoit 1958, 5, 16, 22), Balise de Rabiou (Joncheray and Joncheray 2009, 74, fig. 31, 95-6), and Lardier 4 (Joncheray and Joncheray 2004b, 90, 116-7) shipwrecks are all dated to the 1st century CE. The Kinneret shipwreck (Steffy 1987, 327, 329; fig. 4; Steffy 1994, 65-7) is dated to the end of the 1st century CE to the start of the 2nd century CE.

[96] Sandrin et al. 2013, 51-2.

although this does not become a wide spread phenomenon until the 2nd century C.E.[97] The cause for the beginning of this trend is unclear.

There continues to be a positive correlation between a size of the ship and the size of its frames, although appears to be only a general rule. Upon examination of the three largest ships in this century – the Nemi barges, the Caesarea ship, and the Antirhodos wreck – the correlation between ship size and frame size breaks down.[98] The Nemi barges are nearly twice the size of the Antirhodos and Caesarea wrecks, yet the timber sizes are only marginally larger. On the Caesarea wreck, the floor timbers are surpassed in size by the half-frames. The Lake Nemi Barges demonstrate how the relatively simple pattern of floor timbers alternating with paired half-frames can be applied to large vessels with only minor alterations. The *dolia* wrecks represent perhaps one of the most interesting phenomena relating to framing. This relatively short-lived class of ships expands upon the limited use of successive floor timbers seen in the prior century. Overall, little more than superficial changes are made to the dominant framing arrangement in order to accommodate the diversity of ship sizes and functions.

Built in the 1st century C.E., the wreck discovered off the island of Antirhodos in the *Portus Magnus* near Alexandria was studied from 1998 to 1999. The ship was found in the inner harbor along a jetty and without cargo. The date of the vessel's construction was based on the shape of the hull and other features, such as the use of bolted floor-

---

[97] Steffy 1987, 327. The Kinneret boat is a special case as it was likely constructed in a region where it was very difficult to get timbers of sufficient quality for ship construction.
[98] Ucelli 1950, 373-5; Fitzgerald and Raban 1989, 184-90; Fitzgerald 1995, 233; Sandrin et al. 2013, 57.

timbers.[99] Although the vessel was only examined *in situ*, the researchers observed that the ship was built using pegged mortise-and-tenon joinery, and had a fairly flat floor.[100] The surviving portion of the vessel was 24.6 m in length on which a total of 58 frame stations were preserved, revealing the standard pattern of floor timbers alternating with paired half-frames.[101] Following convention, the floor timbers extended from one turn of the bilge to another. Instead of chocks, shims were used to bridge the gap between the floor timbers and the keel when necessary.

The majority of the paired half-frames were symmetrically placed, with each timber starting on the garboard strake and extending along the hull beyond the turn of the bilge. However, a few of the half-frames pairs were asymmetrically placed, with one of the timbers crossing the central axis of the ship and the other starting much further along the hull as seen in figure 3. Futtocks were placed in-line with their partnered framing timber, but were separated by a distance ranging from 0.05 to 0.18 m. The average center-to-center spacing between the floor timbers was 0.60 m; the timbers had an average sided dimension of 0.24 m and an average moulded dimension of 0.37 m. Smaller than the floor timbers, the half-frames featured average dimensions of 0.21 m (sided) and of 0.28 m (moulded). This gave the ship an overall average center-to-center distance of 0.30 m between framing elements. The frames were fastened to the hull using one or more of three methods. Firstly, the frames were fastened to the planking

---

[99] Sandrin et al. 2013, 47.
[100] Sandrin et al. 2013, 57.
[101] Sandrin et al. 2013, 51.

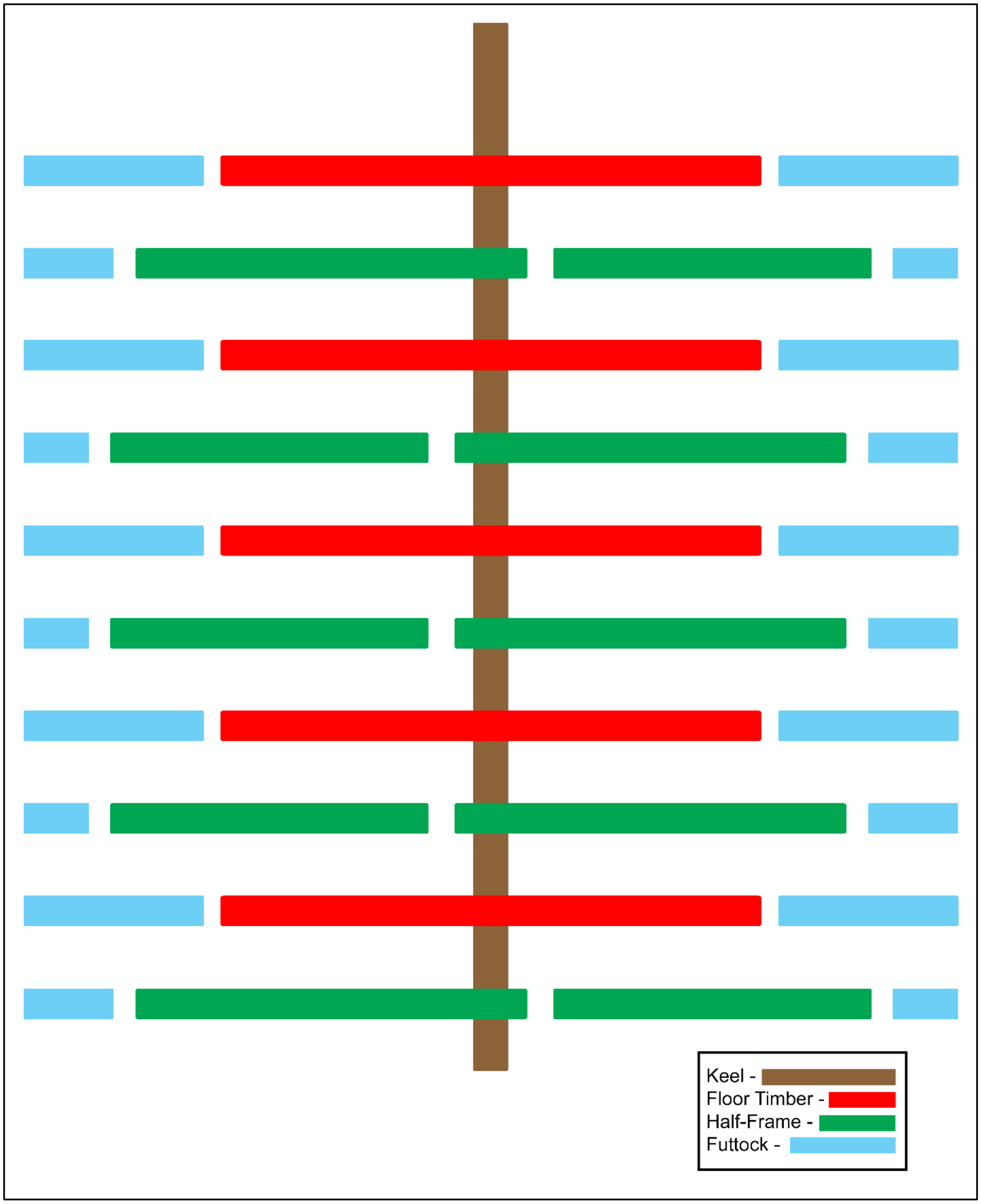

Figure 3. Floor timbers alternating with paired, asymmetrical half-frames.

with treenails that were staggered to prevent the planks from splitting. Secondly, bolts were used to fasten floor timbers and half-frames to planking, side-keelsons, and stringers. Thirdly, some of the floor timbers were bound to the keel and central keelson with additional copper alloy bolts.

The framing seen in the Antirhodos wreck is similar to that of previous centuries, with some notable changes. The floor timbers are essentially unchanged in terms of how they are shaped and positioned, though many more are being bolted to the keel. Likewise, the majority of the paired half-frames follow the standardized pattern, although the application of asymmetrical half-frames is important because this feature becomes increasingly visible in the archaeological record. However, only a few of the ship's half-frames are asymmetrically placed, and these are only slightly offset from the central axis and not fastened to each other or the keel. Since this limited application would not have provided any significant reinforcement, it was likely a consequence of finite resources rather than an attempt to add rigidity to the hull. While the lower portion of the framing system has become more integrated into the hull, the futtocks remain separated and less incorporated.

Two unique shipwrecks to have survived from the turn of the millennium were the Lake Nemi vessels. These two large ships, 73 and 71 m in length, were built for Caligula in the 1st century C.E. to serve as places of worship on Lake Nemi.[102] During the late 1920s and early 1930s, the lake was drained and the ships were excavated by Guido

[102] Bonino 1989, 39.

Ucelli.[103] While the upper portion of either hull did not survive, the lower portions were fairly well-preserved. In one of the more tragic events in the history of nautical archaeology, both ships were burned down, either accidently or purposefully by the Nazis in 1944 while housed in a museum.[104] While these ships are now lost to history, knowledge about their construction has survived due to their excavation and documentation. Despite their immense size, there was no fundamental difference in their construction compared to smaller vessels, like the Barthelemy B ship.[105] They were built shell-first with the planks edge-fastened to each other with pegged mortise-and-tenons and exhibited floor timbers alternating with paired half-frames.

The first ship had a total of 148 frames and the second 118 frames, with an average frame spacing of approximately 0.46 m and 0.59 m, respectively. The floor timbers had a sided dimension of 0.20 m and a moulded dimension of 0.30 m and were fastened to the planking with clenched copper nails driven through treenails. As they were lake barges and not designed for open water, both were flat-floored with straight, flat floor timbers. For both barges, the majority of the frames were arranged as follows: a floor timber was butt-scarfed to a futtock on either end, which alternated with paired half-frames, also butt-scarfed to futtocks. For the first time, frames were continuous – all of the disparate components were adjoined across the entire hull. On the ships' extremities, forward of the 140th frame and aft of the 9th, the frames consisted of

[103] Ucelli 1950, 57-102.
[104] Carlson 2002, 31.
[105] Joncheray and Joncheray 2004, 43-5.

successive paired half-frames. There was no fastening between the futtocks and their partnered framing element, limiting the amount of additional strength the butt-scarfing would have provided.

Interpreting the framing of the Lake Nemi barges relative to seagoing ships presents a bit of a conundrum because they were not designed to deal with the stresses of open water. While some argue that novel features in the Lake Nemi barges, such as the continuous frames, constitute a development in the framing tradition, this is unlikely. As Steffy notes, "…(it) is a bit like comparing improved species of apples by looking at oranges."[106] A potential parallel for the Lake Nemi ships comes from nearly two centuries later with the Conque des Salins vessel.[107] This riverine vessel is lighter and considerably smaller in size, yet bears several similarities in its framing. The vessels display wide frame spacing – 0.80 to 0.96 m for the Conque des Salins wreck and 0.53 m for the Lake Nemi barges. It is difficult to discern whether the closer spacing on the Lake Nemi barges is a product of its non-seagoing design, its immense size, or some unknown reason. All three vessels have flat floor timbers owing to the fact that they are flat-floored craft. Finally, all of these vessels exhibit floor timbers that have been scarfed to their partnering futtocks. This scarfing was unfastened and therefore contributed very limited, if any, additional strength. Although the extent of the application of these scarfed futtocks is less discernible on the Conque des Salins wreck, this feature was

[106] Steffy 1994, 71.
[107] Jézégou 2011, 167-75.

observed on all of the frames of the Lake Nemi barges except at frame extremities. This suggests that the shipwrights believed additional reinforcement of the frames was necessary for vessels of such a large size.

Steffy argues that the framing in the Lake Nemi ships does not signify general shipbuilding progress of its time and this is true – floor timbers alternating with paired half-frames has been, and will continue to be used for centuries.[108] However, the shipwrights clearly understood that the large vessels needed additional transverse support, particularly with the heavy superstructures that each ship carried. They introduced a simple solution – butt-scarfs used to form continuous frames – but this feature had yet to be regularly applied to seagoing craft. As Steffy notes, a ship is built to meet the needs of its user, and it stands to reason that seagoing vessels would have vastly different structural requirements from those of the Lake Nemi barges or the Conque des Salins riverine vessel. Steffy therefore is correct in his argument that the Lake Nemi vessels do not represent a 'major development' in shipbuilding or framing, but it begs the question – why would such different types of craft all exhibit the same framing pattern with only minor variations? Clearly, this framing tradition was highly versatile for the type of construction employed, and at the turn of the millennium had pervaded nearly every type of vessel being built in the Mediterranean.

When discussing changes in the pattern of floor timbers alternating with paired half-frames it is necessary to discuss a noteworthy but brief phenomenon in shipbuilding

[108] Steffy 1994, 71.

that takes place at this time – the *dolia* carriers. *Dolia* are exceptionally large earthenware containers that the Romans are known to have produced; they are round vessels with wide mouths used for carrying a variety of goods including wine, oil, and dry goods.[109] However, the nautical variants of the *dolia* were believed to be specifically used for the transport of wine.[110] Of at least ten *dolia* wrecks known, the earliest is the Cap Benat wreck, dated to the 1st century B.C.E., and the latest is the Punta Ala wreck, dated to the 3rd century C.E.[111] In regards to the construction of the *dolia* carriers, the jars would have to have been put into the ship prior to its completion with at least some features that deviate from the traditional mortise-and-tenon built vessels such as closer frame spacing.[112] It has been hypothesized, based on the relatively short span of time in which these ships wrecked, that there must have been a serious flaw in their design.[113] Unfortunately the poor preservation of most *dolia* wrecks inhibits any definitive conclusions about their construction. Aside from the Ladispoli wreck, the only other *dolia* carriers to be extensively studied, the Grand Ribaud D wreck (1st century B.C.E.) and the Giraglia wreck (1st century C.E.), include only a few poorly preserved hull fragments.[114]

---

[109] Brenni 1985, 6, 18.
[110] Brenni 1985, 60.
[111] Brenni 1985, 53. At the time that Brenni wrote his thesis, only *dolia* wrecks had been discovered. Since then 4 more have been found including the Golfe de Baratti wreck (Olschki and Mannelli 1961), the La Giraglia wreck (Marlier and Sibella 2002), the Cala di Conca wreck and the Meloria B wreck (Bargagliotti et al. 1997).
[112] Marlier and Sibella 2002, 169.
[113] Marlier and Sibella 2002, 161.
[114] Hesnard et al. 1988, 106; Marlier and Sibella 2002, 164-65.

The best preserved of the *dolia* wrecks was found near the town of Ladispoli, Italy – approximately 40 km from Rome and dated to the 1st century C.E.[115] A 6.6 x 3.3 m section of the ship was preserved, from which the ship was estimated to have been 18 m in total length. The ship was built shell-first using pegged mortise-and-tenon joinery and had an estimated cargo capacity of 45 to 50 tons. The hull did not have a wine-glass shaped section, but instead a flat bilge with a relatively straight keel. The frames were spaced between 0.12 to 0.15 m apart, and rarely more than 0.20 m. With an average sided dimension of 0.10 m, the average center-to-center frame spacing was 0.22 to 0.25 m.[116] The floor timbers were described by the excavator as true flat-floored timbers with a fairly consistent moulded dimension – approximately 0.20 m over the keel and 0.18 m at the preserved extremity.[117] The bottoms of the frames were carefully shaped to fit onto the planking but did not make contact with the keel, nor were they fastened to it in any manner.

The remains of futtocks were visible for some of the frames though they were in poor condition. The futtocks did not make contact with the frames, although the ends were beveled and spaced about .02 m apart. There was no apparent regularity as to where in the hull the futtocks and the frames met. The excavator pointed out one peculiarity observed in the framing – instead of being centered on the keel, most of the floor timbers were alternatingly offset. One floor timber was placed with a longer arm

[115] Carre 1993, 12-24.
[116] Carre 1993, 16.
[117] Carre 1993, 16.

on the port side and the next floor timber was placed with a longer arm on the starboard side; two alternating offset frames were considered partnered floor timbers. Like the offset half-frames seen with the Antirhodos ship, these asymmetrical floor timbers were designed to more evenly distribute the loads being exerted on the hull by the cargo of large and very heavy *dolia*. However, the evidence for these asymmetrical floor timbers is speculative due to the wreck's poor preservation. Based on the site plan, it is difficult to discern any set of frames as opposing partners. Even the excavator admits that the data from the wreck are not substantial enough to draw any conclusions about the significance of this pattern to the ship's construction. This system of asymmetrical floor timbers becomes more prevalent over time, likely indicating a shortage of resources for shipbuilding.

While this ship has the same basic framing elements (floor timbers, half-frames, and futtocks), they are not arranged in the standard pattern of a single floor timber alternating with a paired half-frame. The Ladispoli wreck has 21 successive floor timbers in the surviving portion of the hull. Conceptually, the use of successive floor timbers was meant to strengthen the midsection of the hull where the cargo was stored. While the use of successive floor timbers is preceded by the Sud-Lavezzi II and Chrétienne A ships, among others, the Ladispoli ship marks the feature's most extensive application.[118] This is noteworthy because a system of successive floor timbers ultimately replaces floor

[118] Carre 1993, 14; Liou and Domergue 1990, 121.

timbers alternating with paired half-frames, but not until almost a millennium later – in the aforementioned Serçe Limanı vessel, which dates to the early 11th century C.E.[119]

The Serçe Limanı ship provides several other parallels for features seen in the Ladispoli ship. Also a flat-floored merchantman, the Serçe Limanı ship displays successive floor timbers in the hold area, with a similar pattern of alternatingly placed long and short arms of the floor timbers. The better-preserved hull from Serçe Limanı allowed these floor timbers to be more extensively studied and described as 'in-line framing.'[120] The long arm of the floor timber extended above the turn of the bilge, while the short arm terminated inboard of the turn of the bilge. This arrangement would add strength to the ship's most vulnerable zone while minimizing the number of large timbers required for framing. Unfortunately, the limited preservation of the Ladispoli ship makes it impossible to discern whether or not this was related to in-line framing.

It follows logically that the two ships, despite being separated in time by nearly a millennium, would exhibit such similarities in their construction. Since they are both merchantmen, the shipwrights are attempting to maximize the cargo carrying capacities of both ships. These comparable features are not suggestive of any shared framing tradition, or meant to imply that the construction of *dolia* carriers is frame-based. Pegged mortise-and-tenon joints provide the majority of the Ladispoli ship's hull rigidity, but they are completely absent from the Serçe Limanı vessel. Regardless, we see how

[119] Matthews and Steffy 2004, 88-97.
[120] Pulak et al. 2015a, 69.

the function of a ship can greatly influence its shape and construction features, even after the implementation of an entirely new conceptual approach to shipbuilding. Ultimately, as a result of their design or operation, the *dolia* ships were a failure whether by design or impracticality of transporting wine (and other commodities) in huge earthernware vessels that disappeared from the archaeological record by the 3rd century C.E. However, after continued experimentation to determine their effectiveness in reinforcing flat-floored vessels, successive floor timbers, in some form or another, persisted through the next millennium.

A wreck located just south of Corsica, known as the Sud-Lavezzi II ship, dated to the 1st century C.E., was estimated to be 20 m in length and carried 26 tons of cargo consisting of metal ingots and amphorae.[121] Clearly built on shell-based principles, as indicated by the use of closely spaced pegged mortise-and-tenon joinery, the framing pattern deviated from the standard arrangement of floor timbers alternating with paired half-frames by its use of successive floor timbers.[122] Near the bow, a floor timber was followed by one pair half-frames, three successive floor timbers, a paired half-frame, and another three successive floor timbers. Elsewhere on the ship, the framing was much more degraded, which made it difficult to assess the intended pattern, although there was indisputable evidence for the existence of three successive floor timbers.[123] Enough of the framing elements survived for the excavators to conclude that the ship exhibited

[121] Liou and Domergue 1990, 13-21.
[122] Liou and Domergue 1990, 115-21.
[123] Liou and Domergue 1990, 121.

a pattern of three successive floor timbers alternating with two pairs of half-frames throughout the central section of the hull.[124]

Basing the framing pattern on what is seen at the extremities of a ship should be done with caution, as these are areas where the framing tends to be irregular due to the pronounced curvature of the bow and stern and the difficulty in fitting frames to such tightly curved parts of the hull. However, if the Sud-Lavezzi II wreck did exhibit such an irregular framing pattern throughout the hull, it would provide a noteworthy comparison for the Ladispoli wreck. Both of these vessels carried a dense cargo (metal ingots on the Sud-Lavezzi II ship) or an irregular cargo (*dolia* filled with wine), which suggests these hulls were built with a reinforced framing pattern.[125] However, the framing pattern seen in the Sud-Lavezzi II ship was a single occurrence, and the *dolia* carriers may have had critical flaws in their construction; it can be concluded that neither of these irregular framing configurations was significant enough to bring about far-ranging changes in framing hulls.

The 1st century C.E. is marked by several examples of anomalous framing patterns, particularly when looking at the *dolia* wrecks, yet there is very little change in the standard arrangement of floor timbers alternating with paired half-frames. Wrecks like the Antirhodos ship show that the idealized version of framing is mostly consistent

---

[124] Liou and Domergue 1990, 121.

[125] If these vessels were purpose built or modified for the purpose of carrying heavy and concentrated cargos, it marks a conceptual shift in the construction of ships designed to carry heavy, dense, and concentrated cargos. In the Hellenistic period, it appears that stone carrying ships, *navis lapidaria*, were not being purpose built or modified to accommodate their cargo (Littlefield 2012, 153-4).

with the previous centuries: floor timbers extending from one turn of the bilge to the other, non-scarfed paired half-frames that begin near the keel, and futtocks that continue to be used erratically. However, this century also introduces asymmetrical paired half-frames – seen in the Antirhodos, Kinneret, and Rabiou vessels – and asymmetrical floor timbers.[126] Suddenly, after centuries of stasis in frame development, shipwrights from across the Mediterranean began to experiment with what had been a standardized pattern of floor timbers alternating with paired half-frames. But what was the impetus for the changes seen during this century? These early deviations would have had limited effect on increasing the hull's rigidity and may have been caused by resource limitation. However, some of these new features persisted through the next several centuries in a more developed form, suggesting these variations were advantageous or that resource allocation became increasingly less problematic. Otherwise, the overall trend in ship framing in the Mediterranean during the 1st century CE appears to have changed very little.

[126] Steffy 1987, 325; Joncheray and Joncheray 2009, 74.

CHAPTER VIII

2nd CENTURY C.E.

Archaeological evidence for framing in Mediterranean ships in the 2nd century C.E. is significantly reduced in comparison to the previous century; however, based on the available wrecks, the standardized pattern of floor timbers alternating with paired half-frames persists. Six shipwrecks dated to this century are studied.[127] While asymmetrical framing appears in the 1st century C.E., the ships dated to the next century exhibit a more extensive application of this feature, which at first glance appears to mark a significant development in framing. The use of asymmetrical frames is hypothesized as an attempt by shipwrights to avoid creating areas of weakness in the hull.[128] Shipwrights offset the alignment of the joins between futtocks and their partnered frames, which prevents weak points created by a chain of non-reinforced strakes along the hull. Contrary to this prevalent theory, the indiscriminate and nonintegrated application of this feature instead suggests that asymmetrical framing is a consequence of resource limitation, rather than a systematic effort to strengthen the ship. Overall, framing in the 2nd century C.E. is marked by increasing deviation from the standard

---

[127] The Fiumicino 4 (Jézégou 2011, 169; 171; 175), Fiumicino 5 (Boetto 2001, 123; Boetto 2006, 123, 124; http://www2.rgzm.de/navis/home/..%5CShips%5CShip055%5CFiumicino5engl.htm), Grado (Beltrame and Gaddi 2007, 138, 142-4, 145-6), and St Gervais III (Liou et al. 1990, 219-32, 234, 259-9), shipwrecks are dated to the 2nd century CE. The Torre Sgarrata (Throckmorton 1989, 263, 264, 265, 266) and Olbia-Sardinia (Riccardi 2001, 493, 494, 495) shipwrecks are dated to the end of the 2nd century CE to the start of the 3rd century CE.

[128] Pomey et al. 2012, 298.

pattern; this is not, however, indicative of any conceptual changes to the role of framing in ship construction or hull rigidity.

The Grado wreck is a clear example of the use of asymmetrical framing elements that do not significantly impact the hull. The wreck was discovered off the coast of Italy, near the town of Grado, and had a surviving section that measured 13.1 m in length by 6.1 m in width.[129] The cargo, which totaled between 23 to 25 tons in weight, dated the wreck to the 2nd century C.E.[130] What made the framing of this vessel particularly interesting was its overall irregularity. The ship displayed floor timbers alternating with paired half-frames spaced 0.14 to 0.17 m apart on average.[131] Some of the floor timbers were designed in a more traditional manner, spanning from one turn of the bilge to another. Many floor timbers did not fit this pattern – these frames varied greatly in length and were offset from the central axis of the ship, resulting in alternating long and short arms of floor timbers on either side of the keel. The arrangement of asymmetrical floor timbers is shown in figure 4. However, no regular pattern exists in the alternation of the floor timbers, suggesting that the framing system was not designed to purposefully increase the rigidity of the hull.

Many, if not all, of the paired half-frames were also offset from the central axis of the keel, and, like the floor timbers, displayed little consistency in the positioning of the joins between pairs. The floor timbers and half-frames were extended with

[129] Beltrame and Gaddi 2007, 138.
[130] Beltrame and Gaddi 2007, 138.
[131] Beltrame and Gaddi 2007, 142.

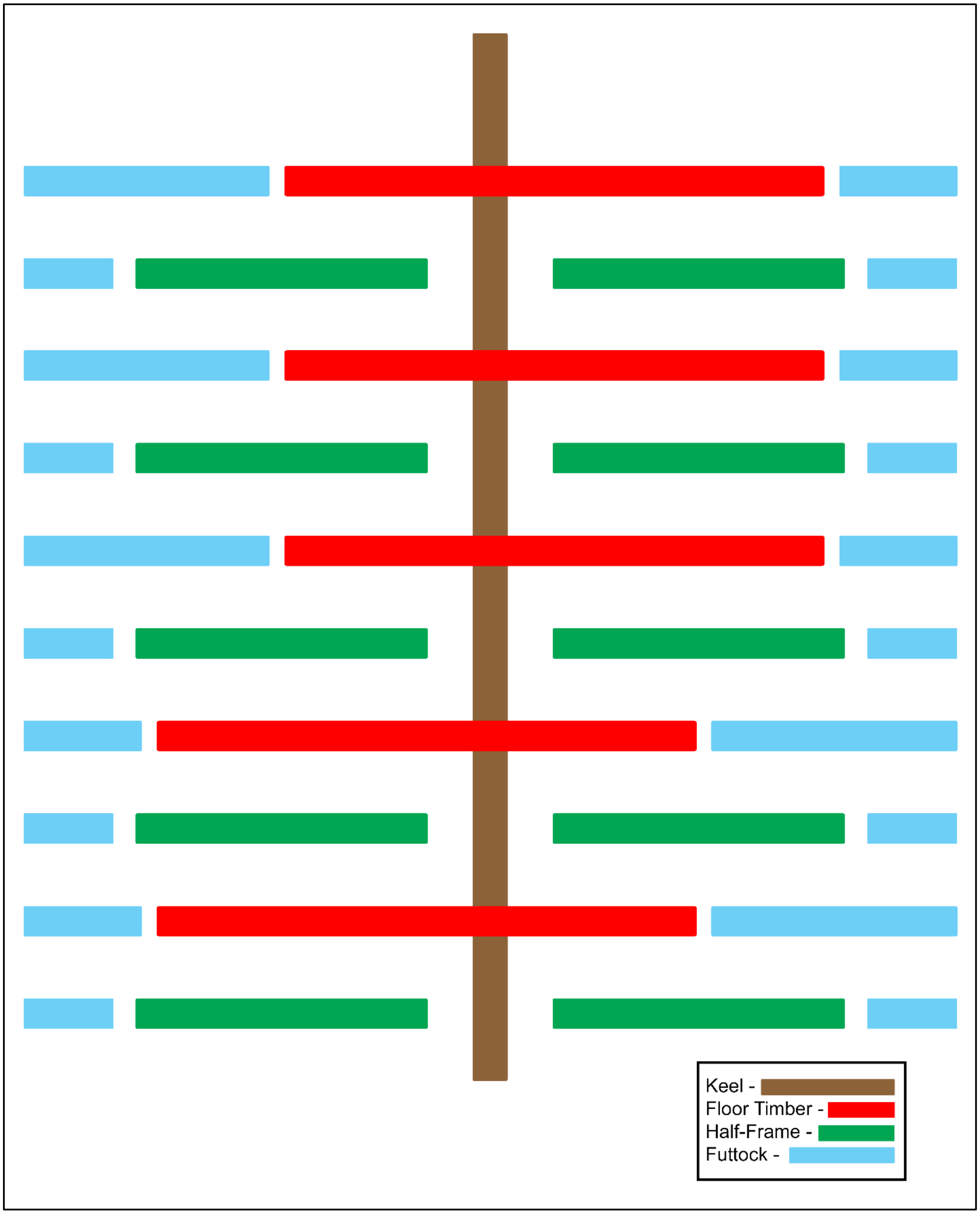

Figure 4. Asymmetrical floor timbers alternating with paired half-frames.

futtocks that were not fastened to their partnered framing element, though there were a few rare instances of the butt-scarfing between the timbers. The frames were fastened to the hull with an assortment of wooden, copper alloy, and iron nails. Two of the floor timbers were fastened to the keel with large nails or spikes.

As previously mentioned, it has been argued that the asymmetrical arrangement of frames within the hull was done purposefully to distribute the weak points between the futtocks and the partnered framing elements.[132] However, taking into consideration the other framing features that are present, this seems unlikely. All of the framing elements in the Grado wreck are from naturally curved branches, or compass timbers, which gives them significant inherent strength. The usage of compass timbers, which are carefully chosen for their uniform and regular appearance, predates even the Kyrenia ship. The Kyrenia ship's frames are square in cross section with relatively little shaping required; in many instances, bark is present on the timbers. In contrast, the Grado ship's timbers are highly irregular in shape and size; their sinuousness suggests either a limitation of adequate wood and/or manpower, a need or desire to reduce costs, or a level of unprecedented carelessness when choosing compass timbers to list a few of the more likely possibilities. Perhaps, the shipwrights were stockpiling a general source of timbers potentially suitable for framing, rather than individually selecting timbers for a given ship. The frames are also disproportionately worked – some are only slightly shaped with adzes, some are just halved branches, and others are sawn on all four sides.

[132] Pomey et al. 2012, 298; Pomey 1998, 68.

All of the frames are leveled on their tops and bottoms – the two functional faces – which corroborate the idea that shipwrights are limited by manpower or time or costs. Their irregular appearance exacerbates the asymmetrical nature of many of the framing elements; therefore, what appears to be a purposefully offset frame might instead be an accidental consequence of timber selection and shaping. The presence of metal nails on the bottom of frames that have no corresponding nails on the planking hints at the fact that some of the framing timbers are reused, substantiating the possible existence of a stockpile of suitable framing timber although it could also be a evidence that the ship had been re-planked. The only comparable vessel from previous centuries is the Kinneret boat – a vessel that is considered to be representative of a timber shortage.[133] While the Grado ship had a long life span, undergoing several repairs, there is only evidence for one frame being replaced (based on wood species identification).[134] Therefore, repair and replacement does not adequately explain the high irregularity exhibited by the ship's framing. The use of unconventional compass timbers, inconsistent shapes of frames, and potentially reused framing elements provides strong evidence that the framing system of the Grado vessel is a result of cost-saving measures, not strategic planning by the shipwrights.

One of several wrecks discovered off the coast of southern France near Saint-Gervais, the Saint-Gervais III wreck was dated to the mid-2nd century C.E. based on its

[133] Steffy 1994, 65.
[134] Beltrame and Gaddi 2007, 144.

associated pottery.[135] The ship was preserved for a length of 14.7 m and a width of 6.6 m, and the reconstructed size was 17 by 7.5 m.[136] The midship frame was flat-floored with a rounded turn of the bilge. There were 55 surviving frames, all of which followed the standardized pattern of floor timbers alternating with paired half-frames. Most of the paired half-frames met over the keel and were not scarfed to each other. There were two pairs of asymmetrical half-frames that would not have had contributed to the hull's rigidity.[137] Both the floor timbers and the paired half-frames were extended by futtocks. Generally, the futtocks were butt-scarfed to their partnered primary framing element but not fastened to them. In a few cases, where the futtocks were not butt-scarfed, wedges were used to fill the gap between the two. The frames averaged 0.14 to 0.16 m sided and 0.13 m moulded, and spaced 0.28 to 0.30 m apart. The frames were fastened to each strake with paired treenails, as well as copper nails at the bow. Three of the floor timbers were fastened to the keel with copper bolts, two of which were in association with the keel scarfs.

One notable feature seen in the framing of the Saint-Gervais III wreck has been interpreted as early evidence for active frames.[138] Three mortise-and-tenon joint pegs were driven from the exterior of the hull at the level of strake 7 and 8 under two floor timbers near the bow, while all the other pegs were driven from the interior of the hull.

[135] Liou et al. 1990, 177.
[136] Liou et al. 1990, 219.
[137] Liou et al. 1990, 219-29.
[138] Liou et al. 1990, 232-33.

This could indicate that the floor timbers in question were erected early on in the construction process, and were already in place when the planking was being assembled. However, the limited application of these exterior-driven pegs is more likely the result of repairs after the initial construction of the vessel.

Framing in the 2nd century C.E. appears to be taking a counter-intuitive step by becoming more irregular as time progresses; however, this does not appear to be strategically driven by the shipwrights and is therefore not indicative of framing development. The offset framing does not signify a purposeful arrangement, a fact that is discernable in the irregularity of the asymmetry. The enduring uniformity in Mediterranean ship framing indicates that regularity and standardization are advantageous to ship construction, as they allow shipwrights to reliably build vessels that are capable of serving their intended purpose. The question then becomes: why would asymmetrical framing be used at all?

Given the irregular and nonintegrated application of asymmetrical framing, it is unlikely for it to be a strategic development by shipwrights designed to increase the rigidity and strength of hulls. The best alternative explanation is a paucity of resources – manpower, timber, or time. This motivating factor appears to be the general desire to reduce costs in ship construction. As framing is still secondary to pegged mortise-and-tenon edge joinery of planking in terms of a ship's structural integrity, it is an easy opportunity to reduce costs. As long as the framing loosely follows the pattern of floor timbers alternating with paired half-frames, it still adequately reinforces the hull.

Overall, the idiosyncrasies of framing in the 2nd century C.E. provide little evidence for growing sophistication or an increased structural role of floor timbers alternating with paired half-frames.

CHAPTER IX

3rd CENTURY C.E.

Hull framing in the 3rd century C.E. shows a continued deviation from the standardized pattern of floor timbers alternating with paired half-frames with the use of asymmetrical framing components that were characteristic of ships in the previous century. The archaeological evidence of framing in this century is limited and primarily comes from the central and western Mediterranean. Five shipwrecks are dated to this century and reviewed.[139] Framing maintains its role as a secondary source of reinforcement to the pegged mortise-and-tenon edge-joinery in the hull, but continues to display less, rather than more, regularity as time progresses. The ideal framing archetype remains as follows: floor timbers spanning from one turn of the bilge to the other, paired half-frames beginning off the keel and extending through the turn of the bilge, and futtocks that are in-line with their partnered frames but still unfastened. However, the unsystematic placement of the frames remains the biggest point of irregularity visible among the wrecks of this period. Whether a consequence of resource limitation or an indicator of their experimentation with the application of novel framing systems, the shipwrights no longer strictly adhered to a standardized framing tradition.

[139] The Laurons II (Gassend et al. 1984, fig. 10, 85-6, fig. 17a-d, 98, fig. 22, 103-5; Ximénès and Moerman 1991, 221), La Bourse (Gassend 1982, 80-1, 94, 121; Cuomo and Gassend 1982, fig. 5; Carre 1998, 101), Laurons III (Ximénès and Moerman 1987, 174-7, fig. 5), and the Marseille 7/ Jules Verne 8 (Pomey 1995, 462-3) shipwrecks are dated to the 3rd century CE. The Napoli B shipwreck (Giampala et al. 2005, 69-72) is dated to the end of the 2nd century and the beginning of the 3rd century CE.

The Bourse, or Lacydon, ship was dated between 190 and 220 C.E., and found near Marseille.[140] The preserved portions of the vessel measured 20 m in length and 7 m in width, while the estimated original dimensions were 23 by 9 m.[141] The vessel was fairly flat-floored, with a rounded turn of the bilge and built using pegged mortise-and-tenon edge-joinery. It had a total of 65 preserved frames that revealed a pattern of floor timbers alternating with paired half-frames.[142] The floor timbers varied significantly in their length and orientation – while several were centered over the keel, many were not. As with other ships that employed asymmetrical floor timbers, there was almost no pattern or regularity to their application. Short floor timbers were used at the extremities of the vessel, often a necessity due to the pronounced curvature of the hull at their locations, but there were several short floors also used near amidships, which was uncommon.

Like the floor timbers, the majority of the paired half-frames were centered over the keel, but several others were offset from the central axis over the keel. Many of these asymmetrical half-frames were found in the center of the hull, in which the meeting points between the paired half-frames were offset in an alternating manner on the starboard and port sides of the vessel. This regular pattern could suggest a certain degree of strategic frame placement by the shipwright to balance the weak points located between the paired timbers. The futtocks and their partnered framing timbers

140 Carre 1998, 101.
141 Gassend 1982, 93-4.
142 Gassend 1982, 80-1.

were butt-scarfed together but not fastened to one another. The frames averaged 0.08 m sided and 0.15 m moulded dimensions, with an average room-and-space of 0.25 m. Frames were fastened to the planks with treenails and eight of the floor timbers were bolted to the keel.

Of the eight bolted floor timbers, four are associated with a keel-endpost scarf. The other four are spaced every 8th to 10th frame.[143] Bolting frames (including those coupled with keel scarfs) is not unprecedented, though the regular spacing of these fastenings is curious. It is possible that shipwrights were interested in expanding the use of bolts to strengthen the spine of the vessel. Although some scholars may argue that the use of frequent bolts is indicative of the development toward framed-based construction, the limited application seen here is a method of keel reinforcement rather than evidence for the expanded role of framing in ship construction.

While the asymmetry of the Bourse vessel is pronounced, at its core the framing system consists of floor timbers alternating with paired half-frames, however irregular it may appear. The combined use of asymmetrical floor timbers with asymmetrical paired half-frames is shown in figure 5. Much of the irregularity appears in the midsection of the ship, which is easily explained by problems in procuring timber for the vessel's construction or another type of resource scarcity, or other economic factors necessitating reduced costs in ship construction. With an estimated breadth of 9 m, it could be very difficult to find timbers that span the entire breadth of the hull, forcing

[143] Gassend 1982, 80-1.

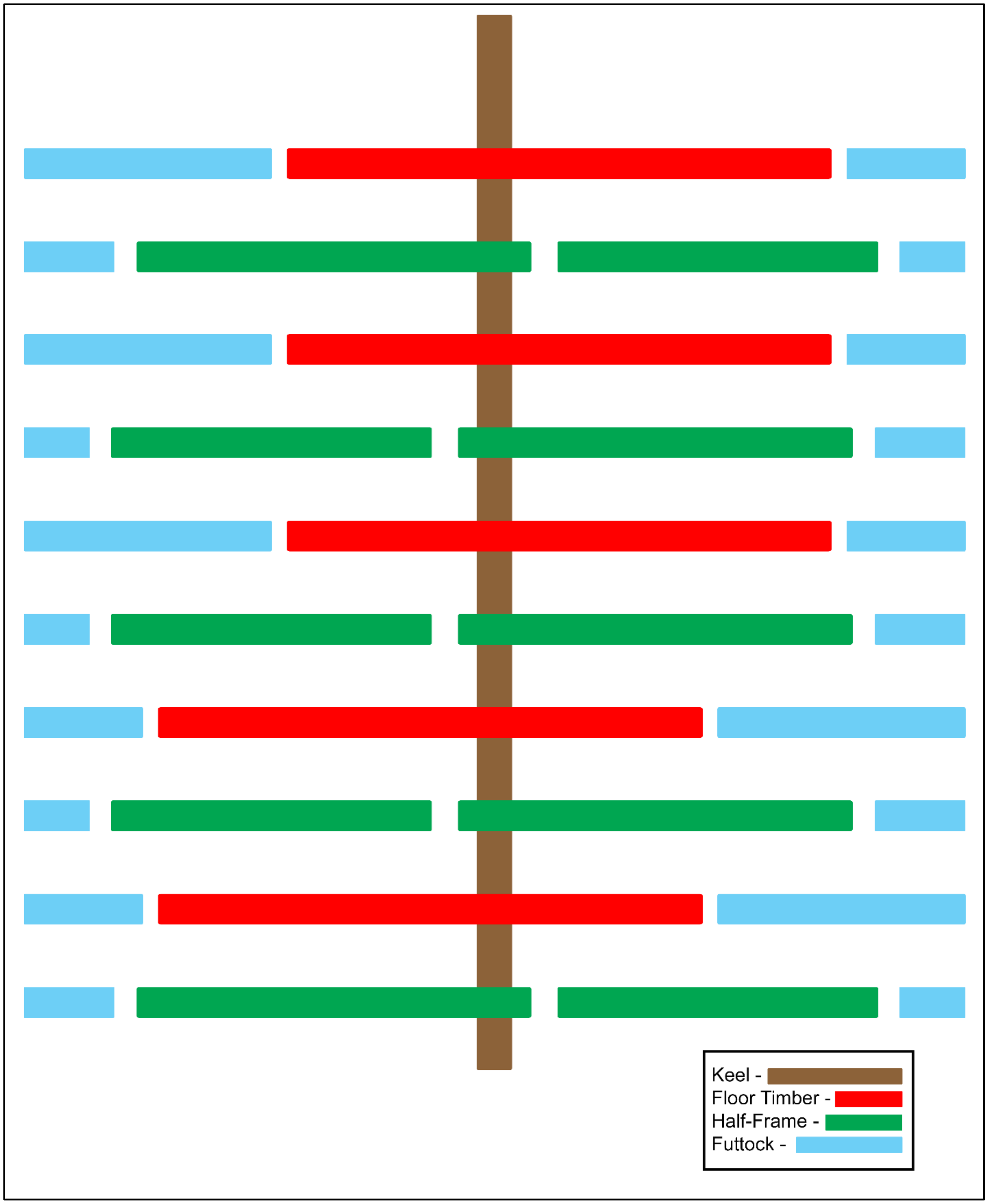

Figure 5. Asymmetrical floor timbers alternating with asymmetrical paired half-frames.

builders to use several smaller timbers. The framing elements of the Bourse ship remain nonintegrated and are comparable to those seen in the 2nd century C.E. Grado wreck. The similarity in framing between these ships substantiates the conclusion that no major conceptual change in framing has occurred in the construction of the Bourse wreck.

A number of wrecks were discovered in the Golfe de Fos in France, one of which was dated to the end of the 3rd century C.E.[144] Relatively flat-floored with a rounded turn of the bilge, the vessel was built using pegged mortise-and-tenon edge-joinery.[145] The ship, called the L'Anse de Laurons II, was preserved for a length of 13.3 m and a width of 6 m, and the reconstructed dimensions were 15 by 5 m. One of the most exceptional features of this ship was that its bulwarks, deck beams, deck planking and other features of the top deck were preserved – including the extremities of the frames.[146] The general framing pattern of the ship consisted of floor timbers alternating with paired half-frames as evidenced by the 55 preserved frames.[147] Floor timbers ranged from 2.5 to 3.0 m in length, and generally extended from one turn of the bilge to the other. There were examples of shorter floor timbers, even amidships, where a small, intermediate futtock was used before a longer, more typical futtock. Some of the paired half-frames began over the keel, but there were many examples of paired half-frames that were offset from

---

144 Gassend et al. 1984, 76. This ship was first dated to the end of the 2nd century CE but was re-dated on the basis of a coin in the pitch covering ceiling planking and an analysis of some of the ship's ceramics (Ximénès and Moerman 1991, 221).
145 Gassend et al. 1984, 88-9.
146 Gassend et al. 1984, 78-86.
147 Gassend et al. 1984, 98.

the central axis. Some of these asymmetrical pairs were only slightly offset while others, particularly towards amidships, were much farther offset. Futtocks were in-line with their partnered framing timbers; either butt-scarfed or slightly spaced, but never fastened.

The unusual preservation of the deck revealed the way in which the futtocks extended above the deck line, where they formed part of the bulwark supports. In addition to supporting the bulwark planting, the futtocks also supported the caprail.[148] The sided dimension of the frames averaged 0.07 to 0.09 m and the center-to-center spacing averaged 0.20 to 0.22 m. The moulded dimension of the floor timbers ranged from 0.20 m over the keel to 0.10 m at their extremity; the half-frames' moulded dimension was more consistent at 0.09 m. Four floor timbers were fastened to the keel with iron bolts; three were used to reinforce a keel-endpost scarf, while the fourth was found at the center of an endpost. Frames were fastened to the planking with a pair of treenails driven from the exterior of each strake, and either copper or bronze nails were added to reinforce the garboard and the second strake.

The framing of the L'Anse de Laurons II vessel is best characterized as traditional, with some irregularity in timber selection and placement, and therefore not suggestive of conceptual or functional changes in the framing system. The unique feature visible in this ship is the use of futtocks, or top timbers in some cases, to form the stanchions for the bulwarks. The majority of the floor timbers continue to span the hull from one turn

[148] These futtocks can also be called top timbers as they are the uppermost frame timber.

of the bilge to another; when the floor timbers are too short to bridge this distance, short, intermediate futtocks are used. Paired half-frames are still applied in a conventional manner, although several asymmetrical half-frames are also present.

The use of short framing timbers as well as highly asymmetrical framing timbers provides further evidence that irregular framing is a tradeoff to limit cost. Since these short timbers do not provide significant structural benefits to the vessel, their use in construction by shipwrights may indicate a shortage of resources. Despite this seeming resource limitation, the shipwrights tried to adhere to the standardized framing tradition by substituting the larger timbers for the more easily procured timbers. The overall usage of floor timbers alternating with paired half-frames remains a secondary form of hull reinforcement.

The Lacydon and the L'Anse de Laurons II wrecks exemplify the continued variability that is characteristic of ship framing in the 3rd century C.E. As with the previous century, this is reflected in the use of asymmetrical floor timbers and half-frames in all areas of the hull. The framing seen in the Lacydon ship is an extreme example of irregularity in both timber size and placement; there is so much internal variation that in some cases, it can be difficult to distinguish the floor timbers and the half-frames. The framing of the L'Anse de Laurons II ship is a more typical example of floor timbers alternating with paired half-frames using the asymmetrical placement of framing elements. In spite of some peculiarities in the framing pattern, the conceptual approach to framing has not changed in the 3rd century C.E.; the idealized pattern persists as floor timbers alternating with paired half-frames – making it obvious that framing has yet to develop a more imperative role in ship construction at this time.

CHAPTER X

4th CENTURY C.E.

The 4th century C.E. marks some of the first signs of the transition from shell to frame-based construction, yet very few of these changes are reflected in the framing. Unfortunately, there are fewer wrecks from this century in comparison to previous centuries, but the available wrecks are well-preserved. There are six shipwrecks reviewed for this century.[149] Some developments continue from the previous century; such as more closely spaced framing elements and the more systematic use of bolts to secure. However, the asymmetry that was common during the last few centuries is noticeably reduced; floor timbers are all fairly centered and there are only a few examples of asymmetrically placed half-frames. Although the pattern of floor timbers alternating with paired half-frames persists as the standard framing system, there is a reduced emphasis on the edge-joinery of planking – the primary source of hull strength in shell-based construction.

One of the most significant wrecks of this period was at Yassıada, known as the Yassıada II wreck. Located off the coast of Bodrum, Turkey, the sinking of vessel was dated to the end of the 4th century or, more likely, to the beginning of the 5th century

[149] The following shipwrecks are reviewed for this century: Port Vendres A (Chevalier and Santamaria 1973, 9, 18-21), Dramont F (Joncheray 1975b, 108, 120-3, 131; Joncheray 1977, 5, 6, 7), Pointe de la Luque B (Clerc and Negrel 1973, 65-6, 68), Fuimicino 1 (Boetto 2000, 99, 100; Boetto 2001, 124-5; Boetto 2003, 66, 67; Boetto 2008, 42-5, 51, 53-5), Fuimicino 2 (Boetto 2001, 124), Yassıada II (Bass and van Doorninck 1971, 29, 31-2, 33-4, 37; van Doorninck 1976, 124-7) shipwrecks.

based on its associated ceramics.[150] The original length and beam of the vessel was 19 by 6.6 m, and luckily, most of the length of the ship was preserved.[151] Following what appears to be a developing trend for this century, the Yassıada II ship was built using loose fitting mortise-and-tenon edge joinery. Forty-eight of the estimated 68 frames survived, revealing a pattern of floor timbers alternating with paired half-frames.[152] The floor timbers terminated variably between the 10th and 17th strakes but most commonly between the 13th and 16th strakes. The paired half-frames were abutted over the keel though not fastened to each other. Similarly, the futtocks were mostly scarfed to their partnered framing timbers with a butt-joint. However, three futtocks slightly overlapped their partnered floor timbers: B4, B8, and B15. The most unusual of these was B4, which had a carefully cut scarf to fit into its partnered floor timber. None of the futtocks were fastened to their partnered framing timbers, though one short futtock was fastened to a second futtock with a treenail.[153] Generally, the frames were fastened to the planking with treenails.

Seven of the floor timbers were bolted to either the keel or the stern post. The bolts had been inserted from the exterior and their primary purpose was to secure the keel to the potential sternson, which was not preserved. The bolted floor timbers had the largest sided dimension, ranging from 0.13 to 0.15 m, while the other floor timbers

[150] Bass and van Doorninck 1971, 37.
[151] Bass and van Doorninck 1971, 29-30.
[152] Bass and van Doorninck 1971, 31-2.
[153] Bass and van Doorninck 1971, 32.

ranged from 0.12 to 0.14 m.[154] Futtocks were as much as 0.04 to 0.05 m narrower than their floor timbers, while the sided dimensions of the half-frames ranged from 0.08 to 0.13 m. The moulded dimension for all the frames was relatively consistent at 0.123 m, although over the keel it increased to 0.15 m. The average center-to-center spacing was just under 0.27 m.[155] Surprisingly, the frame spacing was tightest in the same two areas of the hull where the mortise-and-tenon joints were most closely spaced.[156] One would expect the frame spacing to be tighter where the strength of the mortise-and-tenon joints was weakest, i.e., where they were most widely spread.

Notably, there is indirect evidence for the installation of a pair of half-frames amidships (B7) as early as the placement of the 5th strake.[157] The pegs for the mortise-and-tenon edge joinery of the planking were only found under these paired frames up through the 4th strake, suggesting that the presence of the half-frame impeded any further insertion of pegs on the 5th strake and above. Plank edge joints were not in close proximity to these half-frames; between strakes 6 through 20, the closest were between 0.4 to 0.6 m away. The shipwrights instead fastened the planking to these half-frames using a pair of nails, one from each side of the scarf.[158] The reason for the early placement of these paired half-frames is unclear, but they probably served as a control

[154] It is noteworthy that the sided dimension of bolted floor timbers is the widest. This appears to be a purposeful decision on the part of the shipwrights.
[155] van Doorninck 1976, 124.
[156] van Doorninck 1976, 124.
[157] van Doorninck 1976, 126-7.
[158] van Doorninck 1976, 126.

or a guide in the placement of the subsequent strakes. The unanswered question is why the shipwright, who likely had a great deal of experience building ships in the shell-based method, needed the assistance of a guiding frame.

The framing of the Yassıada II ship remains consistent with the standardized pattern of floor timbers that generally span from one turn of the bilge to the other alternating with paired half-frames that are abutted over the top of the keel or very close to it. The absence of asymmetrical floor timbers could indicate that the shipwright had more sufficient access to resources than those in prior centuries. That the paired midship frame B7 is installed prior to the completion of the planking is a significant marker in terms of ship construction. Based on the frames of the 4th-century B.C.E. Kyrenia wreck, Steffy concluded that the half-frames were not installed until the planking was completed.[159] In the Yassıada II ship, the widening of the planking edge-joinery allows for more shifting of the strakes during the building process; therefore, at least one of the half-frames was installed earlier in the construction sequence to provide additional surfaces to which the shipwrights can secure the planking until all strakes are fastened. More importantly, this frame provided a control for the ship's form as it represents the complete cross-section of the hull. While the framing has yet to be developed in a way that provides additional strength for the hull, there is an increased sophistication in how it was applied to solve structural problems during the construction process.

[159] Steffy 1994, 50.

The Pakoštane wreck was discovered in northern Dalmatia near its eponymous town in Croatia. The wreck was found at depth of 2.5 to 2.75 m and dated to the end of the 4th century C.E. based on its associated ceramics and construction.[160] The ship was preserved in two main sections: the first measured 9 by 2. 7 m while the second measured 7 by 3.5 m. The estimated length of the completed vessel was between 15 to 20 m.[161] A total of 33 framing stations were preserved on the hull presenting a pattern of floor timbers alternating with paired half-frames.[162] Unfortunately, only eight floor timbers and seven paired half-frames could be distinguished in the absence of a surviving keel, in addition to 24 futtocks.[163] There was no evidence to suggest the use of asymmetrical floor timbers or half-frames on the ship, potentially a consequence of the limited preservation of the hull.

The futtocks were generally butt-scarfed with their partnered framing timber though others were separated or placed beside the partnered framing timber.[164] There were a few examples of futtocks that were connected with a more elaborate scarf – there was a single long diagonal scarf and short variants of the S-scarf.[165] Also, the site map revealed several instances of a small futtock placed between a larger futtock and the partnered framing timber. The frames of the Pakoštane ship had a cross-section that

[160] Boetto et al. 2012, 128.
[161] Boetto et al. 2012, 128.
[162] Boetto et al. 2012, 118-20.
[163] Boetto et al. 2012, 118.
[164] Boetto et al. 2012, 120.
[165] Boetto et al. 2012, 120.

was almost square, measuring 0.094 m sided and 0.098 m moulded with some of the bilge corners rounded. At least three of the preserved floor timbers were fastened to the keel with iron bolts that were driven from underneath the keel.[166] The frames were fastened to the planking with a combination of unclenched metal nails (copper and iron) and treenails, both of which were driven in from the exterior.

This wreck is dated to the early stages of the development from shell- to frame-based construction and, consequently, it reveals certain transitional features. Like the Yassıada II ship, the Pakoštane ship has loosely fitting pegged mortise-and-tenons used in edge-joining of its planking.[167] However, unlike the Yassıada II ship, the Pakoštane ship comes from the central Mediterranean, thus revealing that the transition in ship construction is affecting ship building across the Mediterranean. Both the Yassıada II and Pakoštane ships have lost the asymmetrical framing that has been observed since the 1st century C.E. and consequently, the framing appears more regular. The resource scarcity that likely plagued earlier shipwrights may be entirely situational, rather than a regional or a pan-Mediterranean phenomenon. The shipwrights of these vessels may have had access to secure high-quality ship timbers, or those commissioning the vessel have had the means necessary to afford prime shipbuilding timbers. However, the absence of asymmetrical framing appears to be an aberration from the general pattern, as this feature is again observed in ships of the following century.

[166] Boetto et al. 2012, 120.
[167] Boetto et al. 2012, 118.

The 4th century C.E. marks the beginning of the transition away from shell-based construction, most notably in the widening and loosening of mortise-and-tenon edge-joinery. Shipwrights clearly became less dependent upon the internal strength imparted by these edge fasteners and developed a more sophisticated use for framing without significantly altering their pattern or secondary role in reinforcement. In frame-based construction, integrated framing replaces pegged mortise-and-tenon edge joinery as the primary source of hull strength; either the shipwrights did not think that the hull strength had been sufficiently compromised to merit additional reinforcement, or they did not yet conceptualize integrated framing as a means of accomplishing this feature. The ends of the paired half-frames were placed more closely together, the first stage in the eventual trend towards overlapping paired half-frames.[168] The continued use of the standardized framing pattern of floor timbers alternating with paired half-frames in both riverine and seagoing craft speaks to its universal applicability. Ultimately, framing in the 4th century C.E. has yet to develop in terms of design, pattern, or structural function.

[168] There are outliers in this century like the Dramont F wreck, which exhibited half-frames that started one meter away from the keel – however this is drawn from a single example (Joncheray 1975b, 123).

CHAPTER XI

5th CENTURY C.E.

Five shipwrecks are cataloged from the 5th century C.E.[169] Continuing the trend seen in the previous century, the shipwrecks from this century exhibit features that continue the conceptual break from the tightly fitting, closely fitting, and large pegged mortise-and-tenon joint tradition with widely spaced, loose fitting, small edge-fasteners, some of which were not pegged. Still, the framing does not display significant development or conceptual changes in its design or use. The wrecks of the 5th century C.E. indicate that the gradual transitioning from shell-based construction has not yet affected the integrated structural role of frames in shipbuilding.

A 5th-century C.E. wreck was discovered during excavations for the construction of the Theodoric Park in the city of Ravenna, Italy. The preserved dimensions of the vessel were 7.22 m in length by 2.75 m in width.[170] Estimated to have been originally 9 m in length by 3.1 m abeam, this ship had a cargo capacity of 4.85 tons.[171] The ship was almost flat-floored with a relatively gentle turn of the bilge.[172] This was a small vessel primarily designed to operate along the Italian coast, but could still sail in open water.

[169] These shipwrecks are the Ravenna (Medas 2001, 111; Medas 2003, 45-7), Padovetere (Beltrame and Costa 2016, 2, 5-7), Dramont E (Santamaria 1995, 116, 150-60, 175-6), YK 34 (Kocabaş 2015, 21-2), and the YK 35 (Kocabaş 2015, 23-6) shipwrecks.
[170] Medas 2003, 45.
[171] Medas 2003, 45.
[172] Medas 2003, 47.

The vessel was built using shell-based methods as evidenced by the planks that were fastened with unpegged and widely spaced mortise-and-tenon joinery.[173]

What made the Ravenna vessel particularly interesting was that, along with the observed changes in its edge joinery, it was not built with the typical framing arrangement of floor timbers alternating with paired half-frames. Instead, it exhibited successive floor timbers in the central portion of the hull, and what the excavator referred to as "high ribs without corresponding floor timbers or futtocks."[174] These appear to be short half-frames that were likely used to reinforce the steeply angled hull planking at the ship's extremities. Eighteen frames survived, measuring on average 0.07 to 0.08 m sided and 0.08 to 0.09 m moulded with spacing between the frames ranging from 0.20 to 0.30 m.[175] Three of the frames had futtocks that were fastened with an iron nail that was driven laterally, and some of the frames were fastened to the keel with iron nails. The frames were fastened to the planking using a combination of treenails and iron nails.

The Ravenna wreck offers some insight into the relationship between ship framing and the transitioning from the use of closely spaced and tightly fitting strong mortise-and-tenon edge-joinery. This vessel has a weak system of edge-joinery, particularly in comparison to those of earlier wrecks. The ship's framing system is seemingly stronger than the standard pattern of floor timbers alternating with paired

[173] Medas 2003, 46.
[174] Medas 2003, 46.
[175] Medas 2001, 111.

half-frames, leaving one to wonder if this is a purposeful substitution made by the shipwright to supplement any inherent weakness of the planking edge-joinery. The ship's excavator believes so, arguing that the rigidity of the hull is in fact reliant primarily on the framing system.[176] This may be inaccurate, as other vessels employ loose and unpegged mortise-and-tenon joinery, and are not dependent upon frames for their hull rigidity, but the excavator's claims are supported somewhat by the employment of successive floor timbers along the length of the hull.

Discovered near Cape Dramont, the Dramont E ship was dated between 425 and 455 C.E. based on coinage found in association with the wreck.[177] A portion of the hull measuring 12.84 by 5.54 m was preserved from an estimated original length of 15.5 to 16 m.[178] The hull had a wine-glass shaped profile with a round turn of the bilge and relatively loose mortise-and-tenon edge-joinery.[179] The ship exhibited a standard system of floor timbers alternating with paired half-frames.[180] The floor timbers were centered on the keel and varied in length from 2.35 to 3.92 m. There were two examples of asymmetrical floor timbers, with total lengths of 3.92 m and 2.52 m, and only 1.1 m and 0.46 m portions of them extending onto the port side, respectively.[181] As with earlier wrecks, the floor timbers were fashioned from compass timbers – adding considerably

[176] Medas 2003, 46.
[177] Santamaria 1995, 111.
[178] Santamaria 1995, 133, 176.
[179] Santamaria 1995, 150.
[180] Santamaria 1995, 150-60.
[181] Santamaria 1995, 150.

to their strength. Only the bottom faces of the floor timbers showed evidence of significant shaping; there were several instances of shims secured with treenails to fill in gaps between the frames and the planking.[182] The center-to-center distance was approximately 0.27 m, but a precise value was difficult to assess due to the highly sinuous nature of the frames.[183] The frames were fastened to the hull planking with treenails driven from the exterior of the hull, following a general rule of two per plank per frame, with the exception of the garboard strake where either bronze or iron nails were used. Five of the floor timbers were fastened to the keel with iron bolts, four of which did not directly penetrate through the keel-endpost scarfs, but were on either side of them – thus appearing to provide some reinforcement for the scarfing.[184]

The majority of the paired half-frames were centered over the keel, although some were referred to as being asymmetrical.[185] However, these asymmetrical half-frames were only slightly offset from the central axis of the ship, not nearly as extensive as the asymmetrical half-frames seen in hulls of previous centuries. The length of the half-frames varied considerably, ranging from 0.53 to 2.82 m. In all but two instances, the bottom faces of the half-frames were shaped to make contact with the planking.[186] Futtocks were generally butt-scarfed to their partnered framing timbers; there were examples of diagonal scarfing, but they were too short to have any structural

[182] Santamaria 1995, 154.
[183] Santamaria 1995, 150.
[184] Santamaria 1995, 154.
[185] Santamaria 1995, 154.
[186] Santamaria 1995, 154.

significance. There were a few examples of futtocks that overlapped, but were still unfastened to their partnered framing timbers, and instances of many short intermediate futtocks assembled in-line with longer futtocks. The joins between the futtocks and the floor timbers were offset by an additional 0.95 to 1.64 m from those with paired half-frames.

The framing seen in the Dramont E wreck is not noticeably different from those seen in the previous century, continuing the trend towards weaker mortise-and-tenon edge joinery. The framing remains disconnected and irregular, thus adding in no significant way to the hull's strength. Framing still plays a secondary structural role during the early stages of the transition to frame-based construction. The labor required for extensive shaping of frame timbers was applied primarily to the bottom faces, where the frames contact the hull planking, and even then some frames still had gaps that were bridged with shims. The shipwrights continue to rely on the strength inherent in compass timbers. The asymmetrical nature of the framing is best explained as a consequence of logistics rather than design. Like the asymmetrical framing of earlier centuries, this feature does not add strength or rigidity to the hull and likely resulted from difficulty of finding suitable construction timbers.

While framing development shows relative stagnation, the distance between the mortise-and-tenon edge joints increases even though the hull is clearly designed and built using the shell-based approach. This phenomenon continues to show a conceptual disconnect between the application of framing as a structural component and the move away from shell-based construction. This is a strong indication that the beginning phase of the transition is driven by changes in the ability to shape, install, and fasten planking during construction rather than by naval developments in framing systems. The framing in the 5th-century C.E. Dramont E wreck plays only a secondary role to the weak mortise-and-tenon edge joinery.

One other notable ship in the 5th century C.E. is a river barge from St. Maria in Padovetere, Italy. This ship is dated to the beginning of the 5th century based a coin and amphorae fragments found in association with the hull.[187] The hull is estimated to have had an original length of 22 m with a flat-floored cross-section to carry large and bulky cargoes.[188] There are two structural features that make this vessel noteworthy: the use of three types of hull edge-joinery techniques and its framing system. The bottom planking is sewn together, while the side planking uses a combination of unpegged mortise-and-tenon joinery and nails.[189] The hull exhibits successive paired L-shaped floor timbers, some of which are diagonally scarfed to their partnered futtocks.[190] The paired L-shaped floor timbers have an alternating long arm along the hull and are fastened with treenails. When the floor timbers are scarfed to their partnered futtock, it is to the short arm and the futtock is in-line with the floor timber.

[187] Beltrame and Costa 2016, 2.
[188] Beltrame and Costa 2016, 10-12.
[189] Beltrame and Costa 2016, 5-7.
[190] Beltrame and Costa 2016, 7.

The structural features of the Padovetere barge are representative of the construction techniques being used in the Adriatic at this time, but more importantly, the framing system is reflective of what is being used on riverine barges. This flat-floored framing system has yet to be applied to seagoing vessels, but will play an important role in the development of in-line framing beginning in the late 8th to early 9th centuries C.E. In-line framing, as observed in the Serçe Limanı ship, is a series of successive L-shaped floor timbers with alternating long arm along the hull, extended by futtocks.[191]

Despite evidence for some framing peculiarities in the 5th century C.E., the overall pattern, unsurprisingly, remains standard in seagoing ships – floor timbers alternating with paired half-frames. The Dramont E vessel is differentiated only by its asymmetrical framing, comparable to what is seen in the 1st through 3rd centuries C.E., and may indicate that the lack of asymmetry in the 4th century C.E. is anomalous. The wreck from Ravenna is built with successive L-shaped floor timbers and almost entirely without using paired half-frames. Archaeological evidence indicates that riverine vessels may have been using successive floor timbers since the 2nd century C.E., and the shallow-draft Ravenna ship may have followed this trend. Even in shallow-water vessels, which utilize a completely different manner of framing, the mortise-and-tenon edge-joinery of the planking becomes loosely fitted, more widely spaced, and unpegged.

Across the board in seagoing ship construction, all types of vessels now depart from this labor-intensive, closely spaced mortise-and-tenon joinery regardless of their

[191] Steffy 2004, 158.

framing pattern. Therefore, shipwrights are learning to rely less on the inherent strength of these joints, even without any corresponding developments in the design or application of framing. Scholars often consider the weakening of mortise-and-tenon edge-joinery to be an indicator of the shift *towards* frame-based construction, but there have yet to be any major changes in framing systems that could act to compensate for the reduced hull rigidity provided by these mortises-and-tenons joints. Rather, the weakening of edge joinery is indicative of a conceptual step *away* from shell-based construction, almost undoubtedly motivated by economic factors. It is not until the 7th century C.E. that one sees potential evidence for the further integration of framing into the hull.

CHAPTER XII

6th CENTURY C.E.

The archaeological evidence for ship construction in the 6th century C.E. is limited to a single well-published site, the Dor/Tantura Lagoon, in which three wrecks date to the 6th century: the Dor 2001/1, Tantura A, and probably also Dor 2006 ships.[192] Another contemporaneous wreck comes from Port Berteau, France; unfortunately, the ship had turned upside-down while sinking so little of its framing survived.[193] The excavations conducted in the Dor/Tantura Lagoon provide some of the most tantalizing evidence for the study of ancient ship construction to date. Only one wreck, Dor 2001/1, has a well-preserved framing arrangement, but all three shipwrecks reveal significant aberrations from the shell-built tradition, the most prominent of which is the complete lack of edge-fasteners on hull planking. This has led several researchers to suggest that the transition to frame-based construction started in the 6th century C.E. – much earlier than previously thought.[194] Unfortunately, the evidence is geographically limited and difficult to interpret. As discussed in the previous chapter, the weakening of planking edge-joinery only indicates a conceptual step away from the labor-intensive shell-based tradition, rather than a development towards frame-based construction. The Dor 2001/1 wreck exhibits only slight variations from the earlier common framing style, revealing that any

[192] The Dor 2006 ship dates to either the 6th or 7th century CE.
[193] Rieth et al. 2001, 36.
[194] Wilson 2011, 41; Pomey et al. 2012, 296.

weakness caused by the absence of planking edge-fasteners did not necessitate a corresponding advancement in framing. Building a ship that requires neither edge joinery nor any structural innovation suggests that the frames remain an ancillary feature, particularly considering the frames were not larger nor more closely spaced.

The Dor 2001/1 ship represents a coaster transporting 35 tons of construction stone to an unknown destination.[195] The ship was dated to the 6th century C.E. based on analysis of the associated ceramics and ^{14}C dating.[196] The preserved dimensions of the vessel measured 11.5 long by 4.5 m wide while the estimated original dimensions were 16.9 m in length and 5.4 m in breadth.[197] While a large portion of the hull was preserved, only a 2.5 m-long section was removed for careful examination and recording in laboratory conditions, limiting the extent to which the ship's construction can be analyzed.[198] The hull had a flat bilge with a hard turn of the bilge and straight sides, which would have given the vessel a barge-like appearance though the excavators indicate that the ship was not a barge.[199] By far, the most important feature was the absence of planking edge-joinery, which, until this point, had served as the primary source of hull strength and rigidity in the Mediterranean.[200]

A total of 79 framing elements survived at 42 frame stations, with evidence for

[195] Kahanov and Mor 2014, 63.
[196] Kahanov and Mor 2006, 41.
[197] Kahanov and Mor 2006, 62-3.
[198] Kahanov and Mor 2006, 41.
[199] Kahanov and Mor 2014, 41; 46.
[200] Kahanov and Mor 2014, 51.

two additional stations.[201] Frames were preserved up to the turn of the bilge on the south-west side of the wreck and up to the second wale on the north-east side, revealing a pattern of floor timbers alternating with paired half-frames. While the majority of the ship framing followed this pattern, six successive floor timbers were found in the vicinity of the mast-step.[202] The use of successive floor timbers reinforced this vulnerable area, a strategy that had been employed in previous centuries. The floor timbers spanned from one turn of the bilge to the other and most were fastened to the keel with square iron nails measuring 0.012 m per side and 0.210 m in length. In addition to being nailed, six frames were also fastened to the keel with iron bolts inserted from the bottom of the keel, two of which connected to a central longitudinal timber. The frames were fastened to the hull planking with iron nails, rather than treenails. Floor timbers measured 0.09 m sided and 0.12 m moulded, and the average room-and-space measured 0.24 m.

The half-frames were slightly smaller than the floor timbers, measuring 0.085 m sided and 0.104 m moulded. They generally were centered over the keel, although some of the pairs were asymmetrical. As with the floor timbers, the majority of the half-frames were fastened to the keel with a single iron nail – one nail for each half-frame.[203] Each frame was also nailed to one of the wales with a single iron nail driven in from the hull exterior.[204] The central ends of the paired half-frames overlapped at the keel and were

[201] Kahanov and Mor 2014, 46-8.
[202] Kahanov and Mor 2006, 47.
[203] Kahanov and Mor 2006, 47.
[204] Kahanov and Mor 2006, 50.

diagonally scarfed, fastened to each other with a single iron nail.[205] The purposeful and repeated application of overlapping paired half-frames is a novel feature, at least in the configuration seen in figure 6. The overlap provides additional strength to the vessel, and by fastening the half-frame arms together, paired half-frames now function more like floor timbers.

The nailing of the majority of the floor timbers and half-frames to the keel is an innovative feature along with fastening of the frames to a wale. When combined with the overlapping and fastened half-frames, the framing system becomes more extensively integrated into the bottom of the hull, thus making it stronger. However, the individual framing elements are still not fastened to each other above the turn of the bilge. The futtocks and top timbers are abutted their partnered framing element but remain unfastened. The framing of the Dor 2001/1 ship is a conceptual step forward regarding the integration of various structural components, but there continues to be inherent weakness above the turn of the bilge. Clearly, the framing continues to serve its customary role as secondary reinforcement.

The Dor 2001/1 ship is remarkable in that it provides the first archaeological evidence for a vessel built without any planking edge-joinery in the Mediterranean, suggesting that the 6th century C.E. marks an important phase in the transitioning away

[205] Kahanov and Mor 2006, 47.

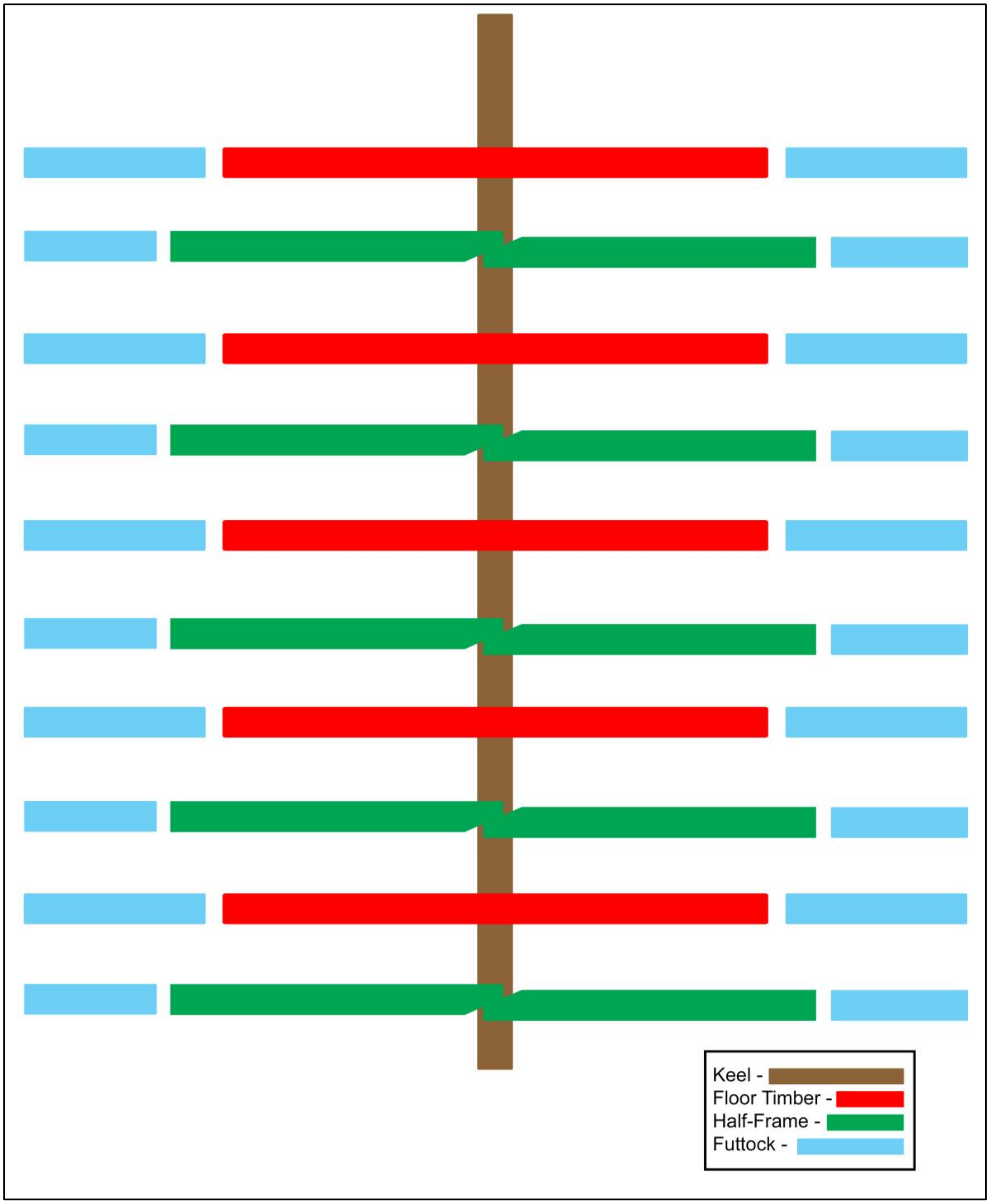

Figure 6. Floor timbers alternating with overlapping paired half-frames.

from shell-based construction.[206] In the span of one century, shipwrights have moved from significantly weakened planking edge-fasteners (as seen in the Yassıada II ship) to none whatsoever, an extreme modification to a thousand year-old shipbuilding tradition. The excavators consider this to be a clear indicator that the vessel was built according to frame-based principles. But this brings up an important question: do any of the framing features in the Dor 2001/1 vessel attest to functional or structural changes? The overlapped and fastened half-frames may impart some additional rigidity, but the framing system remains unintegrated and is therefore still a form of ancillary support. The early stages of economizing shell-based shipbuilding principles only affect the edge joinery and planking, but do not conceptually extend to the function of framing. Frames were being improved to maximize their potential strength, but have yet to become a tool for creating the shape of the hull. Rather, shipwrights across the Mediterranean appear to be independently discovering economically efficient methods of building ships of the same caliber, and this tinkering is reflected in the archaeological record.

[206] In central and northern Europe, boats had been built without edge-joinery prior to the 6th century, yet these vessels are still conceptually shell-based.

CHAPTER XIII

7th CENTURY C.E.

The 7th century C.E., in which five shipwrecks are cataloged, is an important milestone in the development of framing.[207] There is a conceptual change in the way that frames are integrated into the hull, which is particularly evident in the transitional features of the Yassıada I wreck. From the eastern to the western Mediterranean, shipwrights seem to be incorporating the framing into the upper portion of the hull. In this century, the framing begins the transformation to acting as a pseudo-skeleton in the hull – not in terms of the construction sequence, but as one of the primary sources of reinforcement. The difficult aspect of this development to understand is the motivation behind it. It can be argued that this shift is not being driven by shipwrights' desire to incorporate the framing as source of strength but instead another manifestation of the need to reduce costs in ship construction. The lower portion of the hull is not only the most important section of the ship to control the shape of, it is the most difficult due to the complex curvatures that are required to make a ship seaworthy. This area of hull continues to be built on a more traditional shell-based method because of this. However, shipwrights have made the realization that they do not have to follow the same

[207] The Yassıada I (van Doorninck 1982, 41, 56, 57, 71, 73, 75-7, 83. Pomey et al. 2012, 267), YK 11 (Pulak et al. 2015a, 47-50), Pantano Longarini (Throckmorton and Throckmorton 1973, 244, 249, 252; Kampbell 2007, 45, 53-4, 65), Saint-Gervais II (Jézégou 1985, 351, 353-4; Jézégou 1989, 139-40), and the Dor D (Kahanov and Royal 2001, 257, 261, 264) shipwrecks.

procedures on the upper portion of the hull, relying instead on framing to build this less critical section of the hull, a method that is faster and less expensive. While the motivation behind this process is unclear, the outcome is not – framing is being more thoroughly integrated into the upper portion of the hull. Continuing from the 6th century C.E., the paired half-frames are arranged to overlap on the keel, and ships are still built with shell-based methods, although the mortise-and-tenon edge joinery is smaller, more widely spaced, more loosely fitted, and tenons are unpegged.

The Yassıada I ship is one of the two wrecks excavated by the Institute of Nautical Archaeology at the wreck's eponymous island in Turkey, with the earliest date for its sinking suggested by the presence of a coin at 625 C.E.[208] The remains of the ship spanned an area measuring 15 by 6.3 m, and the reconstructed dimensions were estimated to be 20.5 m in length with a breadth of 5.2 m.[209] The vessel had a wine-glass shaped hull cross-section with a rounded turn of the bilge and a displacement of about 73 tons. Loose, unpegged, and widely spaced (particularly in the middle of the hull) mortise-and-tenon joinery was used to align and assemble the first 16 strakes, above which no edge joinery was used.[210] Based on the framing and building methods, this is one of the first clear examples of a ship transitioning away from shell-based construction and advancing *towards* frame-based construction.

The framing timbers were very poorly preserved, but a remarkable amount of

---

[208] Fagerlie 1982, 146.
[209] Steffy 1982, 86.
[210] van Doorninck 1982, 55-6.

information could be gleaned from them. Indirect evidence for 45 successive framing stations (frames and paired half-frames) was discovered, as revealed by the presence of stains on the interior surface of the planking.[211] These stains suggested sided dimensions that varied from 0.12 to 0.16 m and the few preserved framing fragments indicated a 0.14 m moulded dimension.[212] Large iron nails fastened most of the frames to the keel and evidence for bolts was discovered on one of every four frame stations. Using one of these two methods, about three quarters of the frames in total were fastened to the keel. The room-and-space of the frames varied from 0.30 to 0.35 m and the frames were nailed to the planking with short and unclenched iron nails.[213]

While the pattern of the Yassıada I ship does not deviate from the standard arrangement of floor timbers alternating with paired half-frames, it shows a conceptual shift in the overall incorporation of framing into the hull. Perhaps the most noteworthy aspect of this vessel is the use of frame-based methods above the 16th strake, where the use of edge-joinery was discontinued. Above this strake, the planking was fastened directly to the projecting ends of frames that extended upward from the lower portion of the hull, clearly signifying that the Yassıada I ship's construction was conceptually transitioning from a shell-based to a frame-based construction method. In the lower portion of the hull, more of the frames were fastened to the keel than seen in previous shipwrecks; shipwrights were clearly aware of the reinforcement added by this type of

[211] van Doorninck 1982, 41-2.
[212] van Doorninck 1982, 41-2.
[213] van Doorninck 1982, 42-5.

fastening and tried to maximize its use. Every fourth frame is bolted to the wales, beginning the process of integrating the top portion of the hull into the framing system. This feature is also seen in the 7th century Pantano Longarini wreck (Sicily).[214] The precursor to this type of fastening was seen in the Dor 2001/1 wreck, where iron nails were used to fasten a few of the frames to the wales, but the consistency and use of bolts is much stronger in the Yassıada I ship.[215] Shipwrights are compensating for weak edge-joinery with a more thorough integration of framing into the upper hull. This suggests that more integrated framing may be viewed as an alternative for providing necessary hull rigidity than the labor-intensive system of mortise-and-tenon edge-joinery. In effect, the framing is beginning to transform into the 'skeleton' on which the hull will rely for its strength. However, this is still an early stage in the conceptual progression – the futtocks remain unfastened to the framing, limiting the additional rigidity that this integration would have provided. One of the most critical factors in preventing shipwrights from building an entire hull using the frame-based technique is that framing is now integrated into the lower portion of the hull and into the upper portion of the hull but not yet integrated into itself. Integrating the entire framing system together requires futtocks and top timbers to be securely fastened to their partnered framing timbers.

A wreck discovered at Saint-Gervais in southern France in the Golfe de Fos was

[214] Throckmorton and Throckmorton 1973, 252.
[215] Kahanov and Mor 2014, 50.

dated to the mid- to late-7th century C.E. on associated pottery.[216] The preserved section of hull from the Saint-Gervais II wreck measured 9.5 by 4.5 m with an estimated original length of 15 to 18 m in length.[217] The vessel had a wine-glass shaped hull section, a rounded turn of the bilge, straight sides, and was thought to be a small merchantman carrying an amphorae cargo of corn and pitch.[218] Although some mortise-and-tenon joins were observed in the planking, the majority of the hull planking did not utilize edge-joinery – marking the ship's construction as transitional.[219] The vessel exhibited floor timbers that spanned from one turn of the bilge to another alternating with paired half-frames that began over the keel, with evidence for five slightly overlapping pairs.[220] Based on the published hull plan, some of the floor timbers appear to be asymmetrical, although this is not mentioned in the site report.[221] Floor timbers ranged from 0.12 to 0.20 m sided and 0.22 to 0.40 m moulded. The half-frames' sided dimension varied from 0.10 to 0.15 m and the moulded dimension ranged from 0.10 to 0.27 m. In addition, there were six intermediate timbers that did not extend all the way to the keel.[222]

Generally, the futtocks were placed alongside their partnered framing timbers, although some were butt-scarfed but not fastened with nails. The futtocks were fastened to the wales with treenails and iron nails. The room-and-space for the framing

[216] Jézégou 1989, 139.
[217] Jézégou 1985, 351; Jézégou 1989, 139.
[218] Jézégou 1985, 356.
[219] Jézégou 1989, 139-40.
[220] Jézégou 1989, 140-41.
[221] Jézégou 1989, fig. 4.
[222] Jézégou 1985, 354.

ranged as high as 0.36 m in some areas of the hull though it averaged 0.25 m.[223] The five overlapping paired half-frames were nailed to each other and bolted to the keel.[224] All but one of the floor timbers were fixed to the keel with an iron bolt, meaning that 17 out of the 27 preserved frame stations were bolted to the keel. The frames were fastened to the hull with treenails and iron nails, the latter of which was used mostly below the water line.

Although the framing of the Saint-Gervais II wreck is well integrated into the bottom portion of the hull, it does not demonstrate the same level of upper hull integration as the Yassıada I ship. Like the 6th-century C.E. Dor 2001/1 ship, almost two-thirds of the frames are fastened to the keel, but the use of bolts instead of iron nails on the Saint-Gervais II ship would have provided more strength. The primary purpose of these fastenings appears to be securing the central longitudinal timbers, rather than as reinforcement for the spine of the ship.[225] The weak fastening between the futtocks and wales suggests that the shipwrights only attached the wales to the ship, but did not attempt to fully integrate the framing into the upper portion of the hull. This is compounded by the fact that the futtocks are not fastened to their partnered framing timbers – a development not found in the Yassıada I ship either.

The general pattern of floor timbers alternating with paired half-frames did undergo conceptual and observable changes in the 7th century C.E. The majority of the

[223] Jézégou 1985, 353.
[224] Jézégou 1985, 354.
[225] Pomey at al. 2012, 265.

floor timbers continues to symmetrically extend from one turn of the bilge to another and is fastened to the keel with either iron nails or bolts. Most paired half-frames continue to be used in their traditional role; however shipwrights now overlapped and fastened certain pairs to each other – some of which were also fastened to the keel. These are strategic moves by shipwrights to further integrate the framing into the bottom of the hull and, while this type of fastening has appeared before, its use has been purposefully expanded. The robust nature of the fastening between the wale and frames on the Yassıada I ship suggests that conceptually, shipwrights attempted to integrate the framing also into the upper portion of the hull. Wales have always served as a means to gird and stiffen the hull, and now shipwrights are taking the time and effort to bolt them to the inner structure of the hull. So while the limited use of frame-based techniques to build the upper hull may be a cost-saving effort, the robust integration of the wales to framing elements is not; which means that it is being done to further strengthen the hull. Both the Saint-Gervais II and the Yassıada I ships exhibit transitional construction features, but the Yassıada I ship is clearly advancing towards frame-based methods. For the first time in the archaeological record, the function of frames is surpassing that of edge-joinery as the primary source of hull rigidity in ship construction.

CHAPTER XIV

8th CENTURY C.E.

The 8th century C.E. is the final century in which the arrangement of floor timbers alternating with paired half-frames continues to be the dominant framing pattern. Five shipwrecks are reviewed from this century.[226] The evidence for ship construction in the 8th century comes primarily, though not entirely, from the excavations conducted in the Theodosian harbor in Istanbul – also known as the Yenikapı excavations. In this century, some paired half-frames continue to be overlapped and fastened on the keel. For the first time in the archaeological record, there are Mediterranean naval galleys predating the 14th century sufficiently preserved to study their framing systems. There is now clear evidence that warships exhibit floor timbers alternating with paired half-frames, which speaks to the continued and universal applicability of this framing pattern. After this century, in-line framing quickly becomes widespread and replaces the previous framing system. Interestingly, it is in galleys that floor timbers alternating with paired half-frames endures the longest, as evidenced by YK 2 and YK 4, galleys from Yenikapı whose construction dates to the 9th or 10th century C.E.[227]

---

[226] These shipwrecks are: Tantura E (Israeli and Kahanov 2012, 373-5, 383, 385), Tantura F (Barkai and Kahanov 2007, 21, 23), YK 19 (Kocabaş 2015, 17), YK 12 (Kocabaş and Kocabaş 2008, 112, 114, 121-3; Kocabaş 2012b, 10-2; Kocabaş 2015, 15-6), and the YK 27 (Kocabaş 2015, 23) shipwrecks.

[227] Pulak et al. 2015a, 62. Other galley exhibiting floor timbers with paired half-frames from the Yenikapı excavations include: YK 13 which dates to 690-890 CE (Kocabaş 2015, 26); YK 16 which dates to the 8th century CE (Akkemik 2015, 57; Kocabaş 2015, 26-7); YK 25 which dates to the 10th century CE (Kocabaş 2015, 27-31).

The Tantura E vessel was discovered in 1995 within the Dor Lagoon whose analysis is limited in three major ways: imprecise dating, poor preservation of the timbers, and its limited excavation. The Tantura E vessel was roughly dated to somewhere between the 7th and 9th centuries C.E., but the associated pottery and ^{14}C dating made it impossible to narrow this date range any further.[228] The wreck was primarily recorded under water, with only select portions brought to the surface for further investigation.[229] The remains of the vessel covered an area measuring 7.6 by 3.1 m with the original dimensions of the ship estimated at 12.5 m in length with a maximum beam of 4.0 m.[230] The ship was carrying approximately 17.5 tons of cargo at the time of its sinking and was thought to be coaster that operated along the Levantine coast, which would have meant that the ship also operated in open water.[231] Despite the highly irregular shape of the planking, the absence of edge joinery led excavators to conclude that the vessel was built using frame-based method.[232]

A total of 59 frames or frame fragments survived in 28 frame stations with another eight stations identified based on staining on hull planking and nail remains.[233] While the frames were poorly preserved and the framing pattern was highly irregular, there was clear evidence for the presence of floor timbers, half-frames, and futtocks.[234]

---

[228] Planer 2007, 19; Israeli and Kahanov 2014, 383.
[229] Israeli and Kahanov 2014, 370.
[230] Israeli and Kahanov 2014, 385.
[231] Israeli and Kahanov 2014, 386.
[232] Israeli and Kahanov 2014, 375, 386.
[233] Israeli and Kahanov 2014, 373-5.
[234] Israeli and Kahanov 2014, 374-5.

For the majority of the hull, the framing pattern consisted of floor timbers alternating with paired half-frames, although the excavators did not elaborate on the irregular frames.[235] The midship frame, which consisted of a pair of half-frames that overlapped on the keel, each fastened with a single iron nail to the keel but not to one another, provided the only evidence for overlapping half-frames on this wreck. The futtocks overlapped their partnered framing timber though were not fastened to them.[236]

The majority of the frames were nailed to the keel with an iron nail, but there were four frame stations with no evidence of frame-to-keel fastening. Frames were fastened to the hull with one to three iron nails, depending on the width of the plank. The frames had a variety of cross-sectional shapes: those in the center of the ship were the most worked, while others were either minimally shaped or partially worked half-logs. The frames averaged 0.10 m in sided by 0.12 m in their moulded dimensions, and had an average room-and-space of 0.26 m. There were seven different species of wood used for the frames based on the highly irregular nature of the framing, the excavators concluded that the shipwright was facing a shortage of quality wood or other resource limitations.[237]

Dated to the beginning of the 8th century C.E. based on a combination of ^{14}C and ceramic analysis, the Tantura F wreck was discovered in the Dor/Tantura Lagoon and

[235] Israeli and Kahanov 2014, 374.
[236] Israeli and Kahanov 2014, 373.
[237] While this conclusion is fair, it should be noted that there are limited wood species analyses from ancient Mediterranean shipwrecks and therefore the use of a variety of wood species is not necessarily an indicator of crisis.

excavated for five seasons beginning in 2004. The surviving hull section measured 12 by 3.5 m and included most of the original hull length up to the turn of the bilge on both sides.[238] The estimated dimensions of the ship were 15.7 m in length by 5.2 m abeam, and the hull displayed a relatively flat cross-section with a rounded turn of the bilge.[239] Based on the artifacts discovered in association with the vessel, the excavators believed that the remains represented a fishing ship.[240] As with other vessels found in the Dor/Tantura Lagoon, the Tantura F ship had no evidence for the use of edge-joinery in its planking, which led the investigators to conclude that the ship had been built frame-first.[241]

The ship had 36 frame stations exhibiting the traditional pattern of floor timbers alternating with paired half-frames, although under the mast-step a series of successive floor timbers was discovered.[242] Based on the hull plan, the floor timbers extended to the turn of the bilge. Some of the paired half-frames were asymmetrical, while others overlapped at the keel. The amount of overlap varied but was never longer than the width of a plank, and half-frames were scarfed and fastened together with iron nails. Remains of 15 futtocks overlapped their partnered floor timbers and, for the first time, were fastened to them with iron nails driven from one side.[243] The futtocks were placed

---

[238] Barkai and Kahanov 2007, 21.
[239] Barkai and Kahanov 2007, 28.
[240] Barkai and Kahanov 2007, 28.
[241] Dor 2006 used unpegged mortise-and-tenon joinery (Kahanov and Royal 2001, 258).
[242] Barkai and Kahanov 2007, 23.
[243] Barkai and Kahanov 2007, 23.

randomly fore and aft of the partnered framing timber regardless of their location in the hull. Frames averaged 0.08 m sided and 0.11 m moulded, with an average room-and-space of 0.29 m.[244] They were fastened to the planking with one or two square iron nails per plank per frame, driven inwards from the exterior. All of the frames were fastened to the keel with iron nails.[245]

The Tantura E and F ships reveal little progression in framing compared to the 6th-century Dor 2001/1 ship. The only area in which progressive change is evident is in the positioning of the futtocks. In the Dor 2001/1 vessel, the futtocks were in-line with their partnered framing timbers. The futtocks in the Tantura E ship overlap their partnered framing timbers and in the Tantura F ship, the futtocks both overlap and are fastened. By fastening the futtocks, shipwrights attempted to fully integrate the framing system into both the lower and upper portions of the hull. However, the imprecise dating of the Tantura E ship makes it difficult to definitively chronicle this change. Also noteworthy is the reduced usage of overlapping paired half-frames on the Tantura E ship – a feature which is prominent in the Dor 2001/1 and the Tantura F ships. The fastening between the keel and the frames is also weaker on the Tantura E wreck; the square iron nails are 0.007 m in cross-section, nearly half the size of the heads of those in the Dor 2001/1 ship.[246] Like the mixture of wood types seen in the frames of the Tantura E ship, the lack of overlapping half-frames and smaller iron nails may indicate a resource shortage for

[244] Barkai and Kahanov 2007, 23.
[245] Barkai and Kahanov 2007, 23.
[246] Israeli and Kahanov 2014, 374.

the ship's builders.[247] While the framing adjustments seen in the wrecks of the Dor/Tantura Lagoon from the 6th through 8th centuries may not have resulted in weaker framing, it is clear that the framing has not become stronger in the intervening time period. However, the absence of planking edge-joinery and the fastening of futtocks to their partnered framing timbers denote a continued progression away from shell-based and *toward* frame-based construction.

Dated to the late 8th or early 9th century C.E. based on the associated artifacts, the Yenikapı (YK) 23 wreck provides a good comparison for the Tantura E and F wrecks. The surviving portion of the hull measured 9 by 3.7 m and had reconstructed length of 15 by 5 m in beam.[248] Edge joinery between the planks was only utilized in the lower portion of the hull, in the form of coaks or edge-joining dowels.[249] This round ship had a wine-glass shaped hull section and numerous repairs that indicated it had been used for a fairly long time.[250] The framing pattern of the ship was floor timbers alternating with paired half-frames, as evidenced by 22 preserved frame stations.[251] Floor timbers spanned from one turn of the bilge to another and the paired half-frames slightly overlapped the keel. Futtocks overlapped their partnered framing timbers by a length of three or more strakes, though they were not fastened. The frames averaged 0.11 m sided and 0.15 m moulded with an average room-and-space of 0.38 m. Almost all of the

---

[247] Israeli and Kahanov 2014, 375.
[248] Pulak et al. 2015a, 50, 52.
[249] Pulak et al. 2015a, 52.
[250] Pulak et al. 2015a, 51.
[251] Pulak et al. 2015a, 52.

floor timbers and paired half-frames were nailed to the keel with iron nails and several frames were bolted to the keel to reinforce scarfs. The frames were fastened to the planking with short irons nails that were driven from the exterior of the hull.

When looking at ship construction from the Yenikapı Harbor, a fairly unique feature came into play – the use of coaks for edge-joinery between planks.[252] As defined by Steffy, coaks were rectangular or cylindrical pins used in the ends or seams of timbers to align or fortify a joint.[253] These had only been documented in the 9th-century Bozburun Byzantine ship prior to the excavations at Yenikapı, where a total of 25 additional ships were documented with this type of edge joinery.[254] Consequently, it was surmised that this was an important feature of Middle Byzantine period ship construction, at least at a regional level.[255] The fact that this method of edge-joinery was not present after the 10th century C.E. suggests that the use of coaks was a relatively short-lived phenomenon – lasting approximately three centuries. Based on the use of coaks in the Yenikapı 23 vessel and the absence of edge fasteners in the Tantura E and F vessels, the Yenikapı ships are clearly indicative of unique building traditions, yet there is very little difference in their use of frames.[256]

[252] For a more detailed discussion on this feature, see Pulak et al. 2015a, 46-7.
[253] Steffy 1994, 269.
[254] Harpster 2005, 224; Pulak et al. 2015a, 46.
[255] Pulak et al. 2015a, 47.
[256] See the appendix for all of the relevant YK ships, their framing pattern, and their hull edge-joinery method.

The wrecks from Yenikapı Harbor include the first early-medieval galleys ever excavated. Six galleys were found during the course of the Yenikapı excavation, including the Yenikapı (YK) 4 and 16 wrecks. The framing of these warships varies little from their earlier mercantile counterparts, with a few exceptions. The Yenikapı 16 ship was preserved for a length of 22.5 by 2.4 m, and was dated to approximately 720 – 741 C.E. based on its ^{14}C analysis.[257] Yenikapı 4 was dated to the 8th through 10th centuries and was preserved for a length of 18 m.[258] Both ships were categorized as *galea*, a medieval light galley which served to support *dromons*, and were rowed by 50 men, 25 per side.[259] Both of these vessels were built shell-first, using coaks instead of mortise-and-tenons for edge-joinery, and had slightly wine-glass shaped hull sections.[260]

The framing system for these galleys consisted of floor timbers alternating with paired half-frames. On Yenikapı 4, there was a series of successive floor timbers in the area of the mast-step, installed as repairs to reinforce a weakened area of the hull.[261] Both ships exhibited paired half-frames, most of which overlapped on the keel. There were preserved futtocks which overlapped with their partnered framing timbers; however there was no fastening between them. The frames of the Yenikapı (YK) 16 ship were small in cross-section, measuring 0.05 by 0.06 m, and the frames of the Yenikapı (YK) 4 ship were similarly small, between 0.06 to 0.07 m sided and moulded. The

[257] Kocabaş 2012b, 8; Kocabaş 2015, 26-7.
[258] Pulak et al. 2015a, 64-8.
[259] Kocabaş 2012b, 9; Pulak et al. 2015a, 62.
[260] Kocabaş 2012b, 8; Pulak et al. 2015a, 68.
[261] Pulak et al. 2015a, 68.

shipwrights compensated for the fragility of these frames with their close spacing, which ranged from 0.16 to 0.20 m for the Yenikapı 16 ship and 0.23 m for the Yenikapı (YK) 4 ship. The reduction in size of framing timbers has a logistical purpose, since naval galleys are reliant upon their speed and maneuverability, they have to be light vessels for their size. The frames for both ships were fastened to the hull with iron nails and dowels.

Ships from the 8th century C.E. present two unique types of plank assembly: the absence of edge joinery on the Tantura E and F vessels and the use of coak fasteners of the Yenikapı ships. Despite the differences in these regional methods, the framing system remains the same – floor timbers alternating with paired half-frames.[262] Although this standardized pattern had endured for twelve centuries in the archaeological record, it has finally reached its zenith. This framing pattern continues to be characterized by technological stasis, but several new features appear during these intervening 1200 years. The overlapping of paired half-frames on the keel, the application of asymmetrical framing, and the overlapping and fastening of futtocks to their partnered framing timbers all serve to more fully integrate the framing into the lower and upper portions of the hull. These seemingly minor changes indicate a conceptual shift in the role of framing – from secondary to primary reinforcement – and the gradual transition away from shell-based methodologies towards frame-based

[262] The differences in construction may also be attributable to chronological differences as Tantura F (Barkai and Kahanov 2007, 21) dates to the early-8th century CE, while coaks are used on the YK wrecks dating to the late-8th to early-9th century.

construction. Once this pattern is replaced by in-line framing in the 9th century C.E., it appears to mostly persist in galley construction.[263]

[263] Pulak et al. 2015a, 62.

CHAPTER XV

9th CENTURY C.E.

Sometime in the late 8th or early 9th century C.E., in which eight shipwrecks are cataloged dating firmly to the 9th century C.E., a new framing system consisting of floor timbers coupled with unfastened futtocks first appears – in-line framing.[264] The floor timbers are flat and L-shaped with their long arm alternating from port to starboard at each frame. The long arm of these floor timbers extends well beyond the turn of the bilge, while the short arm is extended by a scarfed futtock, typically located on or near the turn of the bilge. This new arrangement of framing is illustrated in figure 7. By the end of the 9th century C.E. this new system of framing supplants the older tradition of floor timbers alternating with paired half-frames as the dominant form. By the 11th century C.E., the 1200 year-old pattern disappears completely from the archaeological record. The origin of this new type of framing is unknown, although frames of similar design have been documented in some Roman-period vessels outside of the Mediterranean, like the Zwammerdam barges in the Netherlands.[265] The remains of

[264] The cataloged wrecks are: the YK 3 (Kocabaş and Kocabaş 2008, 152, 157-61; Kocabaş 2012b, 9-10; Kocabaş 2015, 18-9), Tantura F (Barkai and Kahanov 2007, 21, 23), YK 20 (Kocabaş 2015, 17), YK 16 (Kocabaş and Kocabaş 2008, 180; Kocabaş 2012b, 7; Kocabaş 2015, 26-7), YK 4 (Pulak et al. 2015a, 64-68), YK 31 (Kocabaş 2015, 21), Tantura B (Wachsmann et al. 1997, 10, 13; Kahanov 2000, 151, 153, 154), and Bosburun (Harpster 2002, 409, 411; Harpster 2005, 102-216, 471-85; Harpster 2009, 297, 301, 302) shipwrecks. The YK 13 (Kocabaş 2015, 26), YK 15 (Pulak et al. 2015a, 50-3), and the YK 29 (Kocabaş 2015, 21) shipwrecks date to 8th to 9th century CE, while the YK 23 (Pulak et al. 2015a, 50-3) shipwreck dates to the end of the 8th to the beginning of the 9th century CE.

[265] de Weerd 1978, 16-7.

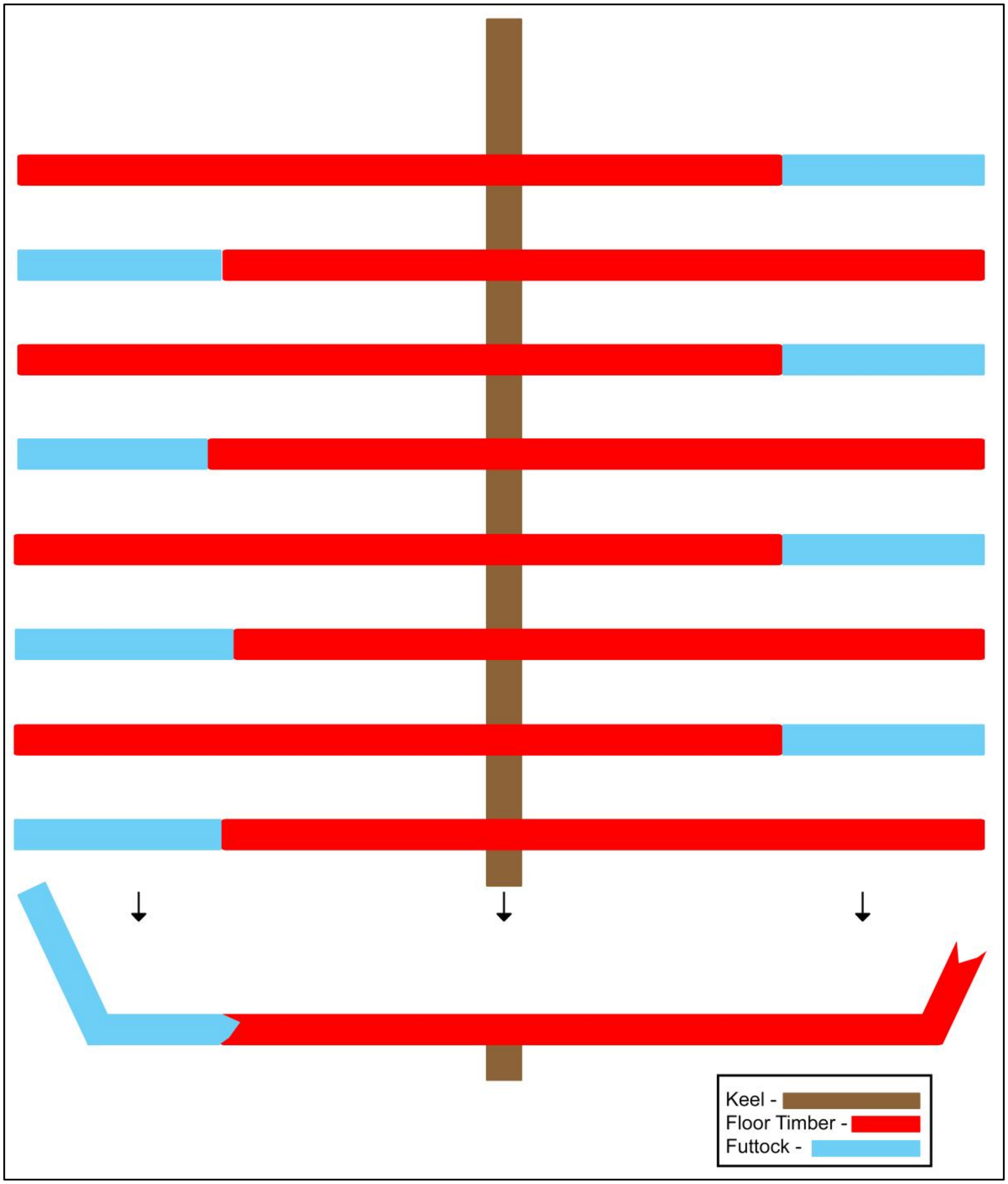

Figure 7. In-line framing.

the 9th century C.E. Tantura B wreck, found in the Dor/Tantura Lagoon, exhibited the standard pattern of floor timbers alternating with paired half-frames, signifying that the two traditions had a brief period of coexistence before in-line framing became dominant.[266] While the Bozburun ship (late 9th century C.E.) was once believed to be the earliest example of this new framing system, the plethora of ships from Yenikapı reveal its use as early as the beginning of the 9th century C.E.[267]

The earliest datable example of this new framing system came from the Yenikapı (YK) 14 ship which, based on AMS dating and dendrochronology, was dated to the first half of the 9th century C.E.[268] The preserved portion of the hull measured 12 by 2.5 m and was reconstructed to be 14.65 m long with a 3.4 m beam.[269] Although the vessel had a mostly flat bilge, it was still slightly wine-glass shaped in cross-section in addition to having a shallow draft and a pronounced turn of the bilge. The ship utilized coaks for edge-fasteners up to the level of the first wale at which point it was surmised that the planking would have been attached to pre-standing frames.[270]

As noted earlier, the framing system of this particular vessel was not one of floor timbers alternating with paired half-frames but that of in-line framing.[271] These frames alternated their long, L-shaped arm across the hull with the futtocks scarfed, but not

---

[266] Wachsmann et al. 1997, 13.
[267] Harpster 2009, 301-10.
[268] Pulak et al. 2015a, 53.
[269] Pulak et al. 2015a, 55.
[270] Pulak et al. 2015a, 54.
[271] Pulak et al. 2015a, 54.

fastened, to the short arms of the floor timbers. A total of 45 frame stations were preserved on the hull with evidence for an additional five more. The frames averaged 0.06 m on their sided dimension by 0.10 m on their moulded dimension, and were regularly spaced 0.23 m apart. Only 21 of the floor timbers were fastened to the keel, corresponding to every 2nd or 3rd frame. The frames were fastened to the hull with treenails and iron nails, the latter used mostly at the turn of the bilge.

The available evidence from the Yenikapı excavations shows that the late 8th century C.E. to the early 9th century C.E. is a period of technological consolidation. In the span of just one hundred years, a centuries-old tradition is replaced by a new system on a pan-Mediterranean scale. It would not be surprising if this framing pattern dates back even further, given its well-developed nature upon its sudden appearance in the archaeological record. Of the three wrecks that date to the 9th century C.E. (YK 23, YK 4, YK 12) in the Theodosian Harbor, one reveals floor timbers alternating with paired half-frames while the other two exhibit in-line framing.[272] Every Yenikapı wreck that postdates the 9th century exhibits L-shaped floor timbers, for example Yenikapı 24 (10th century C.E.), Yenikapı 5 (late 10th century C.E.), and Yenikapı 1 (late 10th or early 11th century C.E.).[273] Although the hull construction is still shell-based, the framing system has transitioned to become the primary source of reinforcement in the hull.

---

[272] Kocabaş and Kocabaş 2008, 112-24; 168-75; Kocabaş 2015, 15-6; Pulak et al. 2015a; 52; 67-8.
[273] Pulak et al. 2015a, 57, 55, 59.

By the end of the 9th century C.E., L-shaped floor timbers had spread into the Mediterranean, as demonstrated by the Bozburun ship from southern Turkey. The planking of the Bozburun vessel revealed evidence for edge joinery using coaks, as was seen in many of the Yenikapı wrecks.[274] The timber remains and amphorae cargo covered an area measuring 20 by 8 m which, using dendrochronology, dated the felling of the timbers to 874 C.E.[275] The original dimensions of the ship were estimated to be 14.3 m in length and 5 m in breadth. The vessel had a slight wine-glass shaped hull cross-section with a rounded turn of the bilge.[276]

There were 34 surviving floor timbers, which alternated their long arm from port to starboard in the same fashion as those of the Yenikapı wrecks.[277] Seven of the floor timbers were made of oak, while the remaining 27 were of pine. The 12 preserved futtocks revealed that the timbers were installed in two different methods: overlapped with but unfastened to its partnered framing timber, or scarfed end-to-end to its partnered framing timber.[278] The distance of the overlap varied anywhere from the length of a single plank to several planks, though there was no fastening between them. On six of the seven oak timbers, there was scarfing between the futtocks and the floor timbers. The scarf used was L-shaped and cut vertically into the heads of framing timbers; there was a single instance of a nail used to fasten the scarf. The oak floor

[274] Harpster 2005, 429.
[275] Hocker 1998, 8.
[276] Harpster 2005, 535.
[277] Harpster 2005, 426-56.
[278] Harpster 2005, 204-5.

timbers' sided dimension varied from 0.11 to 0.13 m, and the moulded dimension from 0.21 to 0.23 m over the keel, and 0.11 to 0.13 m approximately 0.60 m out from the keel. The pine sided dimension ranged from 0.12 to 0.18 m and the moulded dimension from 0.14 to 0.17 m. The futtocks averaged 0.10 m sided and 0.12 m moulded. The spacing of the floor timbers was fairly wide and varied significantly, from 0.30 to 0.40 m center-to-center. All of the floor timbers were fastened to the keel with a single iron nail and six bolts. The frames were fastened to the hull with treenails and iron nails, though the former was used more regularly. The Bozburun ship clearly demonstrates that in-line framing has spread from Constantinople into the eastern Mediterranean. The Bozburun and Yenikapı 14 ships employ the same framing style and edge joinery, speaking to the well-developed nature of this new framing tradition.

The abrupt emergence of this unique framing tradition indicates that it must have imparted significant structural advantages or an increased efficiency in resource usage. Alternating the scarf between the futtock and the short arm of the floor timber from one side of the vessel to the other avoids creating potentially weak points in the hull. The L-shaped floor timbers are also easier to fashion and standardize, which is especially important if compass timbers and quality construction wood are becoming more difficult to acquire. Furthermore, the L-shaped floor timbers facilitate the construction of a more box-like hull, which allows for a more cargo-efficient ship. Ultimately, the introduction of this new tradition marks the final modification of framing in shell-based ships and bridges the gap to frame-based construction; the only distinction is the absence of fastening between the futtocks and their partnered floor timbers. Once these timbers are fastened to one another, the frames become continuous and facilitate the predetermination of the hull shape prior to the installation of the planking. Shipwrights now have every necessary component for developing frame-based shipbuilding except for one – how to design successive frames so that they may be pre-shaped and pre-installed before planking. This will not come to fruition until the late-10th or early 11th century, as evidenced by the 11th-century C.E. Serçe Limanı ship.[279]

[279] Steffy 2004, 154-64.

CHAPTER XVI

CONCLUSION

The arrangement of floor timbers alternating with paired half-frames persists for a remarkably long period of time in Mediterranean ship construction, especially considering the degree to which ship construction changes during this 1200-year period. In the first documented use of this framing arrangement, the 4th-century B.C.E. Kyrenia ship, shipwrights are dependent on closely spaced and tightly fitting pegged mortise-and-tenon hull edge-joinery. In the centuries before this framing arrangement disappears from the archaeological record, it is seen on vessels that utilize widely spaced, loose fitting, and unpegged hull edge-joinery or, in some cases, no edge-joinery at all. All of the shipwrecks along with their relevant framing measurements and features are listed in table 1. Despite the obvious developments in shipbuilding during the span of this enduring pattern, the framing of ancient Mediterranean ships is only given superficial attention. In some ways, it is easy to see why this arrangement has been given so little attention in the scholarly community – its changes are subtle and seemingly without direction. However, while they may be subtle, a better understanding of the changes in framing, specifically floor timbers alternating with paired half-frames, is critical to a broader comprehension of developments in ancient Mediterranean ship construction.

One method to better understand the arrangement of floor timbers alternating with paired half-frames is by studying the changes in ship construction between the building of the Ma'agan Mikhael ship in the late 5th century B.C.E. and the Kyrenia ship in the late 4th century B.C.E. to determine what made this arrangement desirable in the first place. The made-frames present in the partially laced Ma'agan Mikhael ship are discarded along with the rest of the Greek laced tradition upon the emergence of pegged mortise-and-tenon construction in the Aegean. With the adoption of this plank edge-fastening method, there is a slow, adaptive response in ship framing. The decreased center-to-center spacing, non-notched frame bottoms, and the nailing of the frames to the planking in the Ma'agan Mikhael ship are the earliest indicators of this adaptive response before the complete abandonment of the old framing system in favor of floor timbers alternating with paired half-frames. While it is impossible to determine based on the current archaeological evidence when and where this framing system originated, the framing in the Kyrenia ship is indicative of an already well-established shipbuilding tradition.

The Kyrenia ship is important for another reason – it establishes a tradition of a long; and enduring pairing between strong planking edge-joinery and the arrangement of floor timbers alternating with paired half-frames. These paired features spread quickly and are ubiquitous throughout the Mediterranean by the 3rd century B.C.E. Within a single century of its first appearance, this framing arrangement has become uniform in both the placement of the timbers and the spacing of the frames.[280] In a conceptual sense, this framing arrangement is also uniform as a non-integrated and secondary form of hull rigidity – a carryover from framing in the Archaic Greek tradition.

The question becomes: what structural advantage is imparted by this new framing system when implemented alongside pegged mortise-and-tenon joinery, and why did it become almost exclusively adopted for the next millennium in the Mediterranean? Starting with the Kyrenia ship, there are very few examples of pegged mortise-and-tenon seagoing vessels that deviate from this framing tradition in the Mediterranean until the 9th century C.E. with the adoption of in-line framing; clearly, once developed, the use of floor timbers alternating with paired half-frames pervaded and persisted throughout Mediterranean shipbuilding. It is significant that the floor timbers and half-frames loosely overlap at the turn of the bilge, where hydrostatic pressure exerts the most force on the hull and thus requiring additional reinforcement. The use of floor timbers and half-frames that alternate at the turn of the bilge is a logical method for reinforcing that portion of the ship while minimizing both labor and timber requirements.

Another important factor when examining the adoption of floor timbers alternating with paired half-frames is the use of wine-glass shaped hull cross-sections – a design that often leaves the garboard strake unreinforced. Shipwrights were aware of

[280] One would expect more variation is this framing arrangement if it were as young as the archaeological record indicates. This strongly suggests that the arrangement of floor timbers alternating with paired half-frames dates back to before the 4th century B.C.E.

this vulnerability and cognizant that the use of full floor timbers could not easily remedy this deficiency. Due to size and shape limitations, it is difficult to find timber that could be shaped into a single-piece floor timber that also reinforces the garboard strake. This is made evident on several ships, including the Kyrenia vessel where separate chock pieces are fastened to the floor timber with the sole purpose of buttressing the garboard strake.[281] Paired half-frames, relatively easily fitted to a hull's curvature, are a more efficient way of addressing this vulnerability. When the in-line framing system is introduced in the 9th century C.E., it is used on hulls with a wine-glass shaped cross-section. However, wine-glass shaped cross-sectional hulls are much less pronounced at that point in time as compared to earlier examples.

The arrangement of floor timbers alternating with paired half-frames, along with strong hull edge-joinery, clearly conferred structural and/or economic advantages, and was therefore quick to spread among Mediterranean ship builders. However, it initially exists only as secondary method of hull reinforcement while the primary strength of a hull is derived from the planking's pegged edge-joinery. When discussing the role of pegged mortise-and-tenon joinery in the Kyrenia ship, Steffy goes as far as to note that it serves as internal framing within the hull planking; the size and spacing of which are used by shipwrights to impart strength and rigidity to the hull.[282] The design and placement of the floor timbers and paired half-frames are meant to reinforce known

[281] The separate chock pieces are not always fastened to the floor timber.
[282] Steffy 1989, 250.

weaknesses in the hull and areas that undergo high stresses. In this way, the arrangement of floor timbers alternating with paired half-frames is complimentary to the use of strong edge-joinery.

From its first appearance until the 6th century C.E., the pattern of floor timbers alternating with paired half-frames remains in relative stasis with only a few notable developments. In the 1st century B.C.E., metal bolts that fasten certain frames to the keel first appear. However, this is not a development in the use or role of integrated framing since the metal bolts are utilized only in reinforcing the keel scarfs or keel-to-end post scarfs. Thus, any strength or rigidity that is imparted by these bolts to the framing system is negligible – at least in the minds of those building ships. Bolts fastening most or all frames to the keel is more a conceptual step forward in transforming the keel and frames into a more integrated lower skeleton of a vessel. In the first few centuries before and after the turn of the first millennium, the aberrational *dolia* wrecks appear. While these ships may utilize a different framing arrangement that relies on successive floor timbers, their brief appearance in the archaeological record makes them an exception, rather than a development.

Around the 2nd century C.E., asymmetrical framing begins to appear within the arrangement of floor timbers alternating with paired half-frames. Asymmetrical framing timbers are observed with all three of the primary framing elements: floor timbers, half-frames, and futtocks. None of the ships studied reveal any specific pattern to the asymmetry – something one would expect from shipwrights who show a proclivity to standardization and traditionalism. From the 1st through the 5th centuries C.E., asymmetrical framing sees increasing use. It is very unlikely that asymmetrical framing elements were being installed into ships with the conscious purpose of increasing the rigidity of hulls. A better alternative explanation is that shipwrights are beginning to face economic conditions and resource scarcity in obtaining quality framing timbers that are forcing them to limit costs in ship construction. In a general sense, shipwrights understand that in a strong, shell-built vessel, the framing only imparts a certain amount to the hull's rigidity – as long as the frames adhere to their general pattern, the precision of their placement matters little. Steffy argues similarly when discussing the irregular or asymmetrical shapes of frames.[283] He contends that frames did not have to follow designated lines across the hull so long as they are distributed to allow for the greatest reinforcement.

Beginning in the late 4th century or the early 5th century C.E., the use of strong edge-joinery paired with the standard pattern of floor timbers alternating with paired half-frames is disrupted – wrecks appear in the archaeological record with a lighter and thus weakened mortise-and-tenon edge joinery. The changes in edge-joinery are thought to be cost-saving measures, as closely spaced and tightly fitting mortise-and-tenon joinery is intensive in both labor and time. Individually carving out each mortise is a slow process; along with precisely cutting each strake and fitting it onto the next, it requires significant amount of work and mistakes can result often, sometimes requiring

[283] Steffy 2001, 256.

the replacement of sections of planking. The motivation for this change is widely considered to be economic in nature – factors like rise of private entrepreneurs in maritime commerce and the lesser role of slavery in the labor market changed economic conditions under which ships were being built.[284] In effect, this is attributing these changes in ship construction to changes in the Roman economy. While logical as the Roman economy began to undergo large scale changes and possible even decline around this general time period, this attribution has issues of its own. As with the transition from plank-based to frame-based ship construction, there is a debate surrounding what occurred in the Roman economy, why, and when. The biggest issue with relating changes in Roman economy to changes in ship construction is the discrepancy in dates. The decline of the Roman economy is generally believed to have begun around the late 2nd or early 3rd century C.E., while planking edge-joinery does not begin to change until the late 4th to early 5th century C.E.[285] While the beginning of the economic decline does not align well with changes seen in planking edge-joinery, it does correspond more closely with the appearance of asymmetrical framing, lending further credence to the argument that this phenomenon is a result of economic factors, and not of structural concerns. Although economic factors alone could motivate changes in ship construction, some form of technological innovation would also have been necessary to allow

[284] Steffy 1994, 85; Lopez 1959, 79-84; Bass 1982, 312.

[285] Paolilli 2008, 281; Hopkins 1980, 122-4; Scheidel argues that the Roman economy was beginning to strain in the Early Imperial period and that growth was confined to the continental hinterlands after this period (Scheidel 2009, 70). Conversely, Wilson argues that the economy did not decline in this period, only transitioned to being primarily coastal tramping (Wilson 2011, 54-5.).

shipwrights to move away quickly from the closely spaced and tightly fitting pegged mortise-and-tenon plank edge joinery.

The early phase of this shipbuilding transition (late 4th to early 5th century C.E.) mirrors the changes observed in Archaic Greek shipbuilding when pegged mortise-and-tenon joinery and the arrangement of floor timbers alternating with paired half-frames was adopted in place of Greek laced edge-joinery and made-frames. The mortise-and-tenon edge-joinery is first to be affected, with only minor changes taking place to the framing. In the case of the transition away from robust edge-joinery, the relative stasis of the framing pattern continues. The arrangement of floor timbers alternating with paired half-frames does not change in any significant manner and remains prevalent throughout the Mediterranean. This is why the changes in shipbuilding that take place in the late 4th through early 5th centuries C.E. should be considered a transitioning *away* from traditional shell-building methods and not necessarily the start of the transition *towards* frame-based construction.

Beginning in the 6th century C.E., the arrangement of floor timbers alternating with paired half-frames undergoes several important changes. The first and most noticeable is that paired half-frames now overlap on the keel. However, this is most likely a regional variation as none of the 37 shipwrecks (dated to between the 5th and 10th centuries C.E.) excavated at Yenikapı exhibit overlapping paired half-frames. This feature may have spread, as it is found in southern France by the 7th century C.E. on the

Saint-Gervais II ship which had some ties with the eastern Mediterranean.[286] It seems that the use of overlapping paired half-frames is a purposeful attempt by shipwrights to further strengthen the framing of the vessels, as all ships in which they are found exhibit weak (or no) edge-joinery. This is abundantly clear in the Dor 2001/1 ship in which the paired half-frames are not only overlapping but scarfed and fastened together and no edge fastening is used in the hull planking.[287] However, while shipwrights are experimenting to achieve more reinforcement from the framing, the framing itself has not changed conceptually. The arrangement of floor timbers alternating with paired half-frames is a non-integrated and secondary form of hull rigidity while ship construction continues to shift *away* from traditional shell-based construction.

In the 7th century C.E., there is a conceptual shift in framing, although the general arrangement does not change. Frames are fastened to the keel more frequently and substantially than in previous centuries, though it should be noted that this is done with large, iron nails or spikes. This feature began in the 6th century C.E., but it is in the 7th century C.E. that it became widely used in ship construction.[288] When looking at the upper portion of the hull, frames are now fastened with forelock bolts, rather than simply nailed to the wales. This signifies that shipwrights are attempting to fasten the frames

[286] Parker 1992, 373; 142.
[287] From the perspective of the framing, it appears odd that the Dor/Tantura lagoon ships are frame-built as there are such limited construction modifications in their design. Additionally, the arrangement of floor timbers alternating with paired half-frames is not found in other frame-based vessels, particularly in frame-based ships after the 11th century.
[288] The use of large nails, or spikes, to fasten floor timbers to the keel show that the securing of floor timbers is insignificant in transitioning from shell-built vessels to skeleton-based construction, and its primary purpose was its use in strengthening the lower framework of the ship.

more firmly into the upper portions of the hull.[289] When considered alongside the increased secure fastening of frames to the lower portion of the hull, it is evident that the shipwright's view of the role of framing within ships shifts towards perceiving it as an internal skeleton for the vessel – not the skeletal structure upon which the ship is built, but on which the ship is dependent for rigidity. This is not a quick conceptual transition nor an easy one to detect archaeologically, but it is an important turning point in ancient ship construction going forward. Edge-joinery is no longer a significant factor in maintaining the strength of a hull. It is at this point that Mediterranean shipbuilding ceases to be transitioning *away* from shell-based methodologies, rather transitioning *towards* frame-based construction. This conceptual shift occurs with changes only effecting the fastening of the frames and not the arrangement or general design of the timbers. It should be noted that this is not to argue that frame-based construction is based upon the arrangement of floor timbers alternating with paired half-frames, but that the conceptual shift in the role of framing in ancient Mediterranean ship construction is beginning. The arrangement of floor timbers alternating with paired half-frames had been originally designed to supplement strong edge-joinery, but now the long-standing pairing no longer plays a significant role in Mediterranean ship construction.

---

[289] While other changes in ship building in this century, such as the use of frame-based methods above the waterline, are the result of cost-saving measures, the use of forelock bolts (as observed on Yassı Ada 7th century CE) to fasten the wales to the frames is not (Steffy 1994, 83; van Doorninck 1982, 61; Steffy 1982, 79. This is evidenced with the Dor 2001/1 vessel which used iron nails (Kahanov and Mor 2014, 50).

Given that strong hull edge-joinery is no longer a primary factor in ship construction, it is no surprise that a new framing system soon appears – successive and alternating L-shaped floor timbers extended by non-fastened futtocks, or in-line framing. The long arm of these floor timbers alternates from port to starboard and a long and short futtock extend the frame up the sides of the hull. This new framing system emerges in the Mediterranean around the late 8th or early 9th century C.E. and appears to be first centered around Constantinople. It is theorized that this new framing system had been imported from central Europe, as Roman ships from this area exhibit similar framing.[290] These Roman vessels are flat-floored, which is ideal for L-shaped floor timbers, and the frames are used to provide reinforcement to the bottom and the sides of a vessel – the same role that they first serve in the Mediterranean, providing a conceptual link between in-line framing in the Mediterranean and the framing from eastern European riverine vessels. It is further argued that this framing system followed a logical path from the Danube river valley through continental Europe and into the Black Sea, explaining why this framing arrangement first appears around Constantinople.[291] What complicates this reasoning is the 5th century C.E. Padovetere river barge, which uses a system of framing that appears to be a precursor to in-line framing, as it is found in the northern Adriatic.[292] However, it is still a riverine craft, further validating the argument that in-line framing originates in Roman riverine vessels. Part of the adoption of in-line framing then is the

[290] van Doorninck 2002, 902.
[291] Harpster 2005, 499.
[292] Beltrame and Costa 2016, 7.

adoption of riverine framing to the construction of seagoing ships. Why this has happened is not clear. A detailed study of Roman river barge construction and its framing system is a topic that needs to be further researched as it would provide important insight into how in-line framing developed, arrived in Constantinople, and why aspects of riverine ship construction were integrated into the building of seagoing ships.

The arrangement of in-line framing, consisting of alternating L-shaped floor timbers and their corresponding futtocks, is adopted for several reasons. In-line framing finds quick acceptance because these frames facilitate standardization, making it easier for shipwrights to control the shape of their ships. The ability to easily standardize L-shaped frames is also why these frames are ideal for frame-based construction. Alternating the long and short arms of L-shaped floor timbers and varying their length permits shipwrights to distribute potential weak points in the hull.[293] When first adopted, this new framing system is conceptually similar to the previous system of alternating floor timbers with paired half-frames, but economic advantages led to its success over the previous arrangement. The most prominent of these economic advantages is that L-shaped floor timbers facilitate the construction of more box-like hulls resulting in more cargo-efficient merchant ships.

The arrangement of floor timbers alternating with paired half-frames does not immediately disappear from the archaeological record, although it becomes essentially obsolete after the 9th century C.E. Generally, this old framing pattern lasts longer in

---

[293] Steffy 2004, 158.

galleys, as made evident by the six light galleys found during the Yenikapı excavations.[294] The arrangement also continues to be used in some merchant ships until at least the 10th century C.E., likely due to the reluctance of conservative shipwrights to accept an entirely new framing system.[295] While the arrangement of floor timbers alternating with paired half-frames does not directly play an important role in either the shift away from shell-based construction or the development of frame-based construction, the modifications made by shipwrights to this pattern reveal the conceptual development that framing underwent during these processes. A general chronology of the main framing patterns is presented in figure 8.[296]

One of the fundamental reasons that the arrangement of floor timbers alternating with paired half-frames becomes obsolete is that strong hull edge-joinery no longer plays an important role in ship construction. A hull's edge-joinery is meant to be the primary form of strength and this framing arrangement is specifically designed as a secondary form of reinforcement. However, a strong system of planking edge-joinery is expensive and time-consuming for shipwrights, and economic factors forced

[294] Kocabaş 2015, 26-31; Pulak et al. 2015a, 62-8.
[295] Joncheray 2007, 239-40.
[296] In this timeline asymmetrical floor timbers alternating with paired half-frames and floor timbers alternating with asymmetrical paired half-frames have been combined since it has been argued that they come from the same root cause – resource scarcity.

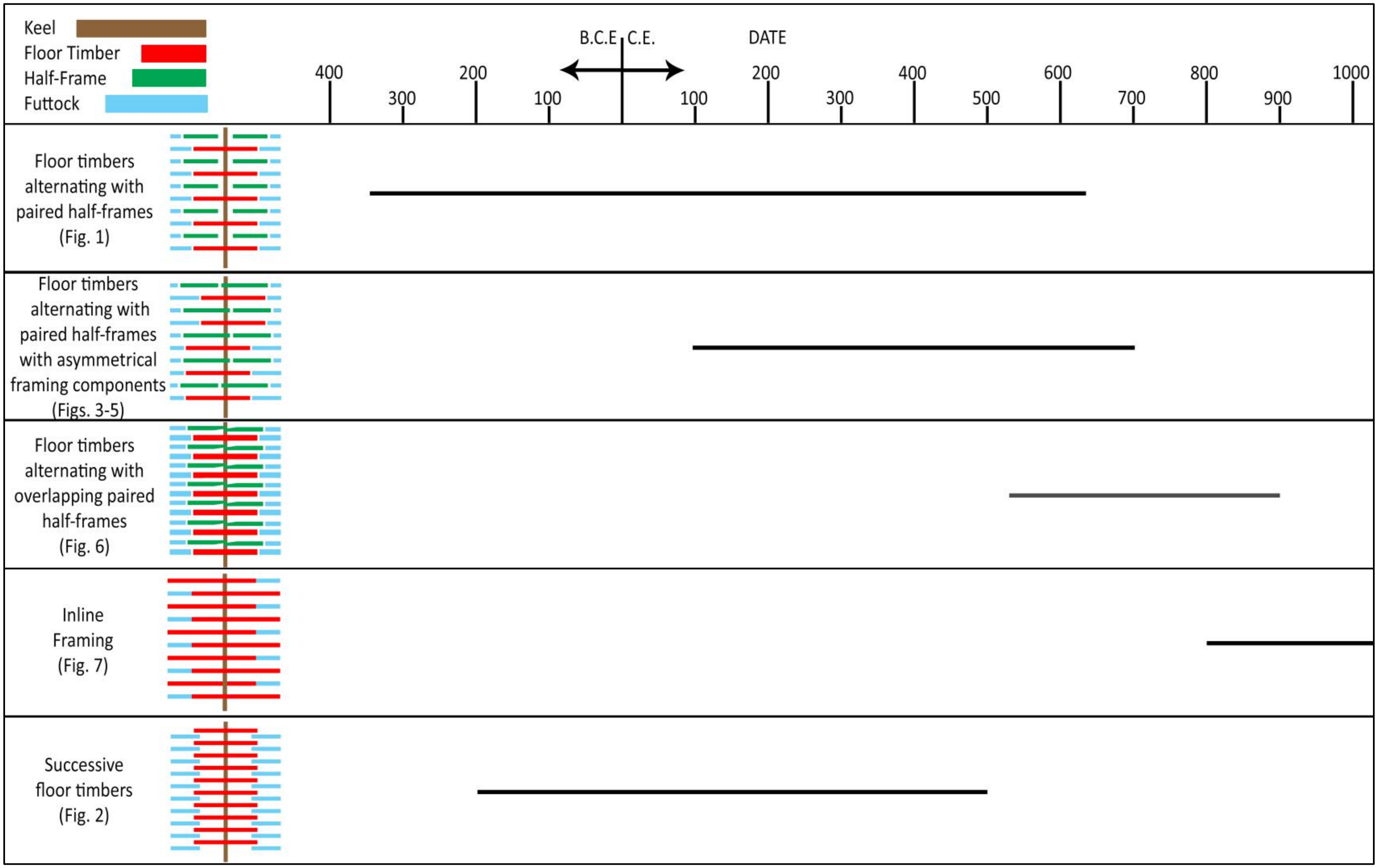

Figure 8. General framing chronology.

them to compromise this system. It is not until planking edge-joinery begins to change that any significant and purposeful changes are observed in the arrangement of floor timbers alternating with paired half-frames. These changes indicate that shipwrights knew the primary form of hull strength was weakened and they attempted to compensate for this by altering the framing system to make it stronger. Shipwrights likely realized the potential of frames in determining the shape of the hull, but technological and conceptual limitations inhibited the building of frame-based ships. By the 8th and 9th centuries C.E., shipwrights around Constantinople have quickly adopted the use of successive L-shaped floor timbers. It is this new system that plays an important role in the transition to frame-based construction as evidenced by the L-shaped floor timbers used in the first incontrovertible frame-based vessel – the Serçe Limanı ship. The use of L-shaped framing continues until it eventually merges into double framing – a framing system that works for hulls of any size.[297]

While framing systems in ancient Mediterranean ships have received little focused attention in the past, it is clear that a detailed study of the incremental changes that take place between the 4th century B.C.E. and the 9th century C.E. reveals important details about larger patterns in ship construction during that same time period. As with almost all studies on ancient ship construction in the Mediterranean, this research is an attempt to analyze changes in the physical characteristics of hull remains and understand the corresponding thought processes of the shipwrights. Some details, like the overall

[297] Steffy 2004, 158.

chronological sequence of development, may be refined with the discovery and excavation of new shipwrecks. However, this is also one of the sources of difficulty in this type of focused research on particular features of ship design and construction. The trend towards underwater recording of shipwrecks and away from total excavation means that the subtle changes in ancient Mediterranean ship construction may go unrecorded or unnoticed. The lack of standardized recording procedures for ancient hulls is further hindered by archaeologists without specialized training in ancient Mediterranean ship construction directing the recording of hull remains. While total excavation is impacted deeply by cost, the difficulties of conservation, and lack of proper storage and exhibition facilities, more standardized and detailed documentation of hulls is needed, especially in face of the few available shipwrecks dating to the 6^{th} and 7^{th} centuries C.E. This is an important time period in which the conceptual purpose of framing begins to change; adding data from this time period will contribute significantly to a deeper understanding of this shift in construction, in particular how shipwrights began to see the framing as the structural skeleton of ships.

WORKS CITED

Akkemik, Ü. 2015. *Yenikapı Shipwrecks: Woods of Yenikapı Shipwrecks*, Volume 2. Istanbul Üniversitesi Bilimsel araştırma projeleri, proje no: 2294. Istanbul: Ege Yayınları.

Averdung, D. and R. Pedersen. 2012. "The Marsala Punic Shipwreck: Reconsidering Their Nature and the Function of the 'Ram.'" *Skyllis* 12(2): 125-31.

Basch, L. 1972. "Ancient Wrecks and the Archaeology of Ships." *IJNA* 1: 1–58.

Barkai, O. and Y. Kahanov. 2007. "The Tantura F Shipwreck, Israel." *IJNA* 36: 21-31.

Bargagliotti, S., F. Cibecchini, and P. Gambogi. 1997. "Prospezioni subacquee sulle secche della Meloria (LI): alcuni risultati preliminary." In *Atti del convegno nazionale di archeologia subacquea, Anzio 1996*, 43-3. Bari: Associazione Italiana Archeologi Subacquei.

Bartolini, M., C. Capretti, G. Galotta, G. Giachi, N. Macchioni, M. Nugari, and B. Pizzo. 2005. "La Scoperta del Porto di Neapolis: dalla ricostruzione topografica allo scavo e al recupero dei relitti." *Archaeologia Maritima Mediterranea* 2: 47-91.

Bass, G. 1982. "Conclusions." In *Yassı Ada I: A Seventh-Century Byzantine Shipwreck*, edited by G. Bass and F. van Doorninck Jr., 311-9. College Station: Texas A&M University Press.

Bass, G. and F. van Doorninck. 1971. "A Fourth-Century Shipwreck at Yassı Ada." *AJA* 75(1): 27-37.

Beltrame, C. and D. Gaddi. 2007. "Preliminary Analysis of the Hull of the Roman Ship from Grado, Gorizia, Italy." *IJNA* 36: 138-47.

Beltrame, C. and E. Costa. 2016. "A 5th-Century-AD Sewn-Plank River Barge at St Maria in Padovetere (Comacchio-FE), Italy: An Interim Report." *IJNA* 46: 1-14.

Benoit, F. 1958. "Nouvelles épaves de Provence." *Gallia* 16(1): 5-39.

Benoit, F. 1960. "Nouvelles épaves de Provence (II)." *Gallia* 18(1): 41-56.

Benoit, F. 1961. *Fouilles sous-marines: l'épave du Grand Congloué à Marseille. XIV^{e} supplément a Gallia*. Paris: Centre National de la Recherche Scientifique.

Benini, A. 2001. “Il secondo relitti di Gela: note di architettura navale.” In *La nave greca aracaica di Gela*, edited by R. Panvini, 97-106, 152-3. Palermo: Salvatore Sciascia Editore.

Boetto, G. 2000. “New Technology and Historical Observations on the Fiumicino 1 Wreck from Portus Claudius (Fiumicino, Rome).” In *Down the River to the Sea: Proceedings of the Eighth International Symposium on Boat and Ship Archaeology, Gdańsk 1997*, edited by J. Litwin, 99-102. Gdańsk: Polish Maritime Museum.

Boetto, G. 2001. “Les navires de Fiumicino.” In *Ostia, port et porte de la Rome antique*, edited by J. Descoeudres, 121-7. Genève: Musées d’art et d’histoire.

Boetto, G. 2003. “The Late-Roman Fiumicino 1 Wreck: Reconstructing the Hull.” In *Boats, Ships and Shipyards, Proceedings of the Ninth International Symposium on Boat and Ship Archaeology, Venice 2000*, edited by C. Beltrame, 66-70. Oxford: Oxford Books.

Boetto, G. 2006. “Roman Techniques for the Transport and Conservation of Fish: The Case of the Fiumicino 5 Wreck.” In *Connected by the Sea: Proceedings of the Tenth International Symposium on Boat and Ship Archaeology, Denmark 2003*, edited by L. Blue, F. Hocker, and A. Englert, 123-9. Oxford: Oxbow Books.

Boetto, G. 2008. “L’épave de l’antiquité tardive Fiumicino 1: Analyse de la structure et étude fonctionnelle.” *Archaeonautica* 15: 29-62.

Boetto, G. 2009. “New Archaeological Evidences Of The Horeia-Type Vessels: The Roman Napoli C Shipwreck From Naples (Italy) And The Boats Of Toulon (France) Compared.” In *Between the Seas: Proceedings of the Eleventh International Symposium on Boat and Ship Archaeology, Mainz 2006,* edited by R. Bockius, 289-96. Mainz: Römisch-Germanisches Zentralmuseum.

Boetto, G., I. Rossi, S. Marlier, and Z. Brusić. 2012. “L’épave de Pakoštane, Croatie (Fin IV^{e} – début V^{e} siècle apr. J.-C.): Résultats d’un projet de recherche franco-croate.” *Archaeonautica* 17: 105-51.

Boetto, G., V. Carsana, and D. Giampaola. 2010. “I relitti di Napoli e il loro contest portuale.” *Navis* 4: 115-22.

Bonino, M. 1989. “Notes on the Architecture of Some Roman Ships: Nemi and Fiumicino.” In *Tropis I: 1st International Symposium on Ship Construction in Antiquity*, *Piraeus 1985*, edited by H. Tzalas, 37-53. Athens: Hellenic Institute for the Preservation of Ship Construction in Antiquity.

Bonino, M. 2001. “Further Steps in the Study of The Nemi Ships: Architecture and Clues for Their Reconstruction.” In *Tropis VI: 6th International Symposium on Ship Construction in Antiquity*, *Lamia 1996*, edited by H. Tzalas, 99-113. Athens: Hellenic Institute for the Preservation of Ship Construction in Antiquity.

Brenni, G.M. 1985. “The *Dolia* and the Sea-Borne Commerce of Imperial Rome.” M.A. Thesis, Texas A&M University.

Carlson, D. 2002. “Caligula's Floating Palaces.” *Archaeology* 55: 26-31.

Carrazé, F. 1977. “Mediterranean Hull Types Compared 3. The Jeaune-Garde B Wreck at Porquerolles (France).” *IJNA* 6: 299-303.

Carre, M. 1993. “L’épave à dolia de Ladispoli (Etrurie Méridionale).” *Archaeonautica* 11: 9-29.

Casson, L. 1965. “Harbour and River Boats of Ancient Rome.” *JRS* 55(1/2): 31-9.

Casson, L. 1995. *Ships and Seamanship in the Ancient World*. Princeton, N.J.: Princeton University Press.

Carre, M.B. 1998. “Les fouilles de la Bourse. Conclusion: la date de l’épave.” In *Fouilles à Marseille. Les mobiliers (Ier–VIIe siècles ap. J-C.)*, edited by M. Bonifay, M-B. Carre and Y. Rigoir, 101. Marseilles: Etudes Massaliètes.

Charlin, G., J.-M. Gassend, and R. Lequément. 1978. “L'épave antique de la baie de Cavalière (Le Lavandou, Var).” *Archaeonautica* 2: 9-93.

Chevalier, Y. and C. Santamaria. 1973. *L’épave de l’Anse Gerbal à Port-Vendres*. Bordighera: Institut International d’Études Ligures.

Clerc, J. and J. Negrel. 1973. “Premiers résultats de la campagne de fouilles 1971 sur l’épave B de la Pointe de la Luque.” *CahArchSubaq* 2: 61-71.

Cuomo, J. and J. Gassend. 1982. “La construction alternée des navires antiques et l’épave de la Bourse à Marseille.” *RANarb* 15: 263-72.

Dangréaux, B., S. François, F. Guibal, S. Wicha and G. Gentric. 2012. “L’épave de la Tour Fondue (presqu’île de giens, Var), un bâtiment de cabotage dans la seconde moitié du IIIe siècle avant J.-C.” *CahArchSubaq* 19: 5-32.

de Weerd, M. 1978. “Ships of the Roman Period at Zwammerdam/ Nigrum Pullum, Germania Inferior.” In *Roman Shipping and Trade: Britain and the Rhine*

Province, edited by J. du Taylor and H. Cleere, 15-30. London: CBA Research Reports.

Dumas, F. 1964. *Épaves antiques; introduction à l'archéologie sous-marine méditerranéenne. Préf. de Michel Mollat*. Paris: G.-P. Maisonneuve et Larose.

Dumontier, M. and J. Joncheray. 1991. "L'épave romaine du Miladou." *CahArchSubaq* 10: 109-74.

Fagerlie, J. 1982. "The Coins." In *Yassı Ada I: A Seventh-Century Byzantine Shipwreck*, edited by G. Bass and F. van Doorninck Jr., 145-55. College Station: Texas A&M University Press.

Fiori, P. and J. Joncheray. 1975. "L'épave de la Tradelière: Premiers résultats des fouilles entreprises en 1973." *CahArchSubaq* 4: 59-70.

Fitzgerald, M. 1995. "A Roman Wreck at Caesarea Maritima, Israel: A Comparative Study of its Hull and Equipment." Ph.D. diss., Texas A&M University.

Fitzgerald, M. and A. Raban. 1989. "Chapter III: The CAHEP Excavations." In *The Harbours of Caesarea Maritima: Results of the Caesarea Ancient Harbour Excavation Project, 1980-1985,* Volume I. *The Site and the Excavations*, edited by J. Oleson, 101-201. Center for Maritime Studies, University of Haifa, Publication 3. BAR-IS 491. Oxford: Archaeopress.

Freschi, A. 1991. "The Sewn Plank Boat of Gela in Sicily. Preliminary Observations about Construction of Hull." In *Tropis IV, 4th International Symposium on Ship Construction in Antiquity*, *Athens 1991*, edited by H. Tzalas, 187-8. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Foerster, F. 1980. "A Roman Wreck off Cap del Vol, Gerona, Spain." *IJNA* 9: 244-53.

Frey, D., F. Hentschel, and D. Keith. 1978. "Deepwater Archaeology. The Capistello Wreck Excavation, Lipari, Aeolian Islands." *IJNA* 7: 279-300.

Frost, H. 1981. *Lilybaeum (Marsala): The Punic Ship: Final Excavation Report*. Notizie Degli Scavi di Antichità 30. Supplemento. Roma: Accademia Nazionale dei Lincei.

Gassend, J. 1982. *Le navire antique du Lacydon*. Marseilles: Musée d'Histoire de Marseille.

Gassend, J. and J. Cuomo. 1982. "La construction alternée des navires antiques et l'épave de la Bourse à Marseille." *RANarb* 15: 263-72.

Gassend, J., B. Liou, and S. Ximénès. 1984. "L'épave 2 de l'anse des Laurons (Martigues, Bouches-du Rhône)." *Archaeonautica* 4: 75-105.

Gianfrotta, P. and P. Pomey. 1981. *Archeologia Subacquea*. Milano: Arnoldo Mondadori.

Giampala, D., V. Carsena, G. Boetto, F. Crema, C. Florio, D. Panza, B. Pizzo, C. Capretti, G. Galotta, G. Giachi, N. Macchioni, M. Nugari, and M. Bartolini. 2005. "La Scoperta del Porto di Neapolis: dalla ricostruzione topogrfica allo scavo e al recupero dei relitti." *Archaeologia maritima mediterranea* 2: 47-91.

Harpster, M. 2002. "A Preliminary Report on the 9th-century AD Hull Found near Bozburun, Turkey." In *Tropis VII, 7th International Sympsium on Ship Construction in Antiquity*, Pylos 1999, edited by H. Tzalas, 409-18. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Harpster, M. 2005. *A Re-Assembly and Reconstruction of the 9th-Century AD Vessel Wrecked off the Coast of Bozburun, Turkey*. Ph.D. diss., Texas A&M University.

Harpster, M. 2009. "Designing the 9th-Century-AD Vessel from Bozburun, Turkey." *IJNA* 38: 297-313.

Harris, W. 2009. "Comment on Andrew Wilson." In *Quantifying the Roman Economy*, edited by A. Bowman and A. Wilson, 213-49. Oxford Studies on the Roman Economy 1. Oxford: Oxford University Press.

Hesnard, A., M. Carre, M. Rival, B. Dangréaux, M. Thinon, M. Blaustein, M. Dumontier, A. Chéné, P. Foliot, and H. Bernard-Maugiron. 1988. "L'épave romaine Grand Ribaud D (Hyères, Var)." *Archaeonautica* 8: 5-180.

Hocker, F. 1998. "Bozburun Byzantine Shipwreck Excavation: The Final Campaign 1998." *Institute of Nautical Archaeology Quarterly* 25: 3-13.

Hocker, F. 2004. "Shipbuilding: Philosophy, Practice, and Research." In *The Philosophy of Shipbuilding*, edited by F. Hocker and C. Ward, 1-11. College Station: TAMU Press.

Hopkins, K. 1980. "Taxes and Trade in the Roman Empire (200 B.C. – A.D. 400)." *JRS* 70: 101-125.

Israeli, E. and Y. Kahanov. 2012. "Tantura E: Hull Construction Report." In *Between Continents: Proceedings of the Twelfth Symposium on Boat and Ship Construction*, *Istanbul 2009*, edited by N. Günsenin, 43-7. Istanbul: Ege Yayınları.

Israeli, E. and Y. Kahanov. 2014. “The 7th-9th Century Tantura E Shipwreck, Israel: Construction and Reconstruction.” *IJNA* 43: 369-88.

Jézégou, M. 1985. “Eléments de construction sur couples observés sur une épave du haut Moyen-Âge découverte à Fos-sur-Mer (Bouches-du-Rhône).” In *VI Congreso internacional de arqueologia submarina, Cartagena 1982*, 351-6. Madrid : Ministerio de Cultura.

Jézégou, M. 1989. “L’épave II de l’anse Saint-Gervais à Fos-sur-Mer (Bouches-du-Rhône): un navire du haut Moyen-Âge construit sur squelette.” In *Tropis I, 1st International Symposium on Ship Construction in Antiquity, Piraeus 1985*, edited by H. Tzalas, 139-46. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Jézégou, M. 2011. “L’épave de la Conque des Salins (Mèze, Étang de Thau, Département de l’Hérault). Une embarkation lagunaire.” In *Batellerie gallo-romaine: pratiques régionales et influences maritimes méditerranéennes*, edited by G. Boetto, P. Pomey, and A. Tchernia, 167-75. Paris: Errance.

Joncheray, A. 1998. “Dramont I: une épave de marbres d’Asie Mineure.” In *Méditerranée antique : pêche, navigation, commerce*, edited by E. Rieth, 139-56. Nice: 121e congrès national des sociétés historiques et scientifiques.

Joncheray, A. and J. Joncheray. 1997. “Dramont I, description et étude de la coque d’une épave de marbres d’asie mineure du premier siècle après J.-C.” *CahArchSubaq* 13: 165-95.

Joncheray, A. and J. Joncheray. 2004a. “L’épave Barthélemy B, à Saint-Raphael (Var, France).” *CahArchSubaq* 15: 7-72.

Joncheray, A. and J. Joncheray. 2004b. “L’épave Lardier 4, à la Croix-Valmer (Var, France).” *CahArchSubaq* 15: 73-117.

Joncheray, A. and J. Joncheray. 2009. “L’épave romaine de la Rabiou, Saint-Tropez (Var).” *CahArchSubaq* 17: 63-102.

Joncheray, J. 1975a. *L'épave "C" de la Chretienne*. Paris: Éditions du Centre national de la recherche scientifique.

Joncheray, J. 1975b. “Une épave du Bas Empire: Dramont F.” *CahArchSubaq* 4: 91-132.

Joncheray, J. and R. Rochier. 1976. “L’épave de la Roche Fouras. Coque du navire, estampilles sur amphores.” *CahArchSubaq* 5: 167-80.

Joncheray, J. 1975. “Une épave du Bas Empire: Dramont F.” *CahArchSubaq* 4: 91-132.

Joncheray, J. 1976. “Mediterranean Hull Types Compared 1. La Roche Fouras.” *IJNA* 5: 107-14.

Joncheray, J. 1977. “Mediterranean Hull Types Compared 2. Wreck F from Cape Dramont (Var), France.” *IJNA* 6: 3-7.

Joncheray, J. 1994. “L’épave Dramont C.” *CahArchSubaq* 7: 5-51.

Joncheray, J. 1997. “Bénat 2, une épave à dolia du prmier siècle avant J.-C.” *CahArchSubaq* 13: 97-119.

Joncheray, A. 1998. “Dramont I: une épave de marbres d’Asie Mineure.” In *Méditerranée antique. Pêche, navigation, commerce, Congrès national des sociétés historiques et scientifiques ; le 120e, Aix-en-Provence, 23-29 Octobre 1995 et le 121e, Nice, 26-31 Octobre 1996*, edited by E. Rieth, 139-55. Paris: Comité des travaux historiques et scientifiques.

Jonheray, J. 2007. “L’épave Sarrasine Agay A. Campagne 1996.” *CahArchSubaq* 16: 223-48.

Kahanov, Y. 1998. “Sewing System” in the Hull Construction of the Ma’agan Mikhael Shipwreck: A Comparative Study with Mediterranean Parallels. Ph.D. diss., Haifa University.

Kahanov, Y. 2000. “The Tantura B Shipwreck. Tantura Lagoon, Israel Preliminary Hull Construction Report.” In *Down the River into the Sea. Eighth International Symposium on Boat and Ship Archaeology, Gdańsk 1997*, edited by J. Litwin, 151-54. Gdansk: Polish Maritime Museum.

Kahanov, Y. 2001. “The Byzantine Shipwreck (Tantura A) in the Tantura Lagoon, Israel: Hull Construction Report.” In *Tropis VI, 6th International Symposium on Ship Construction in Antiquity*, *Lamia 1996*, edited by H. Tzalas, 265-71. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Kahanov, Y. 2010. “From Shell to Skeleton Construction: Introduction.” In *Transferts technologiques en architecture navale méditerranéenne de l’Antiquité aux temps modernes: identité technique et identité culturelle. Actes de la Table Ronde Internationale d’Istanbul, 19–21 Mai 2007, (Varia Anatolica XXX)*, edited by P. Pomey, 87–95. Istanbul: Institut Français d’études Anatoliennes-Georges Dumézil.

Kahanov, Y. and E. Linder. 2003. *The Ma'agan Mikhael Ship, A Recovery of a 2400-Year-Old Merchantman*. Jerusalem: Old City Press.

Kahanov, Y. and H. Mor. 2014. "The Dor 2001/1 Byzantine Shipwreck, Israel: Final Report." *IJNA* 43: 41-65.

Kahanov, Y. and J. Royal. 1996. "The 1995 INA/CMS Tantura A Byzantine Shipwreck Excavation Hull Construction Report." *CMS News* 23: 21-3.

Kahanov, Y. and J. Royal. 2001. "Analysis of Hull Remains of the Dor D Vessel, Tantura Lagoon, Israel." *IJNA* 30: 257-65.

Kampbell, S. 2007. "The Pantano Longarini Shipwreck: A Reanalysis." M.A. Thesis, Texas A&M University.

Katzev, S. 2005. "Resurrecting an Ancient Greek Ship: Kyrenia, Cyprus." In Beneath The Seven Seas: Adventures with the Institute of Nautical Archaeology, edited by G. Bass, 72-9. London: Thames & Hudson.

Kocabaş, I. and U. Kocabaş. 2008. "Technological and Constructional Features of Yenikapı Shipwrecks: A Preliminary Evaluation." In *The 'Old Ships' of the 'New Gate'*, Volume I, edited by U. Kocabaş, 97-185. Istanbul: Ege Yayınları.

Kocabaş, Ufuk. 2012a. *Yenikapı Shipwrecks: The 'Old Ships' of the 'New Gate'*, Volume 1. Istanbul Üniversitesi Bilimsel araştırma projeleri, proje no: 2294. Istanbul: Ege Yayınları.

Kocabaş, U. 2012b. "The Latest Link in the Long Tradition of Maritime Archaeology in Turkey: The Yenikapı Shipwrecks." *European Journal of Archaeology* 15: 1-15.

Kocabaş, U. 2015. "The Yenikapı Byzantine-Era Shipwrecks, Istanbul, Turkey: A Preliminary Report and Inventory of the 27 Wrecks Studied by Istanbul University." *IJNA* 44: 5-38.

Kocabaş, U. and I. Kocabaş. 2010. "Istanbul University construction techniques and features of shipwrecks in the Yenikapı Byzantine Shipwrecks Projects." In *Istanbul: 8000 Years Brought to Daylight, Marmaray, Metro, Sultanahmet excavations*, edited by J. Alguadiş and D. Batchelder, 196-201. Istanbul: Vehbi Koç Foundation.

Lamboglia, N. 1953. "La nave romana di Albenga." *RStLig* 18: 131-236.

Lamboglia, N. 1964. “La campagna 1963 sul relitto di Punta Scaletta all’isola di Giannutri.” *RStLig* 30: 229-57.

Laures, F. 1983. “Roman Naval Construction, As Shown by the Palamós Wreck.” *IJNA* 12: 219-28.

Laures, F., R. Guash and J. Farras. 1987. *El pecio romano de Palamós: excavación arqueológica submarina por el CRIS*. Spain: Centro de Recuperación e Investigaciones Submarinas.

Liou, B. 1973. “Recherches archéologiques sous-marines.” *Gallia* 31: 571-608.

Liou, B. 1974. “L’épave romaine de l’anse Gerbal (Port-Vendres).” *CRAI* 118: 414-33.

Liou, B. and C. Domergue. 1990. “Le commerce de la Bétique au 1er ler siècle de notre ère. L’épave Sud-Lavezzi 2 (Bonifacio, Corse de Sud).” *Archaeonautica* 10: 11-123.

Liou, B., J. Gassend, and R. Roman. 1990. “L’épave Saint-Gervais 3 à Fos-sur-Mer (milieu du IIe siècle ap. J-C.). Inscriptions peintes sur amphores de Bétique. Vestiges de la coque.” *Archaeonautica* 10: 157-264.

Littlefield, J. 2012. “The Hull Remains of the Late Hellenistic Shipwreck at Kızılburun, Turkey.” M.A. Thesis, Texas A&M University.

Long, L. 1988. "The Ancient Wreck of Carry-le-Rouet: Evidence of Sea Transport of Stone in the 2nd or 1st Century B.C." In *Archaeology in Solution: Proceedings of the 17th Conference on Underwater Archaeology, January 8-12, 1986, Sacramento, California*, edited by J. Foster and S. Smith, 22-7. Salinas, CA: Coyote Press.

Lopez, R. 1959. “The Role of Trade in the Economic Readjustment of Byzantium in the Seventh Century.” *DOP* 13: 67-85.

Marie-Brigitte, C. 1993. “L’épave à dolia de Ladispoli (Etrurie Méridionale).” *Archaeonautica* 11: 9-29.

Marlier, S. and P. Sibella. 2002. “La Giraglia, a Dolia Wreck of the 1st Century BC from Corsica, France: Study of Its Hull Remains.” *IJNA* 31: 161-71.

Matthews, S. and J. Steffy. 2004. “The Hull Remains.” In *Serçe Limanı, An Eleventh-Century Shipwreck,* Volume I, edited by G. Bass, S. Matthews, J. Steffy and F. van Doorninck Jr, 81-122. College Station: TAMU Press.

Medas, S. 2001. “Il relitto tardo-romano del Parco di Teodorico a Ravenna.” *Navis* 2: 104-18.

Medas, S. 2003. “The Late-Roman “Parco di Teodorico” Wreck, Ravenna, Italy: Preliminary Remarks on the Hull and the Shipbuilding.” In *Boats, Ships and Shipyards. Proceedings of the Ninth International Symposium on Boat and Ship Archaeology*, *Venice 2000*, edited by S. Medas, 42-8. Oxford: Oxford Books.

Mouchot, D. 1968. “Épave Romaine “A” du Port de Monaco.” *Bulletin du Musée d' Anthropologie Préhistorique de Monaco* 15: 159-201.

Navri, R., Y. Kahanov and D. Cvikel. 2013. “The Byzantine-Period Dor 2006 Shipwreck, Israel: Preliminary Hull Construction Report.” *IJNA* 42: 305-25.

Olschki, A. and G. Mannelli. 1961. “Ricerche subacquee nel golfo di Baratti.” In *Actes du IIe Congrès international d'archéologie sous-marine, Albenga 1958,* edited by A.Olschki and G.Marinelli, 120-3. Bordighera: Institut international d'Études ligures.

Pallarés, F. 1985. “Relazione sulla campagna archeologica sottomarina 1985 sul relitto della nave romana di Albenga.” *RStLig* 51: 632-9.

Paolilli, A. 2008. “Development and Crisis in Ancient Rome: The Role of Mediterranean Trade.” *Historical Social Research* 33: 274-89.

Parker, A. 1990. “The Pattern of Commerce as Evidenced by Shipwrecks.” In *Le commerce maritime romain en Méditerranée occidental*, edited by T. Hackens and M. Miró, 147-68. Strasburg: Conseil de l'Europe.

Planer, D. 2007. “Tantura E—Dor lagoon.” *RIMS News* 33: 19-20.

Polzer, M. 2010. “The VIth-Century BC Shipwreck at Pabuç Burnu, Turkey. Evidence for Transition from Lacing to Mortise-and-Tenon Joinery in Late Archaic Greek Shipbuilding.” In *Transferts technologiques en architecture navale méditerranéenne de l'Antiquité aux temps modernes: identité technique et identité culturelle. Actes de la Table Ronde Internationale d'Istanbul, 19–21 Mai 2007 (Varia Anatolica XXX)*, edited by P. Pomey, 27-44. Istanbul: Institut Français d'études Anatoliennes-Georges Dumézil.

Polzer, M. 2011. “Early Shipbuilding in the Eastern Mediterranean.” In *Oxford Handbook of Maritime Archaeology*, edited by A. Catsambis, B. Ford and D. L. Hamilton, 349-78. Oxford: Oxford University Press.

Pomey, P. 1978a. “La coque.” In *L’épave romaine de la Madrague de Giens (Var), Gallia Suppl. 34*, edited by A. Tchernia, P. Pomey, A. Hesnard, 75-99. Paris: Éditions du Centre National de la Recherche Scientifique.

Pomey, P. 1978b. “Le tonnage du navire.” In *L’épave romaine de la Madrague de Giens (Var), Gallia Suppl. 34*, edited by A. Tchernia, P. Pomey, A. Hesnard, 102-7. Paris: Éditions du Centre National de la Recherche Scientifique.

Pomey, P. 1981. “L’épave de Bon-Porté et les bateaux cousus de Méditerranée.” *The Mariner’s Mirror* 67(3): 225-43.

Pomey, P. 1982. “Le navire romain de la Madrague de Giens.” *CRAI* 126: 133-54.

Pomey, P. 1988. “Principes et méthodes de construction en architecture navale antique.” In *Navires et commerces de la Méditerranée antique, hommage à Jean Rougé, Cahiers d’Histoire* XXXIII, 397-412. Lyon: Comité historique du Centre Est.

Pomey, P. 1995. “Les épaves grecques et romaines de la place Jules-Verne à Marseille.” *CRAI* 139: 459-84.

Pomey, P. 1998. “Conception et réalisation des navires dans l’antiquité méditerranéene.” In *Concevoir et construire les navires. De la trière au picteux. (Technologie, Idéologies, Pratiques, Revue d’Anthropologie des Connaissances, XIII, 1)*, edited by E. Rieth, 49-72. Ramonville Saint-Agne: Érès.

Pomey, P. 1999. “Les épaves romaines de la Place Jules Verne a Marseille: Des bateaux dragues?” In *Tropis V, 5th International Symposium on Ship Construction in Antiquity, Nauplia 1993*, edited by H. Tzalas, 321-24. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Pomey, P. 2001. “Les épaves grecques archaiques du VIe siecle av. J.-C. de Marseille: épaves Jules-Verne 7 et 9 et César 1.” In *Tropis VI, 6th International Symposium on Ship Construction in Antiquity*, *Lamia 1996*, edited by H. Tzalas, 426-37. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Pomey, P. 2002. “Remarques sur la faiblesse des quilles des navires antiques à retour de galbord.” In *Vivre, produire et échanger: reflets méditerranéens, mélanges offerts à Bernard Liou*, edited by L. Rivet and M. Sciallano, 11-9. Montagnac: Monique Mergoil.

Pomey, P. 2004a. “La structure du navire de la Madrague de Giens et le type hellénistique.” *RStLig* 2: 372-73.

Pomey, P. 2004b. “Principles and Methods of Construction in Ancient Naval Architecture.” In *The Philosophy of Shipbuilding*, edited by F. Hocker and C. Ward, 25–36. College Station: TAMU Press.

Pomey, P. and E. Rieth. 2005. *L’archéologie navale*. Paris: Errance.

Pomey, P., Y. Kahanov and E. Rieth. 2012. “Transition from Shell to Skeleton in Ancient Mediterranean Ship-Construction: Analysis, Problems, and Future Research.” *IJNA* 41: 235-314.

Pomey, P., Y. Kahanov and E. Rieth. 2013. “Transition from Shell to Skeleton.” *IJNA* 42: 434-8.

Pulak, C. 1999. “The Late Bronze Age Shipwreck at Uluburun: Aspects of Hull Construction.” In *The Point Iria Wreck: Interconnections in the Mediterranean ca. 1200 BCE, Proceedings of the International Conference, Island of Spetses, 19 September 1998,* edited by W. Phelps, Y. Lolos, and Y. Vichos, 209-38. Athens: Hellenic Institute of Marine Archaeology.

Pulak, C. 2010. “Yenikapı Byzantine Shipwrecks.” In *Istanbul: 8000 Years Brought to Daylight, Marmaray, Metro, Sultanahmet excavations*, edited by J. Alguadiş and D. Batchelder, 202-15. Istanbul: Vehbi Koç Foundation.

Pulak, C., R. Ingram, and M. Jones. 2014. “Galleys and Merchantmen: Shipwrecks of Portus Theodosiacus, Yenikapı-Istanbul.” *TINA Maritime Archaeology Periodical* 1: 8-25.

Pulak, C., R. Ingram, and M. Jones. 2015a. “Eight Byzantine Shipwrecks from the Theodosian Harbour Excavations at Yenikapı in Istanbul, Turkey: An Introduction.” *IJNA* 44: 39-73.

Pulak, C., R. Ingram, and M. Jones. 2015b. “The Shipwrecks at Yenikapı: Recent Research in Byzantine Shipbuilding.” In *Maritime Studies in the Wake of the Byzantine Shipwreck at Yassıada, Turkey*, edited by D. Carlson, J. Leidwanger, S. Kampbell, 102-15. College Station: Texas A&M Press.

Riccardi, E. 1996. “Investigation into the Hull of Wreck B (The “Pozzino”) in the Gulf of Baratti-Livorno-Italy.” In *Tropis IV, 4th International Symposium on Ship Construction in Antiquity*, *Athens 1991*, edited by H. Tzalas, 393-407. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Riccardi, E. 2001. "Olbia-Sardinia Wreck of the Siciliano." In *Tropis VI, 6th International Symposium on Ship Construction in Antiquity, Lamia 1996*, edited by H. Tzalas, 493-504. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Rieth, E., C. Carrierre-Desbois, and V. Serna. 2001. "Le site fluvial." In *L'épave de Port Berteau II (Charente-Maritime). Un caboteur fluviomaritime du haut Moyen Âge et son contexte nautique*, 21-39. Paris: Éditions de la Maison des sciences de l'homme.

Sandrin, P., A. Belov, and D. Fabre. 2013. "The Roman Shipwreck of Antirhodos Island in the Portus Magnus of Alexandria, Egypt." *IJNA* 42: 44-59.

Santamaria, C. 1973. "Note préliminaire sur le mode de construction de la coque de l'épave romaine Dramont "A" (Cap Dramont – Commune de Saint-Raphael)." *CahArchSubaq* 2: 133-36.

Santamaria, C. 1975. "L'épave A du Cap Dramont (Saint-Raphael): fouilles 1971 – 4." *RANarb* 8: 185-98.

Santamaria, C. 1995. "L'épave Dramont «E» à Saint-Raphaël (Ve siècle ap. J-C.)." *Archaeonautica* 13: 5-198.

Scheidel, W. 2009. "In Search of Roman Economic Growth." *JRA* 22: 46-70.

Steffy, J. 1982. "Reconstructing the Hull." In *Yassı Ada I: A Seventh-Century Byzantine Shipwreck*, edited by G. Bass and F. van Doorninck Jr., 32-64. College Station: Texas A&M University Press.

Steffy, J. 1985a. "The Herculaneum Boat: Preliminary Notes on Hull Details." *AJA* 89: 519-21.

Steffy, J. 1985b. "The Kyrenia Ship: An Interim Report on its Hull Construction." *AJA* 89: 71-101.

Steffy, J. 1987. "The Kinneret Boat Project, Part II. Notes on the Construction of the Kinneret Boat." *IJNA* 16: 325-29.

Steffy, J. 1989. "The Role of Three-dimensional Research in the Kyrenia Ship Reconstruction." In *Tropis 1: 1st International Symposium on Ship Construction in Antiquity*, *Piraeus 1985*, edited by H. Tzalas, 249-262. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Steffy, J. 1991. “The Mediterranean Shell to Skeleton Transition: A Northwestern European Parallel.” In *Carvel Construction Technique Skeleton-First, Shell-First, the Fifth International Symposium on Boat and Ship Archaeology*, *Amsterdam 1988*, edited by R. Reinders and P. Kees, 1-9. Oxford: Oxbow.

Steffy, J. 1994. *Wooden Ship Building and the Interpretation of Shipwrecks*. College Station: Texas A&M University Press.

Steffy, J. 1995. “Ancient Scantlings: The Projection and Control of Mediterranean Hull-Shapes.” In *Tropis III, 3rd International Symposium on Ship Construction in Antiquity*, Athens 1989, edited by H. Tzalas, 417-28. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Steffy, J. 2001. “A Mediterranean Ship Construction Database; Dating and Classifying Shipwrecks by their Hull Remains.” In *Tropis VI, 6th International Symposium on Ship Construction in Antiquity*, *Lamia 1996*, edited by H. Tzalas, 547-62. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Steffy, J. 2004. “Construction and Analysis of the Vessel.” In *Serçe Limanı, An Eleventh-Century Shipwreck,* Volume I, edited by G. Bass, S. Matthews, J. R. Steffy and F. H. van Doorninck Jr, 153-69. College Station: TAMU Press.

Tchernia, A. 1971. “Premiers résultats des fouilles de Juin 1968 sur l’épave 3 de Planier.” In *Études d’Archéologie Provençale: extraites des Etudes Classiques III*, Publication Universitaires des Lettres et Sciences Humaines d’Aix-en-Provence, 51-82. Paris: Ophrys.

Throckmorton, P. 1989. “The Ship of Torre Sgarrata.” In *Tropis I: 1st International Symposium on Ship Construction in Antiquity*, *Piraeus 1985*, edited by H. Tzalas, 263-74. Athens: Hellenic Institute for the Preservation of Nautical Tradition.

Throckmorton, P. and J. Throckmorton. 1973. “The Roman Wreck at Pantano Longarini.” *IJNA* 2: 243-66.

Ucelli, G. 1950. *Le navi di Nemi*. Roma: La Libreria dello Stato.

van Doorninck, F. 1976. “The 4th Century Wreck at Yassı Ada: An Interim Report on the Hull.” *IJNA* 5: 115-31.

van Doorninck, F. 1982. “The Hull Remains.” In *Yassı Ada I: A Seventh-Century Byzantine Shipwreck*, edited by G. Bass and F. H. van Doorninck Jr., 32-64. College Station: Texas A&M University Press.

Wachsmann, S., and J. Steffy. 1990. *The Excavations of an Ancient Boat in the Sea of Galilee (Lake Kinneret)*. *'Atiqot 19*. Jerusalem: Israel Antiquities Authority.

Wachsmann, S., Y. Kaakov, and J. Hall. 1997. "The Tantura B Shipwreck: The 1996 INA/CMS Joint Expedition to Tantura Lagoon." *Institute of Nautical Archaeology Quarterly* 24: 3-15.

Willis, S. and M. Capulli. 2014. "Putting The Pieces Together: The Laced Timbers of Venice Lido III Assemblage." *Institute of Nautical Archaeology Quarterly* 41: 10-5.

Wilson, A. 2009. "Approaches to Quantify Roman Trade." In *Quantifying the Roman Economy*, edited by A. Bowman and A. Wilson, 213-49. Oxford Studies on the Roman Economy 1. Oxford: Oxford University Press.

Wilson, A. 2011. "Developments in Mediterranean Shipping and Maritime Trade from the Hellenistic Period to AD 100." In *Maritime Archaeology and Ancient Trade in the Mediterranean*, edited by D. Robinson and A. Wilson, 33-60. Oxford: Oxford Centre for Maritime Archaeology.

Ximénès, S. and M. Moerman. 1994. "La fouille de l'épave 1 de la calanque de l'Âne." *CahArchSubaq* 12: 95-112.

Ximénès, S. and M. Moerman. 1998. "Fouille de l' épave de la calanque de l'Âne (Marseille)." *Archaeonautica* 14: 299-302.

Ximénès, S. and M. Moerman. 1987. "Les epaves I, III et IV du port romain de l'Anse des Laurons." *CahArchSubaq* 6: 171-82.

Ximénès, S. and M. Moerman. 1991. "Le materiel archéologique de l'épave Laurons II (Martigues, Bouches-du-Rhône)." *CahArchSubaq* 10: 209–22.

APPENDIX

CATALOG OF RELEVANT FRAMING DATA FROM REVIEWED SHIPWRECKS (IN CHRONOLOGICAL ORDER)

FT = Floor Timber; HF = Half-frame; FUT = Futtocks; R&S = Room and Space

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
Kyrenia	4th C B.C.E.	14	FT: 0.09 x 0.09; HF: 0.08 x 0.08	Floor timbers, half-frames and futtocks	No	Copper alloy nails through treenails	0.25	NA	Strakes 1-3	Traditional floor timbers alternating with paired half-frames.	Steffy 1985b, 72; 94; 100. Steffy 1994, 49; 51.
Secca Di Capistello	3rd C B.C.E.	20	0.16 x 0.10	Floor timbers, half-frames, futtocks	NA	Copper alloy nails	0.25	Separated by 0.15 m	NA	Traditional floor timbers alternating with paired half-frames.	Frey et al. 1978, 288; 293; fig. 18.
Marsala	3rd C B.C.E.	30-35	NA	Floor timbers, half-frames, futtocks	No	Iron nails	0.20-0.25	Abutted	NA	Traditional floor timbers alternating with paired half-frames.	Frost 1981, 249; 252; fig. 9.
Tour Fondue	3rd C B.C.E.	10-12	FT: 0.07-0.10 x 0.07-0.11; HF: 0.07 x 0.07	Floor timbers, half-frames	No	Treenails, ligatures	0.40	NA	Strake 1	Traditional floor timbers alternating with paired half-frames.	Dangréaux et al. 2012, 5-6; 11-3; 21.
Chrétienne C	2nd C B.C.E.	15-16	0.08 x 0.08	Floor timbers and futtocks	No	Treenails	0.46	Overlapped	NA	Successive floor timbers with overlapping but separate futtocks; evidence of reinforcing frames between some floor timbers.	Joncheray 1975a, 49-60; 71; 77.
Jeune-Garde B	2nd C B.C.E.	NA	NA	Floor timbers, futtocks, top timbers	NA	Iron nails through treenails	NA	NA	NA	Two repair frames fastened with vegetable sennit.	Carrazé 1977, 301-2.
Pozzino	2nd C B.C.E.	15	0.08 x 0.08-0.22	Floor timbers, half-frames, futtocks	Yes	Copper alloy nails through treenails	0.24-0.26	Abutted	Strakes 1-2	Traditional floor timers alternating with paired half-frames; copper nail fastened one floor timber fastened to the keel.	Riccardi 1996, 397; 394-5, fig. 19.
Punta Scaletta	2nd C B.C.E.	30	0.09 x 0.06	Floor timbers, half-frames	NA	NA	0.21-0.24	NA	NA		Lamboglia 1964, 240; fig. 1; fig. 2; 3; 248.
La Rouche Fouras	2nd - 1st C B.C.E.	NA	0.09 x 0.08-0.30	Floor timbers, half-frames	No	Treenails	NA	NA	Strakes 1-2	Traditional floor timbers alternating with paired half-frames.	Joncheray 1976, 110; 112-4; fig. 3. Joncheray and Rochier 1976, 171-3; 180.
Carry-le-Roulet	2nd - 1st C B.C.E.	NA	0.12 x 0.10	NA	NA	Treenails	NA	NA	NA		Long 1988, 26-27.

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
Miladou	2nd - 1st C B.C.E.	15	0.085 x 0.14	Floor timbers, half-frames	No	Treenails	0.25	NA	1st or 2nd strake	Traditional floor timbers alternating with paired half-frames.	Dumontier and Joncheray 1991, 134-6; 173-4.
Dramont C	2nd - 1st C B.C.E.	12-14	HF: 0.07-0.08 x 0.13; FT: 0.06-0.07 x 0.15	Floor timbers, half-frames	NA	Treenails, iron nails	0.27-0.36	NA	Over or near keel	Traditional floor timbers alternating with paired half-frames.	Joncheray 1994, 23-7, 49-51.
Cap Benat B	2nd - 1st C B.C.E.	8	FT: 0.05-0.07 x 0.06-0.13; HF: 0.05-0.07 x 0.06-0.07	Floor timbers, half-frames	No	Treenails	0.21	NA	Over or near keel	Traditional floor timbers alternating with paired half-frames; *dolia* carrier.	Joncheray 1997, 107; 119.
Cavalière	1st C B.C.E.	13	FT: 0.08-0.10 x 0.10-0.20; HF: 0.08-0.10 x 0.09	Floor timbers, half-frames	No	Treenails, copper alloy nails	0.23-0.28	Abutted	Strakes 1-2	Traditional floor timbers alternating with paired half-frames.	Charlin et al. 1978, 50; 72; 79-80; fig. 33; fig. 34.
Albenga	1st C B.C.E.	40	NA	NA	NA	Nails through treenails	0.22	NA	NA		Pallarés 1985, 634. Lamboglia 1953, 203; 206.
Chrétienne A	1st C B.C.E.	24-32	0.08-0.10 x 0.10	Floor timbers, half-frames	No	Treenails	0.07; 0.18	NA	Over or near keel	At least three successive floor timbers near mast-step.	Dumas 1964, 157-7; 165; fig. 15a-b.
Gerona	1st C B.C.E.	18-19	0.08-0.10 x 0.16	Floor timbers, half-frames	No	Iron nails, treenails	NA	NA	NA	Traditional floor timbers alternating with paired half-frames; iron nails and paired treenails fastened alternating frames.	Foerster 1980, fig. 1; 245; 252.
Grand Congloue B	1st C B.C.E.	23	0.08 x 0.10	Floor timbers, half-frames	NA	Treenails, nails	0.18	NA	Strake 1	Traditional floor timbers alternating with paired half-frames.	Benoit 1961, fig. 75; 149-51; 164.
Madraque de Giens	1st C B.C.E.	40	FT: 0.13-0.14 x 0.12-0.60; HF: 0.13-0.14 x 0.06-0.10	Floor timbers, half-frames, futtocks	Yes	Treenails, nails	0.23-0.25	Separated by a few centimeters	Near keel	Traditional floor timbers alternating with paired half-frames; copper alloy bolts fastened some floor timbers to the keel.	Pomey 1978a, 80-3. Pomey 1982, 133; 140. Pomey 2004a, 371-3.
Palamos	1st C B.C.E.	NA	0.09 x 0.09	Floor timbers, half-frames	NA	Treenails, nails	NA	NA	NA	Traditional floor timbers alternating with paired half-frames.	Laures 1983, 220; 223-4. Laures et al. 1987, 21; 33-35.
Dramont A	1st C B.C.E.	NA	NA	Floor timbers, half-frames	NA	Treenails	NA	NA	Garboard	Traditional floor timbers alternating with paired half-frames; four successive floor timbers near the center of the hull.	Santamaria 1973, 133-4; Santamaria 1975, 188, 192-4, fig. 8.
Planier 3	1st C B.C.E.	NA	0.10 x 0.12	NA	NA	Treenails	0.20	NA	NA	Traditional floor timbers alternating with paired half-frames.	Liou 1973, 588-9. Tchernia 1971, 71; 74.
Barthelemy B	1st C C.E.	8-10	NA	Floor timbers, half-frames, futtocks	No	Treenails, nails	0.24	Abutted	Over or near keel	Traditional floor timbers alternating with paired half-frames.	Joncheray and Joncheray 2004a, 26, 37-43, 71.

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
Caesarea	1st C C.E.	40-45	FT: 0.14-0.18 x 0.16-0.26; HF: 0.16-0.22 x 0.14-0.20	Floor timbers, half-frames, futtocks	NA	Treenails, copper alloy nails	0.25	Separated 0.01-0.10 m	NA	Traditional floor timbers alternating with paired half-frames; half-frames were heavier than the floor timbers, particularly near the turn of the bilge.	Fitzgerald and Raban 1989, 184-90; Fitzgerald 1995, 33-40, 237, 240.
Calanque de L'Ane	1st C C.E.	20-25	0.010-0.12 x 0.07-0.16	Floor timbers, half-frames	NA	NA	0.20-0.24	NA	Over or near keel	Traditional floor timbers alternating with paired half-frames.	Ximénès and Moerman 1994, 110; Ximénès and Moerman 1998, 299-300.
Dramont I	1st C C.E.	25	0.10-0.11 x 0.17	Floor timbers, half-frames, futtocks	No	Treenails	0.25	Abutted	NA		Joncheray and Joncheray 1997, 175-84, Joncheray 1998, 150.
Herculaneum	1st C C.E.	9	0.04 x 0.05	Floor timbers	NA	Treenails, copper alloy nails	0.24	NA	Asymmetrical	Floor timbers alternating with paired, asymmetrical half-frames.	Steffy 1985a, 519, 520-1; Steffy 1994, 67-71.
La Giraglia	1st C C.E.	20	0.10-0.15 x 0.08-0.11	NA	NA	Treenails, iron nails	.23-.37	Abutted	NA	*Dolia* carrier.	Marlier and Sibella 2002, 161, 164-5, 169, fig. 2.
Ladispoli A	1st C C.E.	18	0.10 x 0.18-0.20	Floor timbers, futtocks	No	Treenails	0.22-0.25	Abutted	NA	At least 21 successive floor timbers extended by futtocks; *dolia* carrier.	Carre 1993, 14-7, 28.
Nemi 1	1st C C.E.	71	0.20 x 0.30-0.40	Floor timbers, half-frames, futtocks	Yes	Copper nails through treenails	0.65-0.70	Abutted	NA	Traditional floor timbers alternating with paired half-frames; frames nailed to keel; chocks used to join futtocks and partnered framing element.	Ucelli 1950, 153, fig. 153, 157, figs. 158, 159, 379, 382; Bonino 1989, 38-41; Bonino 2001, 106-7.
Nemi 2	1st C C.E.	73	NA	Floor timbers, half-frames, futtocks	NA	NA	0.54-0.61	NA	NA		Ucelli 1950, 153, fig. 153, 157, figs. 158, 159, 379, 382; Bonino 1989, 41-2; Bonino 2001, 107-8.
Sud-Lavezzi II	1st C C.E.	20	NA	Floor timbers, half-frames, futtocks	NA	NA	NA	NA	NA	Irregular framing: succession of a floor timber, two paired half-frames, three floor timbers, one paired half-frame, three floor timbers; three successive floor timbers aft.	Liou and Domergue 1990, 121, 122.
Napoli A	1st C C.E.	15	0.09 x 0.10	Floor timbers, half-frames	NA	NA	0.21	NA	Strake 1	Alternating floor timbers and paired, asymmetrical half-frames at the extremities; succession of mostly floor timbers in the center of the hull.	Giampala et al. 2005, 67-9.
Titan	1st C C.E.	NA	NA	Floor timbers, half-frames	NA	Treenails	NA	NA	NA	Traditional floor timbers alternating with paired half-frames; average space between frame faces was 0.15 m.	Benoit 1958, 5, 16, 22.
Balise de Rabiou	1st C C.E.	15	0.10-0.12 x 0.11-0.12	Floor timbers, half-frames	No	Treenails	0.24-0.28	Abutted	Over or near keel	Floor timbers alternating with paired, asymmetrical half-frames.	Joncheray and Joncheray 2009, 74, fig. 31, 95-6.
Lardier 4	1st C C.E.	22.5	0.06-0.07 x 0.06	Floor timbers, futtocks	No	Treenails, iron nails	0.27	Abutted	NA	One futtock fastened to the side of its partnered floor timber.	Joncheray and Joncheray 2004b, 90, 116-7.

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
Antirhodos	1st - 2nd C C.E.	30-31	FT: 0.24 x 0.37; HF: 0.21 x 0.28	Floor timbers, half-frames, futtocks	Yes	Treenails	0.30	Separated 0.01-0.02 m	Over or near keel	Traditional floor timbers alternating with paired half-frames; copper alloy bolts fastened some floor timbers to the keel.	Sandrin et al. 2013, 47; 51-2; 57.
Kinneret	1st - 2nd C C.E.	9	0.06 x 0.07 m	Floor timbers, half-frames, futtocks	Yes	Iron nails	0.25	NA	Asymmetrical	Floor timbers alternating with paired, asymmetrical half-frames; at least eight floor timbers and half-frames nailed to the keel.	Steffy 1987, 327, 329; fig. 4; Steffy 1994, 65-7.
Conque des Salins	1st - 3rd C C.E.	15	0.10-0.14 x 0.09-0.12	Floor timbers	NA	Iron nails	0.80-0.96	NA	NA	Successive floor timbers; two frame stations scarfed together.	Jézégou 2011, 169; 171; 175.
Fiumicino 4	2nd C C.E.	8	0.04-0.06 x 0.03-0.05	Floor timbers, futtocks	No	Treenails	NA	Abutted	NA	Successive floor timbers extended by futtocks.	Boetto 2001, 123-4; http://www2.rgzm.de/navis/ships/ship054/fiumicino4engl.htm.
Fiumicino 5	2nd C C.E.	5.61	0.04-0.06 x 0.02-0.10	Floor timbers, futtocks	No	Treenails, copper alloy nails, iron nails	0.18-0.20	Abutted	NA	Successive floor timbers extended by futtocks.	Boetto 2001, 123; Boetto 2006, 123, 124; http://www2.rgzm.de/navis/home/..%5CShips%5CShip055%5CFiumicino5engl.htm.
Grado	2nd C C.E.	NA	NA	Floor timbers, half-frames, futtocks	Yes	Treenails, copper alloy nails, iron nails	NA	Abutted	NA	Asymmetrical floor timbers alternating with paired, asymmetrical half-frames; average space between frame faces was 0.14-0.17 m.	Beltrame and Gaddi 2007, 138, 142-4, 145-6.
St. Gervais III	2nd C C.E.	17	0.14-0.16 x 0.13	Floor timbers, half-frames, futtocks	Yes	Treenails, copper alloy nails	0.28-0.30	Abutted	NA	Floor timbers alternating with paired, asymmetrical half-frames; three frames bolted to keel.	Liou et al. 1990, 219-32, 234, 259-9.
Torre Sgarrata	2nd - 3rd C C.E.	33	0.08 x 0.15	NA	NA	Treenails	0.25-0.30	NA	NA		Throckmorton 1989, 263, 264, 265, 266.
Olbia-Sardinia	2nd - 3rd C C.E.	15-18	NA	Floor timbers, half-frames	Yes	Treenails, copper alloy nails	NA	NA	NA	Iron bolt fastened one floor timber to the keel.	Riccardi 2001, 493, 494, 495.
La Bourse	2nd - 3rd C C.E.	23	0.08 x 0.15	Floor timbers, half-frames, futtocks	Yes	Treenails	0.25	Abutted	NA	Asymmetrical floor timbers alternating with paired, asymmetrical half-frames; copper bolts fasten eight floor timbers to the keel.	Gassend 1982, 80-1, 94, 121; Cuomo and Gassend 1982, fig. 5; Carre 1998, 101.
Napoli B	2nd - 3rd C C.E.	15	0.08 X 0.09	Floor timbers, half-frames, futtocks	Yes	Nails through treenails	0.26	NA	NA	Floor timbers alternating with paired, asymmetrical half-frames; nails fastened three floor timbers to the keel.	Giampala et al. 2005, 69-72.
Monaco A	2nd - 3rd C C.E.	12-15	0.07 x 0.12	Floor timbers	Yes	Treenails	0.24-0.25	NA	NA	Bolt fastened one floor timber to the keel.	Mouchot 1968, 176, 181-3, 184.
Laurons II	3rd C C.E.	15	FT: 0.07-0.09 x 0.10-0.20; HF: 0.07-0.09 x 0.09	Floor timbers, half-frames, futtocks	Yes	Treenails, copper alloy nails	0.20-0.22	Abutted	Over or near keel	Floor timbers alternating with paired, asymmetrical half-frames; bolts fastened four floor timbers to the keel.	Gassend et al. 1984, fig. 10, 85-6, fig. 17a-d, 98, fig. 22, 103-5; Ximénès and Moerman 1991, 221.

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
Laurons III	3rd C C.E.	NA	0.08 x 0.25	NA	Yes	Treenails, nails	NA	NA	Over keel	Bolts fastened three floor timbers to the keel.	Ximénès and Moerman 1987, 174-7, fig. 5.
Marseille 7/ Jules Verne 8	3rd C C.E.	NA	0.05 x 0.07	NA	NA	Treenails	NA	NA	NA		Pomey 1995, 462-3.
Laurons I	3rd - 4th C C.E.	NA	0.10-0.18 x 0.12-0.20	NA	NA	Treenails	0.20-0.35	NA	NA		Ximénès and Moerman 1987, 172-4.
Port Vendres A	4th C C.E.	18-20	0.13 x 0.23	Floor timbers, half-frames, futtocks	Yes	Treenails	0.25	Abutted	Over or near keel	Floor timbers alternating with paired, asymmetrical half-frames; iron bolts fastened seven to eight floor timbers to the keel; three successive floor timbers near midships.	Chevalier and Santamaria 1973, 9, 18-21.
Dramont F	4th C C.E.	10-12	0.06-0.11 x 0.09-0.11	Floor timbers, half-frames, futtocks	Yes	Treenails	0.37	Abutted	1.0 m from keel	Traditional floor timbers alternating with paired half-frames; iron bolt fastened one frame to the keel; loose and widely spaced mortise-and-tenon hull edge-joinery.	Joncheray 1975b, 108, 120-3, 131; Joncheray 1977, 5, 6, 7.
Fuimicino 2	4th C C.E.	NA	NA	Floor timbers, half-frames	Yes	Iron nails through treenails	NA	NA	NA	Traditional floor timbers alternating with paired half-frames; loose and widely spaced mortise-and-tenon hull edge-joinery; average space between frame faces was 0.24 m.	Boetto 2001, 124.
Pointe de la Luque B	4th C C.E.	20	0.13 x 0.13	Floor timbers, half-frames	Yes	Treenails	NA	NA	Over or near keel	Floor timbers alternating with paired, asymmetrical half-frames; iron bolts fastened three floor timbers to keel.	Clerc and Negrel 1973, 65-6, 68.
Fuimicino 1	4th - 5th C C.E.	17.18	FT: 0.06-0.10 x 0.08-0.18; HF: 0.06-0.10 x 0.06-0.12	Floor timbers, half-frames, futtocks	Yes	Iron nails through treenails	0.19	Abutted	Over or near keel	Traditional floor timbers alternating with paired half-frames; iron bolts fastened six floor timbers to the keel; loose, widely spaced and unpegged mortise-and-tenon hull edge-joinery.	Boetto 2000, 99, 100; Boetto 2001, 124-5; Boetto 2003, 66, 67; Boetto 2008, 42-5, 51, 53-5.
Pakoštane	4th - 5th C C.E.	15-20	0.09 x 0.10	Floor timbers, half-frames, futtocks	Yes	Treenails, copper alloy nails, iron nails	0.26	Abutted	NA	Traditional floor timbers alternating with paired half-frames; iron bolts fastened some frames to the keel; loose and widely spaced mortise-and-tenon hull edge-joinery.	Boetto et al. 2012, 118-20, 128.
Yassıada II	4th - 5th C C.E.	19	FT: 0.12-0.15 x 0.13-0.35; HF: 0.08-0.15 x 0.13-0.35	Floor timbers, half-frames, futtocks	Yes	Treenails, iron nails	0.27	Abutted	Over keel	Traditional floor timbers alternating with paired half-frames; iron bolts fastened six floor timbers to keel; loose and widely spaced mortise-and-tenon hull edge-joinery; pre-erection of midship paired half-frame.	Bass and van Doorninck 1971, 29, 31-2, 33-4, 37; van Doorninck 1976, 124-7.
Padovetere	5th C C.E.	22	FT: 0.12 x 0.16-0.22; FUT: 0.15 x 0.06-0.07	Floor timbers	NA	Treenails	NA	Overlapped	NA	Successive paired L-shaped floor timbers fastened with treenails; paired floor timbers alternate long arm in orientation across the hulls; some short ends of the futtocks scarfed to in-line futtocks; sewing, mortise-and-tenon, and nails used as hull edge-joinery.	Beltrame and Costa 2016, 2, 5-7.
Dramont E	5th C C.E.	15.6-16	FUT: 0.10-0.15 x 0.10-0.18	Floor timbers, half-frames, futtocks	NA	Treenails, nails	0.27	Abutted	Overlapped	Floor timbers alternating with paired, asymmetrical half-frames; bolts fastened five frames to the keel; loose and widely spaced mortise-and-tenon hull edge-joinery.	Santamaria 1995, 116, 150-60, 175-6.

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
Ravenna	5th C C.E.	9	0.07-0.08 x 0.08-0.09	Floor timbers, futtocks	Yes	Treenails, iron nails	0.25	Overlapped	NA	Successive floor timbers; three futtocks nailed to three frames.	Medas 2001, 111; Medas 2003, 45-7.
YK 34	5th C C.E.	NA	NA	Floor timbers, futtocks	Yes	Treenails	NA	Abutted	NA	Pegged and unpegged mortise-and-tenon hull edge-joinery up to the waterline.	Akkemik 2015, 119; Kocabaş 2015, 21-2.
YK 35	5th C C.E.	NA	NA	NA	NA	Treenails, copper alloy nails, iron nails	NA	NA	NA	Unpegged mortise-and-tenon hull edge-joinery.	Akkemik 2015, 125; Kocabaş 2015, 23-6.
YK 22	5th –6th C C.E.	NA	NA	NA	NA	Treenails, iron nails	NA	NA	NA	Widely spaced mortise-and-tenon hull edge-joinery.	Akkemik 2015, 85; Kocabaş 2015, 23.
Tantura A	6th C C.E.	12	0.09 x 0.10	NA	NA	Iron nails	0.32	Overlapped	NA	No hull edge-joinery.	Kahanov 2001, 265, 266-7, 268; Kahanov and Royal 1996, 21, 22.
Dor 2001/1	6th C C.E.	16.9	FT: 0.09 x 0.12; HF: 0.09 x 0.10	Floor timbers, half-frames, futtocks, top timbers	Yes	Iron nails	0.24	Abutted	Overlapped	Floor timbers alternating with overlapping, scarfed, and fastened paired half-frames; six out of seven frame stations near the mast-step are floor timbers; iron nails fastened most floor timbers and half-frames to the keel; no hull edge-joinery.	Kahanov and Mor 2014, 41, 46-8, 50, 57, 62-3.
Port Berteau 2	6th - 7th C C.E.	14.3	0.14 x 0.10	NA	NA	NA	0.19	NA	NA	Frame timbers not preserved.	Rieth et al. 2001, 30, 36-8.
Dor 2006	6th - 7th C C.E.	25	0.09-0.16 x 0.08-0.19	Futtocks	NA	Iron nails	0.26	Overlapped	NA	Likely floor timbers alternating with paired half-frames; iron nails fastened scarfed framing timbers; unpegged mortise-and-tenon hull edge-joinery at extremities.	Navri et al. 2013, 306-9, 317, 322.
YK 11	7th C C.E.	11.23	0.09 x 0.10	Floor timbers, half-frames, futtocks	Yes	Iron nails	0.31	Adjacent	Over keel	Floor timbers alternating with paired, overlapping half-frames; long iron nails fastened all floor timbers and half-frames to the keel; unpegged mortise-and-tenon joinery.	Pulak et al. 2014, 15; Pulak et al. 2015a, 47-50; Pulak et al. 2015b, 106.
Yassıada I	7th C C.E.	20.5	0.12-0.16 (sided)	Floor timbers, half-frames	Yes	Iron nails	0.30-0.35	NA	Over keel	Traditional floor timbers alternating with paired half-frames; no hull edge-joinery above the waterline; every fourth frame bolted to wale; bolts fastened one out of every four frames to keel; iron nails fastened the other frames to the keel.	van Doorninck 1982, 41, 56, 57, 71, 73, 75-7, 83. Pomey et al. 2012, 267.
Pantano Longarini	7th C C.E.	31.5	0.18-0.25 x 0.18-0.25	Floor timbers, half-frames, futtocks	Yes	Iron nails	0.35	Overlapped	NA	Floor timbers alternating with paired half-frames; loose, unpegged mortise-and-tenon hull edge-joinery up to the waterline; no hull edge-joinery above waterline.	Throckmorton and Throckmorton 1973, 244, 249, 252; Kampbell 2007, 45, 53-4, 65.

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
Saint-Gervais II	7th C C.E.	15-18	FT: 0.12-0.20 x 0.22-0.40; HF: 0.10-0.15 x 0.10-0.27	Floor timbers, half-frames, futtocks	Yes	Treenails, iron nails	0.25	Overlapped	Overlapped	Floor timbers alternating with paired, overlapping half-frames; iron bolts fastened all but one frame to the keel; widely spaced, loose, and occasionally unpegged mortise-and-tenon hull edge-joinery.	Jézégou 1985, 351, 353-4; Jézégou 1989, 139-40.
Dor D	7th C C.E.	15-20	0.11 (sided)	NA	NA	Treenails, iron nails	0.23	NA	NA	Loose, unpegged mortise-and-tenon hull edge-joinery.	Kahanov and Royal 2001, 257, 261, 264.
Tantura E	7th - 9th C C.E.	12.5	0.10 x 0.12	Floor timbers, half-frames, futtocks	Yes	Iron nails	0.26	Overlapped	Overlapped	Floor timbers alternating with paired, overlapping half-frames; no hull edge-fasteners; iron nail fastened each floor timber to the keel.	Israeli and Kahanov 2012, 373-5, 383, 385.
YK 3	7th - 9th C C.E.	18	NA	Floor timbers, futtocks	Yes	Treenails, iron nails	NA	Overlapped	NA	In-line framing extended by futtocks; iron nails fastened floor timbers to the keel; dowels used as hull-edge joinery up to the first wale; no hull edge-joinery above the first wale.	Akkemik 2015, 23; Kocabaş 2012a, 152-63; Kocabaş and Kocabaş 2008, 152, 157-61; Kocabaş and Kocabaş 2010, 196-8; Kocabaş 2012b, 9-10; Kocabaş 2015, 18-9.
Tantura F	8th C C.E.	15	0.08 x 0.11	Floor timbers, half-frames, futtocks	Yes	Iron nails	0.28	Overlapped	Overlapped	Floor timbers alternating with paired, overlapping, scarfed, fastened, asymmetrical half-frames; series of successive floor timbers near mast-step; iron nails fasten floor timbers to the keel; futtocks fastened to floor timbers with iron nails; no hull edge-joinery.	Barkai and Kahanov 2007, 21, 23.
YK 16	8th C C.E.	NA	0.05 x 0.06	Floor timbers, half-frames, futtocks	NA	Iron nails, dowels	0.21-0.26	Overlapped	NA	Floor timbers alternating with paired half-frames; a light galley; coaks used as hull edge-joinery.	Akkemik 2015, 57; Kocabaş 2012a, 176-82; Kocabaş and Kocabaş 2008, 180. Kocabaş 2012b, 7. Kocabaş 2015, 26-7.
YK 19	8th C C.E.	NA	NA	Floor timbers	NA	NA	NA	NA	NA	Coaks used as hull-edge joinery.	Akkemik 2015, 73; Kocabaş 2015, 17.
YK 29	8th C C.E.	NA	NA	Floor timbers, half-frames, futtocks	NA	Iron nails	NA	Overlapped	Overlapped	Floor timbers alternating with paired, overlapping half-frames; no hull edge-joinery.	Akkemik 2015, 105; Kocabaş 2015, 21.
YK 27	8th - 9th C C.E.	NA	NA	Floor timbers, futtocks	NA	Iron nails	NA	Overlapped	NA	Floor timbers neither scarfed nor nailed to futtocks; no hull edge-joinery.	Akkemik 2015, 99; Kocabaş 2015, 23.
YK 17	8th - 9th C C.E.	18	0.06 x 0.08	Floor timbers, futtocks	Yes	Iron nails	0.31	Overlapped	NA	Futtocks and floor timbers fastened to wale with iron nails hammered from the floor timbers; no hull edge-joinery.	Akkemik 2015, 65; Kocabaş 2012a, 168-75; Kocabaş and Kocabaş 2008, 168, 171-2; Kocabaş 2015, 23.
YK 13	8th - 9th C C.E.	NA	NA	Floor timbers, half-frames, futtocks	NA	NA	NA	Overlapped	Overlapped	Floor timbers alternating with paired, overlapping half-frames; coaks used as hull edge-joinery.	Akkemik 2015, 49; Kocabaş 2015, 26.

Name or Shipwreck Location	Century	Overall Length (m)	Frame Dimensions Sided x Moulded (m)	Framing Elements Present	Are Frames Fastened To Keel?	Fastener Between Hull & Frames	Frame Spacing (R&S) (m)	Relationship Between Futtock and Floor Timbers	Where Half-Frame Starts	Additional Notes	References
YK 15	8th - 9th C C.E.	17.40	NA	Floor timbers	NA	Treenails, iron nails	0.35	NA	NA	Iron nails fastened some floor timbers to the keel; coaks used as hull edge-joinery.	Akkemik 2015, 55; Kocabaş 2012a, 164-67; Kocabaş and Kocabaş 2008, 164, 166; Kocabaş 2015, 20-1.
YK 23	8th - 9th C C.E.	15	0.11 x 0.15	Floor timbers, half-frames, futtocks	Yes	Iron nails	0.38	Overlapped	Strake 1	Floor timbers alternating with paired, overlapping half-frames; coaks used as hull edge-joinery.	Pulak et al. 2014, 16; Pulak et al. 2015a, 50-3; Pulal et al. 2015b, 106-7.
YK 4	8th - 10th C C.E.	18	0.06-0.07 x 0.06-0.07	Floor timbers, half-frames, futtocks	Yes	Treenails, iron nails	0.23	Overlapped	Strake 1	Floor timbers alternating with paired, overlapping half-frames; iron nails fastened all floor timbers and half-frames to the keel; coaks used as hull edge-joinery.	Pulak 2010, 213; Pulak et al. 2014, 13-4; Pulak et al. 2015a, 64-68; Pulak et al. 2015b, 111-2.
YK 20	9th - 10th C C.E.	NA	NA	Floor timbers, futtocks	NA	Treenails, iron nails	NA	Overlapped	NA	In-line framing extended by scarfed futtocks; coaks used as hull edge-joinery up to the first wale; no hull edge-joinery above the first wale.	Akkemik 2015, 77; Kocabaş 2015, 17.
YK 12	9th C C.E.	9.6	0.04-0.07 x 0.09-0.10	Floor timbers, futtocks	NA	Treenails, iron nails	NA	Abutted	NA	In-line framing extended by scarfed and fastened futtocks; coaks used as hull edge-joinery.	Akkemik 2015, 43; Kocabaş 2012a, 112-24; Kocabaş and Kocabaş 2008, 112, 114, 121-3; Kocabaş and Kocabaş 2010, 200; Kocabaş 2012b, 10-2; Kocabaş 2015, 15-6.
Tantura B	9th C C.E.	19-30	0.09 x 0.09	Floor timbers, half-frames	Yes	Iron nails	0.26	NA	Over keel	Floor timbers alternating with paired, overlapping half-frames; iron nails fastened each floor timber and half-frame to the keel; no hull edge-joinery.	Wachsmann et al. 1997, 10, 13; Kahanov 2000, 151, 153, 154.
YK 31	9th C C.E.	NA	NA	Floor timbers, half-frames, futtocks	NA	NA	NA	Overlapped	Overlapped	Floor timbers alternating with paired, overlapping half-frames; no hull edge-joinery.	Akkemik 2015, 111; Kocabaş 2015, 21.
Bozburun	9th C C.E.	14.3	FT: 0.12-0.17 x 0.14-0.22; FUT: 0.10 x 0.12	Floor timbers, futtocks	Yes	Treenails, iron nails	0.30-0.40	Overlapped	NA	In-line framing extended by overlapped, scarfed, unfastened futtocks; iron nails fastened each floor timber to the keel; coaks used as hull edge-joinery.	Harpster 2002, 409, 411; Harpster 2005, 102-216, 471-85; Harpster 2009, 297, 301, 302.
Agay A	10th C C.E.	20-25	0.12-0.14 x 0.10-0.13	Floor timbers, half-frames, futtocks	Yes	Nails	0.32	Overlapped	Overlapped	Floor timbers alternating with paired and overlapped half-frames; no hull edge-joinery.	Joncheray 2007, 231, 239-41, 248.