ANALYSIS AND RECONSTRUCTION OF SHIPWRECK YK 11
(C. SEVENTH CENTURY A.D.) FROM THE THEODOSIAN HARBOR
AT YENİKAPI IN ISTANBUL, TURKEY

A Dissertation

by

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ABSTRACT

Since 2004, the Istanbul Archaeological Museums have conducted salvage archaeological excavations at the construction site of an underground railway station at Yenikapı in Istanbul, Turkey. These excavations have unearthed the remains of Constantinople's Theodosian Harbor (*Portus Theodosiacus*), including 36 Byzantine shipwrecks. The detailed study of eight of these wrecks was allocated to a small international team under the direction of Cemal Pulak from the Institute of Nautical Archaeology (INA) at Texas A&M University. One of these shipwrecks, YK 11, was a small, heavily-repaired, pine-built merchantman abandoned as a derelict at the western end of the harbor early in the seventh century. This dissertation serves as a detailed record of the YK 11 hull remains, provides a theoretical reconstruction of the vessel, compares the ship's construction with that of contemporaneous vessels, and explores the ship's historical context.

The YK 11 hull was excavated, dismantled, and removed from the construction zone at Yenikapı in 2008. The author conducted the post-excavation documentation of the ship's timbers between 2009 and 2012, following methods established by Fred van Doorninck and J. Richard Steffy of INA in their work with Mediterranean shipwrecks. This documentation revealed that YK 11 had undergone a series of significant repairs over the ship's lifetime. In these repairs, much of the ship's original planking, edge fastened with unpegged mortise-and-tenon joints below the waterline, was replaced with planks lacking edge fasteners; a considerable number of the ship's frames were also

replaced. These repairs to YK 11 significantly complicated the interpretation of its original construction.

The paucity of edge fasteners, presence of caulking, and attachment of frames to the keel might be taken as evidence that YK 11 was built after a skeleton-based tradition. However, with the detailed documentation of each component timber, a careful analysis of fastening patterns, the identification of repairs, and a thorough study of the preserved surface detail, it is clear that YK 11, although exhibiting evidence of both shell-first and skeleton-first techniques, was initially designed and built as a primarily shell-based vessel. As such, this study of YK 11 contributes valuable new information toward a better understanding of the transition from shell-based to skeleton-based shipbuilding in the Mediterranean.

DEDICATION

For my parents, James and Barbara Ingram.

Thank you for everything.

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CHAPTER I

INTRODUCTION

EXCAVATIONS AT YENİKAPI

In 2004, after decades of planning, the city of Istanbul, Turkey, began construction on the Marmaray Project, a three-billion-dollar undertaking that will result in a 76-kilometer-long rail line between the Istanbul suburbs of Gebze and Halkalı.[1] This new rail line will connect the continents of Europe and Asia via an immersed-tube tunnel underneath the Bosphorus Strait. At Yenikapı, one of the primary interchange stations on the European portion of the new rail line, preliminary archaeological excavations by the Istanbul Archaeological Museums preceded the construction and revealed part of a ship and its cargo that had been wrecked in the late 10th or early 11th century A.D. (YK 1).[2] This was the first of many ships that would be found at the Yenikapı site, soon identified as the remains of Constantinople's Theodosian Harbor (*Portus Theodosiacus*).

The excavations at the 58,000 m^2 site, begun in 2004, were conducted under the auspices of the Istanbul Archaeological Museums, under former director İsmail Karamut and current director Zeynep Kızıltan. These excavations will be completed in 2013. Finds at the site date from the Neolithic to the Late Ottoman period; the extensive Neolithic finds include a settlement, several burials, and an area with hundreds of Neolithic footprints preserved in the sediment.[3] The most extensive finds from the site,

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[1] Özmen 2007, 24-5.
[2] Karamut 2007, 12; Pulak 2007b, 132.
[3] Asal 2007, 180-87; Gökçay 2007, 166-78; İstanbul Arkeoloji Müzeleri 2011, 32.

however, are associated with Constantinople's Theodosian Harbor, one of the main harbors serving the Late Roman and Byzantine capital. The tens of thousands of artifacts recovered, in addition to harbor installations, loose ship timbers, and ships' equipment, reveal that the harbor was in use between the late 4th and 15th centuries A.D. In addition to these finds, the excavations at Yenikapı unearthed 36 Byzantine shipwrecks dating from the 5th to 11th centuries, making this one of the largest and most significant ancient harbors ever excavated.[4]

The shipwrecks found at Yenikapı, buried in sediments below the water table, are exceptionally well preserved. The Istanbul Archaeological Museums' staff identified the wreck locations and removed the sediment overburden. Each of the ships was then allocated for further study by specialists; in the field, this study entailed the in-situ documentation, dismantling, and removal of each shipwreck from the construction zone.[5] The agreement governing the study of each ship also stipulates the post-excavation documentation, conservation, and (if applicable) physical reconstruction of each ship in an eventual museum exhibit in Istanbul.

Eight of the shipwrecks from the site were studied by a small international team under the direction of Prof. Cemal Pulak from the Institute of Nautical Archaeology (INA) at Texas A&M University. These eight ships, ranging in date from the late sixth or seventh to late tenth century A.D., comprise six merchantmen and two galleys.[6] Pulak's team documented and removed these eight ships between July 2005 and

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[4] Pulak 2007a, 208-13; Kocabaş 2008, 99-183; Kocabaş 2012a, 311-13.
[5] Gökçay 2007, 176.
[6] These are merchantmen YK 1, YK 5, YK 11, YK 14, YK 23, and YK 24, and galleys YK 2 and YK 4.

December 2008.[7] The remaining ships at the site were documented and removed by a team from the Department of Conservation of Marine Archaeological Objects at Istanbul University.[8]

THE STUDY OF YENİKAPI SHIPWRECK YK 11

YK 11, one of the site's well-preserved merchantmen, was studied by Pulak and his team on a gratis basis. This small vessel, originally just over 11 m in length, is probably of late sixth- or early seventh-century date. The lower portion of the hull and one side, to the level of the ship's through-beams, were preserved; the wood, predominantly pine, is in excellent condition and is remarkably solid. YK 11, with mortise-and-tenon joinery along plank edges, is one of the oldest ships found at Yenikapı.[9] Based on the ship's size and form, as well as the nature of trade in the seventh century, it is likely that YK 11 engaged in local or regional trade based in Constantinople. Several repairs show that the ship had been used extensively by the time it was abandoned as a derelict in the shallow western corner of the Theodosian Harbor.

The obligations of the research agreement associated with shipwreck YK 11 include the removal, study, conservation, and (if applicable) physical reconstruction of the ship's remains. To begin fulfilling these obligations, the in-situ documentation and removal of YK 11 from the construction zone was accomplished between May and

[7] The author, as part of Pulak's team, participated in this year-round work at the site for the stated date range.
[8] This group, under the direction of Ufuk Kocabaş, will also carry out the conservation of four of the Yenikapı wrecks studied by Pulak: YK 1, YK 2, YK 4, and YK 5.
[9] The vast majority of other ships at Yenikapı, in contrast, were edge-fastened with dowels or coaks, which were a later, perhaps late eighth- or ninth-century, development.

November of 2008. In order to fulfill the second obligation, the detailed analysis of the hull, Pulak granted the post-excavation study of YK 11 to the author as a Ph.D. dissertation topic.

Goals of the Study

The three essential elements of shipwreck study, as outlined by J. Richard Steffy, are recording, research, and reconstruction.[10] In following these guidelines, the objective of this dissertation—the study of shipwreck YK 11—is threefold. First, I will discuss the excavation and recording of YK 11 (Ch. III) and provide a thorough description of the hull remains (Ch. IV). In order to produce the most accurate reconstruction of a vessel and allow comparison with contemporaneous material, ship timbers must be recorded in careful detail. Because the Yenikapı excavation was a salvage project, conducted under strict time-limits imposed by the Turkish government, only basic preliminary data were collected during the excavation and dismantling of YK 11. As a result, the primary post-excavation research goal is the complete and thorough documentation of each ship timber.

Second, in this dissertation I will explore the context of shipwreck YK 11, both in terms of the ship's construction as well as its historical setting. Over the course of the first millennium A.D., shipbuilding in the Mediterranean gradually evolved from being shell-based, in which the hull's strength and form were derived primarily from its exterior planking, to being skeleton-based, in which the hull's strength and form were derived primarily from its internal framework. Research into the construction of similar

[10] Steffy 1994, 191-234.

vessels of contemporaneous date helps pinpoint YK 11's position within this development and elucidates what new details YK 11 contributes to our understanding of this transition (Ch. V). Research into the historical setting of YK 11 will furthermore help to place the vessel within the broader context of seventh-century maritime commerce in Constantinople (Ch. II). In Chapter II, I also present a brief history of the Theodosian Harbor.

Finally, the third goal of the dissertation is the development of a theoretical reconstruction of the vessel, based on the recorded data and the creation of digital models (Ch. V). This also facilitates comparison with contemporaneous material noted above and allows for a more accurate assessment of the ship's function and capabilities. The reconstruction of YK 11 will also include a hypothetical reconstruction of the ship's rig based on the hull remains as well as evidence from other archaeological, iconographic, and ethnographic sources (Ch. VI).

Research Questions

During the second half of the first millennium A.D., shipwrights within the heartland of the Byzantine Empire used a combination of shell-first and skeleton-first techniques. Some of the best examples of this transitional ship architecture may be seen in the seventh-century Byzantine ship at Yassıada and the merchantmen recovered from Yenikapı.[11] In many of these ships, the lower portion of the hull was built shell-first, with planks laid edge-to-edge and secured with wooden fasteners such as tenons or dowels called coaks. Once the lower portion of the hull up to the waterline was built in

[11] Bass and van Doorninck 1982, 70-81; Pulak 2007a, 204-6.

this manner, the ship's framing, cut to fit, was inserted and fastened to the planks. Above the waterline, however, skeleton-first techniques prevailed, in which the upper planking was attached directly to the already-installed framing.

In light of the nature of transitional ship construction, a number of specific research questions arise for the study of ship YK 11. First and foremost, how was this vessel built, and is there any indication that the shipwright's basic philosophy was inclined toward either a shell-based or a frame-based tradition? What factors help identify the construction sequence or processes?

Second, it was already evident during the in-situ documentation phase in 2008 that YK 11 had undergone repairs. Do these repairs influence the interpretation of the ship, and how? Were there techniques that were used during both the initial construction and the later repair of the vessel? Likewise, were there techniques that were employed during the initial construction but not utilized in later repairs?

Finally, there are a number of features that have traditionally been used by archaeologists to identify a shell-first or a skeleton-first construction for a ship. These include the presence of edge fasteners on planks as well as their style and pattern, the presence of caulking, and the manner of attachment of framing to the ship's keel. What is the nature of these particular features on YK 11? What new evidence does YK 11 provide for the validity of using these features to help interpret the construction of a vessel dated to this significant and enigmatic transitional period?

The following study, based on the recording, research, and reconstruction of Yenikapı shipwreck YK 11, will attempt to answer these questions. In addition to fulfilling the obligations of the research agreement and providing a thorough analysis of the ship, this study will contribute new information toward a better understanding of transitional ship construction in the Mediterranean in the second half of the first millennium A.D.

CHAPTER II

THE CITY OF CONSTANTINOPLE AND MARITIME TRADE IN THE LATE SIXTH AND EARLY SEVENTH CENTURIES

LITERARY SOURCES

The latter part of the sixth and the first half of the seventh century, a time of loss and transition for the Byzantine Empire, mark the end of Late Antiquity. Contemporaneous or roughly contemporaneous literary works, including histories, lives of saints, and legal documents, provide an outline of the history and daily life of the era, and modern scholarship has attempted to analyze this complex period in several detailed works.[1]

There are three main historical works covering the late sixth and seventh centuries: the *Chronicon Paschale*, the *Breviarium* of Patriarch Nikephoros I, and the *Chronographia* of Theophanes Confessor. The *Chronicon Paschale,* an anonymous work, was completed in A.D. 630 during the reign of Emperor Heraclius. It covers the period from the creation of the world (with most detail only starting in A.D. 284) to A.D. 628, although it likely originally terminated in A.D. 630.[2] This work focuses on the city of Constantinople and is a valuable resource for understanding public life in the period.[3] The *Breviarium*, or Short History, of Patriarch Nikephoros I covers the period from the

[1] These include Ostrogorsky (1959a), Haldon (1990), and Stratos (1968), whose five-volume work provides a detailed history of Byzantium in the seventh century. Kaegi (2003) provides a thorough biography of the life of Emperor Heraclius, who ruled from 610 to 641 and whose policies shaped much of the period under consideration.
[2] Whitby and Whitby 1989, ix-xiv, xxviii-xxix, 190-91.
[3] Whitby and Whitby 1989, x.

accession of Phocas in A.D. 602 to A.D. 769, a date of no obvious significance, suggesting the work may have been left unfinished.[4] Nikephoros was a layman who was ordained patriarch of Constantinople in A.D. 806; his *Breviarium* was probably written in the 780s, although most of his other works are of early ninth-century date.[5] The *Chronographia* of Theophanes Confessor is a combination of the work of two monks, George Synkellos and Theophanes, both of whom probably died in the second decade of the ninth century.[6] The work covers the period from A.D. 284/5 to A.D. 813 and is a primary source for the period A.D. 602-813.[7] Based on their anti-iconoclastic viewpoints, it is likely that neither the *Breviarium* nor the *Chronographia* were widely circulated prior to 843.[8] In addition to these histories, perhaps in the 620s, Theophylact Simocatta, a classicizing historian, produced a history of the reign of Emperor Maurice (582-602).[9] Despite the brief time period covered, this account reflects the Empire's struggle to balance hostilities with the Slavs and Avars in the Balkans with war with the Persians along its eastern frontier, a struggle that continued into the seventh century.

Literature detailing the lives and miracles of saints sheds some light on the economy and daily life of the period. Although neither dwelt in Constantinople, Theodore of Sykeon and John the Almsgiver, patriarch of Alexandria, lived during the turn of the seventh century.[10] Daniel the Stylite spent the latter half of the fifth century in

[4] Mango 1990, 5-7.
[5] Mango 1990, 1-2, 8-12.
[6] Mango and Scott 1997, xliii-lii.
[7] Mango and Scott 1997, v.
[8] Mango 1990, 12.
[9] Whitby and Whitby 1986, xiii-xx.
[10] Dawes and Baynes 1948, 87, 196-97.

Constantinople.[11] The recorded lives of these three saints offer significant insight into the Byzantine world of Late Antiquity. Daily urban life during the challenging period of the late sixth and early seventh centuries is detailed in the recorded miracles of Sts. Demetrius and Artemios. St. Demetrius of Thessalonica, martyred in the early fourth century, intervened to deliver the city from siege and famine on several occasions during the sixth and seventh centuries when Thrace was overrun by Slavs.[12] The remains of St. Artemios, also martyred in the fourth century, were brought from Antioch to Constantinople after his death and deposited in the Church of St. John Prodromos.[13] The miracles attributed to this saint, recorded in the second half of the seventh century, are particularly valuable for their depiction of daily urban life in the capital at the time YK 11 was in use.

Finally, two legal texts, the *Farmer's Law* and the *Rhodian Sea-Law*, are of seventh- or eighth-century date and provide insight into the economy, culture, and seafaring life of the period. The *Farmer's Law*, the earliest manuscripts of which date to the 11th to 13th centuries, suggests a freer movement of peasants and goods in the Thracian hinterland of Constantinople by the late seventh or first half of the eighth century.[14] The *Rhodian Sea-Law*, first compiled between A.D. 600 and 800, contributes valuable detail on the laws and traditions of seafaring during this period.[15]

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[11] Dawes and Baynes 1948, 6.
[12] Lemerle 1979a, 2:182-89, 197-203.
[13] Crisafulli and Nesbitt 1996, 1-8.
[14] Lemerle 1979b, 27-35, 47-51; Ashburner 1910, 85-8; Fine 1983, 84-5.
[15] Ashburner 1909, xlvi-l, lxxv-lxxvii.

A BRIEF HISTORICAL OVERVIEW

The Legacy of the Late Sixth Century

At the turn of the seventh century, the Byzantine Empire was burdened with a number of serious problems that had developed over the course of the previous century. Due to an economy based primarily on agriculture, problems relating to the Empire's land, tax system, and army were closely intertwined.[16] By A.D. 600, financial instability, demographic change, hostile incursions and frequent warfare had had a detrimental impact on the Empire and its land-based economy.[17]

After Justinian I (527-565) had fought to reclaim valuable territories in Italy, Spain, and North Africa, the Mediterranean and Black Seas were, for the most part, under Byzantine control, and a revival of Byzantine trade resulted.[18] Justinian's military campaigns, however, had drained the Empire financially, and a dwindling treasury hampered the administration of the Empire through the remainder of the sixth century.[19] The Empire's wealth was insufficient for its needs. In response, the Emperor Maurice reduced cash payments to soldiers in 594, converting part of their salary to in-kind payments of clothing and equipment.[20]

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[16] Jones 1964, 769-70; Lemerle 1979b, 1, 6-7; Whittow 1996, 36-7.

[17] Morrisson and Sodini 2002, 212; Teall 1971, 44-5. Whittow (1996, 38-68), while acknowledging these challenges, nevertheless views the situation of the Empire around A.D. 600 to be relatively favorable. He notes that the Empire was prosperous by admittedly harsh contemporaneous standards and, considering the short-lived peace with Persia, was furthermore in a good position militarily (Whittow 1996, 53).

[18] Ahrweiler 1966, 7-8; Jones 1964, 273-78, 288-93; Laiou and Morrisson 2007, 23; Morrisson and Sodini 2002, 172; Whittow 1996, 38-40.

[19] Jones 1964, 298-302. The preface of a Novel of Justin II of A.D. 566 (*Cod.Just.* Novel 148) states that, at the beginning of Justin II's reign, the treasury was utterly exhausted, although Jones notes that this criticism is probably exaggerated.

[20] Theoph.Simok. 7.1.2. Maurice made a similar attempt to reduce their pay in 588 (Theoph.Simok. 3.1.2-11; Whitby and Whitby 1986, 72 n. 2).

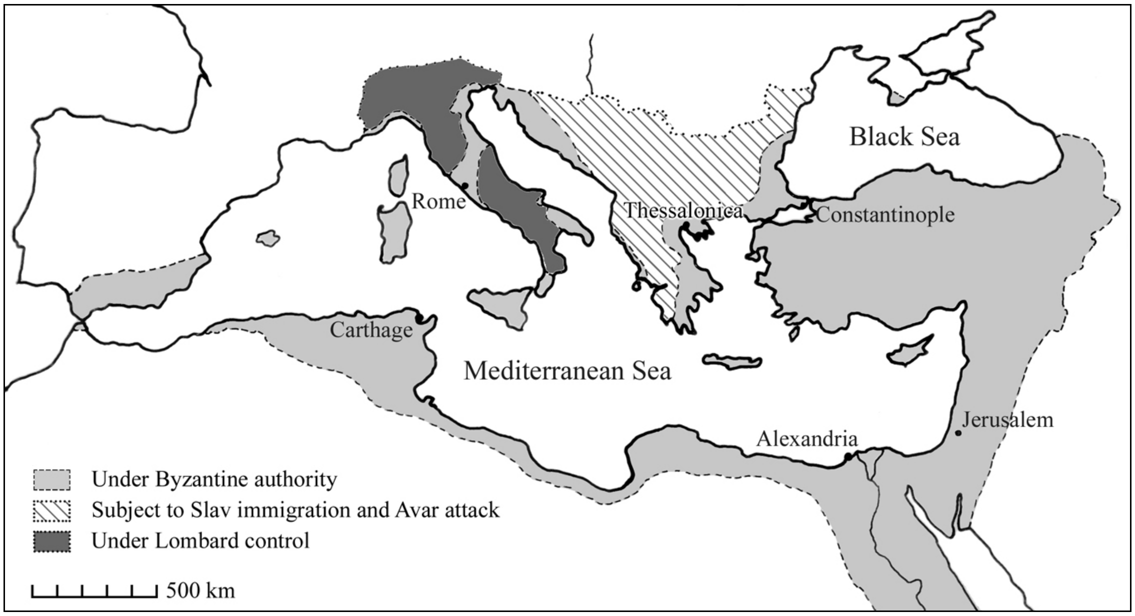

Figure 2.1. The Byzantine Empire in A.D. 600 (after Kaegi 2003, 20 map 1).

Concurrently, a major demographic change was caused by the bubonic plague, which swept through the Mediterranean in the 540s; it was especially devastating for maritime cities and may have killed as much as one-half of the population of Constantinople.[21] Although its first wave was the most devastating, there were several recurrences of plague in Constantinople throughout the late sixth and seventh centuries.[22] Although the degree to which the population was affected has been called into question, the plague must have had an adverse effect on agricultural production and,

[21] Procop. *Wars* 2.23.1-21; Theoph. 222; Allen 1979, 11, 19-20; Mango 1985, 51; McCormick 1998, 52-65. Teall (1971, 44-5) cites this first wave of the plague as one of the four primary factors that led to the transformation of Byzantine society in the seventh century. A decrease in the population, however, may have somewhat softened the loss of Alexandria and its grain supply later in the seventh century (Teall 1959, 92).
[22] Allen 1979, 13-4, 18; Haldon 1990, 111-2. Recurrences are recorded in Constantinople in 555-556 (Theoph. 232), 560-561, 572-573, 585-586, 592, 598-599, 608-609 (Theoph. 296), 618 (Nikeph. 8.4-6, 12.6-10), and 698 (Theoph. 370). After the plague of 747-748, the city is described as nearly deserted (Nikeph. 67.4-43, 68.1, Theoph. 422-23).

therefore, on the Empire's tax revenue in the latter half of the sixth century, further weakening the economy.[23]

Throughout the sixth century, both immigration and hostile incursions in the Balkans also proved detrimental to the Empire's agrarian economy (fig. 2.1). Slavs began appearing on the borders of the Byzantine Empire as early as the fifth century, engaging in looting throughout the Balkan peninsula from the 550s.[24] Despite their looting, the Slavs, on their own, possessed no national unity; they generally settled peacefully in the Balkans, although their overwhelming number resulted in the degradation of Byzantine authority in the region and a further loss of tax revenue.[25]

The Slavs could, however, be a serious threat when exploited by the Avars, a militaristic steppe-nomad group from Central Asia that crossed the Danube in 581-2 and began ravaging Thrace and the Balkan plains.[26] The Slavs were forced to serve in the naval or military service of the Avars.[27] At Avar prompting, Slavs besieged Thessalonica, albeit unsuccessfully, on several occasions in the late sixth and early seventh centuries, as recorded in the *Miracles of St. Demetrius*.[28] The Avars had made such advances in the Balkans that they reached the Long Walls of Constantinople in

[23] Allen 1979, 16-7; Durliat 1989, 118-19; Morrisson and Sodini 2002, 193-95; Whittow 1996, 66-8. According to Procopius (*Wars* 2.23.17-9), many in the city of Constantinople starved and artisans abandoned their work during a three-month period of the initial sixth-century outbreak.
[24] Procop. *Wars* 7.29.1-3; Procop. *Aed.* 4.9.17-21; Jones 1964, 293; Lemerle 1979a, 2.179-81.
[25] Ostrogorsky 1959a, 4-6; Whittow 1996, 49-50.
[26] Theoph. 247, 253; Stratos 1968, 1:31-2; Whittow 1996, 49.
[27] Theoph. 254; Theoph.Simok. 1.7.1, 6.3.9; Whittow 1996, 49-50.
[28] *Demetrius* I.8, I.13-15, II.1, II.4; Lemerle 1979a, 2.182-85, 2.187-89. Both Theophanes (268) and Theophylact Simocatta (6.1.3) also reference damage in Heraclea from Avar attacks in the late sixth century.

584.[29] By the final years of the sixth century, the city's population, terrified by the Avar threat, had considered withdrawing to Chalcedon (Kadıköy) across the Bosphorus.[30]

Along the Empire's eastern border, the long-standing conflict with Persia continued through much of the sixth century. Notable confrontations occurred during 572-591, concluding with the accession of Chosroes II in Persia with the support of the Byzantine army.[31] The subsequent peace with Persia allowed the Empire to shift its military focus to the Avar threat in the Balkans. This peace was, however, short-lived, for Emperor Maurice was overthrown in a military coup in 602, in favor of Phocas (602-610), an army officer.[32] The uneasy balance achieved by the Empire in the last decade of the sixth century was shattered with the accession of Phocas. Chosroes seized the opportunity to recommence hostilities, claiming support for the family of the deposed Maurice.[33] Starting in 603, the Persians conquered valuable Byzantine territory in Mesopotamia. Phocas proved unable to stem the combined hostile incursions by Slavs, Avars, and Persians, and the concurrent famine which resulted from the harsh winters and destruction of crops in 608-609 created the perfect climate for a revolution.[34]

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[29] Theoph.Simok. 1.7.1; Theoph. 254.
[30] Theoph.Simok. 7.15.5-6; Theoph. 279.
[31] Theoph.Simok. 4.10.1-5.11.9; Theoph. 244-47, 250-51, 253-56, 259-67; Whittow 1996, 47-8. The *Life of St. Theodore of Sykeon* (73) reports an eastern saint who had gone to Constantinople to plead with the emperor on behalf of the region, which was being ravaged by barbarians.
[32] Theoph.Simok. 8.6.2-8.10.6; *Chron. Pasch.* 693-94.
[33] Theoph. 292-96; Theoph.Simok. 8.12.10-11, 8.15.7. Maurice's son, Theodosius, was sent to petition Chosroes for assistance in the midst of the coup (Theoph.Simok. 8.9.11-12, 8.13.3-6; Theoph. 288-89). While Theodosius may have been successful in reaching Chosroes, the histories suggest that he was not and was instead killed during the slaughter of the emperor's family. Whittow (1996, 72) suggests that, had Theodosius been successful, Heraclius, in power at the time of Theophylact's work, would have had a pointed interest in having this fact suppressed.
[34] Nikeph. 1.1-2.8; Theoph. 290, 296-97; Stratos 1968, 1:78-81.

The Seventh Century

Throughout the seventh century, the Byzantine Empire gradually adapted to face its many challenges, which eventually led to significant changes in both state and society.[35] When Heraclius deposed Phocas in 610, the Byzantine Empire was under threat, and the histories indicate that the Roman administrative system had ceased to function properly.[36] Hostile incursions and a drop in agricultural production resulted in decreased tax revenues, which in turn left the treasury empty.[37] Heraclius' violent overthrow of Phocas did not solve these problems immediately, and the fact that Heraclius considered moving his capital to Carthage probably in 618 reflects the dire state of affairs in Constantinople at the time.[38]

Soon after Heraclius' accession, the Persians raided ever deeper into Byzantine territory, reaching Chalcedon and Chrysopolis in 615, in full view of the city of Constantinople.[39] Archaeological evidence from the cities of western Asia Minor, including Ephesus, Sardis, and Aphrodisias, indicate a series of particularly destructive raids throughout the second decade of the seventh century and reveal the devastating extent of Persian advances.[40] The Persian acquisition of Alexandria in 619 held dire consequences for the Empire; not only was the largest port on the Mediterranean lost,

[35] Haldon 1990, 436-58; Teall 1971, 44-7.
[36] Theoph. 299-300; Nikeph. 1.1-6; Stratos 1968, 1:97-100.
[37] Theoph. 302-3.
[38] Nikeph. 8.1-8; Kaegi 2003, 88-9; Ostrogorsky 1959a, 9. Kaegi (1982a, 308-20) has suggested that, based on the *Life of St. Theodore of Sykeon*, Heraclius struggled to win the allegiance of the Anatolian armies upon his accession and narrowly avoided a civil war. In Constantinople, the situation was further exacerbated by a large earthquake in 611, which caused the city notable damage (*Chron. Pasch.* 702.7-10).
[39] *Chron. Pasch.* 706.9-13; Nikeph. 6-7; Theoph. 296; Foss 1975, 724. The Persians did not, however, have a fleet and were therefore not a serious threat to Constantinople at the time (Stratos 1968, 1:115-17).
[40] Foss 1975, 728, 736-41.

but the resultant loss of grain shipments to Constantinople affected its provisioning and led to the eventual abandonment of the state distribution of bread (the *annona*).[41]

While the Persians had been attacking the Empire's eastern frontier, the Slavs and Avars had continued their raids throughout the Balkans. Soon after Heraclius embarked upon a series of military campaigns within Asia Minor, the Avars, Slavs and Persians made a coordinated assault on the Empire, including a siege of the city of Constantinople from late June to early August of 626.[42] Despite their much larger force, the Avars were unsuccessful in their siege due to the city's strong walls and sufficient provisions.[43] Byzantine military and, perhaps, merchant vessels played a significant role in this siege; a naval cordon along the Golden Horn protected the city from the Slav *monoxyla*, probably expanded dugouts, and Byzantine warships in the Bosphorus prevented the Persians from advancing beyond Chalcedon.[44] The siege was effectively ended after Byzantine ships defeated a fleet of Slav *monoxyla* on August 7.[45]

Farther east, the subsequent battle outside of Nineveh in 627 was a crushing defeat for the Persian army, after which the Byzantine Empire enjoyed a brief respite of

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41 *Chron. Pasch.* 711.11-15; Theoph. 301; Nikeph. 6.1-7, 8.1-4; Stratos 1968, 1:113-14; Whitby and Whitby 1989, 164 n. 449.

42 To fund his campaigns, Heraclius borrowed money from the church (Theoph. 302-3); the *Parastaseis* (42) notes that he even melted down the bronze statue of an ox from the Forum Bovis, the closest forum to the Theodosian Harbor. The most extensive account of the 626 siege of Constantinople is provided in the *Chronicon Paschale* (716.9-726.10); it is also mentioned by Nikephoros (13) and Theophanes (303, 316).

43 Howard-Johnston (1995, 137) suggests an Avar force of 80,000. Stratos (1968, 1:183-84) estimates a Byzantine home guard of 25-30,000, in addition to 12,000 cavalry sent from Asia Minor by Heraclius prior to the investment of the city (*Chron. Pasch.* 718).

44 *Chron. Pasch.* 723.15-21; Stratos 1:1968, 190. Howard-Johnston (1995, 133) has suggested that the Persians, not having ships of their own, never intended to participate in the Avar assault on the city, but had traveled to Chalcedon to distract the Byzantines and erode their morale. The naval force of the Avars consisted of a fleet of Slav *monoxyla*, probably expanded dugouts capable of carrying 5 to 20 men; these had been used throughout the previous century to raid the coasts at Thessaly, Crete, the Cyclades, and the Peloponnese (Stalsberg and le Beau 2006, 103; Stratos 1968, 1:120). These boats had been hauled to Constantinople overland on carts.

45 *Chron. Pasch.* 724-25; Nikeph. 13.19-37; Theoph. 316.

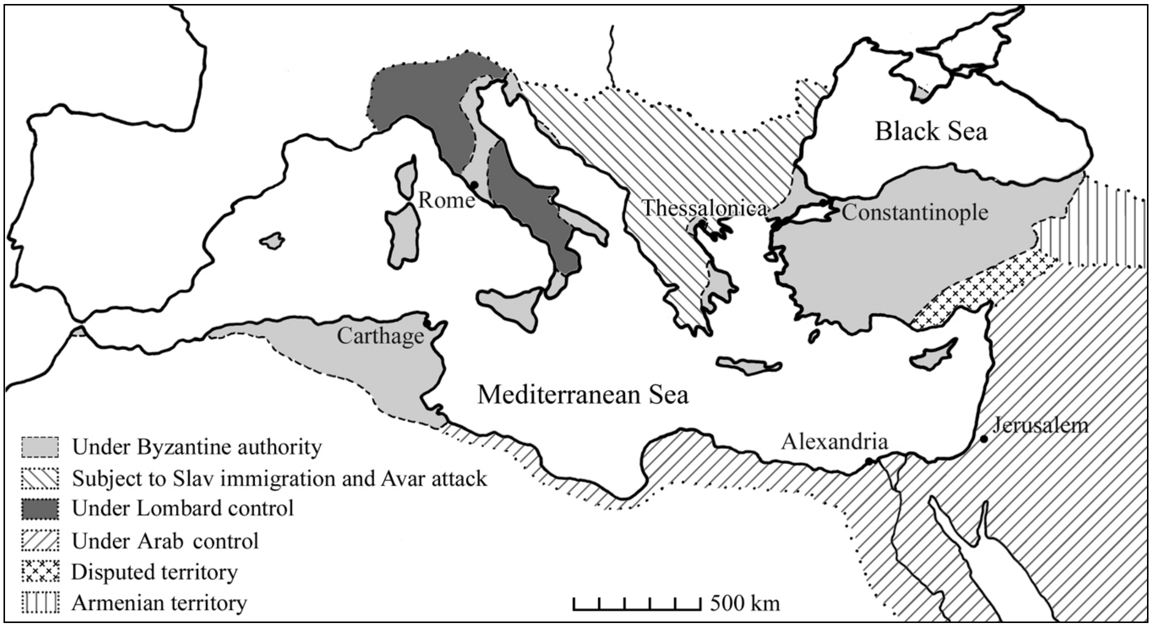

Figure 2.2. The Byzantine Empire ca. A.D. 645 (after Kaegi 2003, 298 map 10).

peace.[46] The Persians were no longer a threat, and the Byzantine Empire began recovering its eastern provinces, including Alexandria, in 629.[47] In the north, the defeat of the Avars freed Serbs, Croats, and Slavs from Avar domination in the Balkans, which created a buffer zone for the Empire against further Avar attack.[48] Yet both the Persian and Byzantine Empires had been substantially weakened by the war, and, prior to his death in 641, Heraclius was compelled to witness renewed territorial losses, as Muslim Arab armies took Syria in 636, Mesopotamia in 639-640, and began the conquest of Egypt in late 639 (fig. 2.2).[49] By the end of Heraclius' reign, decades of war and instability had resulted in the continued decrease in trade, production, and tax revenues;

[46] *Chron. Pasch.* 727.7-14; Nikeph. 14.1-17.16; Theoph. 317-27.
[47] Nikeph. 17.13-6; Kaegi 2003, 192-213; Stratos 1968, 1:297.
[48] Ostrogorsky 1959a, 4-8; Stratos 1983a, 376.
[49] Theoph. 337-39; Kaegi 2003, 239-59, 326-27; Ostrogorsky 1969, 110-11.

in short, the problems Heraclius had inherited at the beginning of his reign (610) still remained at the end of his reign (641).[50]

The first Arab naval expedition against Cyprus in 649, under Muawija, signaled the beginning of an Arab advance toward Constantinople, and Aegean territories were raided regularly from the 650s.[51] The Byzantine navy was defeated by the Arabs at the Battle of the Masts at Phoenix in Lycia in 655, which exposed the Mediterranean to further Arab attacks.[52] Terrestrial raids throughout Asia Minor also occurred regularly between 663 and 678, and an Arab force had reached Chalcedon, across from the capital, by 667.[53] Between 674 and 678, the Arab fleet, having reached Constantinople, engaged in daily naval skirmishes with the Byzantines between April and September, withdrawing to Cyzicus in the Sea of Marmara each winter.[54] The Byzantine victory over the Arab fleet in 678, due in part to the use of Greek fire, resulted in the payment of annual tribute by the Arabs and improved the tarnished reputation of the Empire abroad.[55] The actual gravity of the threat, however, might have been exaggerated; there

[50] Kaegi 2003, 301-5; Laiou 2002, 699-700; Stratos 1968, 1:257-59. Heraclius may have compounded these problems somewhat when, overzealous to repay the church, which had funded his military campaigns (Nikeph. 11.21-3), he reinstated harsh taxes soon after the conclusion of the war with Persia (Stratos 1968, 2:166-68).
[51] Theoph. 344; Pryor and Jeffreys 2006, 24-5; Stratos 1983b, 233.
[52] Stratos 1983b, 235-44. The Carabisian Theme, based in Samos, was probably organized in response to this event, in order to form a line of defense against future Arab attacks (Theoph. 345-46; Pryor and Jeffreys 2006, 25).
[53] Theoph. 348-55; Brooks 1898, 183-89. These raids hampered trade and production and contributed to a more localized economy in Asia Minor (Stratos 1968, 3:228).
[54] Nikeph. 34.11-4; Theoph. 353-54; Ostrogorsky 1969, 124-25; Stratos 1968, 4:29-39.
[55] Nikeph. 34.21-37; Theoph. 354-56. Much of what remained of the Arab fleet was subsequently destroyed by a storm whilst fleeing (Nikeph. 34.18-21; Theoph. 354).

is no suggestion that the city was truly in danger, as the blockade was only enacted in the summer months.[56]

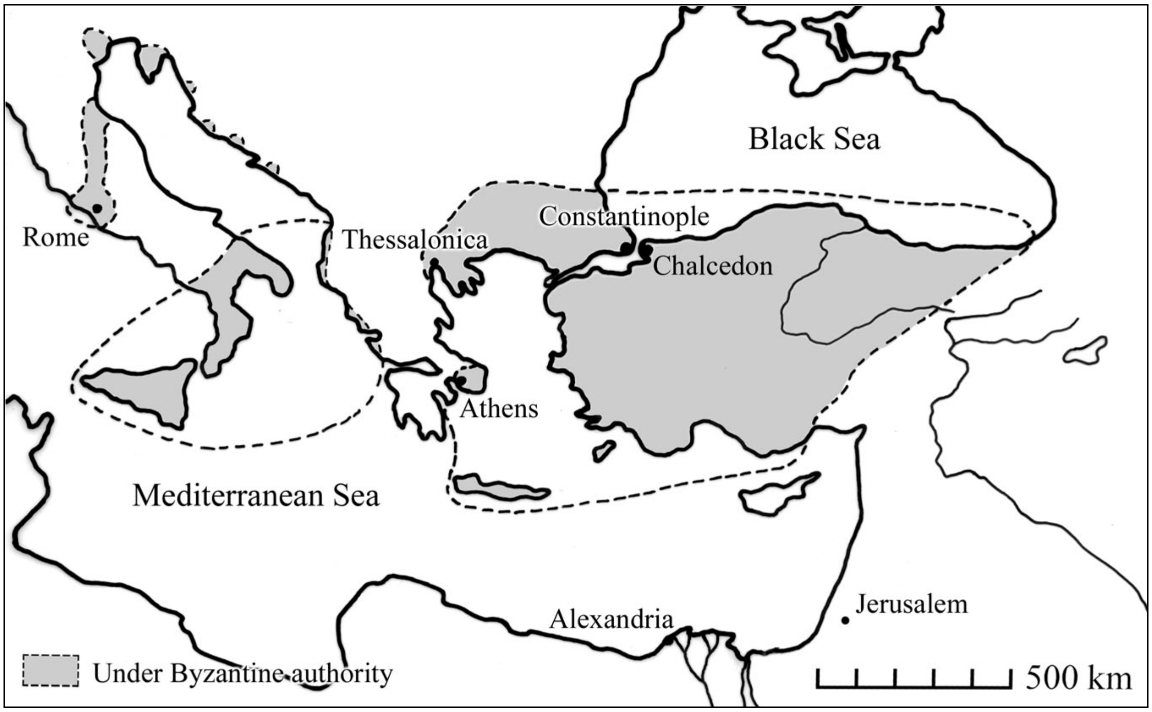

Figure 2.3. Extent of Byzantine authority at the end of the seventh century (after Jenkins 1987, 388).

The Persian and Arab raids in Anatolia throughout the seventh century were especially damaging, as these led to a decrease in agricultural production and a breakdown in communication and security, which in turn caused a sharp decrease in both tax revenues as well as long-distance trade.[57] Even sizable Late Roman cities of

[56] Nikeph. 34.9-11; Theoph. 354; Stratos 1968, 4:33-4. In contrast, while preparing for a second Arab siege in the early eighth century, Anastasios, following Maurice's *Strategikon*, requested that all those who could not sustain themselves for three years were to leave the city; this had not been requested in the previous sieges, indicating a more serious threat in the eighth century. Nikeph. 49.9-14; Theoph. 384; Pryor and Jeffreys 2006, 31; *Strat.Maurik.* 10.3.
[57] Haldon 1990, 102-5; Stratos 1968, 3:228.

Asia Minor contracted to villages centered around fortresses or other defensible areas; Ankara, Sardis, and Ephesus are well-known examples.[58] Literary evidence indicates that the Balkan Peninsula was almost completely colonized by Slavs by the latter half of seventh century, with only a few cities remaining under Byzantine control (fig. 2.3).[59] These changes to the Empire's territory and even the largest of its cities, along with the outright collapse of other cities, resulted in an economy that became increasingly more ruralized.[60]

The *Farmer's Law* (*Nomos Georgikos*), of late seventh- or perhaps early eighth-century date, reflects the growing importance of free peasants after these seventh-century changes.[61] The scarcity of rural labor, a serious problem in previous centuries, seems to have been alleviated.[62] However, large estates continued to exist, as did the collective liability for taxes, in effect since A.D. 366.[63] Based on this continuation, Lemerle has suggested that the agrarian economy underwent an evolution rather than a revolution in response to events of the late sixth and seventh centuries.[64] The *annona*, which comprised the basic land tax, was collected primarily in kind by the second half of

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[58] Foss 1975, 736-39; Foss 1977a, 472-77; Foss 1977b, 70-5; Foss and Scott 2002, 617-18.
[59] Ostrogorsky 1959a, 4-6. During an offensive in the Balkans in 688, Justinian II fought through Bulgars and Slavs to reach Thessalonica from Constantinople (Theoph. 364). The Byzantine cities, including Thessalonica and (in the late sixth century) Asemus, near the Danube, seem to have been responsible for their own defense to some extent (*Demetrius* II.1.190, II.4.251; Theoph.Simok. 7.3.1-4).
[60] Oikonomides 2002, 980-83.
[61] Ashburner 1912, 83; Lemerle 1979b, 32, 52.
[62] Lemerle 1979b, 48-50; Ostrogorsky 1966, 208. Haldon (1990, 142-47), on the contrary, believes that the political instability of the period led to a decreased rural labor force, and changes in the tax system represent government incentives to attract cultivators.
[63] *Farmer's Law* 18; Ashburner 1912, 70; Lemerle 1979b, 51-2. Under this collective liability, the estate owner was responsible for the taxes owed by the *coloni* that worked his land, and free peasants owning smaller tracts of land were collectively responsible for all taxes owed by the tax district to which they belonged (*Cod.Theod.* 11.1.14; Lemerle 1979b, 7-8, 19; Ostrogorsky 1966, 213-14).
[64] Lemerle 1979b, 40, 58.

the seventh century; by the late eighth century, it was again collected in coin.[65] Although there was a decrease in the production of bronze coinage, gold coinage was sustained, possibly even increased, during this century, reflecting the continuation of the Empire's monetary economy.[66]

Cities still remained the centers of trade, and these, Constantinople chief among them, guaranteed the wealth of the Empire.[67] Constantinople nevertheless experienced a decline in population, both due to plague and other factors, and there was a pointed halt to new construction soon after the beginning of the seventh century; once building activity resumed around A.D. 800, the focus was on renovation rather than new construction.[68] By the end of the seventh century, decades of war and constant threats from abroad had created a more militarized Byzantine society which had become accommodated to living with risk, a characteristic that facilitated the Empire's survival in this difficult transitional period.[69]

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[65] Haldon 1990, 147-49, 231; Oikonomides 2002, 980-81. The annual rate of contribution was variable (Tengström 1974, 15-6).

[66] Haldon 1990, 117-20; Ostrogorsky 1959b, 49-51, 63-4. Following the reforms of Maurice, soldiers were paid in both cash and equipment, and this likely continued through the seventh century (Theoph.Simok. 7.1.2; Whittow 1996, 118-19). Some scholars, notably Ostrogorsky (1966, 207-8), believe that the organization into themes and hereditary grants of land to soldiers in return for military duty began during the reign of Heraclius as a direct response to the devastating raids of the seventh century. Lemerle (1979b, 58-64), in contrast, argues that hereditary land grants in return for military service are not reflected in the sources prior to the tenth century and that this system did not exist in the seventh century. Theophanes (486), as late as the early ninth century, seems to instead link default on land taxes with the consequence of being enrolled in the army. Kaegi (1982b, 41-3) furthermore questions the overall effectiveness of such "farmer soldiers." He also doubts the military effectiveness of the themes, as they were seemingly unable to prevent Arab raids and were far too prone to revolt against Byzantine rule (Kaegi 1982b, 43-50).

[67] Dagron 2002, 403-5; Lopez 1959, 72-3; Ostrogorsky 1959b, 62-6.

[68] Haldon 1990, 115-17; Mango 1985, 61-2; Mango 1986, 128-31. The relatively few recorded instances of famine in the latter part of the century, despite a lack of organized grain shipments and only one functioning granary, attest to the degree to which the city's population had declined (Mango 1985,53-4). During the eighth century, Constantine V brought families from Greece and the Aegean to help repopulate the city, which had been reduced by plague (Nikeph. 68.1-3; Theoph. 429).

[69] Teall 1959, 121.

PROVISIONING THE CITY OF CONSTANTINOPLE

Even before the establishment of Constantinople as a capital city in the fourth century, the town possessed abundant fisheries and an established maritime trade in both grain and wine.[70] In the Byzantine period, most of the city's food continued to be supplied by sea.[71] From the fifth to the early seventh century, the food supply in Constantinople was based on a two-tiered system involving both the state (*annona*) and private enterprise.[72] The *annonae civicae* included both the *annonae populares* and the *panes aedium*; the latter were granted to those who built a house in the city.[73] The *annonae populares*, established by Constantine in 332, were granted to 80,000 of the city's inhabitants, increasing to 81,000 in 394. Distributions included not only bread, but perhaps also oil, wine, dried goods such as lentils, and pork or lard; this helped attract residents to the developing city.[74] Variable tax rates on these items are listed in the Tariff of Abydos of A.D. 500.[75]

In total, the *annonae civicae* provided for approximately 85,000 individuals; yet the total amount of wheat imported into Constantinople during the reign of Justinian was far greater, sufficient for 600,000 individuals.[76] This, combined with the greater number of private bakeries (approximately 120) than public bakeries (20 or 21) in the fifth-

[70] Strabo 7.6.2; van Millingen 1906, 12.
[71] Mango 2000, 192. Procopius (*Aed.* 1.5.2) describes in detail the beauty and utility of the waters surrounding the city, noting "…the quiet shelter of harbors… abundantly providing the city with the necessities of life…"
[72] Mango 2000, 190.
[73] *Chron. Pasch.* 531.4-5; *Cod.Theod.* 14.17; *Cod.Just.* 11.25.2; Jones 1964, 696-97. The *panes aedium* were granted at least to the end of the fourth century.
[74] Durliat 1990, 223; Mango 2000, 190.
[75] *Letter of the Urban Prefect (?) on Tariff for Shipments to Constantinople,* in Johnson et al. 1961, 253.
[76] Durliat 1990, 257-58; Jones 1964, 698. Under Justinian (*Cod.Just.* Edict 13.8), 8,000,000 *artabae* (27,000,000 *modii)* were shipped annually from Egypt to Constantinople.

century *Notitia urbis Constantinopolitanae*, reflects the significance of the private sector in the city's food supply.[77] Both state and private supply of bread, the main staple of the Byzantine diet, was heavily dependent on regular shipments of grain, primarily from Egypt; delay in its delivery and consequent shortage of bread often led to insurrection within the city.[78] Bread distributions under the *annona* were halted temporarily in 618, then permanently in 626, in association with the loss of Alexandria.[79] Wheat and barley continued to be shipped to the city from its Thracian hinterland, principally through the port of Raidestos on the north shore of the Sea of Marmara, and from Sicily, Thessaly, and Macedonia, although these shipments were smaller and less regular.[80]

In addition to bread, both wine and olive oil were essential elements of the Byzantine diet and valuable trade commodities as well as elements of the *annona*.[81] In the *Life of St. John the Almsgiver*, the emergency shipment of grain, wine, oil, and pulses (legumes) from Alexandria to Jerusalem after a Persian attack in the early seventh century implies that these goods were considered basic necessities.[82] Wine was one of the most profitable trade commodities, and wines of varying quality were imported from Asia Minor, Thrace, and the Aegean and Black Seas.[83]

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[77] Jones 1964, 701; Mango 2000, 194; Seeck 1876, 230, 234, 237.
[78] Theoph. 230; Dalby 2003, 77-9; Durliat 1990, 226-28; Teall 1959, 91-2. Fifth-century bread shortages are noted in *Chron. Pasch.* 571.5-11 and 593.13-4. Shipments of grain were also received from Africa, and the withholding of these shipments in 608 resulted in shortages in the city (Theoph. 296).
[79] *Chron. Pasch.* 711.11-5; Teall 1959, 89.
[80] Magdalino 1995, 36-7, 40; Teall 1959, 97-100, 135-37.
[81] Jones 1964, 768, 845.
[82] *John Alms.* 9. In his fasting, St. Theodore of Sykeon shunned even the basic staples of bread and legumes, preferring to eat just fruit and vegetables (*Theod.Syk.* 28).
[83] Dalby 2003, 87; Pieri 2012, 36. This was, of course, also the case in areas other than Constantinople; in Alexandria, St. John the Almsgiver rejected an expensive, high-quality wine imported from Palestine for a cheaper local vintage (*John Alms.* 10).

The vacant lands within and without the city's Theodosian Walls were also cultivated.[84] This had naturally been the case since the days of Constantine, and Themistius notes that, only during the reign of Theodosius I (379-395) did the area of inhabited land within the city walls (those of Constantine) begin to surpass the area of cultivated land.[85] Book 12.1 of *Geoponika*, a 10th-century collection of earlier farming texts, records a variety of fresh vegetables grown in Constantinople, including salad greens, dill, cabbage, onion, and root vegetables such as beet, turnip, radish and carrot.[86] Common vegetables that were omitted from the list, such as olives or eggplant, could probably either not be grown in the climate of the city or could be shipped very easily.[87]

Estimates of the population of the city vary greatly. Teall suggests a population of approximately 250,000 in the seventh century, roughly half that of A.D. 400; Mango has suggested a population closer to 40,000 by the end of the century.[88] Calculations on the yield of available lands indicate that the city and its environs could have grown enough fresh vegetables for 500,000 inhabitants, much more than would have been needed for the city's population in the late sixth or seventh century.[89]

Contemporaneous sources make frequent reference to the cultivation of lands in and around the city. Orchards within the Constantinian walls were used as a makeshift graveyard for victims of plague during the eighth century.[90] During the Avar-Persian siege of 626, there is mention of the city's residents traveling overland up to ten miles

[84] Jones 1964, 845.
[85] Them. *Or.* 18.9; van Millingen 1899, 42.
[86] *Geoponika* 12.1.
[87] Koder 1995, 50.
[88] Teall 1959, 92, 105; Mango 1985, 54.
[89] Koder 1995, 51-4.
[90] Theoph. 423.

outside of the city walls in order to harvest their crops.[91] The city's residents also maintained vineyards in the surrounding areas, including Chalcedon and the shores of the Bosphorus.[92] During the Arab siege of 717-718, ships from Constantinople were sent to obtain provisions from the Asian shores, supplemented by goods obtained from captured Arab ships.[93]

The area around Constantinople is an abundant source of fish, which formed a significant part of the diet of those in the city and helped to sustain the city throughout its history.[94] According to Strabo, tuna from the Black Sea arrived in the waters around the city thanks in part to the local currents, and these provided a noteworthy income to the city's inhabitants.[95] During lulls in the fighting, fishermen continued their work in the waters around the city during the eighth-century Arab siege, thereby helping to sustain the defenders while the besieging force perished from famine.[96]

The Late Roman city of Constantinople, with numerous fountains and public baths, was in need of a plentiful water supply, which the city did not naturally possess.[97] The only local sources of water were the Lycus River, which drained into the Theodosian Harbor, and a few small springs.[98] Therefore, in the late fourth century, approximately when the city's harbors were being expanded, the city's water supply was enhanced as well. The Aqueduct of Valens became operational in 373, and a series of

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[91] *Chron. Pasch.* 717.13-22; Stratos 1968, 1.182.
[92] *Daniel Styl.* 25; Nikeph. 31.1-5.
[93] Nikeph. 54.35-9; Theoph. 397.
[94] Browning 1993, 100-1; van Millingen 1906, 12.
[95] Strabo 7.6.2; Dalby 2003, 15.
[96] Theoph. 397; Brooks 1898, 195-96.
[97] Mango 1986, 119, 122.
[98] Mango 1995, 9-10.

cisterns were built, the largest in the sixth century, to prevent the water shortages that occurred in the summer months.[99] However, as the population declined and the public baths were abandoned beginning in the sixth century, the need for water consequently decreased, and the Aqueduct of Valens, damaged by the Avars in 626, was not repaired until 767.[100] That the city survived for more than a century without its main supply of water says much about the state of decline in that period.[101]

SHIPPING AND MARITIME TRADE

Prior to the loss of Egypt, the main maritime trade route followed that of the *annona*, from Alexandria, through Cyprus, Chios, Tenedos, and Abydos, up to Constantinople.[102] The military and civic *annonae* were transported by the guild of shippers, the *navicularii*. These wealthy landowners were obliged to build, maintain, and sail ships in the service of the state.[103] They received a return of just 4%; although lower than the commercial rate of approximately 12%, the *navicularii* also received certain tax exemptions in return for their services.[104] Nevertheless, membership in the guild may have been considered a financial burden after the third century.[105]

With the loss of Alexandria and the cessation of the distribution of bread, the guild of *navicularii* was replaced by a growing class of independent ναύκληροι

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[99] Procop. *Aed.* 1.11.10-5; Mango 1985, 40-1; Mango 1986, 122-23; Mango 1995, 16.
[100] Nikeph. 85.5-8;Theoph. 440; Mango 1986, 130; Mango 1995, 17.
[101] Mango 1985, 56-7.
[102] Durliat 1990, 225-31; Laiou and Morrisson 2007, 35; Rougé 1966, 85-93. Two of the grain shipments noted in the *Miracles of St. Demetrius* were sent via Chios (*Demetrius* I.8.70, I.9.76).
[103] Tengström 1974, 35-6. The regulations governing the members of this guild are detailed in *Codex Theodosianus* 13.5 (*de naviculariis*).
[104] *Cod. Theod*. 13.5.7; Jones 1964, 771, 828-29.
[105] Mor 2012, 48-56.

(*naukleroi),* sea merchants or captains, in the seventh century.[106] *Naukleroi* were often independent traders who could become quite wealthy; the *Rhodian Sea-Law* provides extensive detail on their undertakings.[107] The option of splitting shares, even on a small ship, allowed sailors of low income to invest in shipping and thus gain advancement.[108] Rougé hypothesized that the *navicularii* were concerned with state-controlled shipping (including the transport of grain to the capital) while the *naukleroi* were concerned with private trade.[109] However, the seemingly independent *naukleroi* cited in the *Miracles of St. Demetrius*, bringing shipments of grain to the capital, seem to indicate that the distinction was not always clear.[110]

The church was also involved in maritime transport and commerce; the Alexandrian patriarchate maintained a sizable fleet that regularly conveyed goods throughout the Mediterranean and, in one account, as far as Britain.[111] The seventh-century shipwreck excavated at Yassıada, Turkey, was likely in the service of the church and may have been transporting a cargo of wine and olive oil to Heraclius' army in the east when it sank in 626 or shortly thereafter.[112] An inscription on a steelyard found in

[106] Lopez 1959, 79-80.
[107] The state is conspicuously absent in the regulations of the *Rhodian Sea-Law* (Laiou 2002, 707).
[108] *Rhodian Sea-Law* II.1-7; Lopez 1959, 79; van Doorninck 2002, 903.
[109] Rougé 1966, 256.
[110] Laiou 2002, 701. In one account, Stephanos, a *naukleros* transporting a cargo of grain to Constantinople during the reign of Maurice, is persuaded by St. Demetrius to divert the shipment to Thessalonica, then besieged by Avars and Slavs (*Demetrius* I.8.70-2). Somewhat increased state control, however, is noted in the following miracle, in which the prefect of Illyricum intervened to divert ships, traveling from Chios to Constantinople, to Thessalonica instead (*Demetrius* I.9.76-7).
[111] *John Alms.* supplement of Leontius 10, 13, 26, 28; Monks 1953, 355-57.
[112] van Doorninck (forthcoming).

the ship, GEORGIOU PRESBYTEROU NAUKLEROU, may indicate that the *naukleros* (owner or captain of the ship), Georgios, was also a church elder or priest.[113]

Toward the end of Late Anqituity, there was a general trend toward the use of smaller ships, which to some extent reflected the contracting economy.[114] This decrease in ship size is indicated in the legal texts, which specified the size of ships involved in the *annona* transport. In the mid-second century A.D., Gaius noted a minimum capacity of 10,000 *modii* (approximately 67 tons burden) for *annona* ships carrying grain to Rome; an identical capacity is required for tax exemption as late as 371.[115] However, the minimum capacity was lowered to 2,000 *modii* (approximately 13 tons burden) for ships carrying grain to Constantinople in a Novel of Theodosius II of 439.[116]

According to Mango, during the sixth century, 2,400-3,600 ships were annually involved in the Egyptian grain trade.[117] The difficulties involved in such shipping were noteworthy; during the sailing season, between March and November, the winds in both the Mediterranean and the Aegean are northerly, which, combined with the powerful current through the Hellespont, could result in delays of days or even weeks during return trips from Alexandria with grain, which might in turn prompt civil unrest.[118] In response, Justinian I built *horrea* or storehouses on the island of Tenedos, outside the entry to the Hellespont, in the sixth century; here, the large ships traveling from Egypt

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[113] Bass and van Doorninck 1982, 212-18, 314; van Doorninck (forthcoming).
[114] Magdalino 2000, 215; Rougé 1966, 71-3; Rougé 1975, 87.
[115] This had been established under Claudius. Gai. *Inst.* 1.32; *Cod.Theod.* 13.5.14; Jones 1964, 843; Rougé 1966, 72. The figure of 50,000 *modii* (approximately 333 tons), noted in *Digest* 50.5.3, may refer to a cargo carried in multiple ships (Garnsey and Saller 1987, 88). Calculations for tonnage are based on the average ton of wheat equal to approximately 150 *modii* (Rickman 1980, xiii; Plin. *HN* 18.12.66).
[116] *Cod.Theod.* Theodosius II Nov. 8; Jones 1964, 843.
[117] Mango 1986, 120.
[118] Casson 1995, 272-73; Makris 2002, 97; Mango 1986, 120; Pryor 1992, 12-3. Theophanes (237) notes an extended period in 562 when an unrelenting north wind prevented ships from reaching the capital.

offloaded their cargo, and smaller ships, which could more easily navigate the Hellespont, carried the grain onward to Constantinople.[119]

Smaller ships paid lower port dues and could shelter in small, natural harbors or bays when in danger.[120] Due to their size, such ships were more maneuverable and were better suited for coastal sailing in the Black Sea and Sea of Marmara; the emerging dominance of the lateen rig during Late Antiquity further improved the maneuverability of these ships.[121] Such maneuverability would be vital in escaping Slav or Arab pirates; although prevalent, these do not seem to have had a heavy impact on trade.[122] Ships could also sail in a convoy for defense, and ports were often secured with a chain after sunset.[123]

After the territorial losses of the seventh century and the consequent decrease in security, shipping became more localized, but regular maritime traffic through the Aegean and Black Seas continued.[124] Regular trade between Constantinople and both Rhodes and Chios are indicated in the seventh-century *Miracles of St. Artemios* and *Miracles of St. Demetrius.*[125] A small ship such as YK 11 would have been less efficient for long-distance trade and may have engaged in exchange in the waters around

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[119] Procop. *Aed.* 5.1.7-16; Magdalino 2000, 215; Müller-Wiener 1994, 9. According to Procopius (*Aed.* 5.1.10), eliminating the delays associated with the Hellespont allowed the large ships to make two or even three round trips to Egypt in one season. The use of large ships continued at least into the early seventh century, when a ship of 20,000 *modii* (approximately 133 tons) is noted in the fleet of the Alexandrian church (*John Alms.* supplement of Leontius 10).
[120] Khalilieh 2005, 246 n. 8.
[121] Khalilieh 2005, 245; Makris 2002, 95-6; Pomey and Tchernia 1978, 251.
[122] Lopez 1959, 71.
[123] Khalilieh 2005, 258-61; Mango 1985, 54; McCormick 2001, 411-15; Rougé 1966, 63. The chain across the Golden Horn in Constantinople, instrumental in the siege of 1453, was first mentioned in association with the Arab siege of 717-718 (Theoph. 396; Mango and Scott 1997, 548, n. 25).
[124] Lopez 1959, 70-1; van Doorninck 2002, 902.
[125] *Artemios* 5, 9, 35; *Demetrius* I.8.70, I.9.76; Lemerle 1979a, 1.104 n. 2. There is also, however, mention of a merchant sailing between Constantinople and Gaul (*Artemios* 27).

Constantinople, especially the Sea of Marmara and perhaps even the Black Sea.[126] Although deep-water sailing was not unknown, coastal sailing was most common in this period.[127] Cabotage would have been especially desirable along the coasts of Thrace due to the insecurity of the overland routes during the sixth and seventh centuries.[128] Several ports were in use on the Sea of Marmara, including Heraclea and Selymbria on the north coast and Abydos, Lampsacus, and Cyzicus in the south; the island of Tenedos just outside the Hellespont was also a port of significance (fig. 2.4).[129] There is ample literary evidence that ships were frequently beached to avoid a storm, to obtain fresh water, or to allow the crew to rest.[130] On the seventh-century Saint-Gervais 2 shipwreck, a horizontal hole through the keel, bearing traces of rope, was likely used for hauling the ship;[131] similar holes were found on many of the merchantmen at Yenikapı, although none was present on YK 11.

Ships engaging in private exchange in and around Constantinople were subject to certain tariffs. The Tariff of Abydos (A.D. 500) outlines the toll required of ships carrying cargoes of grain, wine, oil, pulses, or pork through the Hellespont.[132] Later in the sixth century, in an effort to exert control over trade with the capital, Justinian I built

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[126] Pomey and Tchernia 1978, 251. According to McCormick (2012, 77), this type of short-range trade around Constantinople was an important element of the region's infrastructure.

[127] McCormick 2001, 422-23.

[128] Avramea 2002, 71-2; Laiou 2002, 701; Rougé 1966, 84-5.

[129] Ahrweiler 1966, 13-4; Rougé 1966, 130. Justinian I contemplated fleeing to Heraclea by *dromon* during the Nika riots in 532 (Theoph. 184). Although Heraclea seems to have been ravaged by Avars at some point in the latter half of the sixth century, Heraclius' fleet stopped here as well as at Abydos on its way to Constantinople in 609-610 (Theoph. 268, 298-99; Theoph.Simok. 6.1.3).

[130] *Rhodian Sea-Law* III.2, III.15. McCormick (2001, 418-21) records several instances of beaching gleaned from travelers' accounts and other contemporaneous documents.

[131] Jézégou 1983, 32.

[132] *Letter of the Urban Prefect (?) on Tariff for Shipments to Constantinople*, in Johnson et al. 1961, 253. Durliat (1990, 221-22) has suggested that exemptions for Cilician shippers reflect their function in transporting *annona* goods.

customs houses both at Abydos and at Hieron on the Bosphorus.[133] Procopius, in a contemporaneous work, suggests that, due to excessive taxation on goods passing through Constantinople's harbors under Justinian I, higher costs were passed along to the merchants and, in turn, to the city's population.[134]

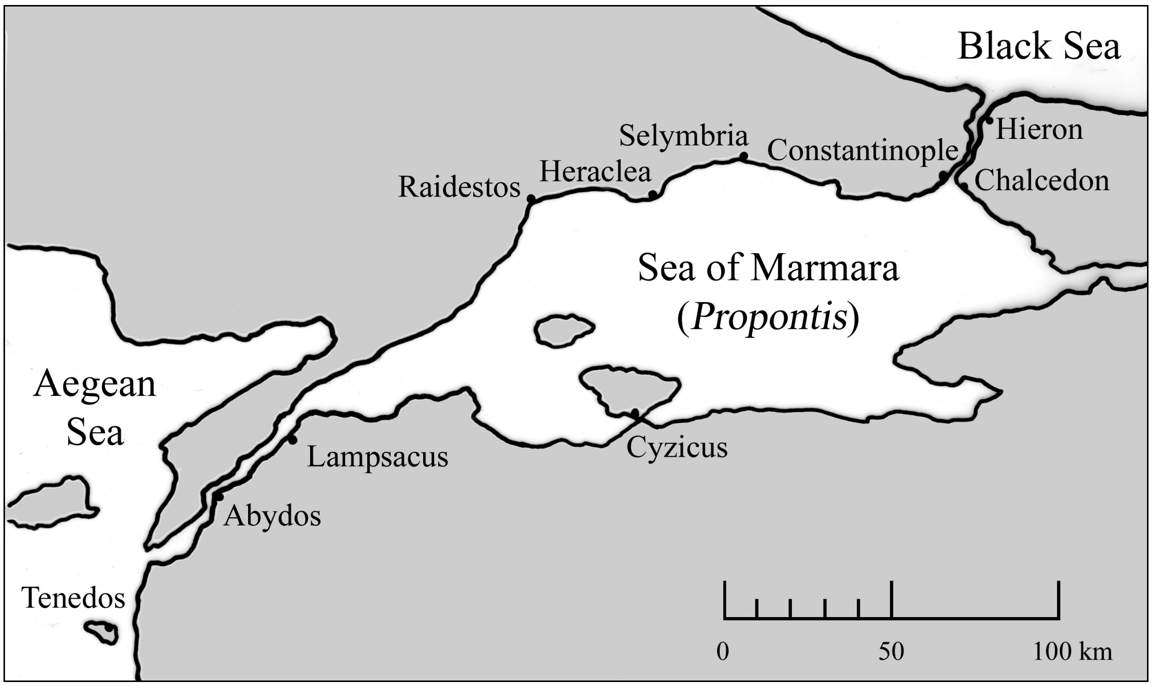

Figure 2.4. Ports on and near the Sea of Marmara (after National Geographic Society 1981, 163).

One of the greatest advantages of Constantinople's harbors was their location within the city; goods could be unloaded very near their intended marketplace, which was not the case in Rome.[135] Although Constantinople's commerce in the sixth and seventh centuries was centered on the two large harbors on the Sea of Marmara, there

[133] Procop. *Anek.* 25.2-6; Oikonomides 2002, 986-87.
[134] Procop. *Anek.* 25.7-10.
[135] Himer. *Or.* 16.5; Rougé 1966, 131.

were likely smaller harbors or piers throughout the city, at which merchandise could be bought or sold.[136] Themistius, speaking of the city of Constantinople in the fourth century, notes that it imported a wide variety of goods but exported only shiploads of builders' refuse.[137] This had clearly ceased to be the case by the sixth century, as Procopius notes the loading of goods for shipment outside the city.[138] Constantinople served as a hub of local, regional, and interregional trade and was noted as a market for luxury goods, as reflected in the contemporaneous sources.[139] The early 10th-century *Book of the Eparch*, a detailed description of the many guilds operating in the city, reveals a thriving community of artisans within Constantinople, with trades such as silk dressers and dyers, perfumers, and wax- and soap-chandlers noted.[140]

Maritime trade was primarily conducted during the accepted sailing season, between March and November.[141] The cost of transporting goods by ship was significantly lower than that of overland transport.[142] Sea travel was also faster, with one day by sea roughly equivalent to a week by land, although this was subject to weather

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[136] Magdalino 1995, 42; Magdalino 2002, 532. Procopius (*Aed.* 1.8.6-9) notes one such harbor, constructed by Justinian, along the shore of the Bosphorus.

[137] Them. *Or.* 4.21; Jones 1964, 857.

[138] Procop. *Aed.* 5.1.11.

[139] Laiou 2002, 725. Theophylact Simocatta (1.11.6) and the *Life of St. Theodore of Sykeon* (42) mention members of the clergy purchasing silver liturgical vessels in Constantinople whilst visiting the city from Heraclea and Sykeon, respectively.

[140] *Eparch* 7-8, 10-12, 14; Dagron 2002, 407-10.

[141] Veg. *Mil.* 4.39; Casson 1995, 270-73. Because YK 11 most likely operated in the environs of Constantinople, an area with many protected bays and coves, the ship probably also operated, albeit in a reduced capacity, outside the accepted sailing season.

[142] Jones (1964, 841-42) estimates that, based on Diocletian's Edict on Prices, a quantity of wheat could be shipped from Alexandria to Constantinople for the same price as traveling overland, by cart, for a distance of just 36 miles. Arnaud (2007, 331-34), however, cautions that the figures listed in Diocletian's Edict are artificial and oversimplified bureaucratic constructions that disregard the reality of sailing; he also notes that prices for land and maritime or fluvial transport were calculated differently (Arnaud 2007, 325). Justinian I's reforms to the *demosios dromos* (postal routes) may have further hampered overland trade (Procop. *Anek.* 30.8-11; Avramea 2002, 59).

and the sailing season.[143] Due to the efficiency of sea travel, troops and supplies for the army were often transported by ship.[144] Merchantmen regularly accompanied warships as well; in 533, a fleet of 500 merchant ships accompanied 92 *dromons* in Belisarius' expedition to North Africa.[145]

Despite its advantages, coastal sailing, even within the Sea of Marmara and the waters around Constantinople, could be unpredictable. Along the Bosphorus, falling rocks near Anaplus (modern Rumeli Hisarı) were known to sink ships, and the complexities of the currents and winds led to many ships being towed through this difficult area.[146] Procopius cites the vicissitudes of sea travel in his lament of Justinian I's having abolished the overland postal route between Chalcedon and Daciviza.[147] The fear of storms was widespread and not without justification.[148] The sudden storms along the Bosphorus complicated the provisioning of Theodora's retreat at Hieron.[149] During a brief voyage between Selymbria and Heraclea, a distance of approximately 22 miles, the *dromon* on which the emperor Maurice was travelling in 598 was nearly wrecked by a violent storm.[150]

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143 Avramea 2002, 77-8.
144 van Doorninck 1972, 135-36. In 627, some of Heraclius' troops were transported to Lazica by ship (van Doorninck (forthcoming); Kaegi 2003, 142; Nikeph. 12.12-14).
145 Procop. *Wars* 3.11.13-16; van Doorninck 1972, 135.
146 *Daniel Styl.* 14, 18, 22; the falling rocks and the sinking of ships were said to be caused by demonic activity.
147 Procop. *Anek.* 30.8-9.
148 McCormick 2001, 403-4.
149 Procop. *Anek.* 15.36-7.
150 Theoph. 268; Theoph.Simok. 6.1.2; Whitby and Whitby 1986, 158 n. 1. A similar situation occurred in 602 when Maurice fled Constantinople, again by *dromon*, to the Gulf of Nicomedia, a journey of just 45 miles (Theoph. 288; Theoph.Simok. 8.9.9; Whitby and Whitby 1986, 224 n. 49). On the other hand, in 475, Zeno and his family, under cover of a heavy storm, managed to escape to Chalcedon by ship and thus avoided an assassination plot (*Daniel Styl.* 69).

In addition to inclement weather, during the first half of the sixth century, a great whale, named Porphyrion, had become a menace to local shipping for 50 years, having sunk several ships and driven others off their course.[151] Piracy was also a danger, and Slav pirates were especially active along the Thracian coast after the sixth century, as reflected in the *Miracles of St. Demetrius*.[152] Slavic terrestrial raiders may also have had an adverse effect on local shipping, as indicated by Procopius.[153] Nevertheless, as McCormick notes, piracy was less of a risk than shipwreck, and since pirates could only operate in areas with a supply of potential victims, contemporaneous references to piracy offer additional proof of thriving sea-borne trade in these areas.[154] As late as the ninth century, the dangers inherent in seafaring, including the threat of storm, shipwreck, or piracy, were still fewer and less perilous than those tied to overland travel through Slav-controlled portions of the Balkan Peninsula.[155]

PORTUS THEODOSIACUS AND THE HARBORS OF CONSTANTINOPLE

During the sixth and seventh centuries, Constantinople possessed four main harbors: two on the Golden Horn and two on the Sea of Marmara (fig. 2.5). Those on the Golden Horn, the Prosphorion and Neorion Harbors, were the primary harbors used by ancient Byzantium and formed the commercial center of the city during the reign of

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[151] Procop. *Anek.* 15.37; Procop. *Wars* 7.29.9-16. The whale, nearly 14 m in length, was eventually grounded in a shallow cove, killed by the local population, and eaten (Procop. *Wars* 7.29.14-6).
[152] According to the *Miracles of St. Demetrius* (II.4.277-78), even the customs houses were subject to raids by Slav pirates later in the seventh century. McCormick (2001, 147, 170-71, 199, 201-2) details several other accounts of piracy during the Byzantine period.
[153] Procop. *Aed.* 4.9.17-21.
[154] McCormick 2001, 170-71, 208.
[155] Avramea 2002, 71; Ostrogorsky 1959a, 11-2.

Constantine I (306-337).[156] The *Notitia urbis Constantinopolitanae* of A.D. 425, a list of the city's structures, names three granaries as well as the *horrea olearia* (a storehouse for oil) that were located near the Prosphorion Harbor, which reflects the early importance of this harbor in the provisioning of the city.[157] The Neorion Harbor, just to the west of the Prosphorion, was the naval dockyard of the ancient city and continued to be used as such during the Byzantine period.[158] After the seventh century, the Prosphorion Harbor fell out of use; the Neorion Harbor was dredged by the Emperor Leontios in 698, most likely in order to better accommodate naval vessels.[159] This activity was also associated with an outbreak of plague.[160]

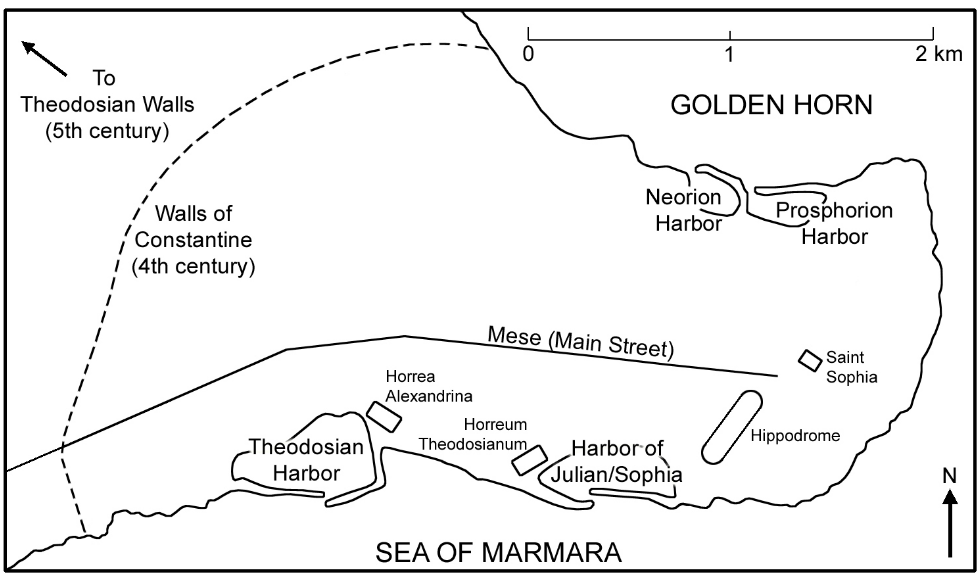

Figure 2.5. Map of Constantinople showing harbors and other features (after Mango 2000, fig. 4).

[156] Magdalino 2000, 211; Mango 1985, 33; Müller-Wiener 1994, 6; van Millingen 1906, 15.
[157] Mango 1985, 14-5; Seeck 1876, 233-34.
[158] Magdalino 2000, 211; Mango 1985, 15, 55-6.
[159] Magdalino 2000, 213; Mango 1985, 56; Mango 1986, 121; Müller-Wiener 1994, 7.
[160] Theoph. 370. The plague is also mentioned by Nikephoros (41.23-4, Mango 1990, 199).

In order to accommodate the city's rapid expansion in the latter half of the fourth century, two new artificial harbors were built on Constantinople's Sea of Marmara shore. The first, initially known as the New Harbor or Harbor of Julian, was built in A.D. 362.[161] The harbor was adversely affected by the accumulation of silts and was dredged on multiple occasions; it was also affected by several fires, in 461, 560, 897, and 956.[162] The *Parastaseis Syntomoi Chronikai*, an early eighth-century work on the monuments of Constantinople, notes that the city's center of maritime trade was transferred from the harbors of the Golden Horn to the Harbor of Julian during the reign of Justinian.[163] Between 565 and 574, Justin II dredged and renovated the harbor, renaming it in honor of his wife, Sophia, after which point the harbor was also known as the Harbor of Sophia.[164]

The Theodosian Harbor (*Portus Theodosiacus*) was built along the city's Sea of Marmara shore as part of the extensive building program conducted during the reign of Theodosius I (379-395), probably around 390.[165] According to Mango, the construction of the Theodosian Harbor brought the city's total available wharfage to 4.5 km.[166] This represents the maximum port capacity of Constantinople, which did not expand but rather contracted in later centuries. The construction of the Theodosian Harbor would

[161] Mango 1985, 39; Müller-Wiener 1994, 8; van Millingen 1906, 30.
[162] Theoph. 235; Magdalino 2000, 212; Müller-Wiener 1994, 8; van Millingen 1899, 291-92.
[163] *Parastaseis* 72; Cameron and Herrin 1984, 17, 152-53.
[164] *Patria* II:62, III:37; Magdalino 2000, 212-13; van Millingen 1899, 291. Heraclius defeated Phocas at this harbor in A.D. 610 (*Chron. Pasch.* 700.14-701.10; Theoph. 299).
[165] Mango 1985, 39-40; Mango 1986, 121.
[166] Mango 1986, 121.

have been a costly undertaking, and van Millingen notes that this should be considered one of the city's most significant public works.[167]

Before the Yenikapı excavations, the Theodosian Harbor was known almost exclusively from textual sources. Although its precise date of construction is unknown, the harbor is mentioned in the *Notitia* of 425 as one of the structures in the city's twelfth district.[168] Pierre Gilles, visiting the filled-in harbor in the mid-16th century, equates it with the Eleutherian Harbor.[169] The latter, known only from the late 10th-century *Patria Konstantinupoleos*, was said to have been built during the reign of Constantine the Great but was filled in by Theodosius I.[170] There remains much confusion over the location and nature of the Eleutherian Harbor; several scholars agree with Gilles, more or less equating the two harbors, van Millingen suggesting the name change was due to improvements made by Theodosius in the late fourth century.[171] Berger, in contrast, stresses that the Eleutherian Harbor should not be confused with the Theodosian Harbor and must have been located farther east, although he calls its very existence into doubt.[172] It is interesting that the *Patria* does not mention the Theodosian Harbor; although Berger attributed the lack of recognition to the fact that the harbor had been

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[167] van Millingen 1899, 268.
[168] Seeck 1876, 239; Müller-Wiener 1994, 9.
[169] Gilles 1988, 201-2.
[170] *Patria* II.63; Müller-Wiener 1994, 9;
[171] Guilland 1953, 209-10; Janin 1950, 218-20; Mango 1985, 55; Mordtmann 1892, 58-9; van Millingen 1899, 296-98. van Millingen furthermore points out that, if the Theodosian and Eleutherian Harbors are the same, the Theodosian Harbor is the oldest harbor on the Sea of Marmara coast. Both Guilland and Janin specify the Eleutherian Harbor as the northwestern portion of the harbor area, the area where YK 11 was found.
[172] Berger (1988, 581-82) argues for a location farther east based on the location of the palace *ta Eleutheriu* as well as the statement in the *Patria* that the harbor had been filled in with soil from the *Forum Tauri*. Müller-Wiener (1977, 60-1) initially equates the Eleuterian and Theodosian Harbors but later supports Berger's view (Müller-Wiener 1994, 9).

filled in by the time of writing, the recent excavations have confirmed that the harbor was indeed in use at that time.[173]

The Theodosian Harbor may also be associated with the Harbor of Caesarius or Kaisarios; several scholars equate the two, although van Millingen placed the Harbor of Caesarius somewhat east, between the Kontoscalion (probably near modern Kumkapı) and the Theodosian Harbor.[174] van Millingen's primary reasoning for this view seems to be the belief, based on the reference in the *Patria*, that the Theodosian (Eleutherian) Harbor had been abandoned by the seventh century, at which time the Byzantine fleet gathered at the Harbor of Caesarius, according to Theophanes.[175] A fire in the Tülbentçi Mahallesi near Yenikapı in 1819, and subsequent investigations by the Patriarch Constantius at the request of the Ottoman government, resulted in the discovery of part of the harborworks of what van Millingen believed to be the Harbor of Caesarius.[176] It is unclear how the finds at Tülbentçi may relate to those at Yenikapı, but it is perhaps noteworthy that four of the six rowed galleys found at Yenikapı are located in the eastern portion of the harbor, toward the Tülbentçi area. Both Janin and van Millingen suggest that yet another port, the Heptascalon, may also be associated with the 1819 finds at Tülbentçi.[177] Guilland goes so far as to identify the Theodosian harbor not only with the

[173] Berger 1988, 575.
[174] Berger 1993, 468-69; Guilland 1953, 222-25; Mango 1985, 55; van Millingen 1906, 97-8. The area around the harbor of Caesarius was burned in 610 during the overthrow of Phocas (*Chron. Pasch.* 700.3-13; Whitby and Whitby 1989, 151 n. 423).
[175] Theoph. 353.
[176] van Millingen 1899, 310-15. The Tülbentçi area is east of modern Atatürk Boulevard, the eastern limit of the excavations at Yenikapı. The excavations have revealed that the Theodosian harbor extended beyond Atatürk Boulevard, but the original extent of the harbor is unknown.
[177] Janin 1950, 221; van Millingen 1899, 308-12.

Eleutherian Harbor and the Harbor of Caesarius, but also with the Heptascalon and the Kontoscalion Harbors as well, although Berger disputes the latter.[178]

Gilles describes the Theodosian Harbor's mole, still visible in the 16th century, as 600 paces in length; Berger, having calculated Gilles' pace as 65 cm in length based on his descriptions of other monuments, estimates the actual circumference of the harbor at 1,900 m, which is well over a mile.[179] Mango suggests that the Theodosian Harbor was the largest of the city's harbors, and the recent excavations have indeed revealed a harbor of considerable size.[180] The artificial mole built to protect the harbor aided its demise, however, as the silts deposited from the Lycus River were pushed into the harbor's western corner.[181] The size, date, and distribution of shipwrecks found in the Theodosian Harbor confirm that the harbor shrank steadily due to the accumulation of these silts, starting in the western corner (whence YK 11 was recovered) and spreading eastward, as suggested by Janin.[182] Although the latest shipwrecks found at the site, toward the eastern end of the excavation, are of late 10th- or early 11th-century date, Peter Kuniholm's dendrochronological analysis of oak posts used as dock or jetty pilings at Yenikapı indicates that some vessels continued to use the area as late as the 15th century.[183] Only small fishing boats could use the remaining portion of the harbor at this

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[178] Berger 1988, 576; Guilland 1953, 237-38.
[179] Berger 1993, 476; Gilles 1988, 201.
[180] Mango 1986, 121. The recent excavations at the site, covering more than 58,000 m^2, do not cover the entire area of the harbor (Gökçay 2007, 166).
[181] Mango 1985, 55; Müller-Wiener 1977, 61. van Millingen (1899, 268) also suggests that sand deposited by waves of the Sea of Marmara contributed to the harbor's demise, and that such sand proved detrimental to all of the harbors along the Sea of Marmara coast.
[182] Janin 1950, 219; Liphschitz and Pulak 2009, 165.
[183] Kuniholm et al. 2007, 381-83.

late date, while, according to a report of 1432, three or four larger boats or ships could also be moored in the mouth of the Lycus River.[184]

Thus, although the harbor was in use from the 4th to the 15th centuries A.D., its usable area became progressively smaller. Based on the eyewitness account of Gilles, the harbor had filled in completely by the middle of the 16th century, and the area, known as *Blancha*, *Vlanga* or *Langa*, was being used as gardens, a use which persisted well into the 1970s.[185] Based on the work of Niketas Choniates, the area bore this name as early as the 11th century, and several streets in the area still bear the name *Langa*.[186] A large part of the harbor structure remained visible until the construction of the railway in 1871 and the subsequent construction of the coastal road and Atatürk Boulevard.[187]

Although the Theodosian Harbor was primarily commercial in nature, there is some evidence of its use by military vessels. Theophanes notes that, during the first Arab siege of Constantinople in the latter half of the seventh century, the newly-restructured fleet of Constantine IV was stationed at the Harbor of Caesarius, most likely the Theodosian Harbor.[188] This military function of the harbor is echoed by Guillame-Joseph Grelot, who, visiting the site in the late 17th century, described the harbor as "…un Port de Galeres où les Empereurs Theodose, Arcade & leurs successeurs ont longtems tenu leur Chiourme."[189]

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[184] Berger 1993, 470-72; Liphschitz and Pulak 2009, 165.
[185] Gilles 1988, 201; Janin 1950, 220.
[186] Nik.Chon. 2.4.130.
[187] Müller-Wiener 1977, 61.
[188] Theophanes (353) calls this the Proclianesian Harbor of Caesarius, which Mango and Scott (1997, 493 n. 4) equate with the Theodosian Harbor. The Arab fleet was anchored between the Magnaura and the Kyklobion (or, between modern Bakırköy and Zeytinburnu) (Theoph. 353, Nikeph. 34.2-8).
[189] Grelot 1680, 80; van Millingen 1899, 299.

Six 10th-century galleys were found at Yenikapı, thus confirming the literary accounts. These shipwrecks, the first of this kind discovered from the Byzantine period, were probably what the Byzantines called *galea*, a light naval vessel used for scouting, speedy communication, and perhaps light warfare.[190] Two of these galleys, YK 2 and YK 4, were studied by Pulak and his team. They exhibit a regulated and specialized construction aimed toward creating a fast and flexible vessel; they were originally approximately 30 m in length and would have been propelled by a single bank of oars with 25 rowers per side. These finds indicate that the harbor continued to serve some military function even late in its service life.

The *annona*, or state-supplied food system, relied heavily on the city's harbors and *horrea* or granaries.[191] The *Notitia* lists two large granaries, the *Horrea Alexandrina* and the *Horreum Theodosianum,* in the city's ninth district, just east of the twelfth district; these were located between the Theodosian and Julian Harbors.[192] The name of the *Horrea Alexandrina* clearly denotes its association with the grain shipments from Alexandria, Egypt, before the loss of that city early in the seventh century.[193] Although little is known of these granaries, Gilles associates both with the Theodosian Harbor.[194]

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[190] *Taktika* 19.10, 19.81.

[191] Mango 2000, 190. Mango also notes that, although *horrea* might be used for storing a variety of goods, those in Constantinople, unless noted otherwise, were probably intended for grain storage (2000, 193).

[192] Seeck 1876, 236-37.

[193] This granary was probably the last in use in the city in the early 10th century, by which time the other granaries had been abandoned, confirming the notable decline in the city's population by this time (Mango 1985, 54-5). It is the setting for the saint's encounter with a granary guard in the *Miracles of St. Artemios* (Miracle 16).

[194] Gilles 1988, 160. Modern scholarship associates one or both granaries with the Theodosian Harbor as well (Janin 1950, 61; Mango 1986, 121; Müller-Wiener 1994, 9).

If he is correct, one of the purposes of the Theodosian Harbor was to receive large shipments of grain, including those from Egypt.[195]

Sometime after the construction of the Harbor of Julian/Sophia and the Theodosian Harbor, perhaps by the sixth century, the commercial center of the city appears to have shifted away from the Golden Horn and toward the Sea of Marmara, as stated in the *Parastaseis*; this remained the case until the tenth century.[196] Textual references which support this shift favor the Harbor of Julian/Sophia and include references to the maintenance of this harbor, to its use by travelers, and to new construction around the harbor.[197] Similar textual evidence regarding the Theodosian Harbor is rare, although an early 10th-century reference to a granary known as Lamia, seemingly the last functioning granary in the city at that date, likely refers to a granary associated with the Theodosian Harbor (Mango suggests the *Horrea Alexandrina*).[198]

The construction of the *horrea* on Tenedos, the loss of Egypt, and the general trend toward the use of smaller ships likely resulted in a decline in demand for large docking space; this could explain why the Theodosian Harbor, although already silting in by the seventh century, was not noted as having been dredged or renewed.[199] Nevertheless, the sustained use of the Theodosian Harbor, despite its diminishing size, from the 4th to the 11th century, has been amply proved by the recent excavations at the

[195] Müller-Wiener 1994, 9.
[196] *Parastaseis* 72; Cameron and Herrin 1984, 17, 152-53; Magdalino 2000, 212.
[197] Magdalino 2000, 212-14.
[198] Mango 1985, 54-5; Magdalino 2000, 213.
[199] Magdalino 2000, 215; Müller-Wiener 1994, 9.

site, which uncovered more than a dozen shipwrecks of late 10th- or early 11th-century date.[200]

[200] The concentration of aristocratic residences between the Harbor of Julian/Sophia and the Theodosian Harbor between the 8th and 11th centuries also reflects a sustained emphasis on both of the Sea of Marmara harbors; in contrast, similar residences in this period near the harbors on the Golden Horn are lacking (Magdalino 2000, 214; Mango 1985, 59; Mango 1986, 129).

CHAPTER III

EXCAVATION AND DOCUMENTATION OF SHIPWRECK YK 11

DISCOVERY OF YK 11

YK 11 was first located by the staff of the Istanbul Archaeological Museums in late 2005, in the Third District near the western end of the Yenikapı excavation, soon after Pulak and his INA team began work at Yenikapı (fig. 3.1). The forward portion of the wreck had been exposed by January 5, 2006, the date of the earliest photos (fig. 3.2). Part of the port stern was subsequently cleared for a preliminary examination in March 2006, during which Pulak, director of the INA team working at Yenikapı, determined that it was the wreck of a small, well-preserved merchantman, likely of late sixth- or early seventh-century date; mortise-and-tenon joints were observed along some plank edges. This ship, one of the earlier wrecks found at the site, was designated YK 11; as the fifth wreck found on the Marmaray portion of the excavation, it also has an alternate designation of MRY 5.[1] YK 11 is the westernmost shipwreck excavated at Yenikapı, found near the Yüzada ("Plot 100", Second District) area of the excavation site; as such, it may also be referred to as the Yüzada wreck.

The Yüzada area, at the westernmost extremity of the excavation, contains architectural remains dating from the 4th to the 13th centuries A.D.[2] It is thought to comprise the waterfront along the harbor's western end and includes what is possibly the

[1] In the early photo shown in figure 3.2, the wreck was labeled MRY 06.
[2] Karamut 2007, 13.

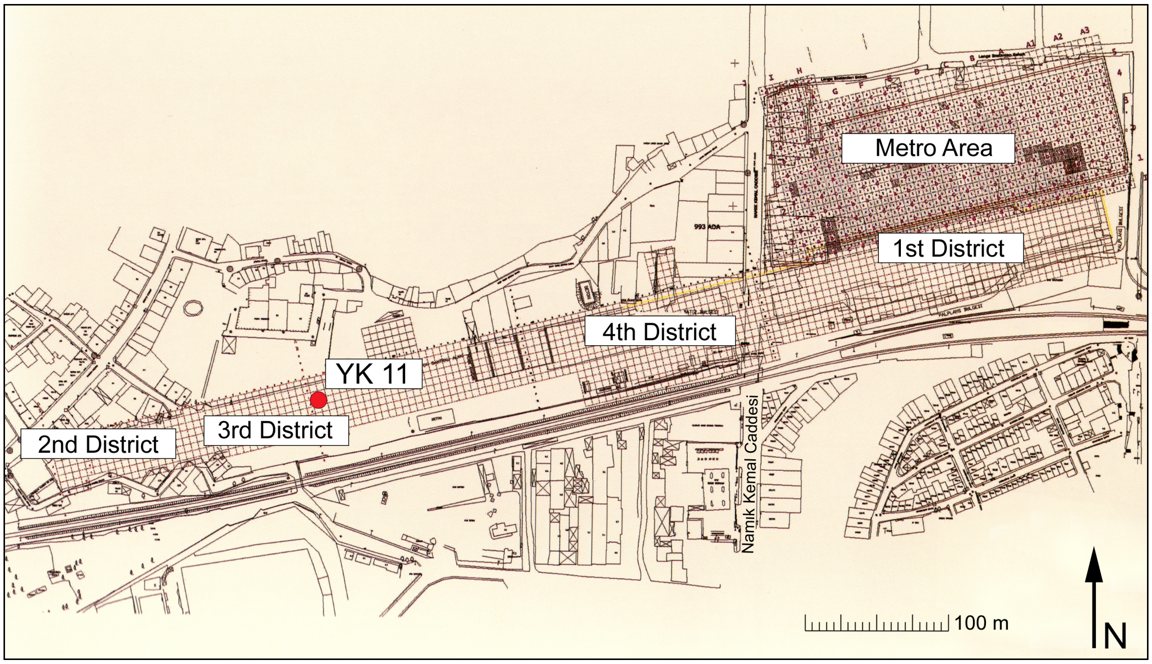

Figure 3.1. Map of the excavations at Yenikapı (after Gökçay 2007, 167 plan P1). The location of shipwreck YK 11 is marked with a red dot in the Third District, toward the western end of the site. Each grid square is 25 m^2.

Figure 3.2. Shipwreck YK 11 shortly after discovery. January 5, 2006. Photo by Bekir Köşker (used with permission.)

only known portion of the city's Constantinian wall.[3] Other structures in the area include a vaulted brick tunnel, workshops (possibly for leatherworking), and an 11th-century *hypogeum*; due to the unique finds in this part of the site, the Regional Protection Board declared that the Yüzada area would be preserved for use as an archaeological park.[4]

Figure 3.3. Final removal of overburden from YK 11 by Istanbul Archaeological Museums' staff; looking northeast (toward the stern). January 16, 2008. Photo by M. Jones/INA.

[3] Gökçay 2007, 172-73.
[4] Gökçay 2007, 173-74; Karamut 2007, 13.

Because the nearby Yüzada area was to be preserved, excavation of YK 11 was a low priority and work focused on other wrecks farther east, in the construction zones of the excavation. YK 11 was therefore reburied in situ after March 2006. The protocol for work with the wreck was drawn up on January 17, 2007; thereafter, Pulak's offer of gratis excavation was accepted, and an agreement with INA was signed on March 1, 2007. A protective tent was erected over the site in early January, 2008, after which the Istanbul Archaeological Museums' staff began the final removal of overburden (fig. 3.3); this was completed by January 19, 2008, and the shipwreck area was signed over to INA on January 26, 2008. In February 2008, heavy snows resulted in several days of lost work and damage at several areas throughout the site; although YK 11 was unharmed, the weight of the snow caused damage to the tent structure, which was then reinforced to prevent collapse.

THE YK 11 WRECK SITE

The ship was located in a viscous, muddy layer of sediment with shell inclusions within grid squares J88-89 and K88-89 in the Third District of the Marmaray portion of the Yenikapı excavation (fig. 3.1).[5] The wreck was at a depth of 1.7-2.0 m below sea level, and excavations elsewhere in the Third District revealed that the layer of mud continued to 2.5 m below sea level.[6] This was in stark contrast to the thick layer of sand farther east in the First District and Metro Area, from which most of the other shipwrecks at Yenikapı were recovered.

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[5] Each grid square is 25 m^2 in area (Gökçay 2007, 169 fig. D2).
[6] Gökçay 2007, 166.

The YK 11 shipwreck and other scattered fragments covered an approximately five- by ten-meter area, in a north-northeast by south-southwest orientation, with the bow pointing south-southwest. The north-northeast end of the ship was initially believed to be the bow, based primarily on the robust longitudinal timber (KS 1) in this area, and this initial identification influenced the labeling of timbers. However, during a study of the ship's hypothetical rig on the basis of the extant hull remains in spring 2009, evidence for the location of the ship's mast indicated that the designation of bow and stern would need to be reversed.[7]

Like the other wrecks at Yenikapı, YK 11 was located in sediments below the water table; in order to prevent damage or distortion due to drying, the ship's waterlogged timbers were kept wet throughout the excavation. This was achieved through the installation of a sprinkler system with two lines over the centerline and to one side of the wreck as soon as the wreck was fully exposed (late January 2008); this prevented the ship and its associated, scattered fragments from drying out (fig. 3.4). This sprinkler was kept on at all times when work was not being done on the wreck or when the wreck area had not been inundated. At the time the wreck was turned over to INA, work had recently begun on YK 23 (MRY 8), a late eighth- or early ninth-century wreck in the First District of Yenikapı, near Namık Kemal Caddesi, adjacent to ongoing construction; as a result, work on YK 11 was postponed until most of the work on YK 23 had been completed.

[7] This is based on the location of a gap in the planking between the first and second wales that would have held the mast-partner through-beam; the ship's hypothetical rig is presented in detail in Chapter VI.

Figure 3.4. Shipwreck YK 11 during in-situ documentation. Two sprinkler lines (marked with red arrows) were installed above the wreck after it was uncovered. Long pallets, laid across sawhorses, provided access to the central part of the ship. June 21, 2008. Photo by R. Ingram/INA.

The mud surrounding YK 11 was very soft, in some areas nearly liquid; in order to facilitate work with the timbers, dozens of sandbags were laid around the wreck to provide a solid surface. Because the sediment supporting the wreck was so soft, placing additional weight on the timbers was avoided.[8] To allow archaeologists to work on the

[8] Other wrecks at Yenikapı were supported by less pliant sediment; on these wrecks, archaeologists could cautiously step onto an intermediate layer of thick Styrofoam that prevented surface damage to the planking timbers.

interior area of the shipwreck, sawhorses were placed on either side of the ship with a long pallet laid over the top (fig. 3.4). The nature of the sediment on this site, combined with the depth of the excavation pit in relation to its surroundings, led to frequent flooding. This was exacerbated by a poorly-functioning sump pump and electricity problems; as a result, the pit was flooded and the shipwreck became inaccessible approximately 15% of the time during the course of INA's work on the wreck.[9]

2008 IN-SITU DOCUMENTATION AND REMOVAL OF YK 11

The in-situ documentation and removal of YK 11 from the site was conducted by a small team under the guidance and direction of Prof. Pulak.[10] The team followed the methodology developed by INA in their work with other shipwrecks at the Yenikapı site and elsewhere. Because this was a salvage excavation, with strict time constraints imposed by the Istanbul Archaeological Museums and other organizations involved in the construction of the new rail line, the shipwrecks at Yenikapı could not be fully documented during their disassembly and removal. Since YK 11 was located outside the primary construction zone, these time constraints were somewhat more relaxed for this shipwreck; nevertheless, due to the complexity of YK 11, only basic documentation of the ship's construction could be recorded in 2008.

[9] The INA team worked on removing the wreck for approximately six and one-half months between May and November 2008; the shipwreck was inaccessible for a total of 22 work days during this period. There were no water outages during our work with this wreck; water outages are a more serious potential problem than flooding due to possible damage to ship timbers resulting from desiccation and had been an issue with some of the other wrecks at the site.

[10] The INA YK 11 team consisted of Sheila Matthews, veteran INA archaeologist and assistant director of the INA team working at Yenikapı; Yasemin Aydoğdu, a former museum archaeologist who had worked with the INA team on galley YK 4; Rebecca Ingram and Michael Jones, nautical archaeologists working with the INA team at Yenikapı since 2005; İlkay İvgin, one of the first museum archaeologists hired at Yenikapı in 2004; and INA archaeologist Orkan Köyağasıoğlu.

Table 3.1. Abbreviations used in labeling timbers from YK 11.

Label	Timber Description
SS	Port strake (of exterior planking and wales); initially thought to be on the starboard side
PS	Starboard strake (of exterior planking); initially thought to be on the port side
FR	Frame, including floors, half-frames, and support piece FR12A
F	Futtock
KS	Keelson-like sternson
SST	Port stringer; initially thought to be on the starboard side
PST	Starboard stringer; initially thought to be on the port side
CST	Central stringer
SC	Port common ceiling; initially thought to be on the starboard side
PC	Starboard common ceiling; initially thought to be on the port side
S-Block	Stanchion block
BH	Bulkhead partition
UM	Unidentified member (fragment of unknown origin)

The INA team began working on shipwreck YK 11 on May 3, 2008. The initial work on the wreck entailed the labeling and mapping of unidentified fragments (labeled Unidentified Member, or "UM") that were scattered across the wreck site. White plastic labels, created with a Dymo LetraTag label maker, were affixed to each fragment with stainless-steel wire pins; abbreviations used for the different types of hull components are presented in table 3.1. Several of the UM timbers were later identified as specific elements of the ship's construction that had been displaced; most, though, could not be identified beyond a general type of timber, and some may have simply been scraps of wood that were discarded at this end of the harbor.

One-third of the UM timbers (64 of 192) had been removed from the sediment by Istanbul Archaeological Museums' workers or archaeologists in January 2008 with no recorded provenience. The remaining, in-situ UMs were labeled and roughly mapped

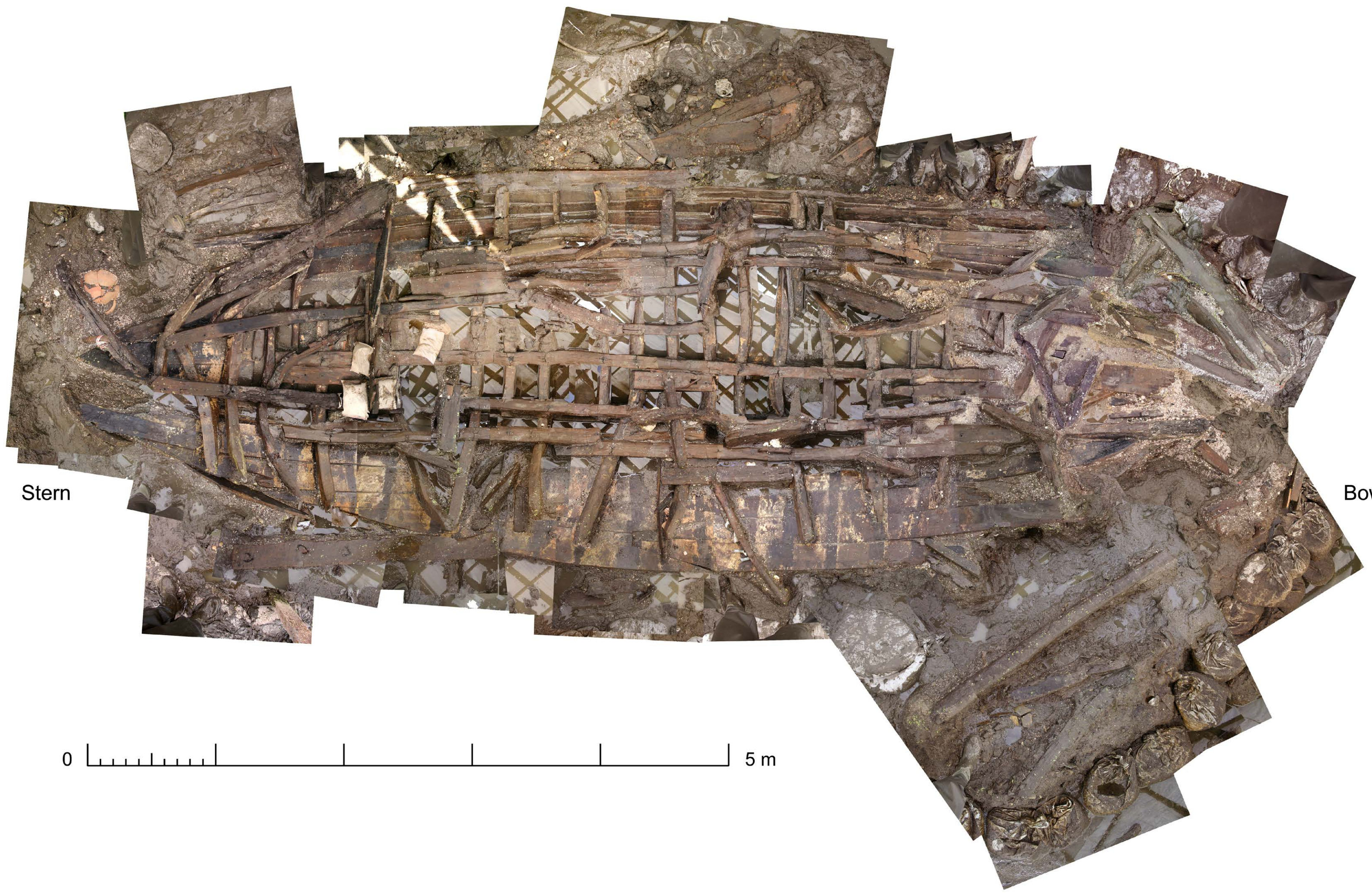

Figure 3.5. Initial (upper-most layer) photomosaic of wreck YK 11, including all timbers. Photos by O. Köyağasıoğlu, mosaic by S. Matthews. May 3, 2008.

with the aid of the photomosaic of the upper-most layer created by Sheila Matthews and Orkan Köyağasıoğlu (fig. 3.5). Once each timber was labeled and its approximate position indicated on a sketch plan based on the photomosaic, the wreck was scanned using a Total Station (May 23-24, 2008) by a team from İmge Harita under the direction of Sadık Demir. Matthews used the resultant data to create a precise, three-dimensional map of the wreck using Rhinoceros modeling software (fig. 3.6).

Each UM timber was then sketched and photographed in situ prior to being removed from the wreck. After removal and cleaning, a worksheet was completed for the piece, including basic measurements and a brief description; this information was later incorporated into an inventory submitted to the Istanbul Archaeological Museums. Additional photos and samples for wood-species identification were also collected at this time. Once documentation and sampling were completed, the timber was packed in a custom-made, foam-lined wooden crate and moved to an on-site, covered freshwater storage tank. By June 23, 2008, the upper-most layer of UM timbers had been removed and basic catalog worksheets completed.

To facilitate the mapping and in-situ documentation of the ship, the YK 11 timbers were conceptually divided into four layers. The upper-most layer consisted of scattered UMs and was the first to be mapped and removed. While most of the UMs were located in this upper-most layer, UMs were also found in the other three layers. The other three layers, from upper to lower, are upper-level in-situ ship timbers (ceiling, bulkhead, stanchion blocks, stemson, and sternson), framing, planking and keel

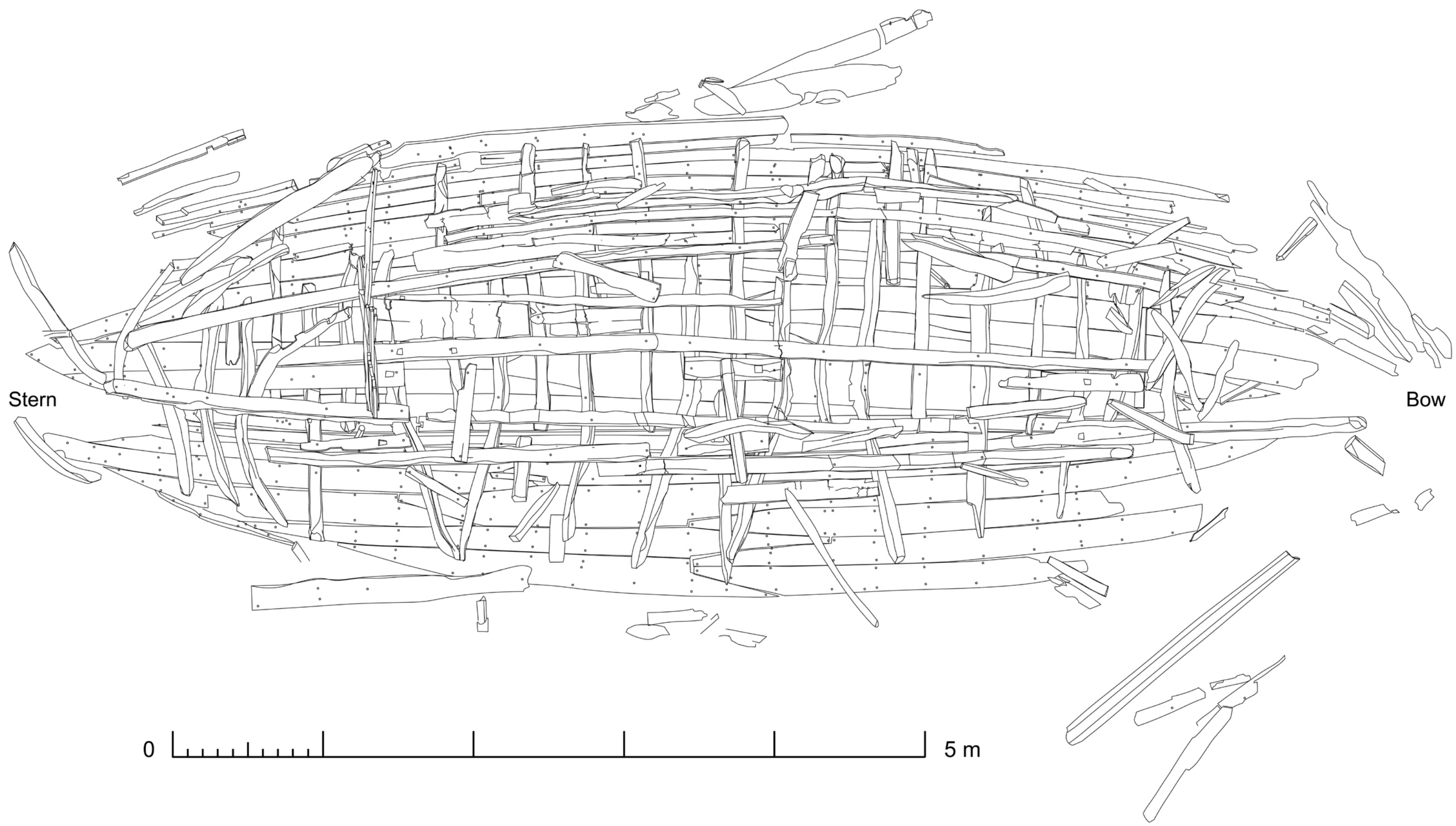

Figure 3.6. Total Station plan of wreck YK 11 in situ, including all timbers. Plan by S. Matthews.

Figure 3.7. Photomosaic of wreck YK 11 with all in-situ timbers, after removal of upper-level UM fragments. June 8, 2008. Photos and mosaic by R. Ingram.

timbers.[11] Once the process outlined above for the UM timbers of the upper-most layer (cleaning and labeling, photomosaic, Total Station scanning, in-situ photos, removal, basic catalog, packing in crates, and moving to temporary storage) had been completed, a similar process was carried out for each timber of the remaining three layers. General notes on the construction of the ship were recorded throughout this process.

The well-preserved ceiling of YK 11 was mapped, documented and removed June 24-July 21, 2008. This layer included the stringers, common ceiling, stemson, sternson, stanchion blocks, and the bulkhead partition, located near the ship's stern (fig. 3.7). At this time, several artifacts were found and removed from the ship's bilges, including a folded lead seal, a bronze lamp hanger, and small wooden objects associated with the ship's rig; the seal and lamp hanger are discussed below when considering the date of the vessel.

The ship's framing was mapped, documented and removed July 22-August 23, 2008 (fig. 3.8). The one-page worksheet for each frame was more detailed than those for the ceiling or UM timbers and entailed the matching of fastener holes on the lower face of the frames with those on the inner (upper) face of the planking. Several frames had many more nail holes than were found on the corresponding area of the planking; this was the first indication of extensive repairs to this hull.

The ship's planking and keel timbers were mapped, documented and removed August 25-November 17, 2008 (fig. 3.9). In addition to the usual sequence of documentation, these timbers were traced on clear plastic film prior to their removal

[11] The extensive layer of both UMs and ceiling on YK 11 differentiate this wreck from most of the other wrecks documented by INA at Yenikapı, which usually had two or, for the galleys, three layers.

Figure 3.8. Photomosaic of wreck YK 11 with frames, keel, and planking, after removal of ceiling planking. July 23, 2008. Photos and mosaic by R. Ingram.

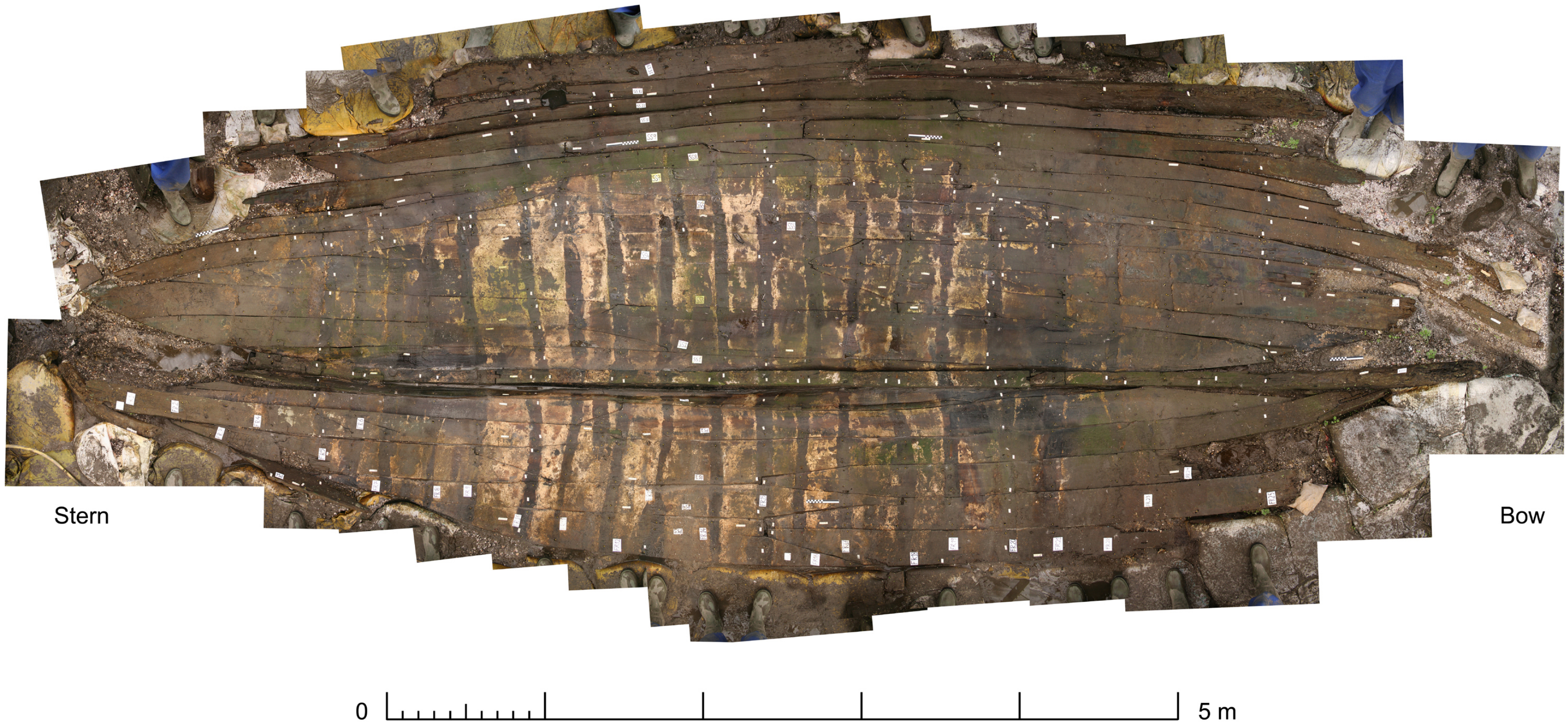

Figure 3.9. Photomosaic of wreck YK 11 keel and planking, after removal of frames and ceiling. August 23, 2008. Photos and mosaic by R. Ingram.

Figure 3.10. R. Ingram (L) and M. Jones tracing YK 11 planking on clear plastic film. Oct. 23, 2008. Photo by S. Matthews/INA.

from the wreck (fig. 3.10). This additional documentation was required in order to preserve surface detail which might not be discernible once planks are disassembled. To facilitate the eventual digitization of the drawings, the plastic film was no more than 90 cm in width and 6 m in length. Each drawing covered multiple strakes of planking and overlapped adjacent drawings by one strake to allow the drawings to be joined later.

The in-situ documentation and removal of planking required significantly more time than did the other layers of timbers. The cleaning of viscous mud from the outer face of planks prior to dismantling proved time consuming. In addition to the scale drawings, mortise locations were also recorded at this time; only upon the dismantling of the ship and identification of mortises did it become clear that a significant number of the original planks had likely been replaced. The delicate caulking, sandwiched between planks and easily washed away after dismantling, was also photographed, recorded, and sampled at this time. Finally, the autumn weather severely hampered work on the wreck; heavy rains, combined with runoff from other areas of the site, flooded the pit on several occasions.[12] The excavation pit was intentionally allowed to flood in late September in order to facilitate the removal of wale SS11, which remained unbroken for a length of nearly 7 m.[13]

Due in part to its lack of cargo, many of the ship's planks remained unbroken along most of their length and retained their original curvature to some extent. In order to preserve this form, Matthews used the Total Station data to design customized molds for each curved plank. These molds were later secured in foam-lined crates for storage and transport.

Throughout the process of photographing, mapping, documenting and removing the timbers from the wreck, the many artifacts found scattered throughout the pit were drawn and photographed prior to being turned over to the Istanbul Archaeological Museums for final conservation and study. The last timber had been removed and authority over the wreck pit was signed back to the Istanbul Archaeological Museums on November 19, 2008. The following week, the foam-lined crates containing the timbers were sent by container truck to INA's Bodrum Research Center in southwest Turkey.

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[12] Of the 22 work days lost due to flooding in the excavation pit, 13 occurred during the removal of planking.

[13] Once the pit had flooded, archaeologists, aided by the buoyancy of the timber in water, were able to carefully remove the wale from the ship and secure it in a custom-built crate.

THE DATE OF YK 11

Shipwreck YK 11 was located near the harbor's western end, which, due to the placement of the breakwater, was the first part of the harbor to become silted in. The variety of objects found in and around the shipwreck, including sherds of amphorae and other ceramics, terracotta oil lamps, and various items of bone, glass, and metal, confirm that this area of the harbor had been used for dumping between the sixth and eighth centuries A.D. It would therefore have been an appropriate location for the abandonment of an old, worn-out vessel such as YK 11. Artifact analysis by the Istanbul Archaeological Museums indicates that this area of the harbor had become filled in completely during the eighth century.

Most of the broken amphoras scattered about the YK 11 area correspond to Riley's Late Roman 2 class, which dates from the fifth to early seventh centuries.[14] Similar amphoras have been found on the seventh-century Yassıada ship and may be associated with the shipment of *annona* contributions from the Aegean.[15] Although less prominent, fragments of Late Roman 1a amphoras were also found around the wreck area. This type was also found at Yassıada and is very common throughout the Eastern Mediterranean between the fourth and seventh centuries.[16] The ceramics also included more than 80 broken terracotta lamps; the majority of those that were found after INA began work with YK 11 are of the Balkan Type, common in Constantinople and areas to

[14] Riley 1982, 217-19.
[15] Bass and van Doorninck 1982, 157-60, 163-64; Karagiorgou 2001, 150-54.
[16] Bass and van Doorninck 1982, 155-57, 163; Riley 1982, 212-16. This is the most common type found at Saraçhane in the sixth and seventh centuries (Hayes 1992, 63-4 type 5).

the north.[17] Similar lamps were recovered from the seventh-century Yassıada ship as well as from sixth- or seventh-century levels at Saraçhane, an archaeological site in Istanbul very close to Yenikapı.[18]

Figure 3.11. Folded lead seal MRY5/19, found within the ship.

Although most of the scattered ceramics and other artifacts are not associated with the shipwreck and are thus of limited value in dating the vessel, two objects were found within the ship that corroborate the late sixth- or early seventh-century date indicated by details of the ship's construction. Lead seal MRY5/19 was found between frames just above the level of planking, in the port turn of the bilge forward of amidships. Only one face of the lead seal is visible due to its having been rolled or

[17] Bass and van Doorninck 1982, 196; Iconomu 1967, 28-9, 147-50, type XXXIII; Wulff 1909, 251-52 nos. 1270-1274.
[18] Hayes 1992, 81-3; Bass and van Doorninck 1982, 196-99. The Saraçhane site comprises the remains of the sixth-century Church of St. Polyeuktos.

folded in half (fig. 3.11). The visible face of the seal shows the Theotokos, standing to front, wearing a chiton and maphorion; Christ, framed in an oval mandorla, is held before her (fig. 3.12). There is a cross potent to left and right. This particular design was used in imperial seals from the reign of Maurice to the end of the first reign of Justinian II (A.D. 582-695).[19] This seal appears to show the more naturalistic position of the Theotokos first seen during the reign of Heraclius; thus, the date of the seal could be slightly narrowed to A.D. 610-695.[20] Based on its find location, the seal was either in the ship when it was abandoned or was deposited very soon thereafter, before sediment filled the submerged hull. As a result, this seal provides a *terminus post quem* of ca. A.D. 610 for the abandonment of the vessel.[21] Based on other artifacts in the excavation pit, the seal had likely been rolled or folded over for use as a net weight for fishing.[22]

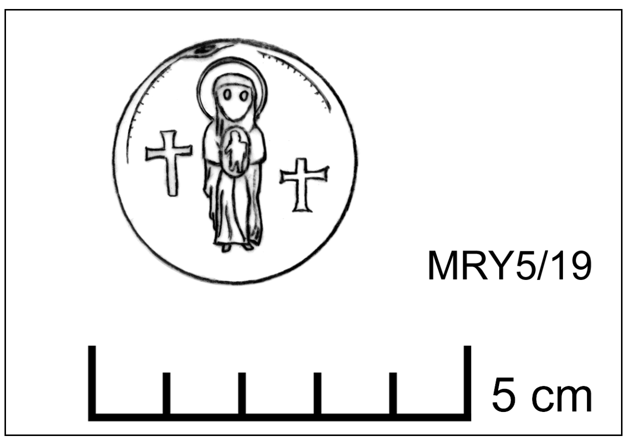

Figure 3.12. Design of lead seal MRY5/19.

[19] Nesbitt 1991, 2-3; Seibt 1987, 36-7. The design was used during the reigns of the emperors Maurice (582-602), Phocas (602-610), Heraclius (610-641), Constantine III (641), Heraclonas (641), Constans II (641-668), Constantine IV (668-685), and the first reign of Justinian II (685-695).
[20] Nesbitt 1991, 3.
[21] A.D. 610 is the earliest possible date at which the vessel may have been abandoned.
[22] Folded-over lead strips for use as net weights were also found on the seventh-century Yassıada ship (Bass and van Doorninck 1982, 303-6) and the 11th-century Serçe Limanı ship (Bass et al. 2004, 400-10).

Figure 3.13. Bronze lamp hanger MRY5/16, found within the ship.

The bronze lamp hanger or incense burner (*thymiaterion*) hanger shown in figure 3.13, while less securely dated than the lead seal, was almost certainly part of the ship's equipment during its lifetime. This nearly perfectly-preserved lamp hanger, complete and intact with the exception of the tips of two hooks, was found under the bulkhead partition frame. This object had probably been stored with other valuables in the stern cabin and had fallen into the bilges and under the ceiling level, thus escaping notice.

Partial remains of similar lamp hangers, the finely-made Type A, were found, usually in sixth- or seventh-century levels, at Saraçhane in Istanbul.[23]

Altogether, the scattered fragments of amphoras and oil lamps, the lead seal, and the bronze lamp hanger suggest that ship YK 11 was built in the late sixth or early seventh century and abandoned at some point after ca. A.D. 610, but prior to the eighth century.[24] This date is compatible with the ship's construction and that of contemporaneous vessels.

POST-EXCAVATION DOCUMENTATION

According to Steffy, research on and reconstruction of any given shipwreck are contributions that can be made in several ways and without time constraints; recording, on the other hand, is an obligation of the archaeologists who uncovered the wreck and is often conducted under a restrictive time-frame.[25] Ship YK 11 and the other ships found at Yenikapı were necessarily excavated and dismantled to prevent their destruction due to the new rail line. Thus, once YK 11 was contracted for study, the primary goal was the documentation of the ship's timbers to provide a permanent record of this vessel. As noted above, some of this documentation occurred prior to dismantling in 2008; most, though, was carried out after the ship had been safely removed from the construction zone in Istanbul to the INA research facilities in Bodrum.

[23] Harrison 1986, 239-41, nos. 169-189.
[24] Due to relatively low rings counts on the timbers used in the construction of YK 11, dendrochronological dating was not possible for this ship. It is hoped that future studies will provide a more reliable date for this vessel, perhaps through radiocarbon dating or carbon-14 wiggle-match dating.
[25] Steffy 1994, 191.

Upon arrival in Bodrum, the crates holding the YK 11 timbers were moved into an outdoor freshwater storage tank, 90 m^3 in volume (fig. 3.14). This tank housed the timbers from YK 11 as well as those of the late eighth-century Yenikapı shipwreck YK 23. An adjacent storage tank held the timbers of YK 14 and YK 24. The water in the timber storage tanks was treated with a 0.02% solution of borax and boric acid as a pesticide and fungicide. Per local municipality regulations, guppies were also added to the tanks to reduce the mosquito population.

The keel timbers and many of the ship's planks were not removed from the tank for cataloging due to their weight and size. Instead, the crates or molds holding the timbers were raised to just above the level of the water so that the timbers could be cataloged inside the tank.[26] The detachable planking molds greatly facilitated this process and allowed even the largest timbers to be moved by two people. A sturdy, flat pallet, covered in white vinyl oilcloth, was custom-built to accommodate the long, heavy keel timbers of YK 11.[27] A light-colored, knitted shade cloth, 3.5 by 6.2 m in size, was suspended above part of the tank for shade and protected the timbers from direct sunlight during recording (fig. 3.14).[28]

Smaller timbers or those that were not intact, including frames, ceiling, and UM timbers, could more easily be removed from the tank and were cataloged in a covered

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[26] The wooden crates or plank molds were supported above the level of the water with plastic crates resting on the submerged stacks of timber crates.

[27] The use of the white vinyl oilcloth (called *muşamba* in Turkish) helped prevent surface damage to the timbers and provided a suitable backdrop for photos.

[28] This shade cloth was hand-sewn from three pieces of 90% UV-blocking Coolaroo brand knitted shade cloth, 1.8x4.5 m in size, to form a large shade approximately 3.5x6.2 m in size. A light color ("Wheat") was chosen to reduce heat and to facilitate photography of the timbers. A cord sewn into a pocket along the edges of the shade allowed it to be suspended from nearby trees; this cord helped distribute the stresses from high winds across the entire shade, thus helping to protect the fabric from damage.

outdoor work area. A table top on plastic crates could be easily raised or lowered and facilitated drawing the timbers at 1:1 scale.

Figure 3.14. The large timbers of shipwreck YK 11 were stored in this 90 m^3 freshwater tank at INA's Bodrum Research Center. July 31, 2010.

The post-excavation documentation was conducted by the author in June-August 2009 and June 2010-April 2012. The documentation was carried out prior to the conservation of the timbers in Polyethylene Glycol (PEG), as this treatment tends to darken the wood and may obscure tool marks or other surface detail.[29] Furthermore, timber dimensions are most reliable prior to conservation, during which they may shrink up to 10% in lateral dimension.[30] A total of 26 months was required to complete the

[29] Mor 2004, 180.
[30] Steffy 1994, 208.

documentation.[31] The wood was kept wet throughout the recording process through frequent rewetting with a hose or bucket and sponge. The documentation of the YK 11 hull remains was conducted according to methods established by Fred van Doorninck and J. Richard Steffy in their work with Mediterranean shipwrecks.[32] The publication on the hull of the early 11th-century shipwreck at Serçe Limanı, Turkey, by Steffy and Matthews, was especially helpful.[33] Practical experience in documenting timbers from seven other shipwrecks at Yenikapı also proved to be extremely valuable.

Complete documentation of each timber entails 1:1-scale drawings, sectional drawings, photographs, samples, and a catalog including dimensions and a written description of the timber. During this documentation, additional labels were added as a preventative measure to ensure identification of parts of timbers that possibly might break off; after 2009, the plastic labels applied in 2008 were replaced with stainless-steel labels that can withstand treatment in PEG. Labels were affixed with short pins formed from stainless-steel wire; longer pins were used to reattach small fragments that had broken away or to stabilize cracked timbers.

The most important piece of documentation is the 1:1-scale drawing made of one or more faces of each timber. These drawings were created on clear plastic PVC film with a thickness of 90 microns using waterproof felt-tip pens; such drawings were not damaged by water but could easily be amended using rubbing alcohol to erase marks. Timber outlines and details were drawn in black, with red, blue, and green added to

[31] During this period, work was conducted nine hours per day and six days per week.
[32] Bass and van Doorninck 1982, 34-40; Steffy 1994, 191-213.
[33] Bass et al. 2004, 73-169.

denote particular details: red for mortises or section locations, blue for iron fasteners, and green for pitch.

The inner face of planks and the sides and inner face of the longest keel timber (Keel 2) were drawn by applying the clear plastic film directly to the timber surface and securing it with pins. Most of the other timbers were first drawn on a piece of glass that was set up above or adjacent to the timber, then traced onto clear plastic film. This was achieved by matching the point on the timber to be drawn with the pupil of the eye reflected in the glass; this resulted in very accurate drawings.[34] Use of glass as a flat drawing plane allowed for the accurate recording of complex surfaces. In order to draw surfaces perpendicular to the flat face of a timber, weighted, L-shaped brackets were set up and the glass clamped onto these in a vertical position.[35]

The timbers were drawn as follows: planks, inner face only; frames, four faces; keel timbers, three faces (outer not drawn); common ceiling and stringers, inner face only; stanchion blocks, three or four faces; sternson and stemson, three or four faces; unidentified timbers (UMs), one to four faces, depending on the complexity and function of the timber.

Sections of each timber were recorded at one or more locations with the aid of a homemade adjustable tool (fig. 3.15). This tool consisted of two plastic triangles joined across the top by an aluminum rule; holes drilled into all components at precise locations

[34] Using a hand-held light in one hand to enhance the reflection of the eye facilitated this process. Orkan Köyağasıoğlu and Matthew Harpster contributed valuable advice for this technique. A discussion of various methods of drawing is also presented in Harpster 2005, 53-61.
[35] The bracket system was designed by Köyağasıoğlu.

allowed the height and the width of the tool to be adjusted. Offsets measured from the framework formed by the tool provided an accurate sectional form of the timber.

Each timber was photographed with a Canon EOS Rebel XS digital camera; natural outdoor lighting proved the most effective illumination for wet timbers but limited the hours during which the timbers could be photographed. The timbers were placed on a layer of white vinyl oilcloth as a backdrop. For timbers that were photographed from the side, a white photo backdrop was created from cotton sheet-like material hung on an adjustable frame. This movable sheet backdrop also helped shade timbers from direct sunlight. Each evening, the digital photos—often in the hundreds—were sorted and labeled. The usable photos were organized in folders by timber on an external data storage drive.

Figure 3.15. Sections were created with the aid of an adjustable, custom-made tool.

Additional samples were also taken during the post-excavation documentation of YK 11. Most of the ship timbers had been sampled for wood-species analysis during the excavation in 2008. Additional wood samples were taken in 2009-2012 for those timbers which were not sampled in 2008 or which could not be identified due to damage or insufficient sample size. The typical wood sample consisted of a fragment measuring 0.5 x 0.5 x 1.0 cm. Care was exercised not to take samples from original surfaces, edges, and extant tips of timbers. In addition to sampling for wood-species identification, samples of caulking, pitch, and organics were collected during the 2009-2012 documentation of YK 11.

Finally, the written catalog for the YK 11 timbers was created with the aid of worksheets tailored to each category of timber. These evolved throughout the recording process, as unnecessary fields were omitted and other fields added or expanded. Basic fields common to each category of timber include dimensions, condition, surface covering, tool marks, wood grain, and fasteners. Other category-specific fields include, for example, mortises, scarf detail, and frame impressions. For unidentified (UM) fragments, an attempt was made to classify each piece based on its features, wood type, and find location. For complex timbers such as frames, a worksheet was often up to four pages in length. The only timbers for which worksheets were not used for the written catalog are the keel timbers and sternson KS 1 (itself a recycled keel). Due to the complexity of these timbers, they were cataloged by means of several pages of handwritten notes as well as charts of the timbers' dimensions and fasteners.

Perhaps the most challenging aspect of the post-excavation documentation of YK 11 was a determination of which fastener holes in each timber matched up with fastener holes in contiguous timbers and which did not. The in-situ documentation in 2008 indicated that YK 11 had been repaired, but the extent and nature of the repairs could only be truly understood after these determinations had been made. During the post-excavation documentation of the ship's framing, it soon became clear that frames as well as planks had been replaced on this ship. Careful scrutiny was necessary to determine whether a fastener hole was in use when the ship was abandoned or was an old, empty hole from a nail that had been extracted. Disused nail holes on the ship's planking were often filled in with pitch or caulk fibers out of necessity; disused holes on the framing or other timbers were more difficult to identify.[36] Had this ship not been dismantled, or had the fastening patterns not been studied in detail, many of the ship's repairs might have gone unnoticed, which could very easily have affected the interpretation of the ship's construction adversely.

FUTURE WORK: CONSERVATION AND EXHIBITION

The timbers of YK 11 will be conserved in Polyethylene Glycol or PEG at INA's Bodrum Research Center.[37] This method of conservation is relatively simple and reliable; it replaces excess water from the waterlogged timbers with PEG, which

[36] Surrounding concretion, iron-oxide staining, and a slushy, black paste within the hole indicate a nail that had dissolved. A lack of these features, and soft walls within the nail hole, generally indicate a nail that had been extracted.
[37] The conservation of shipwreck YK 11 is scheduled to begin in 2013.

contributes to the mechanical strength of the wood's cellular structure.[38] Each timber will be immersed in a solution of water and PEG in a stainless steel tank. Smaller timbers will be conserved in indoors tanks in the Hethea Nye Wood Conservation Facility of INA's Bodrum Research Center, while larger timbers—such as the seven-meter-long wale SS 11—must be conserved in one of the large, 30-ton outdoors tanks currently serving as freshwater storage tanks for shipwrecks YK 14 and YK 24.

Once conservation is complete, the YK 11 timbers will be returned to the Istanbul Archaeological Museums for potential reassembly and exhibition. Although plans are not yet finalized, a proposed museum in Istanbul, perhaps at Yenikapı, will house finds from the site including an as-yet unknown number of reassembled shipwrecks. The only shipwreck in Turkey that has thus far been conserved and reassembled in this manner is the 11th-century shipwreck excavated by INA at Serçe Limanı, on display in the Bodrum Museum of Underwater Archaeology.[39]

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[38] Hamilton 1999, 24-5.

[39] The reassembly of that ship was carried out in large part by Sheila Matthews and Robin Piercy (Bass et al. 2004, 123-51), both of whom worked with the INA team at Yenikapı.

CHAPTER IV

THE HULL REMAINS

Approximately 40% of the wooden hull of YK 11 was preserved, most of it in very good condition. The wineglass-shaped bottom had settled on the floor of the harbor with a slight list to port. As a result, the port side exhibited excellent preservation up to the second wale, just above the first level of through-beams. This includes most of the planking, parts of two wales, and elements of framing (some of which are complete) at 26 frame stations (fig. 4.1). The planking had opened up slightly, with parts of the upper strakes, above strake nine, slipping downward behind lower strakes. The preservation of the starboard side was far less extensive, with planking preserved to the turn of the bilge and only one extant half-frame. A significant portion of the ceiling and other internal timbers, including a stemson, a sternson, stringers, common ceiling, sills, stanchion blocks, and part of a bulkhead partition, were also preserved on the port side of the vessel and on the starboard side near the ship's centerline.

Based on the numerous repairs to which this ship had been subjected over the course of its lifetime, YK 11 was an aging hull that had been in use for an extended period of time. The presence and location of damage from various types of shipworm, including *Teredo navalis* (teredo) and *Limnoria* (gribble), indicate that the hull did not sink in a sudden, catastrophic event that resulted in its quick burial under soil that would have prevented shipworm damage. Rather, this dilapidated vessel had been abandoned in the shallow western corner of the Theodosian Harbor, an area that was quickly becoming unusable by larger ships due to increasing siltation. After the ship had been abandoned, and no doubt stripped of any useful timber, it slowly settled into the viscous mud and was inundated. Inside the hull, the timbers formed a habitat for countless barnacles and other marine organisms before the ship was glutted with mud.

Figure 4.1. Hull of YK 11 in situ. July 2008. Photo by O. Köyağasıoğlu/INA.

The area around the ship continued to be used by fishing boats and other small vessels, and these may have caused some of the scattering of the YK 11 timbers throughout the area. Several poles, oar blades, and oar handles, found sticking upright in the mud around YK 11, are a testament to the continued use of this area despite the siltation. The abundance of broken oil lamps, amphoras, and other ceramics indicate use as a dumping ground as well.

The hull remains are grouped by type in the following description; these types include the keel, frames, planking, wales, through-beam, stemson and sternson, ceiling, stanchion blocks, and bulkhead. When possible, unidentified fragments will be discussed with each category. Unidentified fragments that are not part of the hull, or that cannot be classified, will be presented at the end of the chapter.

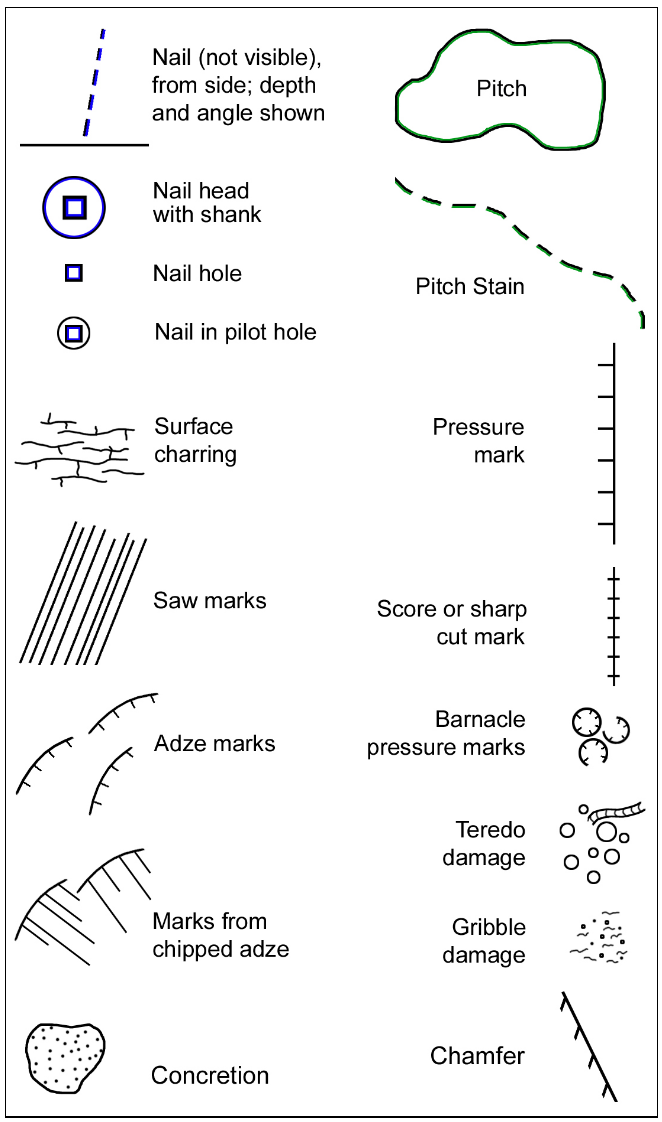

Figure 4.2. Key to detail shown in timber drawings.

All post-excavation recording discussed in this report was carried out by the author prior to conservation. While keeping the timbers wet during recording is a concern, treatment in Polyethylene Glycol can obscure tool marks and other surface detail while enhancing others.[1] In the drawings, green denotes areas of pitch or pitch stain, blue denotes iron nails or bolts, and red denotes mortises. In some drawings, sections are presented along a red line indicating their position on the timber. These details and others to aid in interpreting the timber drawings are presented in figure 4.2.

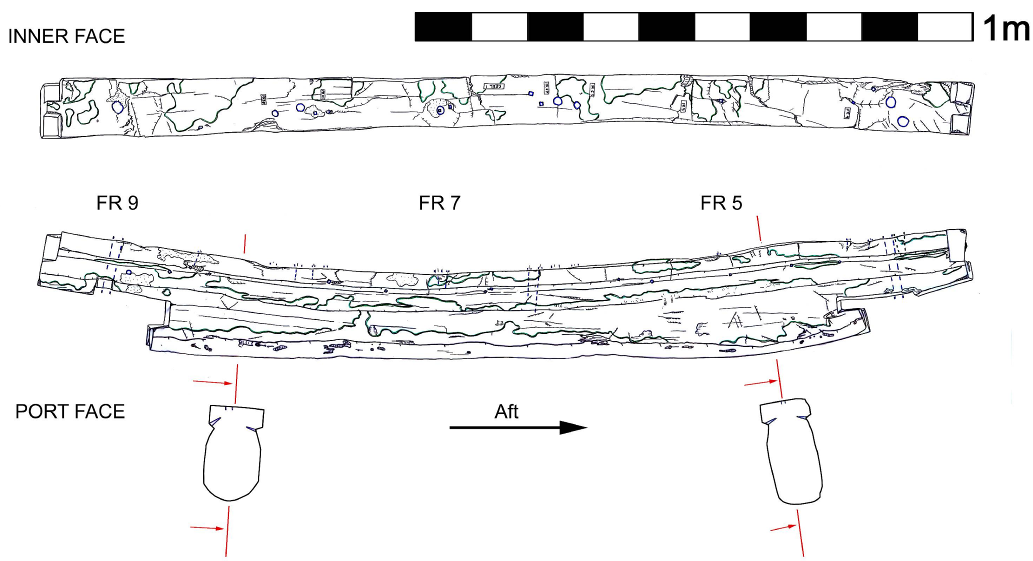

Figure 4.3. YK 11 Keel 1 (aft portion), port and inner faces and select sections.

[1] Mor 2004, 180.

THE KEEL

The tripartite keel consisted of three scarfed timbers preserved for a length of 7.94 m. The aft timber (FR4-FR 9) was labeled Keel 1 (fig. 4.3); the central timber (FR 9-FR 21), Keel 2 (fig. 4.4); and the forward timber (FR 21-FR 29), Keel 3 (fig. 4.4). The keel timbers at the ship's extremities are gently curved while the central (and longest) portion, Keel 2, is approximately straight. All were found in their original locations.

Description

All three keel timbers are in an excellent state of preservation. Keel 1 (1.67 m) and Keel 2 (4.02 m) are complete and intact, with only minor breakage involving some small fragments. Keel 3 (2.82 m) is incomplete, its forward end broken and eroded; its original length is unknown. Whether Keel 3 is part of the ship's stem or a transitional piece like Keel 1 (almost certainly the latter), its curve suggests a bow that sweeps upward gently in a relatively simple hull configuration. The keel timbers were joined by well-preserved, keyed hook scarfs at FR 4, FR 9, and FR 21.

In the reconstruction, the central (flat) portion of the keel was corrected for slight hogging and distortion along the scarf at its forward end. Otherwise, the keel timbers do not appear to be distorted along their length; overall longitudinal form, including the gentle curvatures of Keel 1 and Keel 3, are probably original. A slight hollowing along the outer face of Keel 1, around FR 7, may have resulted from repetitive beaching of the vessel. There is some distortion and damage to the inner faces caused by pressure from frames; this is most evident at the aft end of Keel 1, where there is also some distortion to the scarf.

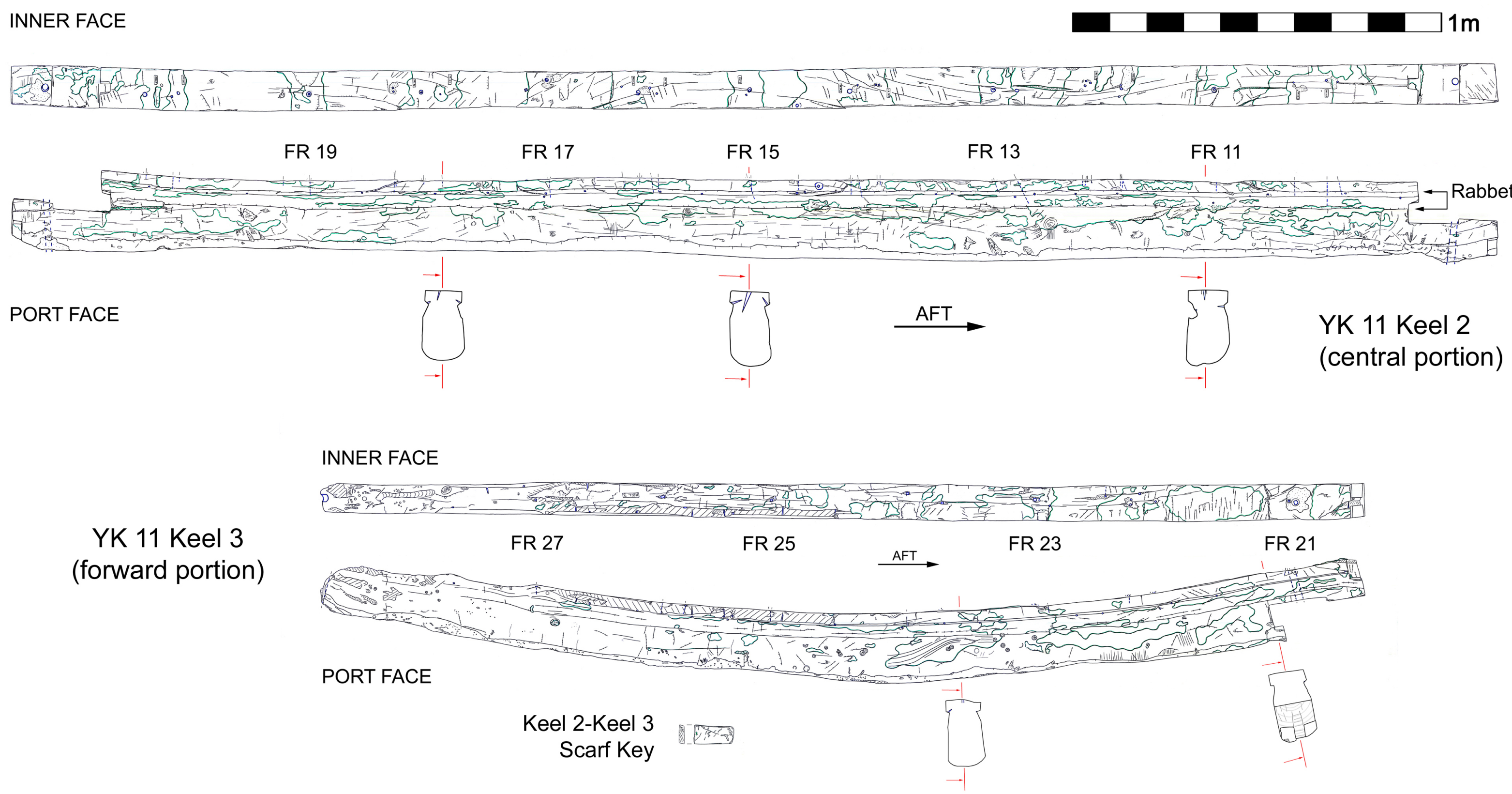

Figure 4.4. YK 11 Keel 2 and Keel 3, port and inner faces and select sections.

Several sectional drawings were created of the keel timbers in order to record form and presence of wear; some of these are shown in figures 4.3-4.4. All three timbers possess a similar form, varying slightly in dimension. The inner (top) surface is generally flat where undamaged, and the flat sides are interrupted by a rabbet near the inner face. The outer (lower) surface is rounded to varying extents and is heavily worn, often marred by damage from *Teredo navalis*, especially on Keel 2. While much of this damage was incurred during the life of the ship, enhanced wear along the starboard side may reflect greater exposure of this area after sinking, since the ship had heeled to port. A thick, compacted layer of mud, shell, and organic matter was removed from the outer surface of each keel timber. Many of the sections seem to indicate a somewhat asymmetrical timber, or this may simply represent minor distortion or damage to surfaces, especially along the inner and outer faces. On Keel 3, the sections reflect increasing degradation toward the broken forward end, while those sections closest to the scarf are representative of the keel's original form.

All of the keel timbers are very solid. Due to the wood species (Turkey oak; *Quercus cerris*), the surfaces are slightly softer and more easily damaged than those of other timbers (primarily pine). Surfaces are nevertheless very well preserved, and edges are usually sharp and well-defined. Despite cracking in several areas, none of the keel timbers seems likely to break. Longitudinal cracking along the inner face and sides are often in association with nails. Some of the inner face cracks on Keel 2 predate the sinking of the ship; these were stuffed with grassy caulking and covered with pitch. Concretion around the many nails on these timbers has obscured some surface detail.

A split on the inner-port edge of Keel 2 at FR 14-FR 15 was repaired or prevented from further splitting with two nails, one driven into the inner face and one driven into the port edge. Based on its location, this repair edge nail was probably added while the port garboard was being replaced. There is also a large, deep area of damage to the port face of Keel 2 near FR 11; the damaged area is 10.6 x 3.5 cm and 2.9 cm in depth. It is located just at and below the rabbet and was filled in with grassy caulk, some of which was stained black by iron corrosion products. A rabbet nail within the damaged area, without a match on the replaced port garboard, may indicate that the damage was caused during the removal of the original garboard plank.

Dimensions

Basic representative dimensions of each keel timber are provided in table 4.1; these do not include measurements at damaged or heavily worn areas. The inner faces are slightly narrower than the overall sided dimension of the timbers; these are also included in table 4.1.

Table 4.1. Dimensions of YK 11 keel timbers at well-preserved areas.

Keel Timber	Length	Molded Dimensions (cm)	Sided Dimensions (cm)	Sided Dimensions, Inner Face (cm)
Keel 1	1.67 m	16.0-19.2	9.3-10.8	8.7-10.4
Keel 2	4.02 m	17.9-22.2	11.1-12.2	10.0-11.1
Keel 3	2.82 m*	16.8-19.0	9.5-10.3	9.4-9.9

*The forward end of Keel 3 was not preserved; the length measurement is not original.

Keel 1, the short transitional piece between the flat part of the keel and the sternpost, gradually narrows to the stern, both on the inner face and in overall sided dimension. This suggests a narrower sternpost, with a sided dimension about 25% smaller than the average sided dimension of Keel 2. Dimensions toward the after end of Keel 1 indicate a starting dimension of the sternpost of 9.5 cm sided and 18.5 cm molded. The average molded dimension of Keel 1 is 17.1 cm.

Keel 2 is relatively consistent in sided dimension, varying not more than 1.1 cm along its entire length; its average sided dimension is 11.7 cm. Excluding the scarf ends, this central keel timber is 17.9-22.2 cm in molded dimension, smallest at FR 19, and generally larger toward the aft end. The maximum molded dimension is at the start of the forward scarf, although this is to some extent affected by a large split near this end, stuffed with grassy caulk during construction or later. The average molded dimension of Keel 2 is 20.3 cm.

Keel 3 is even more consistent in sided dimension, ranging from 9.5 to 10.3 cm where undamaged, with an average sided dimension of 10.0 cm. At the heavily eroded forward end, Keel 3 tapers to 9.0 cm in sided dimension; this width is not representative. Where undamaged, there is relatively little variation in the molded dimension of Keel 3; it is 16.8-19.0 cm, largest at FR 24. Its average molded dimension is 17.8 cm.

Wood Species

Wood-species analysis was conducted by Dr. Nili Liphschitz of the Institute of Archaeology, The Botanical Laboratories, at Tel Aviv University. Her findings indicate that each of the three keel timbers is *Quercus cerris* (Turkey oak). According to

Theophrastus, oak keels were better suited for hauling the ship onto shore, although he notes that fir was more often used for the keels of merchantmen.[2] Scarf keys, preserved in the Keel 1-Keel 2 and Keel 2-Keel 3 scarfs, are of *Pinus nigra* (European black pine) and *Quercus cerris*, respectively. A small fragment of wood found within the aft scarf of Keel 1 was also identified as *Pinus nigra* and may represent a portion of the original scarf key at this location.

The keel timbers are the largest oak timbers used in the construction of YK 11, most other timbers being of pine or cypress. As such, these were the most promising timbers for dendrochronological dating. However, these timbers were cut from relatively young trunks of oak and had only 20-30 annual rings per timber, which is insufficient for obtaining an accurate date. The pith of the original trunk seems to run through the approximate center of each keel timber. A section cut from Keel 3 was found to have only 28 rings, with the pith slightly to starboard.

Rabbets

Each keel timber had a shallow rabbet cut along the port and starboard faces, near the inner face. This rabbet accommodated the garboard and hood ends of the planking; it is formed by a steeply-angled back rabbet, joined by a longer, more gradual rabbet that forms the portion against which the lower edges of the garboards and hood ends butted (fig. 4.5). On Keel 3, the rabbet is only well preserved along the aft half of the timber. Erosion toward the forward end has obliterated the rabbet in most areas, but

[2] Theophr. *Hist. pl.* 5.7.2.

traces thereof are preserved up to FR 27, suggesting the form seen near the after end and on the other keel timbers was continued at least to this point.

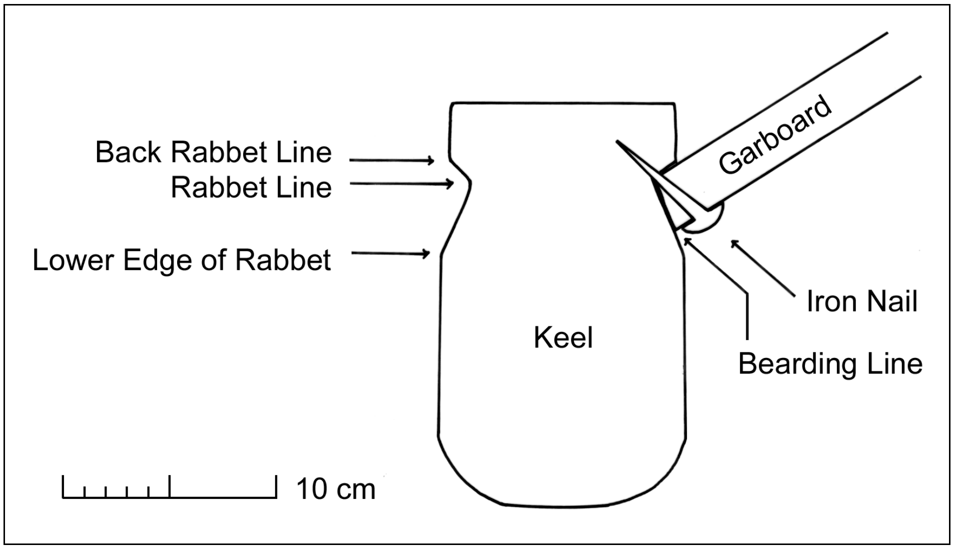

Figure 4.5. Typical section of YK 11 keel, showing garboard attachment.

The back-rabbet line is located 2.8-3.3 cm from the inner face on both Keel 1 and Keel 2; the lack of variation here reflects the precise placement of the garboards. There is slightly more variation in this distance on Keel 3, where the back-rabbet line is 2.2-3.1 cm from the inner face. Rabbet depth is relatively consistent on all keel timbers, ranging from 0.9 to 1.5 cm. Rabbet width, the distance from the back-rabbet line to the lower edge of the rabbet, is more variable, 3.1-4.5 cm on Keel 1 (average width 4.0 cm), 3.8-4.7 cm on Keel 2 (average width 4.2 cm), and 2.9-4.8 cm on Keel 3 (average width 3.6 cm).

A sharp pressure line visible in parts of the rabbet represents the bearding line, or the outer edge of the garboard plank. The bearding line is usually higher on the timber than the lower edge of the rabbet, the point at which the angled cut forming the rabbet was begun. The bearding line on these keel timbers is usually 2.0-3.0 cm below the rabbet line (corresponding to the thickness of the garboard).

Fasteners

Three types of iron fasteners were used on the keel timbers: short nails along the port and starboard rabbets, longer nails on the inner face, and bolts at the keel scarf joints. The keel timbers were entirely lacking in wooden fasteners; neither tenons nor treenails were observed.

<u>Rabbet Nails</u>

The garboards and hood ends of planking were attached to the port and starboard faces of the keel timbers with short nails. These nails were driven from the outer face of the hull planking near plank edges, upward and inward into the keel rabbet at an oblique angle (fig. 4.5). Most of the rabbet nails are located at or around the rabbet line, although a few nails on each timber were located slightly too high, above the back-rabbet line, closer to the keel's inner face. The extensive caulking preserved in some parts of the rabbet and intermixed with concretion, especially on Keel 1, tended to obscure the location of some rabbet nails.

Due to the extensive repairs to the planking along the bottom of the hull, approximately half of the keel timbers' rabbet nails do not have any corresponding nail on the ship's planking, but rather are the abandoned rabbet nail holes from original planks that had been replaced. The presence of iron sulfide staining within many of these holes seems to indicate that some of the original rabbet nails were broken off within the hole rather than pulled individually when the garboards were replaced; such an action may have caused the damage previously noted on the port side of Keel 2 around FR 11. Concretion did not surround the nail holes of the abandoned rabbet nails; this is in contrast to the rabbet nails in use when the ship sank, which were surrounded by stubborn concretion. The latter were spaced on average 29 cm apart.

The short iron rabbet nails are square in section, usually 0.3-0.6 cm in sided dimension. Most depths seem to be concreted and are thus not representative; however, rabbet nails at damaged areas on Keel 3 reveal original depths of approximately 3.0-5.4 cm, and this fits what was observed on the deepest rabbet nails of other keel timbers. These indicate a total nail length of 5.5-8.0 cm.

In one area on the starboard side of Keel 3, between FR 24 and FR 25, there are no fewer than eight rabbet nails in a 20 cm-long section of rabbet; only one of these can be matched to the extant planking. This large number of nails so close together suggests that part of the original plank here was damaged and replaced with a short repair segment (perhaps similar to SS 2-4), which later failed, after which both the original plank and the short repair piece were replaced with the current plank (PS 2-4).

In addition to the rabbet nails, there is one shallow nail located just below the rabbet on the starboard side of Keel 2, around FR 12. The function of this nail is unclear, but it may have served to hold the garboard in place temporarily during construction.[3] As noted above, a nail was also driven into the port face of Keel 2 above the back-rabbet line at FR 14-FR 15 in order to arrest the damage from a split.

Inner Face Nails

Frames were attached to the keel primarily with long nails that did not extend to the keel's outer face. Holes from these square nails are usually 0.5-0.9 cm in sided dimension. The nails at every floor, and a few of the half-floors, were driven into a drilled pilot hole, 0.9-1.4 cm in diameter. Pilot hole depths are often unclear, but the drilled holes at FR 7 on Keel 1 and at FR 22P on Keel 3 are only 1.2-1.3 cm in depth (fig. 4.6). Corrosion within these pilot holes reveals that the holes were left empty and served to prevent the nail from bending before it was fully driven into the keel. Every frame that crossed or contacted the keel was attached to it with at least one iron nail (or, at scarf joints, with a bolt). In many cases, there is more than one nail at a frame location on the keel, either because the frame had been replaced, or because, as at FR 23, additional nails were added to correct damage or to reinforce the keel-frame joint. Whether the presence of multiple nails is due to replacement or reinforcement of framing is only clear at extant frames.

The nail holes on the inner face are heavily concreted, which obscures the original depth of these nails. With the exception of the bolt holes at the ends, none of the nail holes extends to the outer face, indeed they rarely extend more than 3.0 cm into the keel itself. While the nails would not have extended to the outer face, they probably

[3] This function has been suggested for a similar nail found on the keel of the seventh-century Yassıada shipwreck (Bass and van Doorninck 1982, 59).

extended a few centimeters deeper into the timber than the measurements reflect, and a few exceptional nail holes are up to 4-7 cm in depth, indicating original nail lengths of approximately 14-17 cm. The bending of the nail within the keel would also obscure its original depth.

Figure 4.6. Square nail hole next to a nail in a pilot hole on Keel 1 inner face at FR 7.

Iron Bolts

Finally, iron bolts fastened the keel timbers together at the keyed hook scarfs and also fastened floors and the sternson KS 1 and (originally) stemson UM 47 to the keel at these locations. The holes from three such bolts were found, at FR 4, FR 9, and FR 21. There is evidence for a fourth bolt, at the broken and eroded forward end of Keel 3, at the location of FR 29 (not preserved). There is no clear evidence of a scarf at this location and no framing preserved here, so the function of this bolt remains unclear.[4]

[4] A scarf was likely located very near this location and has been added in the reconstruction.

The iron bolts were inserted through drilled holes 1.8-2.0 cm in diameter. Although the bolts have disintegrated, the iron corrosion products in the bolt holes indicate that the actual bolts were smaller than the drilled holes, closer to1.5-1.6 cm in diameter. A lining of a white substance, possibly pitch or lard, was found within some of the holes; this would have filled in some of the gap between drilled hole and bolt shaft and may have prevented leakage into the hull or facilitated the insertion of the bolt. These bolts would have been disassembled during the replacement of frames under KS 1 and UM 47.

A lump of concretion surrounded the bolt head at FR 9 on Keel 2. Analysis of this concretion indicates a shallow, domed bolt head 3.6 cm in diameter and 1.5 cm deep. A small ring of grass-like fibers formed a seal between the bolt head and the keel's outer surface. Iron impregnation of the wood around the bolt here protected the area to some extent from damage due to *Teredo navalis*.[5] A ring of concretion on the outer face of Keel 2 at FR 21 suggests a bolt head 3.3 cm in diameter (fig. 4.7). Neither bolt head was countersunk into the outer face of the keel. The bolt ends were not preserved and there is no concretion to indicate their form, but forelock bolts similar to those on the Yassıada 1 shipwreck were likely used.[6]

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[5] The presence of iron bolts also led to enhanced preservation of some timbers from the seventh-century Yassıada shipwreck (Bass and van Doorninck 1982, 33-4; van Doorninck 1967, 13).
[6] Bass and van Doorninck 1982, 57-8, 256-57.

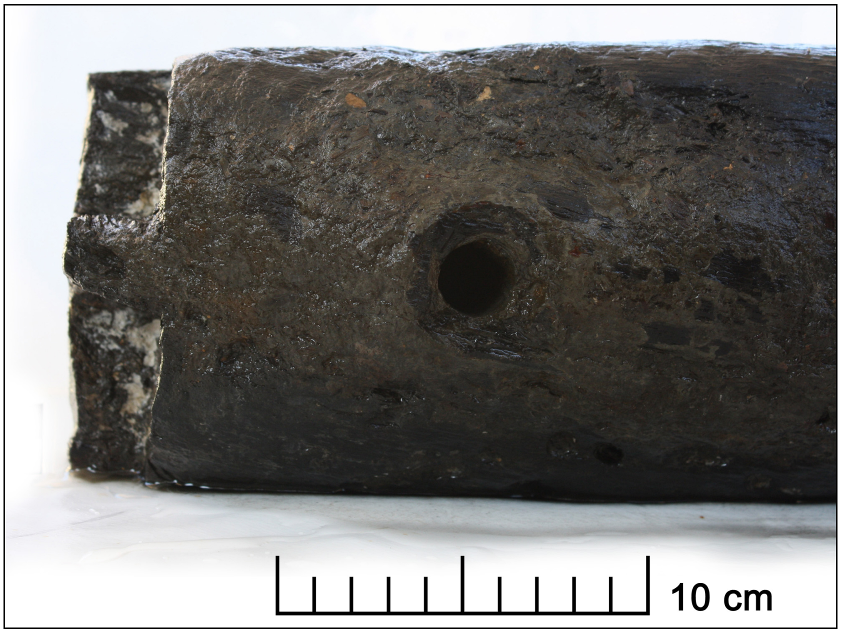

Figure 4.7. Outer face of Keel 2 at FR 21, showing bolt hole with surrounding flat surface, corresponding to bolt head.

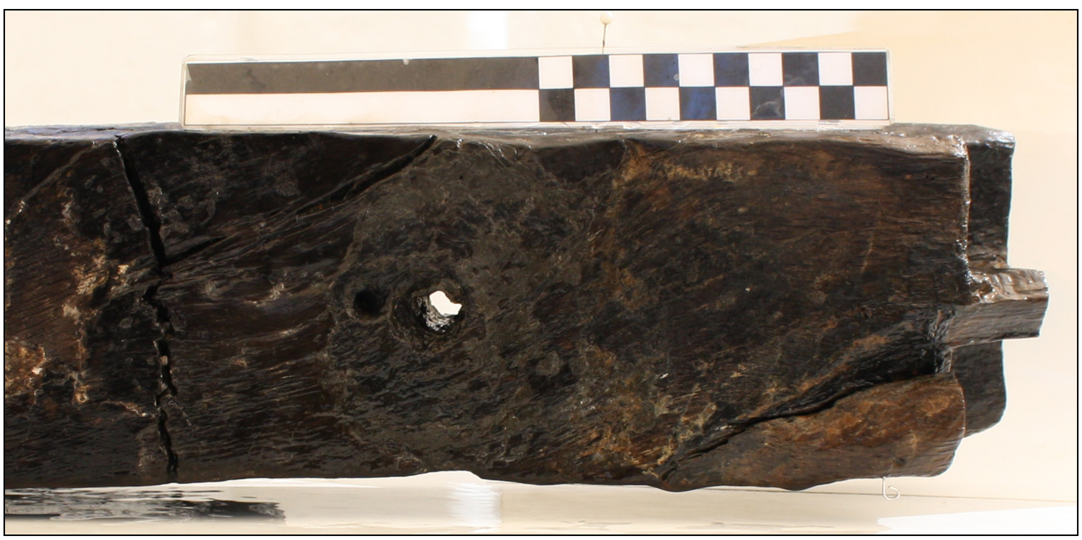

Figure 4.8. Inner face of Keel 3 at aft scarf end. Note transverse crack near FR 21 and iron nail adjacent to bolt hole, used in attaching the replacement floor.

On FR 21, a replacement floor, the bolt does not extend through the floor, but was located just aft of it (fig. 4.8). The replacement floor was fastened to Keel 3 with an iron nail, and a portion of the floor's aft face was roughly cut out around the bolt, suggesting either a hasty or sloppy repair. The original floor at this location was probably attached using the keel scarf bolt.

On the inner face of Keel 1 at FR 4, the drilled hole was started in the wrong location; after drilling to a depth of 3.7 cm, this hole was abandoned and filled in with pitch. Perhaps the misplaced hole was too close to the step in the scarf table and was therefore reoriented. On both ends of Keel 1, the bolt was placed through the scarf key that locked the hook scarf joints together. At the forward end of Keel 2, at FR 21, the bolt does not run through the scarf key, which greatly facilitated the removal of this key.

Frame Locations

Where frames were not preserved, their location on the keel could be identified through iron fastener holes and pitch outlines. Pressure damage is relatively common on the inner face at or near frame locations; it may be minor, causing cracking or a shallow pressure mark, or more significant, causing distortion and damage to the inner face. Pressure damage was not observed where frames had undergone dissolution or had been displaced, confirming that most of the pressure damage from framing likely occurred after the ship had sunk. This may have been caused in part by workers kneeling on the shipwreck during excavation.

Tool Marks

Several tools were used in fashioning the keel timbers, most prominently an adze, but also a chisel, drill, and saw. Based on the extant tool marks, most surfaces were shaped by adze, including the inner faces and the flat areas on the port and starboard faces. While adze marks were not preserved on the outer face, this rounded face was likely also trimmed with an adze.

Inner faces were dubbed flat through a series of short adze blows, from an adze blade 3.5-4.0 cm in width (fig. 4.9). These are usually spaced approximately 1 cm and are approximately perpendicular to the length of the keel. The inner face may have been trimmed down slightly at some frame locations, noted on Keel 2 at FR 11, FR 13, FR 14, FR 16S, and FR 20; it is noteworthy that all of these frames, with the exception of FR 20, were replaced during the life of the ship.

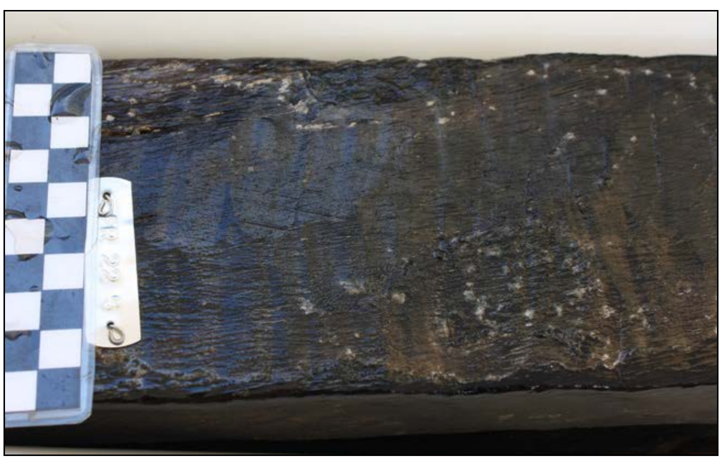

Figure 4.9. Adze marks on the inner face of Keel 3 at FR 21-FR 22.

On the port and starboard faces, tool marks are best preserved on the broad, flat area below the lower edge of the rabbet. These faces were trimmed with an adze blade of about 4.5 cm width. Usually, the adze marks are relatively indistinct, forming a subtle scallop-pattern over the surface. This probably represents more cautious adzing, which produced a smoother keel surface. The area of the sides above the back-rabbet line was also dubbed with an adze. On Keel 2, an area of teredo damage on the outer-starboard edge near FR 20 was roughly adzed.

Tool marks within the rabbets are somewhat muted and more difficult to interpret, due to greater wear and damage in these areas. The rabbet appears to have been cut with a flat-bladed adze or chisel 2.0-2.5 cm in width. However, blade marks up to 4.3 cm in width were noted on parts of the Keel 1 rabbet, and may indicate additional trimming with an adze.

Most surfaces of the well-preserved hook scarfs were adze- or chisel-cut. Clear tool marks reflect use of multiple blades, up to 4.0 cm wide, 2.5-3.0 cm wide, and another 2.2 cm wide (fig. 4.10). Even smaller chisel blades (1.3-1.4 cm wide) are indicated in some areas of the Keel 1 scarfs. Parts of the back wall of the scarfs were chiseled from multiple directions, which resulted in a slightly uneven surface. Although uncommon, some scarf surfaces on Keel 1 and Keel 2 retain tool marks that indicate cutting with a saw; perhaps the scarf form was first roughly formed through saw cuts, then carefully adzed and chiseled into the final form. There were also two cut marks on the port face of Keel 1 along the edge of the forward scarf. These may have served to mark the location of the bolt.

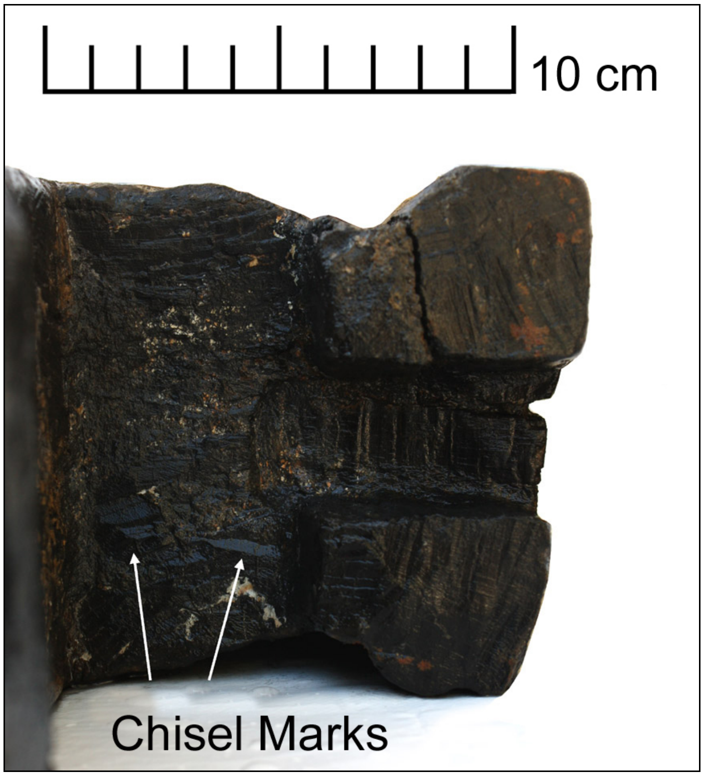

Figure 4.10. Chiseled back surface of the aft scarf on Keel 2.

Notably, there do not appear to be any score marks on the keel timbers' inner faces, although there is a possibility that these simply were not preserved.

Scarf Joints

Each keel timber terminated in a keyed hook scarf similar to those observed on the seventh-century shipwreck at Yassıada;[7] two such scarf ends were preserved on each keel timber with the exception of Keel 3, which was broken and eroded at its forward end. These hook scarfs locked the three keel timbers and the sternpost together; the joints were held in place by means of a small, rectangular scarf key placed within the scarf table, pressed up against the vertical step in the scarf table (figs. 4.11-4.13).

[7] Bass and van Doorninck 1982, 49-50, fig. 3-26.

Figure 4.11. Starboard face of Keel 1-Keel 2 scarf, in situ.

Figure 4.12. Aft scarf of Keel 3 with scarf key in place, as seen from starboard-outer.

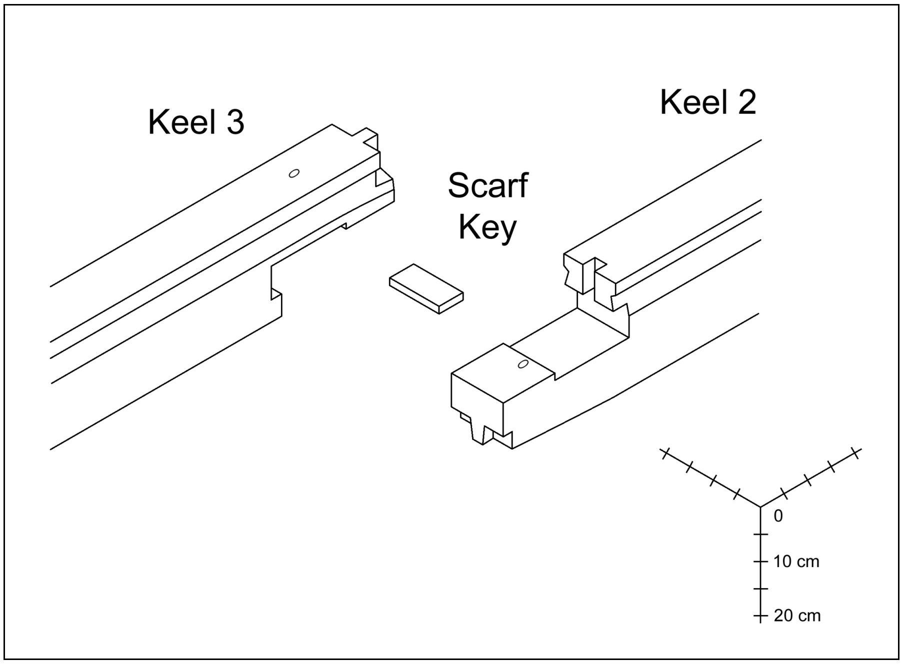

Figure 4.13. Keel 2-Keel 3 scarf.

The scarfs are 24.3-26.5 cm in length: the Keel 1-sternpost scarf is 24.5 cm long, the Keel 1-Keel 2 scarf, 24.3 cm long, and the Keel 2-Keel 3 scarf, 26.5 cm long. The keel scarfs are very well preserved; for the Keel 1-Keel 2 and Keel 2-Keel 3 scarfs, the lack of distortion is due in large part to the fact that both timbers in each joint were preserved. There was some compression and distortion on the aft scarf of Keel 1, as the adjoining timber (the sternpost) was not preserved. The curvature of the Keel 1 outer face just forward of the aft scarf is probably a good indication of the curvature of the sternpost. There is a wide crack starting at the back wall of the forward scarf on Keel 2 and running aft into the keel; this crack, up to 0.5 cm in width, was filled in with caulk fibers mixed with pitch.

The scarf surfaces were liberally coated with thick pitch, 0.3-0.6 cm thick in some areas. Grassy caulk fibers were found intermixed with much of the pitch; a layer of pitched caulk fibers up to 0.3 cm thick was preserved on parts of the scarf tables. In crevices, as between scarf tenons, even thicker lumps of pitched caulking were observed, including one up to 1.4 cm thick in the Keel 2-Keel 3 scarf. The thick layer of pitch and caulking within these scarf joints helped improve watertightness and also corrected slight discrepancies in these complex joints.

The two preserved scarf keys were 10.5 cm in length, 4.5-5.1 cm in width, and 1.5-2.0 cm in thickness. The Keel 2-Keel 3 key was very well preserved (figs. 4.4, 4.12). The Keel 1-Keel 2 key, through which the bolt was inserted, necessarily endured some surface damage during removal, but remains largely intact. Splintered fragments of *Pinus nigra* removed from the aft scarf on Keel 1 may be part of that scarf's key.

Surface Treatment

The keel timbers had been coated with a thick layer of pitch on the port, starboard, and inner faces, as well as within the scarf joints. Thin pitch was observed in some parts of the outer face, but it was poorly preserved due to wear and damage along this surface. Nevertheless, the presence of pitch within some teredo holes indicate that the outer face had been scraped and repitched at some point in the ship's lifetime.

Most of the pitch was removed from the timbers in preparation for conservation in Polyethylene Glycol, but some areas of pitch—especially when intermixed with concretion from nails—proved difficult to remove and was left in place to prevent damage to the wood surface. Pitch varied in color but was usually brownish-yellow, similar to that observed elsewhere on the ship's planking. In some areas, the layer of pitch on the sides of the keel was up to 0.5 cm in thickness; it was also used to fill in small knot holes or other wood abnormalities. A distinct pitch line along the bearding line indicates multiple pitch applications after the garboard was installed (fig. 4.14). This is confirmed by the presence of pitched-over barnacles below the bearding line. Above the rabbet, pitch seems to have pooled in the deep crevices between the garboards and keel, forming thick lumps in these areas.

Figure 4.14. Pitch on Keel 2 port face, below rabbet.

Dark yellow pitch, 0.2-0.4 cm in thickness, was prominent between frame locations on the keel timbers' inner surfaces (fig. 4.15). Tiny stones and various organics, especially olive pits, pine-cone scales, and wood chips, were found embedded in the inner face pitch; this inclusion was especially heavy between FR 10 and FR 13, just forward of the bulkhead and in the open portion of the hull (fig. 4.16). Small hairs and plant fibers were observed in the pitch but were uncommon. Between FR 10 and FR 11, inner face pitch was exceptionally thick (up to 1 cm).

Figure 4.15. Thick pitch between frames on the Keel 2 inner face, with sparse patches under FR 19.

Figure 4.16. Organics in Keel 2 inner face pitch between FR 10 and FR 11.

Faint traces of pitch under some frames probably indicates that the outer face of the ship's frames were pitched prior to their installation in the hull; application of pitch to the entire inner face of the keel timbers before the addition of framing would not have been conducive to the construction process. The traces of pitch at frame locations is much more common on the keel than on the ship's planking, which could indicate that the frames and keel were not in such close contact as were the frames and planking. A white substance, presumably degraded pitch, was also noted on each keel timber, and it was often found below a layer of yellow pitch. The white substance varied in color from bright white to a sandy or grayish white (fig. 4.17).

Caulking was observed along the keel rabbets and within the scarf joints. In the rabbets, it was usually approximately 2.5 cm in width and 0.2-0.3 cm thick, although thicker patches—up to 0.5 cm—were observed in some areas. Caulking fibers vary in orientation but seem mostly to be perpendicular to the plank edge. The fibers form a lip at the outboard edge of the garboard in some areas.

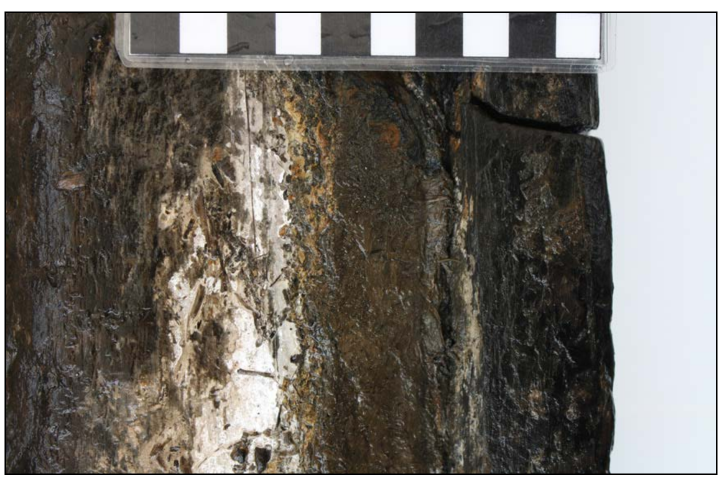

Figure 4.17. White pitch(?), yellow pitch, and caulk on the starboard face of Keel 1.

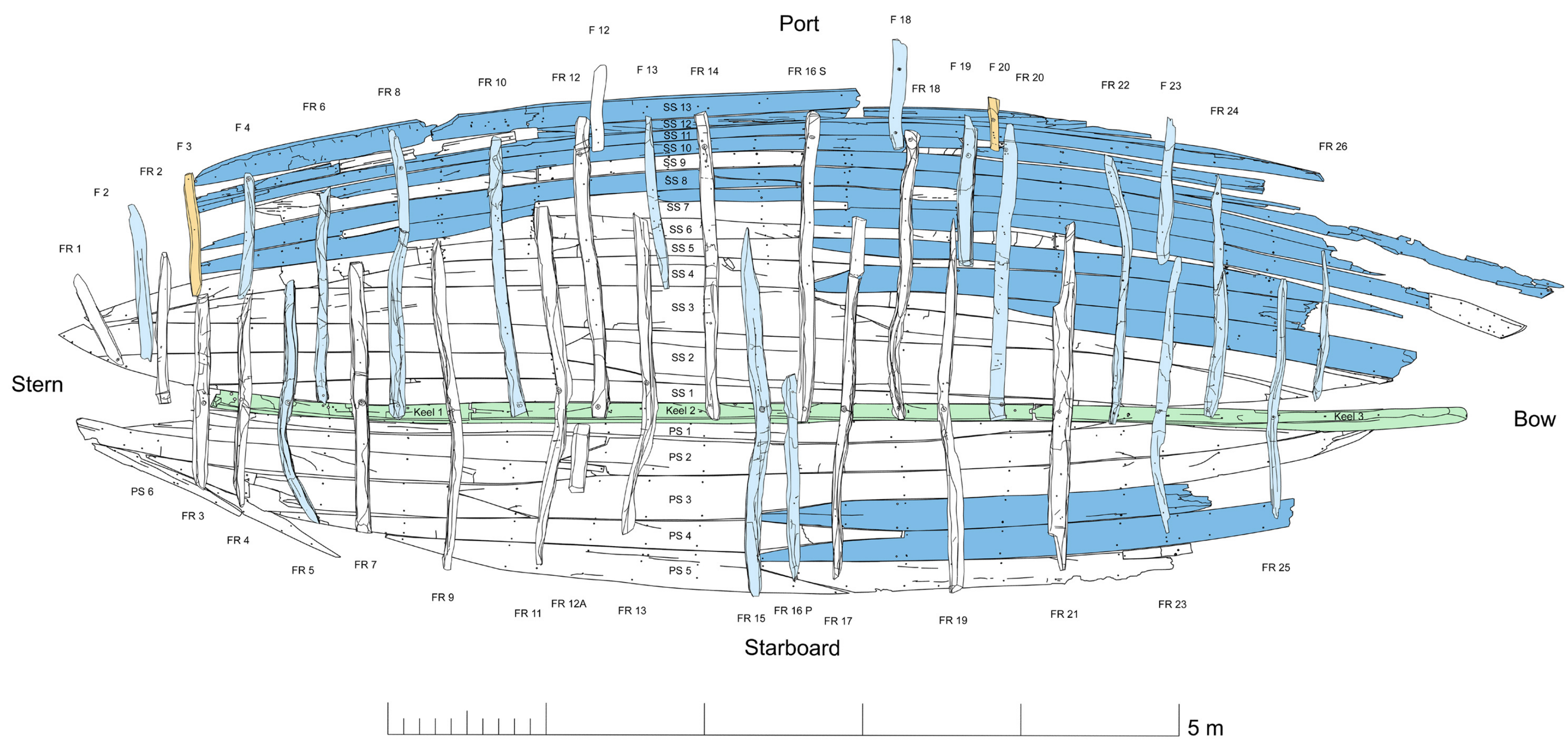

Figure 4.18. YK 11 framing and planking. Original frames in light blue; replacement or reinforcement frames in white. Yellow frames (F 3 and F 20) could not be identified as either original or replacement. Original planks in dark blue; replacement planks in white. Keel (original) in green.

THE FRAMES

Thirty-seven frame timbers representing 26 extant frame stations were recovered from the wreck site (figs. 3.8, 4.18). These include 13 floors, crossing the keel and spanning the bottom of the ship; 14 half-frames, attached to the keel and extending up along part of the ship's side; and 9 futtocks, 5 associated with floors and 4 paired with half-frames. Table 4.2 provides an overview of the identified framing. There was also one small, frame-like repair piece, FR 12A, placed aft of half-frame FR 12 on the starboard side. Nails on the keel and planking indicate 4 additional frame stations in the bow where framing was not preserved, FR 27-FR 30.

Table 4.2. Overview of extant YK 11 frame timbers. Lengths of complete frames are shown in red.

Frame Number	Type	Wood Species	Preserved Length (m)	No. of Pieces (+Frags.)	Original or Replacement
FR 1 (UM 66)	Half-frame	*Ulmus campestris*	0.715	1	Replacement (?)
UM 1 (F 2)	Futtock	*Ulmus campestris*	1.11	1	Original
FR 2 (UM 162)	Half-frame	*Fraxinus excelsior*	0.975	1	Replacement
F 3 (UM 11)	Futtock	*Pinus brutia*	0.885	1	(Unclear)
FR 3	Floor	*Fraxinus excelsior*	1.242	2	Replacement
FR 4	Floor	*Pinus brutia*	1.398	1	Replacement
F 4 (UM 165)	Futtock	*Pinus nigra*	0.885	1	Original
FR 5	Floor	*Pinus brutia*	1.57	2	Original
FR 6	Half-frame	*Pinus brutia*	1.39	1 (+3)	Original
FR 7	Floor	*Pinus brutia*	1.76	1	Replacement
FR 8	Half-frame	*Pinus brutia*	1.79	2 (+1)	Original
FR 9	Floor	*Pinus brutia*	2.16	1	Replacement
FR 10	Half-frame	*Pinus brutia*	1.81	2 (+2)	Original
FR 11	Floor	*Pinus brutia*	2.29	1 (+1)	Replacement
FR 12A	Small Repair	*Pinus brutia*	0.448	1	Reinforcement
FR 12	Half-frame	*Pinus brutia*	1.9	3	Replacement

Table 4.2. Continued.

Frame Number	Type	Wood Species	Preserved Length (m)	No. of Pieces (+Frags.)	Original or Replacement
F 12 (UM 7)	Futtock	*Pinus brutia*	0.81	1	Replacement
FR 13	Floor	*Pinus brutia*	2.07	1	Replacement
F 13	Futtock	*Tamarix* (x5)	1.15	1	Original
FR 14	Half-frame	*Pinus brutia*	1.965	2 (+1)	Replacement
FR 15	Floor	*Quercus cerris*	2.38	2 (+1)	Original
FR 16P	Half-frame	*Quercus cerris*	1.35	10 (+many)	Original
FR 16S	Half-frame	*Pinus brutia*	1.98	1	Replacement
FR 17	Floor	*Pinus brutia*	2.316	2	Replacement
F 18 (UM 13)	Futtock	*Pinus brutia*	0.92	1	Original
FR 18	Half-frame	*Pinus brutia*	1.84	1	Replacement
F 19	Futtock	*Acer pseudoplatanus*	1.025	3	Original
FR 19	Floor	*Pinus brutia*	2.38	1	Replacement
F 20	Futtock	*Pinus brutia*	0.397	1 (+1)	(Unclear)
FR 20	Half-frame	*Pinus brutia*	1.89	2	Original
FR 21	Floor	*Pinus brutia*	2.22	1	Replacement
FR 22	Half-frame	*Pinus brutia*	1.74	3	Original
F 23 (UM 22)	Futtock	*Pinus brutia*	1.06	3 (+1)	Original
FR 23	Floor	*Tamarix* (x5)	1.745	4	Original
FR 24	Half-frame	*Pinus brutia*	1.55	2 (+1)	Original
FR 25 (UM 153)	Floor	*Quercus cerris*	1.525	2 (+2)	Original
FR 26 (UM 35)	Half-frame	*Pinus brutia*	0.94	5	Original

The number of frames includes several UM ("unidentified member") timbers that had been displaced but were later matched to hull planking on the basis of fastening patterns. Some of these were matched with planking with relative certainty during excavation in 2008, while others were identified during cataloging in 2010-2012. The identification of some UM timbers, including FR 1 (UM 66), F 12 (UM 7), and F 18 (UM 13), is not absolutely certain due to insufficient planking at the extremities or higher along the ship's side.[8] Other UM timbers, UM 3 and UM 109, had broken off of in-situ framing and were identified during post-excavation recording as parts of FR 8 and FR 22, respectively. In addition to these, 22 other UM timbers were identified as pieces of framing but could not be matched satisfactorily with planking or framing due to insufficient preservation of either plank or frame.[9]

Wood-species identification revealed that the framing was predominantly *Pinus brutia*, or Turkish pine, also known as Calabrian pine (70%). Several other wood types are represented, including *Acer pseudoplatanus* (sycamore maple), *Fraxinus excelsior* (European ash), *Pinus nigra* (European black pine), *Quercus cerris* (Turkey oak), *Tamarix* (x5) (tamarisk), and *Ulmus campestris* (elm) (table 4.2). Where clearly visible, the frames usually exhibit 15-35 annual rings. Compass timbers or grown curvatures were used for nearly every element of framing, and patches of natural, minimally-worked surfaces abound.

Surprisingly, many of these frames were found to be replacement frames, presumably for rotten, damaged, or worn-out pieces. Excluding F 3 and F 20, the two timbers which cannot be verified as repairs or originals, as well as the small reinforcement FR 12A, only 18 of the 34 frames (53%) were installed during the initial construction of the ship.

All framing was attached to the keel and hull planking with iron fasteners, usually short nails; no wooden fasteners were found. Floors FR 4, FR 9, and (originally)

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[8] F 18 (UM 13) is the least certain, with only one matching nail on the extant planking. However, its identification as a futtock paired with a half-frame is most likely.

[9] While such fragments are likely parts of shipwreck YK 11, this is not necessarily always the case. Extensive repairs to both planking and framing further complicate attempts to match other unidentified fragments.

FR 21 were attached to the keel with bolts; these are present only at keel scarf joints. Otherwise, all of the frame timbers that made contact with the keel were attached to it with one or more iron nails.

Condition

Most of the frames are in excellent condition, with surface detail, tool marks, and fasteners easily discernible. The extensive preservation is due in part to the soft, silty mud which surrounded the ship timbers, as well as the frequent inundation of the wreck area during excavation.

The lower (closest to the keel) ends of half-frames and futtocks and the port ends of floors are preserved in nearly every case, although pressure damage might distort these areas. Starboard ends of floors and top ends of half-frames and futtocks are more frequently worn, broken, or not preserved. The majority of frames (20) are intact, although many have small fragments that broke away and were reattached to the frame with stainless-steel wire pins or clamps. Of those that are not intact, breaks in floors usually occurred just to one side of the keel area, and breaks in half-frames usually occurred just above or below the turn of the bilge.

The inner faces of frames often exhibit severe pressure damage and distortion where stringers, ceiling, or other internal timbers were located. This is likely a result of workers kneeling in the soft mud during excavation and exerting pressure on the ship’s upper-level timbers. These pressure marks sometimes preserve the pattern of the wood grain of the timber in contact with the frame. Compression of frames often caused one or more faces to appear wrinkled or wavy (fig. 4.19); a similar phenomenon was noted on other ships at Yenikapı.

As only iron fasteners were used on the framing, surface concretion and iron oxide staining was prevalent on the outer and, to a lesser extent, inner faces of all frames. The concretion was mechanically removed using dental picks or a small chisel in areas where removal did not cause damage to the frame surface. The vast majority of nails had been reduced mostly to ferrous sulfide, and the resultant slushy, black substance was cleaned out of nail holes as completely as possible in preparation of the timbers for conservation in PEG. Some nails were solid or concreted for part or all of their depth. Concretions preserving the form of nail heads were very rare from this wreck, with only two nail head concretions recovered.[10]

Figure 4.19. Compression damage to the forward face of FR 10, causing a wrinkled appearance to the frame surface.

[10] The preservation of nail heads on YK 11 contrasts greatly with that of other wrecks from Yenikapı, which often had a great number of nail head concretions preserved.

The soft mud adhering to the frames was easily removed with a gentle spray of water and light cleaning with a sponge or hand. Light marine growth or encrustation was present on some frames, usually near the outboard or upper ends; while usually easily removed with light sponging, this was not always the case. For areas where marine encrustation was too difficult to remove without damage to the timber surface, it was left in place.

Framing Pattern

The framing of YK 11 follows a pattern of alternating floors with paired half-frames, a shipbuilding tradition in use since the classical period. The earliest known evidence of this tradition in the archaeological record is on the fourth-century B.C. merchantman found at Kyrenia, off the northern coast of Cyprus.[11] Other finds at Yenikapı indicate that this framing pattern remained in use on merchantmen until the late eighth century A.D.[12]

There are, therefore, two types of frame timbers that make contact with the keel: floor timbers, which span the bottom of the ship, with tips extending just beyond the turn of the bilge; and half-frames, which cover the entire width of the keel and extend up one side of the ship, either to or above the first wale (SS 11). Both types were labeled with a FR designation during excavation, in order to simplify the numbering of frame stations. Thirteen floors and fourteen half-frames were either found in situ or were later matched

[11] Steffy 1985, 84.
[12] Yenikapı shipwreck YK 23 (MRY 8), tentatively dated to the late eighth century, is one of the latest known merchant ships to exhibit this framing pattern. Unlike YK 11, though, YK 23 planks were edge-joined with coaks or dowels rather than mortise-and-tenon joints. The framing pattern of alternating floors and paired half-frames was, however, continued until at least the late 10th century in the construction of galleys based on the study of Yenikapı galleys YK 2 and YK 4.

with fasteners on the planking.[13] All timbers in both types were attached to the keel. For the FR 16 half-frames, a designation of S or P specifies the side to which the frame belongs, either S for port or P for starboard, due to the later reversal of the ship's ends. FR 16P is the only starboard-side half-frame preserved, and its condition is quite poor in comparison to other YK 11 half-frames. One other starboard-side element of framing was preserved, the small reinforcement piece FR 12A.[14]

The alternating pattern of floors and half-frames is consistent from FR 5 to FR 26. Due to a lack of preserved planking in the bow, it is unclear what occurs forward of half-frame FR 26. At the stern, the pattern deviates, with three floors, FR 5, FR 4, and FR 3, followed by two half-frames, FR 2 and FR 1. However, abandoned nail holes on the keel, combined with evidence from sternson KS 1, suggest that floor FR 4 was installed to replace a pair of original half-frames; if this is indeed the case, all frames between FR 2 and FR 26 originally followed the alternating framing pattern.

Remains of five futtocks associated with floors were found, all on the port side: F 3, F 4, F 13, F 19 and F 23. These futtocks start just below the turn of the bilge and extend up the side of the ship to the second wale (SS 13). The futtocks paired with half-frames usually start around the first wale and run up the side of the ship to the fourth wale. Four such futtocks, F 2, F 12, F 18, and F 20, were identified on YK 11, only one of which, F 20, was in situ. The others were unidentified timbers later matched to planking based on both form and extant fasteners.

[13] Floors: FR 3, FR 4, FR 5, FR 7, FR 9, FR 11, FR 13, FR 15, FR 17, FR 19, FR 21, FR 23, and FR 25. Half-frames: FR 1, FR 2, FR 6, FR 8, FR 10, FR 12, FR 14, FR 16S, FR 16P, FR 18, FR 20, FR 22, FR 24, and FR 26.
[14] Other than FR 12A (reinforcement piece) and FR 16P (half-frame), all elements of extant framing, other than floors (which cross the keel), are associated with the port side of the ship.

Neither type of futtock was attached to its associated floor or half-frame. The area of planking covered by each floor or half-frame and corresponding futtock overlapped by one or more plank widths, and some frames appear to have been trimmed down on one face in order to accommodate the placement of its associated futtock (fig. 4.20). FR 4 and F 4 were both trimmed to fit closely together, and a nail was unintentionally driven between the two. Only one frame, replacement floor FR 21, was notched at either end to accommodate futtocks, neither of which were preserved.

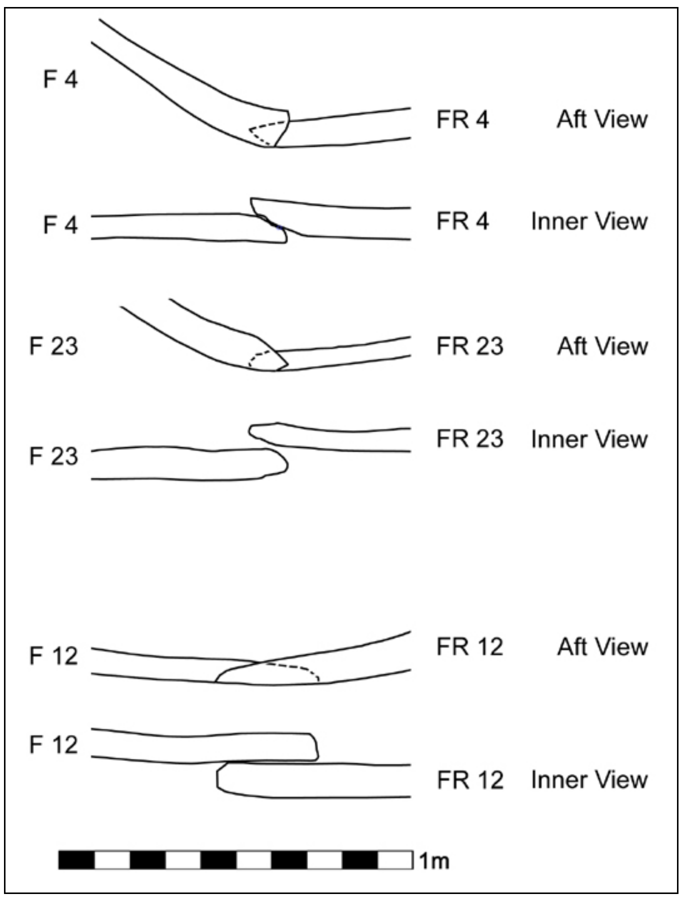

Fig. 4.20. Overlap between floors or half-frames and futtocks.

Room and Space

Due to the ship's excellent preservation, frame spacing could be determined for FR 1-FR 30, based either on the placement of frames themselves on the keel or, where frames or the keel were not preserved, the spacing of fasteners on the planking (table 4.3). Distances were measured from the center of the floors on the keel and from the estimated mid-point of the paired half-frames. At the ship's extremities, where the keel was not preserved, the distances are less reliable. Those numbers at the bow are the least reliable, having been measured at a point around the waterline.

Table 4.3. Distances between centers of frames at keel.

Interval	**Space (cm)**	**Interval**	**Space (cm)**
FR 1-FR 2	33.8*	FR 16-FR 17	27.0
FR 2-FR 3	24.9*	FR 17-FR 18	31.3
FR 3-FR 4	25.0*	FR 18-FR 19	33.7
FR 4-FR 5	30.6	FR 19-FR 20	39.4
FR 5-FR 6	29.9	FR 20-FR 21	32.4
FR 6-FR 7	19.5	FR 21-FR 22	39.7
FR 7-FR 8	27.1	FR 22-FR 23	27.8
FR 8-FR 9	31.8	FR 23-FR 24	30.5
FR 9-FR 10	39.0	FR 24-FR 25	41.2
FR 10-FR 11	26.2	FR 25-FR 26	28.8
FR 11-FR 12	29.3	FR 26-FR 27	39.7
FR 12-FR 13	30.0	FR 27-FR 28	29.7
FR 13-FR 14	35.3	FR 28-FR 29	23.9*
FR 14-FR 15	32.3	FR 29-FR 30	23.1*
FR 15-FR 16	27.1	Average	30.7

* designates space measured from planking due to lack of preservation of the keel at this location.

Spacing between frames is variable and ranges from 19.5 to 41.2 cm, with an average spacing of 30.7 cm, close to one Byzantine foot.[15] There is no distinct pattern which emerges in the spacing of only floors or only half-frames. The shortest distances are generally located at the ship's extremities, where the construction deviates from the pattern of alternating floors and paired half-frames. The shortest interval is between FR 6 and FR 7, near one end of the typical framing pattern. Spacing is above average between FR 13 and FR 22, but for the spacing between FR 15 and FR 16 and between FR 16 and FR 17, both of which are approximately 27 cm. This is around the center of the ship and could indicate that FR 16 is the midship frame.

Identification of Replacement Framing

As noted above, a surprising number of the extant frames, 16 out of 34, or 47%, were identified as replacement frames (fig. 4.18).[16] The identification of a frame as a replacement rather than an original is based on a comparison of the frame's nails with those of the keel and corresponding planking. Prior to this comparison, it was clear that the 11 planks with mortise-and-tenon edge joinery were original. Furthermore, the overabundance of nails on the keel relative to both framing and the garboards reveal that the keel timbers were also original and both garboards replacements. No assumptions were made for other elements of planking, although it seemed likely—and has been confirmed—that planks lacking mortise-and-tenon edge joinery below strake nine were later replacements.

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[15] This is based on a Byzantine foot (*pous*) equal to 31.23 cm (Schilbach 1970, 13-6).

[16] Two futtocks, F 3 and F 20, could not be identified as either original or replacement due to insufficient preservation of planking. FR 12A, the small addition on the starboard side, was also not included in this total.

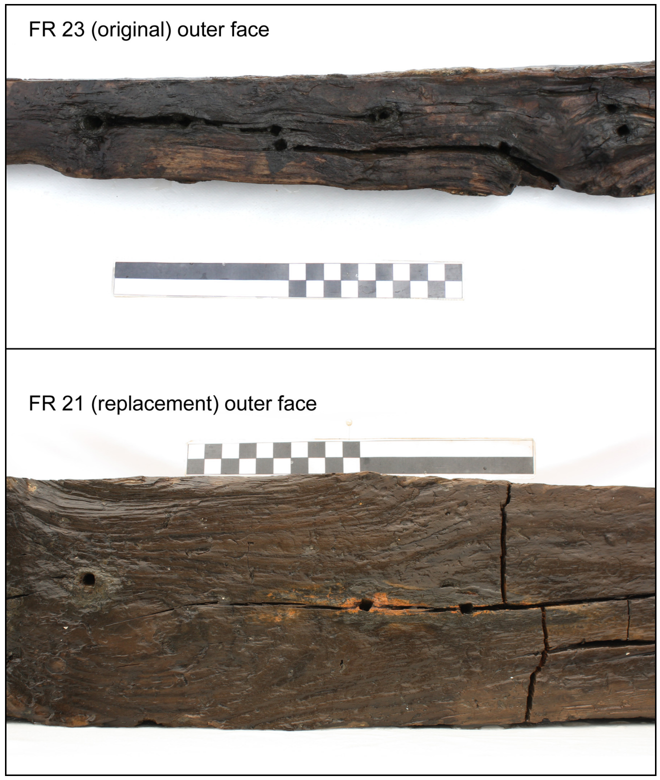

Figure 4.21. Comparison of the outer face of original and replacement floors. Note splitting and abundance of nail holes on original floor (above), and fewer nail holes and better surface preservation on replacement floor (below).

In most cases, the fasteners on a replacement frame would be found to match the fasteners on replacement planks, while the keel and original planks would have extra, unmatched nails at this frame location. Likewise, the fasteners on an original frame would be found to match the fasteners on the keel and original planks, while replacement planks would have fewer nails at this frame location. These patterns were generally reliable, although the shipwrights appear to have reused old nail holes in several cases, which complicates the matter. Whether a replacement frame was installed before or after a particular replacement plank was not clear in every case; analysis of the nails indicates that timbers were replaced on multiple occasions.

In addition to nail patterns, general preservation and number of nails present on the inner and outer faces of a frame were often an excellent indication of the frame's status. In addition to exhibiting generally poorer preservation than replacements, original frames were often more severely cracked and split on the outer face due to the presence of excess nails, usually approximately twice as many as a replacement frame (fig. 4.21).[17]

Caulked or abandoned fastener holes on original planks or the keel suggest that F 17, FR 18P, and FR 22P, although not preserved, were replacement frames. Caulked holes, score marks, and an adzed area on the inner face of SS 7-1 and SS 8-1 suggest that futtock F 5, which was not preserved, may have been a replacement for an original futtock located farther forward. Caulked or abandoned fastener holes on SS 4-2, SS 5-4, SS 6-2, and SS 7-3, as well as score marks on SS 4-2 and SS 5-4, show that the original FR 19 angled toward the bow along its port arm.

Limber Holes

Triangular limber holes were cut into the outer face of nearly every floor or half-frame; these holes allowed the free passage of bilge water in the bottom of the hull.[18] There are two limber holes on each floor, one to either side of the keel; half-frames, which do not extend beyond one edge of the keel, only possess one limber hole each. On average, limber holes are 4.0 cm in width and 2.4 cm in depth. While all of the limber holes recorded on YK 11 are approximately triangular in form, there are three different

[17] For example, original floor FR 15, 2.38 m in length, had 61 iron nails on its outer face and 15 on its inner face. Replacement floor FR 17, the next floor in the sequence and only slightly shorter at 2.32 m in length, had only 30 nails on its outer face and 8 on its inner face.
[18] FR 1, the aftermost preserved half-frame, lacks a limber hole. Located so far in the ship's stern and higher up in the vessel, a limber hole would not have been necessary here.

variations, illustrated in figure 4.22. Each of the three types is represented in both floors and half-frames as well as in both original and replacement frames.

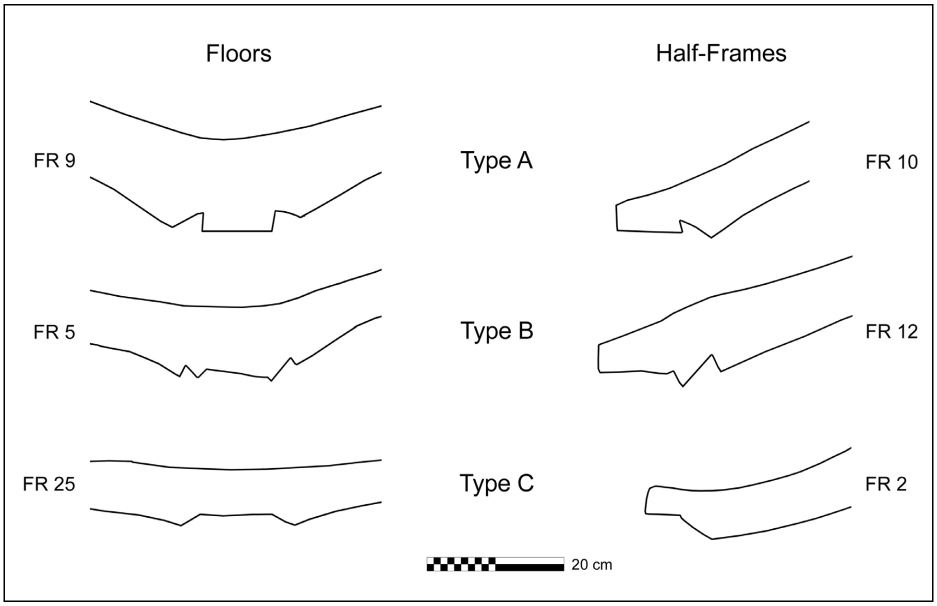

Figure 4.22. The three types of triangular limber hole on YK 11.

The most common, Type A, is present on 17 of 26 frames with limber holes; this type is comprised of two cuts to the floor's outer face. One cut, that closest to the keel, is more or less perpendicular to the inner face of the keel, while the outboard cut, usually longer, is angled inward (in relation to the ship's hull) and toward the keel.

Type B, present on only 5 of the 26 frames with limber holes, reverses the angle of cuts in Type A, with the shorter, perpendicular cut placed outboard, and the angled cut inboard. This type always exhibits a notched area on the frame's outer face meant to accommodate the keel; the reversal of the angles of the limber hole in Type B is almost certainly associated with preventing breakage between the keel notch and limber hole.

Whether the shipwrights used limber holes of Type A or Type B probably depended solely on the presence of a keel notch, which probably would have been cut during the initial shaping of the frame, prior to the cutting of limber holes. The limber holes on replacement floor FR 21 were a combination of both Type A and Type B.

Type C is present on only three frames at the ship's extremities, FR 2, FR 25 and FR 26. This type eliminates the limber hole edge closest to the keel. Instead, each limber hole is comprised of an angled cut, similar to the longer, outboard arm of Type A; the area of the outer face between the port and starboard cuts was removed, resulting in a large, open area that acts as a keel notch with limber holes. This form was only used at extremities, reflecting the steep angle of planks at the endposts.

Description

Because the four types of frame components preserved on this shipwreck—floors, half-frames, futtocks, and short repairs—are so distinct in terms of form, each type will be described separately. For the floors and half-frames, these will further be divided into original and replacement frames, in order to elucidate any differences between the two groups.

<u>Floors</u>

Thirteen floors were preserved on YK 11 (figs. 4.23-4.25); of these, only four (31%) are original floors, while nine (69%) are replacement pieces. All floors were attached to the keel with one or more nails or, in the case of FR 4 and FR 9, an iron bolt. Twelve of the thirteen floors are complete or nearly so, and range in length from 1.24 to

2.38 m, with an average length of 1.96 m. They exhibit an average sided dimension of 7.4-9.9 cm and average molded dimension of 7.4-12.3 cm.[19]

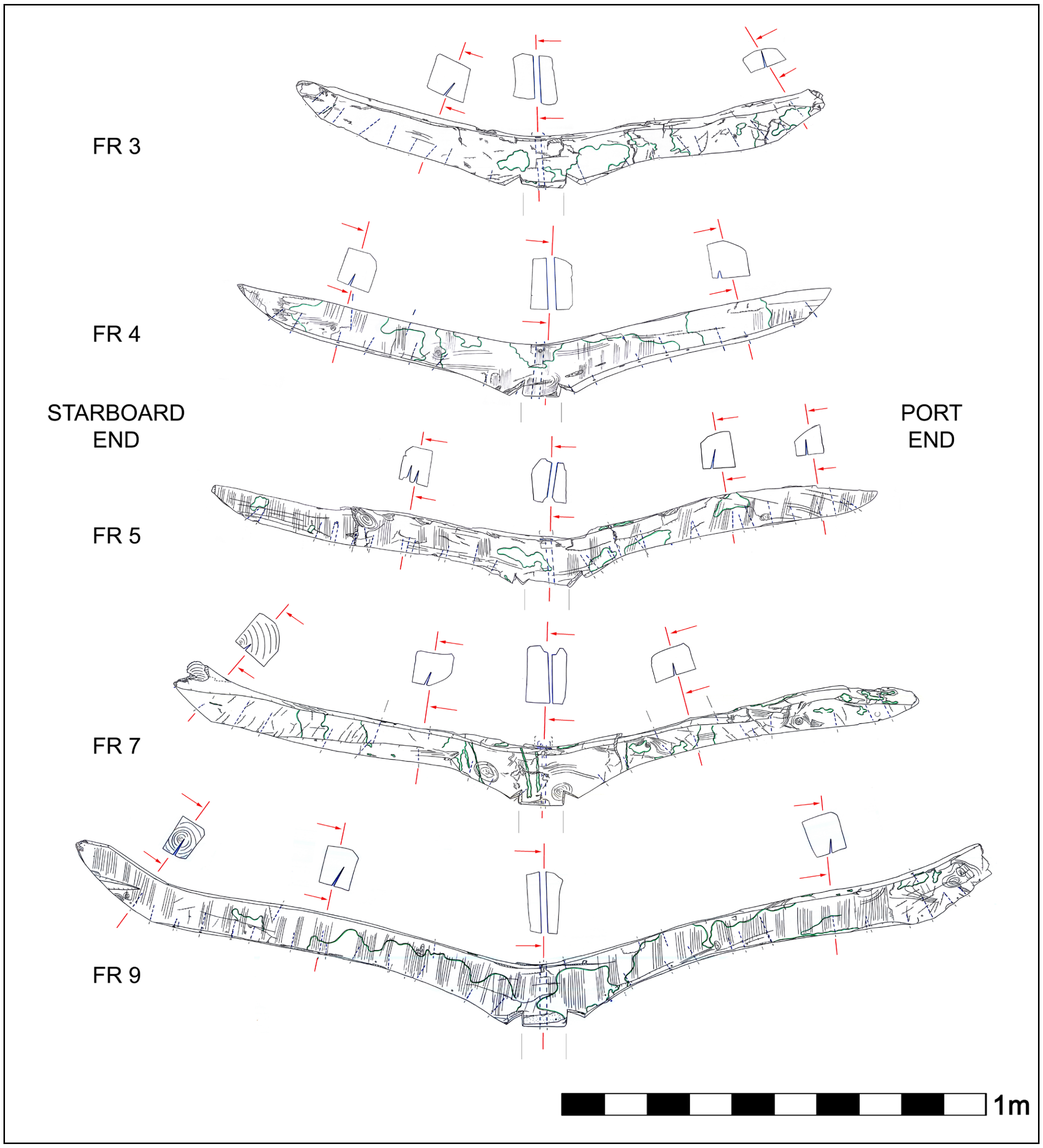

Figure 4.23. YK 11 floors FR 3 through FR 9, forward face.

[19] These dimensions represent the average of the range of dimensions (minimum and maximum) of each frame. Measurements of tapered ends are not included here; including tapering, the frames exhibit a minimum average sided dimension of 4.4 cm and a minimum average molded dimension of 3.0 cm. The largest molded dimensions usually represent the area at the keel or limber holes.

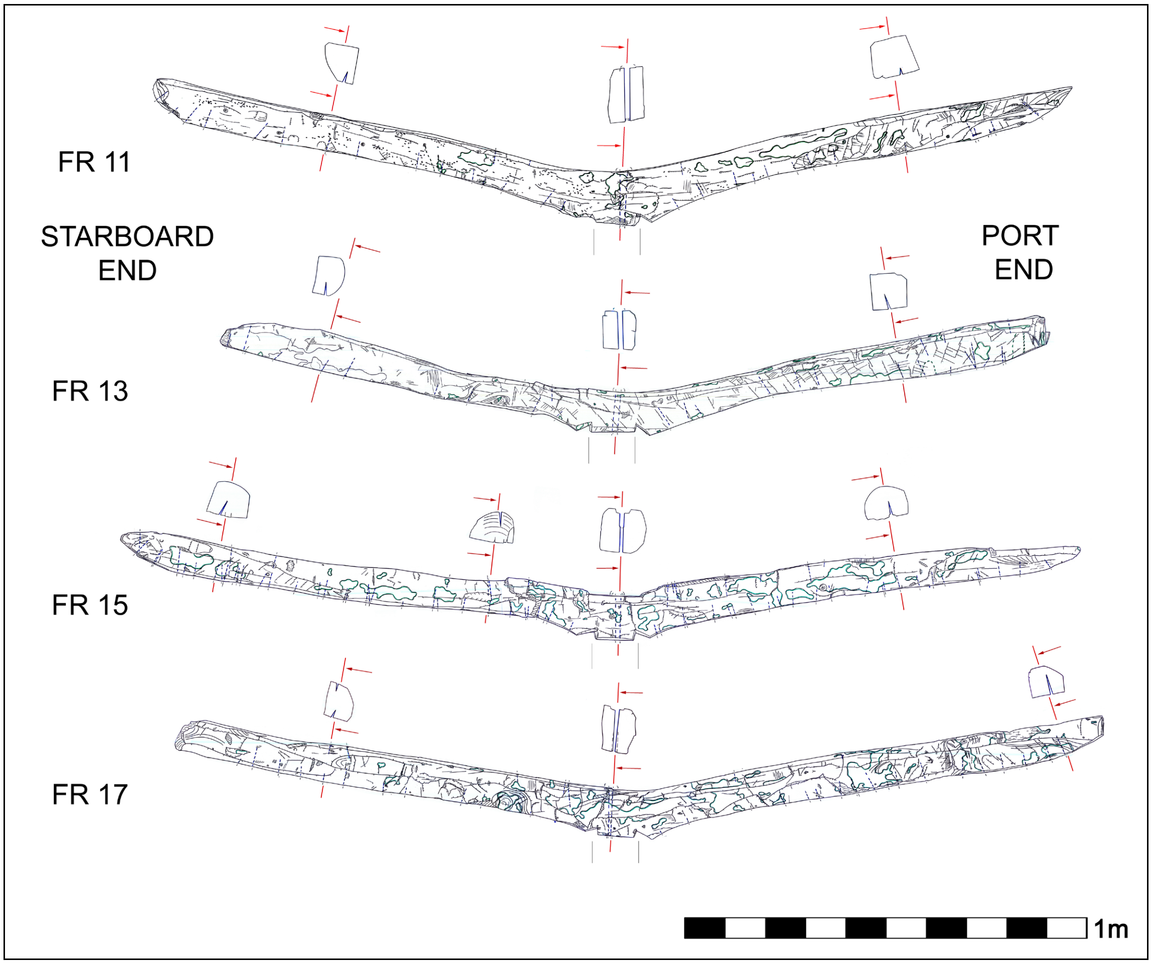

Figure 4.24. YK 11 floors FR 11 through FR 17, forward face.

Original Floors

The four original floors are FR 5, FR 15, FR 23, and FR 25. Excluding broken floor FR 25, lengths of preserved floors range from 1.57 to 2.38 m, with an average length of 1.90 m. Original floors exhibit an average sided dimension of 6.6-8.9 cm and average molded dimension of 6.9-11.4 cm. Floor ends taper toward the extremities, where they are either blunt cut or taper to a point.

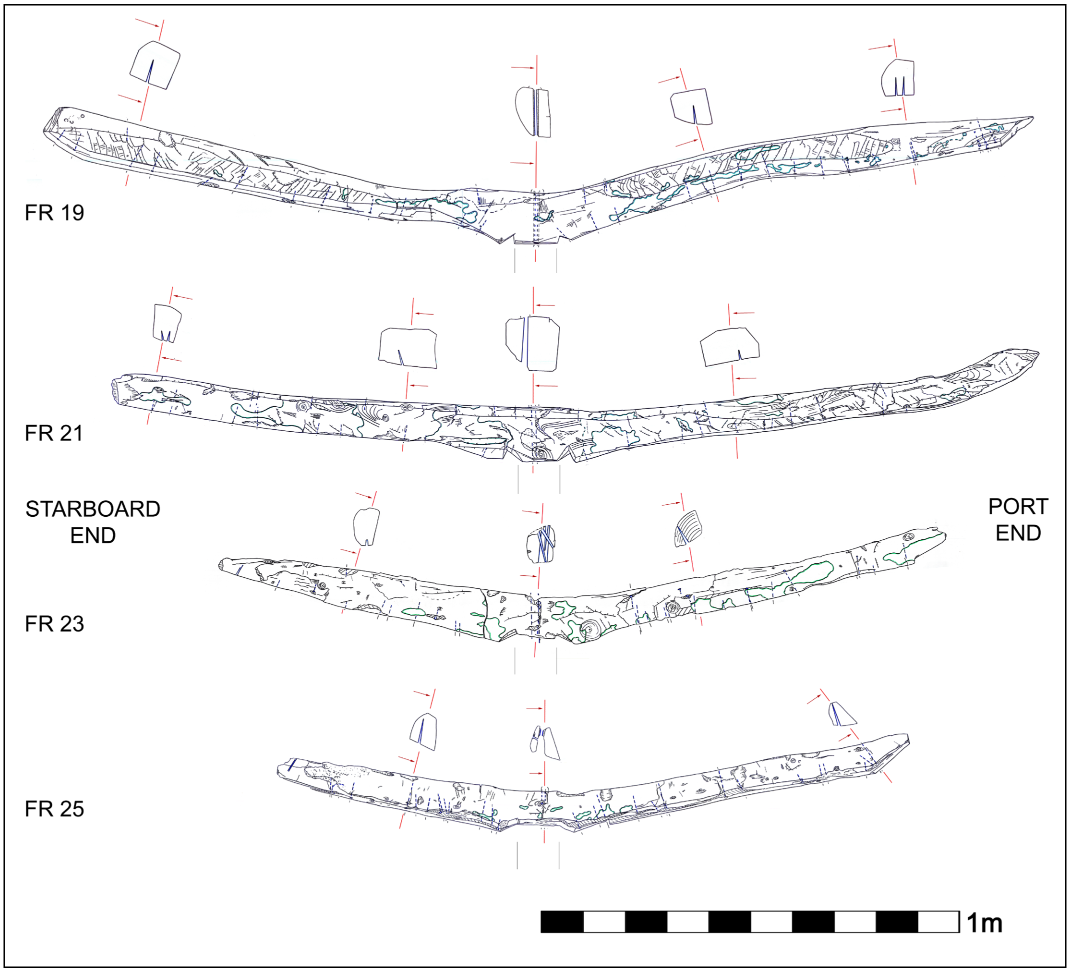

Figure 4.25. YK 11 floors FR 19 through FR 25, forward face.

The condition of original floors is generally very good, but somewhat degraded in comparison to that of replacement floors. Dry rot damage is common on the outer face of these floors. The abundance of nails on the inner and, especially, outer faces has led to severe cracking, splitting, and, in some instances, breakage of these floors. None of the original floors appears to be a recycled frame previously used elsewhere.

Two of the original floors are *Quercus cerris* (Turkey oak), one is *Pinus brutia* (Turkish pine), and one is *Tamarix* (x5) (tamarisk). It appears that the shipbuilders were more eclectic in their choice of timber for floors during the initial construction of the ship than during later repairs, when the choice was predominantly *Pinus brutia*. Furthermore, the original preference for oak rather than pine floors is noteworthy.

Floors FR 5, FR 23, and FR 25 were cut from young, sawn half-logs, with the sawn face toward amidships. FR 15, at or close to amidships, is adzed on all faces and lacks a sawn face. All four original floors exhibit “natural chamfers” on the inner-adzed face edge. This is a minimally worked area (where the bark has been removed but the surface uncut) that is naturally rounded; this acts as a chamfer or softened transition between two cut faces. FR 5 exhibits both natural and adzed chamfering to parts of the inner-aft (adzed) face. Most of these floors have large areas that are minimally worked, with occasional patches of bark or cambium noted.

Each original floor possesses two approximately triangular limber holes, one on either side of the keel. On average these are 4.0 cm in width and 2.3 cm in depth. The form of the limber hole varies, with all three limber hole types (discussed above) represented. Limber holes were primarily adzed or chiseled, with chamfering to some edges.

There are three areas on these floors which were notched or trimmed to accommodate other timbers. On FR 15, part of the inner face along the ship’s centerline was notched to accommodate the mast step, which was not preserved (fig. 4.26). This indicates a mast step at least 13.4 cm in width. Also on FR 15, the port end of the floor is adzed down along its forward face for a length of 37.5 cm, presumably to accommodate futtock F 15 (which was not preserved). FR 5 is the only original floor with an outer face notch to accommodate the keel; it is up to 1.7 cm in depth, although this dimension may be affected by pressure damage.

Figure 4.26. FR 15 inner face, cut down to accommodate the mast step.

Replacement Floors

The nine replacement floors are distributed fairly evenly along the aft three-quarters of the ship: FR 3, FR 4, FR 7, FR 9, FR 11, FR 13, FR 17, FR 19, and FR 21. All replacement floors are either complete or very close to it, with lengths ranging from 1.24 to 2.38 m and an average length of 1.98 m. Replacement floors are larger than original floors in sided (average 7.8-10.4 cm) and molded (average 7.6-12.7 cm) dimension. There is a larger discrepancy between original and replacement floors in sided rather than molded dimension; a notable difference in molded dimension would complicate the installation of stringers or other internal timbers.

Similar to the original floors, replacement floors have ends that often taper to varying degrees, terminating in a point or with a smaller tip that is blunt-cut, either with an adze, axe or chisel. The port end of FR 9 is tapered with adze cuts on the forward face, but is roughly split on the aft face, resulting in a sharp, pointed end. The port and, perhaps, starboard ends of FR 4, and the port ends of FR 9 and FR 11, have been adzed down, possibly to accommodate a futtock (fig. 4.27). FR 21 is the only frame on the ship which is distinctly notched for futtocks. Both notches are cut out of the frame's aft face, to a depth of 5.6 cm and length of 24 cm on the starboard side, and a depth of 5.0 cm and length of 50 cm on the port side.

Figure 4.27. Aft face of FR 4, adzed down for futtock F 4 at the port end.

The high percentage (69%) of floors that are replacements for worn or damaged timbers reflects the high degree of degradation in the bottom of the hull. This is undoubtedly a result of rot due to the constant wetting of this part of the ship by bilge water, and it is noteworthy that evidence of dry rot, prevalent on original floors, was not observed on replacement floors.

Indeed, all replacement floors are in an excellent state of preservation, with part or all of the original surfaces remaining on each face. Nearly all are intact, with only minor broken fragments which have been wired back on. Most damage to replacement floors was caused by stringers or other internal timbers being pressed into the inner face of the floors, causing severe cracking and pressure damage to this face and compression damage in the form of bulging and wrinkling on forward or aft faces. The cracking in association with outer face nails is far less significant than the splitting observed on original floors, undoubtedly due to fewer nails having been used on the replacement pieces.

Replacement floors differ from original floors in their consistency of wood species used: eight of the nine replacement floors (89%) were *Pinus brutia* (Turkish pine). Only floor FR 3, the shortest preserved floor, was made of *Fraxinus excelsior* (European ash). This is consistent with replacement half-frames, which are also predominantly *Pinus brutia*.

Like the original floors, replacement floors usually possess one face that is sawn flat, while all remaining faces are adzed. However, the sawn face is oriented toward amidships only on FR 4, FR 9, FR 17 and FR 19. FR 3 and FR 21, like FR 15, are entirely adzed.

Use of younger timber is reflected in the prevalence of naturally-rounded, minimally-worked surfaces, most common at the transition from inner to forward or aft faces. Much of FR 11's forward face, especially along the starboard arm, is a minimally-worked surface riddled with small holes from wood-boring insects; many of these holes had been filled in with pitch (fig. 4.28).

Figure 4.28. Natural surface of the FR 11 forward face. Note pitched holes from wood-boring insects.

Four of the longest replacement floors, FR 11, FR 13, FR 17, and FR 19, were cut from fire-scarred Turkish pine. This appears in areas of original surface as a smoother lower layer surmounted by a thick, uneven border (fig. 4.29). Three deep, rough cuts to the forward face of FR 17 may represent an attempt to remove the scarred timber (fig. 4.30).

On replacement floors, the edge formed by the inner and adzed side face, whether forward or aft, is softened through a cut or naturally. Thus, chamfering is usually only present along one edge. FR 7 is anomalous in that chamfers were cut along both the inner-forward and inner-aft (sawn) face edges. FR 3 and FR 21, entirely adzed, are also exceptions, with chamfers on both edges of the floor's inner face.

Figure 4.29. Fire scarring on the outer face of FR 11.

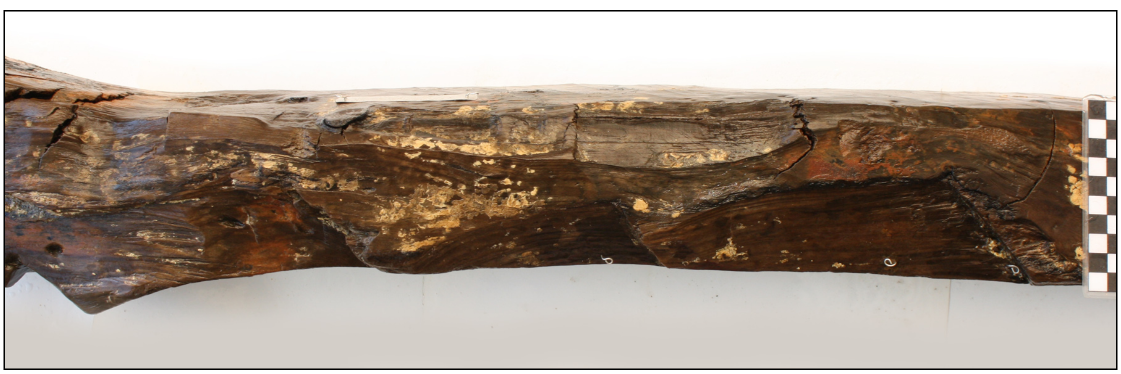

Figure 4.30. Forward face of FR 17, with three large cuts, possibly to remove fire-scarred surfaces.

Eight of the nine replacement floors possess two triangular, Type A limber holes. FR 21, again an exception, has limber holes that seem to be a combination of Types A and B: in orientation, they are more like Type B, but lack a keel notch. Perhaps the limber holes were cut in this fashion in order to minimize breakage in association with the cutting of the outer-aft face edge to accommodate the Keel 2-Keel 3 bolt. The average width of limber holes on replacement floors is 3.9 cm and the average depth 2.5 cm. Chamfers were usually cut into the long, outboard edges of limber holes but not the inboard edges.

Half-frames

Fourteen half-frames were preserved at thirteen frame stations (figs. 4.31-4.33). Eight of the half-frames (57%) belong to the initial construction of the ship, while six (43%) are replacement frames. Nine of the fourteen half-frames are complete or nearly so; the complete half-frames range in length from 0.98 to 1.98 m, with an average length of 1.70 m. On average, half-frames are 7.4 to 9.1 cm in sided dimension and 7.1-9.9 cm in molded dimension. Every half-frame was attached to the keel with one or more nails.

Originally, each half-frame was paired with a corresponding half-frame on the opposite side of the ship. However, with the exception of FR 16P, none of the starboard half-frames was preserved. Nails on the keel and starboard planking, however, do not suggest any particular pattern of frame placement. For the ten pairs of half-frames in which position can be determined, the port half-frame is placed aft of the starboard half-frame six times (FR 6, FR 8, FR 12, FR 20, FR 22, and FR 24), and the starboard is placed aft of the port four times (FR 10, FR 14, FR 16, FR 18.) It is interesting that, in

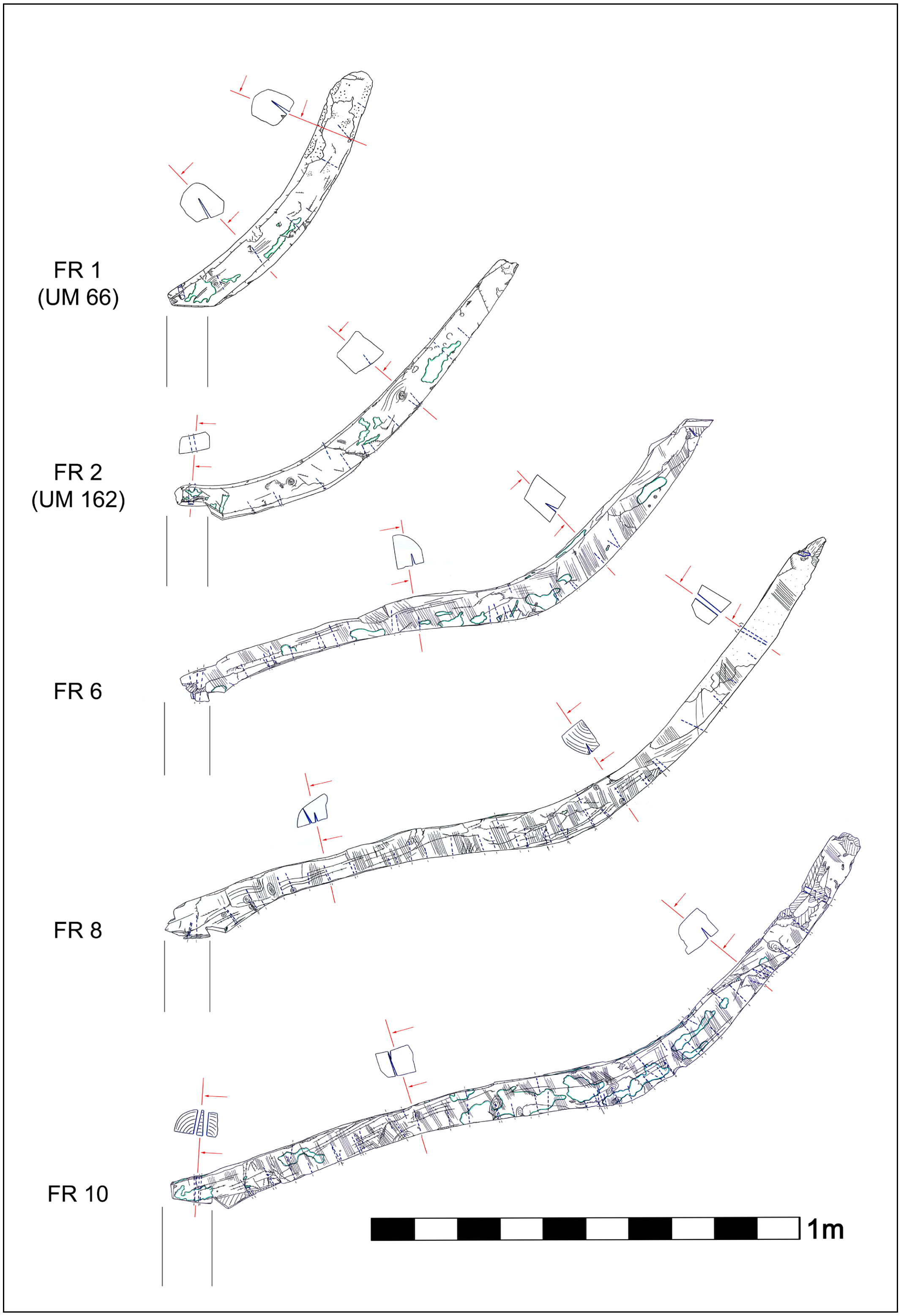

Figure 4.31. YK 11 half-frames FR 1 through FR 10, forward face.

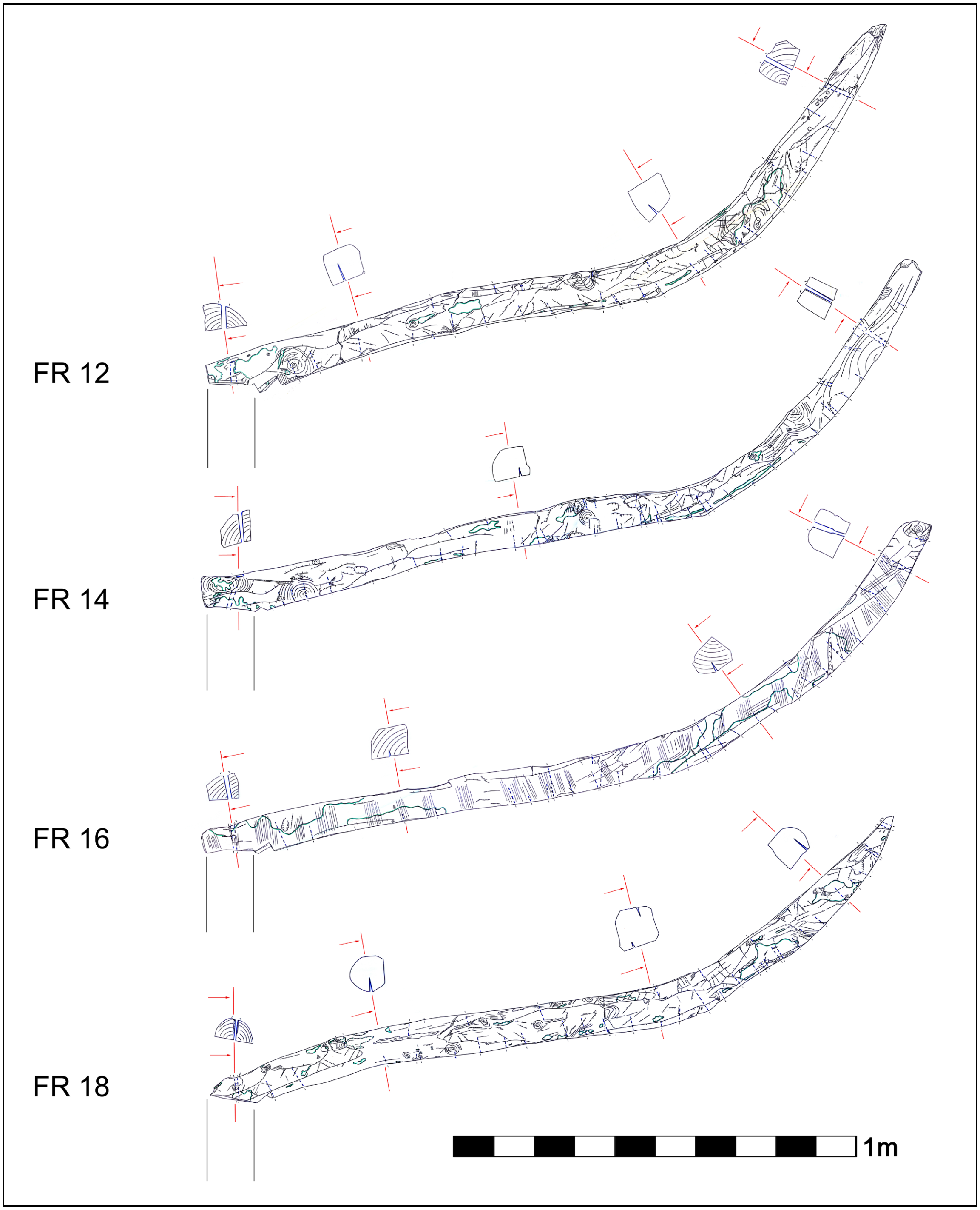

Figure 4.32. YK 11 half-frames FR 12 through FR 18, forward face.

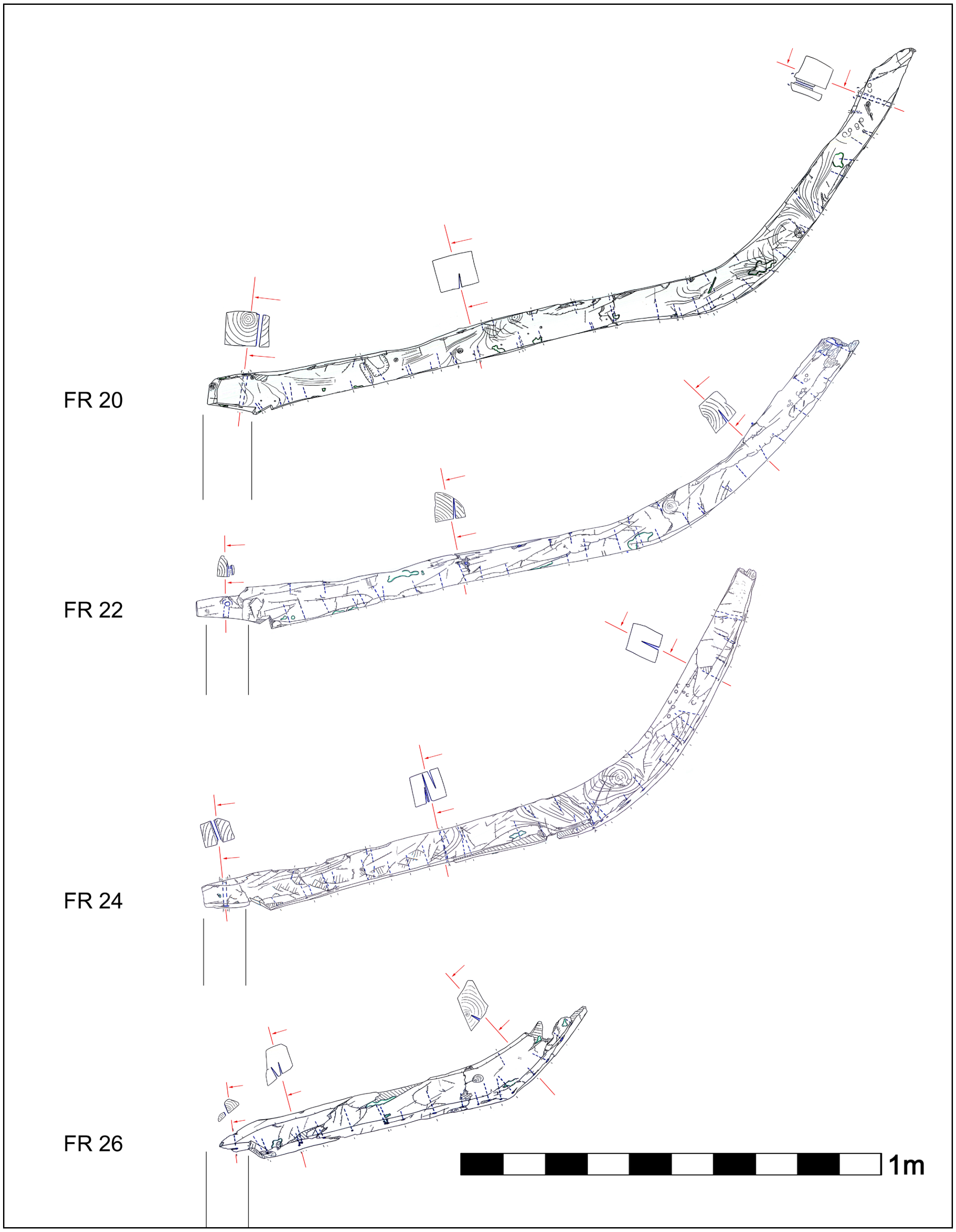

Figure 4.33. YK 11 half-frames FR 20 through FR 26, forward face.

FR 16, the one preserved pair of half-frames, there are two different wood species represented, one half-frame being original and the other a replacement.

Original Half-frames

Eight of the half-frames are original; these are distributed fairly evenly throughout the shipwreck (FR 6, FR 8, FR 10, FR 16P, FR 20, FR 22, FR 24 and FR 26). Only four of the original half-frames, FR 6, FR 8, FR 20, and FR 24, are complete or nearly so, ranging in length from 1.39 to 1.89 m, with an average length of 1.66 m. The remaining original half-frames are incomplete. The original half-frames range from 6.6 to 8.5 cm in average sided dimension and 6.9 to 9.9 cm in average molded dimension.

Where undamaged, the keel ends of original half-frames were blunt-cut (fig. 4.34). The keel end of FR 22 is exceptionally small, seemingly cut down on the aft and inner faces, possibly in association with the replacement of FR 22P (not preserved). The presence of pitch and multiple nails indicate that the keel ends of FR 6 and FR 8 were both badly damaged during the ship's lifetime.

In general, the original half-frames are very well preserved. FR 6 is the only original half-frame that is both complete and intact. All other original half-frames are broken into two or more pieces; FR 16P, without question the worst preserved half-frame, is broken into many pieces and badly compressed. All exhibit varying degrees of cracking and splitting along the outer face in association with nails. Damage from dry rot was noted on the outer face of several original half-frames. Compression damage is common, most often appearing as a wrinkled surface to the sawn face, or as bulging or distortion in sections. Original half-frame ends tend to be damaged, including distortion to the keel end and damage from shipworm at the top end. None of the original half-frames appears to be a recycled frame previously used elsewhere, but UM 157, a bulkhead frame whose original location could not be identified, is a recycled frame, possibly an original frame of YK 11 that had been replaced.

Figure 4.34. FR 20 keel end. The tip was blunt-cut, likely with an adze.

Wood species used for original half-frames is relatively consistent: seven of the eight are *Pinus brutia* (88%), while only one of them is *Quercus cerris*. There is evidence of fire-scarring on three of the original pine half-frames (fig. 4.35).

All eight original half-frames were cut in the same fashion from naturally-bent timbers. Each half-frame had one flat, sawn face, oriented toward amidships; other faces were adzed. There is no evidence that the flat, sawn faces of a pair of half-frames would have faced each other; rather, the positioning of FR 10, FR 16 (both half-frames), FR 20, and FR 22 precludes this arrangement at these frame stations. Moreover, since these half-frames appear to have been fashioned from an angled timber sawn in half along the pith of the wood, one would expect the two halves to be paired as the port and starboard portions of the same frame station, and if this were indeed the case, the flat, sawn faces of a half-frame pair would both face the same direction, presumably toward amidships. Whether or not this occurred on YK 11 is impossible to tell, as the one preserved pair of half-frames includes one original and one replacement frame.

Figure 4.35. Fire scarring on the forward face of FR 22.

Natural chamfering was observed on every original half-frame, reflecting the relatively small size of timbers used to fashion these frames. Other than the adzed chamfer on part of the inner-forward edge of FR 26, no cut chamfers were noted on the original half-frames. FR 20 did not exhibit any chamfering whatsoever on its inner face, but had an area of natural chamfering on its outer face near the turn of the bilge. Natural surfaces sometimes comprise much of a half-frame surface.

Each original half-frame possesses one limber hole, with an average width of 4.0 cm and depth of 2.6 cm. Five of the limber holes correspond to Type A, the triangular limber hole lacking a keel notch. Two of the limber holes are Type B and exhibit a clear keel notch. FR 16P is unique in that the keel end extends beyond the port edge of the keel, after which the outer face angles up sharply, much like the edge of a second limber hole (fig. 4.36). FR 26 has a Type C limber hole, appropriate for its location in the bow. The limber holes were adzed or chiseled; edges are usually not chamfered. The two keel notches, on FR 16P and FR 20, both appear to have been saw-cut.

Figure 4.36. Type B limber hole on FR 16P, forward face. Note angling of outer face near keel end (at arrow), which might have acted as a second limber hole.

Figure 4.37. Notch on the inner face of FR 10, near the broken top end.

The only other possible notch on the original half-frames is near the top (broken) end of FR 10. This notch runs across the inner face of the frame and is 1.4 cm in depth; it seems to have been cut with an adze or chisel with a 3 cm blade (fig. 4.37). The function of this notch is unclear, but would have been located at approximately the same level as the top of a through-beam; perhaps part of the stern deck fit into this notch.

Replacement Half-frames

Six of the preserved half-frames (43%) appear to be replacements for older, damaged or worn frames. The lower percentage in comparison with that of replacement floors (69%) reflects the generally better preservation of the upper portions of the ship's hull during the life of the ship. Four of these half-frames, FR 2, FR 12, FR 16S, and FR 18, are definite replacements. FR 1 is probably a replacement, although only two planks preserved at this location leave us with little to go on. FR 14 is problematic but evidence indicates that it is more likely a replacement; the problem is discussed in more detail below (*Problem Areas*.)

All of the replacement half-frames, with the exception of FR 1 (broken at its top end), are complete or nearly so. These range in length from 0.98 to 1.98 m, with an average length of 1.73 m. They have an average sided dimension of 8.2-10.0 cm and average molded dimension of 7.3-9.9 cm. As such, the replacement half-frames are slightly larger in sided dimension but comparable to original half-frames in molded dimension.

As on all other frames, the replacement half-frames tend to taper toward original ends, either through the natural form of the timber used (best exemplified by FR 18, fig. 4.38), or through the cutting down of one or more faces. Keel ends that do not taper to a point (as do FR 1 and FR 18) were blunt cut, perhaps with a chisel or adze (FR 2, FR 12, FR 14, FR 16).

All six replacement half-frames are relatively solid with original surfaces preserved. All but FR 12 and FR 14 are intact. Top ends tend to exhibit some damage, especially due to shipworm. Compression damage was observed but is less intense than that seen on original floors and half-frames. Traces of fire scarring were noted on FR 18.

Four of the six replacement half-frames are *Pinus brutia*; FR 1 is *Ulmus campestris* (elm) and FR 2 is *Fraxinus excelsior* (European ash). The use of pine matches with other replacement framing as well as the majority use of pine for original half-frames. The longest replacement half-frames were pine, likely representing what was most readily available for longer timbers.

Figure 4.38. Tapering, minimally-worked keel end of FR 18.

In form, only three of the six half-frames were cut from larger compass timbers that had been sawn in half; on these, the flat-sawn face is oriented away from, rather than towards, amidships. The other frames were cut from smaller compass timbers that were finished on all faces with an adze. While all of the replacement half-frames have some areas with natural chamfering (on both the inner and outer faces), four of the six also exhibit one or more areas of adzed chamfering on one or both inner face edges. There is no chamfering to any sawn face edge. Natural surfaces are common on the replacement half-frames, especially so on FR 18, which was cut from a large limb, with smaller branches and bark removed (fig. 4.38). Patches of cambium on natural surfaces were observed on three of the pine half-frames, reflecting minimal working of young timbers.

All three types of triangular limber hole are represented in the replacement half-frames. FR 1, high in the stern, lacks a limber hole; instead, the outer face angles to meet the sternpost, and the gap which would have been formed by the frame, sternpost and plank would have allowed the passage of water, if necessary. The Type B limber holes on FR 12 and FR 16S have a distinct notch for the keel, and the Type C limber hole on FR 2 has no inboard edge (fig. 4.39).

Figure 4.39. Type C limber hole on FR 2, keel end.

Futtocks

Futtocks are curved timbers that reinforce the planking at and above the turn of the bilge; they do not meet the keel. Each futtock is associated with either a floor or a half-frame and is placed directly either just forward or just aft thereof. Five futtocks, all from the better-preserved port half of the ship, were associated with floors: F 3, F 4, F 13, F 19, and F 23 (fig. 4.40). In addition to the extant futtocks, nails or pitch outlines on the planking indicate the presence of eight additional futtocks associated with floors on the port side and seven on the starboard side.

Two of the floor futtocks, F 13 and F 19, were found in situ; the remaining three had been displaced and were initially assigned UM numbers. Only three of the floor futtocks, F 4, F 13, and F 19, are complete or nearly so; these range in length from 0.89 to 1.15 m, with an average length of 1.02 m. In molded and sided dimensions, the floor futtocks are comparable to the original floors and half-frames, with an average sided dimension of 6.5-8.7 cm, and an average molded dimension of 6.3-9.6 cm. Nearly all original ends exhibit some degree of taper, usually in association with the curvature of the outer face, corresponding to the turn of the bilge. The lower end of F 4 was roughly trimmed with an adze along its forward face, in order to fit against FR 4.

Due to insufficient planking, it is unclear whether F 3 is original or a later replacement; a line of caulked or disused fastener holes just forward of the futtock seems to indicate the latter. All other floor futtocks, however, are original to the initial construction of the ship. As with the original floors, the futtocks were made from a variety of different wood species, including two futtocks of *Pinus brutia* and one each of *Pinus nigra*, *Tamarix* (x5), and *Acer pseudoplatanus*.

The floor futtocks are in very good condition, especially so at their lower ends. Top ends are often broken and, in every case, are damaged by teredo or gribble worms, often both. Three of the futtocks remain intact, two of which, F 4 and F 13, are complete

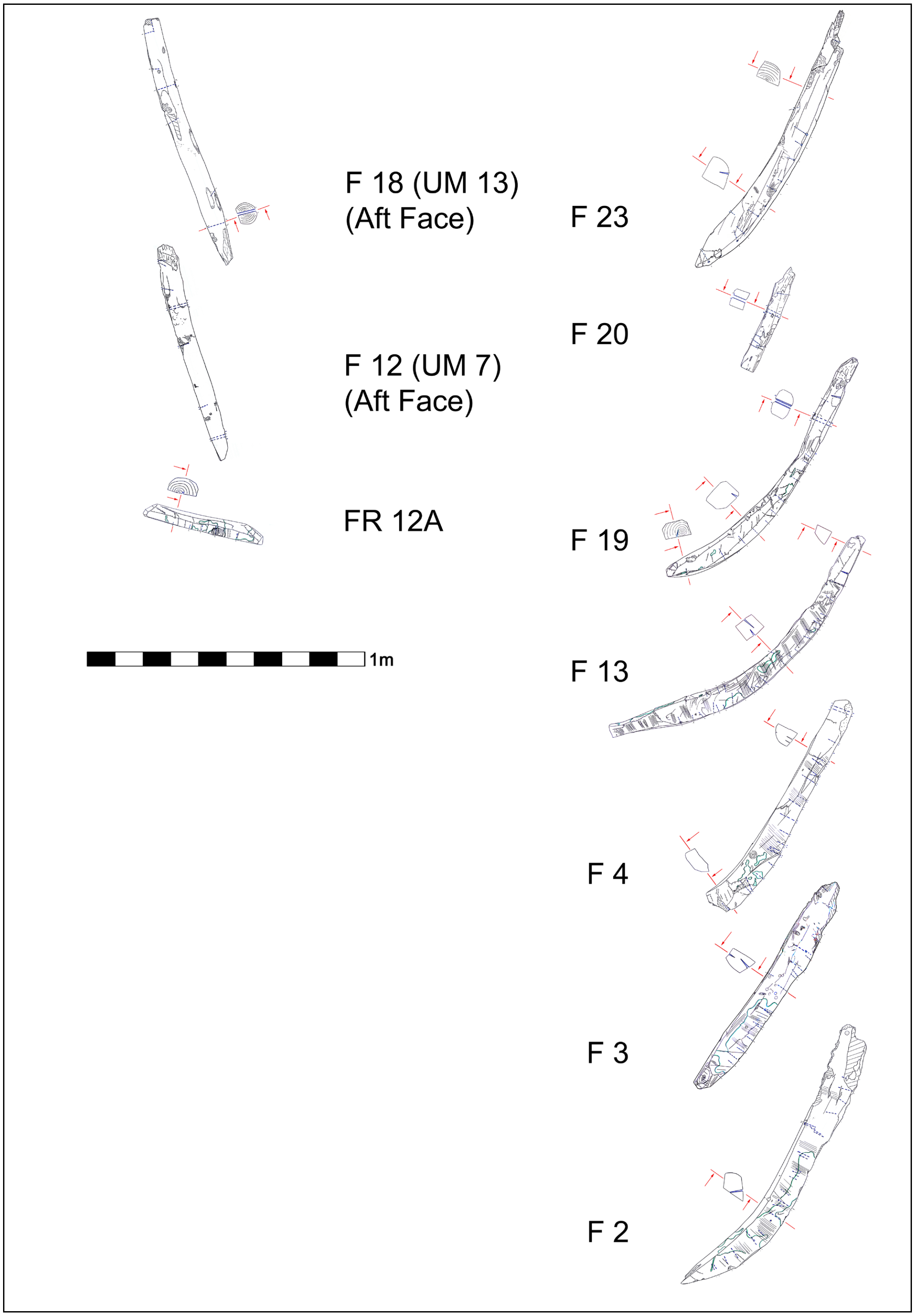

Figure 4.40. YK 11 futtocks and reinforcement piece FR 12A. Forward face shown for all but F 12 and F 18, which show the aft face.

or nearly so. Cracking is common as is surface wear and pressure damage from sediment, shell, and barnacles (fig. 4.41).

Like other original framing, the floor futtocks were cut from compass timbers sawn lengthwise; the flat-sawn face was oriented toward amidships. All other faces were adzed. F 19 is the only floor futtock lacking a sawn face; it was entirely adzed, and the variable location of the pith indicates than an entire limb was used for this futtock. It is larger in sided dimension than the other futtocks, which could indicate that framing dimensions on YK 11 were based to a great extent on timber economy and availability. Edge chamfering is variable on the floor futtocks; there is no chamfering whatsoever on F 3 or F 23, but F 4 and F 19 have both adzed and natural chamfers along parts of the inner face edges. Natural, rounded surfaces are visible on some part of every floor futtock.

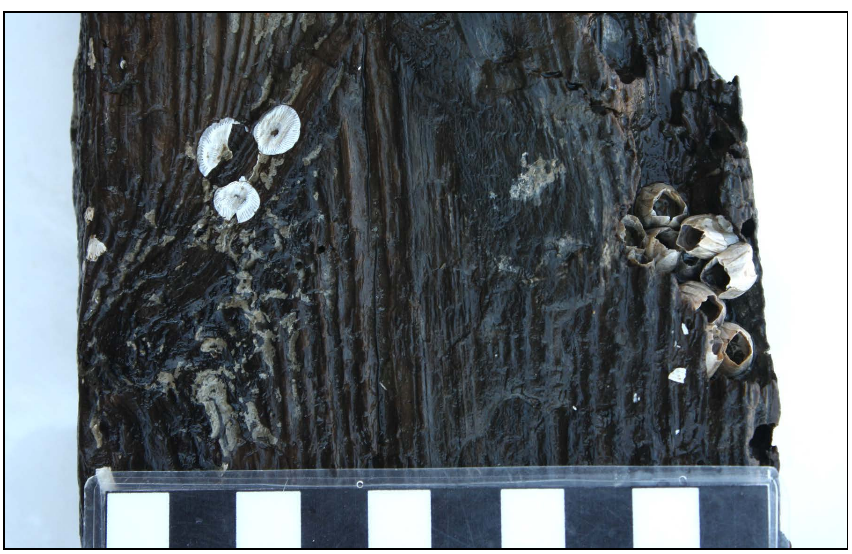

Figure 4.41. Barnacles on the sawn forward face of F 3.

There are three areas where floor futtocks were trimmed down to accommodate other timbers or fasteners. On F 4, the sawn face was trimmed down along the lowest 9.7 cm, in order to fit the futtock against FR 4 (fig. 4.42). Also on this futtock, a shallow concavity was cut from the inner face for the nail which fastened the futtock to SS 13. Finally, there is a shallow, sawn notch cut into the outer face of F 19, apparently to accommodate SS 12.

Figure 4.42. Lower end of F 4, from the forward/inner face edge, showing trimming for the FR 4 port end.

The displaced futtocks associated with half-frames, being the topmost-preserved elements of framing, were difficult to identify. These supported the sides of the ship above the waterline, starting around the first wale and extending up to the fourth wale and perhaps to the sheer strake. Each was associated with a half-frame and was located either immediately forward or aft of the associated frame, overlapping for two or three plank widths. Only one half-frame futtock, F 20, was found in situ; although it can be matched to planking with only one iron nail, it appears to have been found in its original position, having slipped downward only slightly. The remaining three half-frame futtocks, F 2 (UM 1), F 12 (UM 7), and F 18 (UM 13), had been displaced and were initially designated as unidentified fragments. Nails on the upper strakes of the port side (strakes 11, 12 and 13) indicate three other half-frame futtock locations (F 6, F 10, and F 22), although more were surely present.

F 2 was found very near its original location at the ship's stern. Its association with FR 2 designates this as a half-frame futtock; however, due to its placement in the stern, it started much lower than the typical half-frame futtock (at strake 2 rather than strake 11) and overlaps significantly with FR 2. Because the top end was not preserved, it is unclear whether it extended to the sheer strake.

F 12 was identified primarily by its find location, as this half-frame futtock had pivoted forward, leaving its lower end near its place of origin. Comparison of the iron nails on F 12 with those of strakes 11, 12, and 13 indicates that this futtock is a replacement. UM 13, based on its form and fasteners, is a displaced half-frame futtock very similar to F 12. Its only possible location on the port side is at F 18, but with only one nail matching on the wale, this designation is far from certain; nevertheless, it matches what would be expected at this part of the hull. That the fastening pattern on the timber matches precisely what is seen on original strakes 11 and 12 seems to indicate that it is original.

Three of the four identified half-frame futtocks are *Pinus brutia*; the fourth, F 2, is *Ulmus campestris*. These timbers vary in length, from 0.40 to 1.11 m, but only F 12 (81 cm) and F 18 (92 cm) retain their original length. On average, the half-frame futtocks are 7.1-8.5 cm sided and 7.0-8.1 cm molded. F 2 is larger than average, up to 9.9 cm sided and 12.1 cm molded. Although only two of the timbers are complete, all are intact and thus provide a reliable curvature of some part of the upper portion of the hull. As noted above, F 2 and F 18 are probably original timbers. F 12 appears to be a replacement, while F 20 is insufficiently preserved to determine whether it was original or a replacement; however, multiple nail holes around the same area on the inner face of F 20 suggest the former.

The half-frame futtocks are in a very good state of preservation, especially at the lower ends, all of which are in their original state. The top end is broken away on both F 2 and F 20, although there is evidence of cutting near the top end of F 2, which suggests the end might be close to its original state. The top ends, whether broken or in their original state, have been damaged by teredo and gribble. The lower ends vary in form, either tapering to a point or cut flat. The top ends are partly in their original state on F 12 and F 18 and were also cut flat; an iron nail driven downward into the top end of F 18 is of unknown function.

The half-frame futtocks vary in overall and sectional form depending on their location in the hull and the type of wood used. F 12 and F 18 are very similar in form, having been fashioned from large, minimally-worked pine branches; after the bark was removed, the outer face and some areas on the other faces were adzed flat, while most of the sides and inner face remained naturally rounded. As a result, these half-frame futtocks are rounded in section, in contrast to the squared section of F 20. Due to the steep bevel of the outer face on F 2, several of the nail holes extend through the timber's forward face. The lower portions of the forward face of both F 2 and F 18 were trimmed with an adze in order to accommodate the associated half-frames, both of which were replacements.

Figure 4.43. Original notched end of UM 53. Possible top timber?

Three other unidentified fragments, UM 36, UM 51, and UM 53, could represent half-frame futtocks or top timbers whose location could not be identified due to insufficient planking. The most likely of these is UM 53, a minimally-worked timber with a rounded section very similar to F 12 and F 18. There is a deep notch cut into the original (top?) end of this timber (fig. 4.43), reminiscent of futtocks from the Port-Berteau II ship.[20]

Figure 4.44. Reinforcement piece FR 12A.

Reinforcement Piece FR 12A

One other framing element was found on the ship in situ. FR 12A is a short, low-profile timber that was attached to the starboard planking in order to provide a surface onto which the damaged forward end of PS 2-2 could be fastened (fig. 4.44). This timber was located aft of FR 12P (not preserved). This short timber of *Pinus brutia* was 45 cm long, 10.3-11.2 cm sided, and 5.3-6.0 cm molded. It was fastened to five separate pieces of planking with one iron nail each; none of the nails extended through the inner face of the timber, and none was driven through a pilot hole.

[20] Rieth et al. 2001, 49-51.

The timber is in an excellent state of preservation; it is complete and intact, with very little damage. The outer face was sawn flat while the inner remained naturally rounded; sides were adzed. The inner face edges and ends were cut with a wide, adzed chamfer.

Fasteners

All elements of framing were attached to the ship's planking with short nails driven from the hull exterior. The number of nail holes found on the outer face of each frame is variable, depending upon its size, degree of preservation, and whether or not the frame was a replacement. Original frames usually have approximately twice as many nail holes as replacement frames. The nail holes are square in section, usually 0.4-0.7 cm in sided dimension. In most cases, these nails did not extend through the inner face of the frame. Depths are variable, and maximum depths average about 5 cm (indicating an original shank length of approximately 7 cm). Many shallower depths probably represent nail holes that are concreted, or nails that bent while being hammered into the wood (fig. 4.45). This phenomenon was also noted on the timbers from the wreck at Serçe Limanı; it may only be positively identified at broken areas. On rare occasion, an outer face nail will break through the side (most often seen toward the ship's extremities, due to the sharp bevel to the frame's outer face) or just barely break the inner face of the frame.

Pilot holes, while relatively uncommon on outer face nails, were recorded at one or more fasteners on approximately 1/3 of the frames (fig. 4.46); there are usually not more than one or two per frame. These pilot holes are usually 0.8-0.9 cm in diameter and were filled with concretion around the square outline of the nail. They were not plugged with wooden pegs.

Figure 4.45. Traces of iron nails on the broken aft face of FR 25. Note straight nail next to a nail which bent upon insertion (red line added for clarification.)

Figure 4.46. Pilot holes on the outer face of FR 4.

Internal timbers, such as stringers and ceiling planking, were also attached to the framing with short iron nails. These nail holes are slightly smaller than those of the outer face, only 0.4-0.6 cm in sided dimension, with an average maximum depth of 4 cm. Due to the light fastening of internal timbers, there are far fewer inner face nails, on average 5, than outer face nails, on average 27 per frame.

Nail head impressions were present on nails driven from the frame's inner face at the location of the keel and wales; there is usually only one or two such nails per frame. The nail holes are understandably larger, being closer to the head of the nail; they are on average 0.7-0.9 cm sided. Most if not all of these nails were driven through a pilot hole 1.1-1.6 cm in diameter, on average 1.3 cm. Like the pilot holes on the outer face, these drilled holes remained empty and prevented the nail from bending within the timber and also prevented breakage. Pressure marks indicate nail heads 2.4-2.7 cm in diameter. On some frames, FR 7, FR 15, and FR 17, the nail head of the keel nail is countersunk into the surface of the frame (fig. 4.26). At floors FR 15 and FR 17, this allowed the mast step to fit more snugly over the frames; the countersinking of the FR 7 nail indicates the presence of the sternson here. The presence of multiple nails on frames at the keel seems to suggest an attempt to repair or reinforce this joint, as at FR 8, FR 10, and FR 16P, all of which are original half-frames.

Tool Marks

The well-preserved surfaces of the framing provide evidence for the use of several different tools, predominantly adze and saw, but also chisel, knife or scriber, and drill.

Figure 4.47. Adze marks on the forward face of FR 11. Overlapping tool marks obscure the original blade width. Note striations due to the use of a chipped adze blade.

Adzing is prevalent on the framing, with three or four faces of each frame finished with an adze. Tool marks indicate use of a chipped blade 3.5-5.1 cm in width (fig. 4.47). The chips in the blade result in light striations visible within the tool marks, at times more distinct than the start and end of an adze blow. Overlapping tool marks may obscure original blade width. Adze marks are surprisingly well preserved on the outer faces of some frames. Adzing is usually the only tool mark observed on minimally worked surfaces, where small branches or knots were trimmed with a chipped adze. Edge chamfers, where present, were dubbed with an adze, and an adze was also used to trim down areas of some sawn surfaces. The roughly-cut area on the outer-aft edge of FR 21, just over the keel, was probably dubbed with an adze up to 5 cm in width (fig. 4.48).

Figure 4.48. Outer face of FR 21 at the keel. The outer-aft edge was roughly cut down.

Figure 4.49. Cut marks on the outer face of FR 20.

Some tool marks are more difficult to interpret and may indicate the use of either a flat-bladed adze or a chisel in the forming of limber holes, cutting of notches, and trimming of surfaces. Well-preserved tool marks indicate that limber holes were primarily cut with a blade 2-3 cm in width, although wider tool marks, up to 4.7 cm in width, were observed. Some of the limber holes, as on FR 4 and FR 17, may have first been started with a saw prior to adzing or chiseling. The FR 21 futtock notches may have been cut with a combination of adzing and chiseling. Cut marks on the outer face of frames at plank seam locations, likely from an adze or chisel, are not uncommon and indicate where planks were cut down for repair (fig. 4.49); other marks at plank seam locations might have resulted from the cutting of tenons prior to the recaulking of the ship. A narrow chisel, 1.5-2.0 cm in width, was used to countersink nail heads on FR 7, FR 15, and FR 17 (fig. 4.50).

Sawn surfaces exhibit closely-spaced parallel lines that vary slightly in orientation along the length of the timber. Curved scratch-like marks on the sawn faces are probably saw return marks (fig. 4.51).[21] FR 5 is the only large frame that is partly sawn on its outer face; saw marks are present to either side of the FR 5 limber holes for a short distance (approx. 5 cm), while the remainder of the outer face was adzed. On FR 17 and FR 19, the floor was saw-cut for most of the aft face, then roughly split toward the end. Sawing appears to have been done in two different directions on FR 6, FR 8, and FR 16, with the keel end sawn from the keel toward the top end, and the top end

[21] Such marks were also noted on the framing of the Serçe Limanı shipwreck (Bass et al. 2004, 100).

sawn from the top toward the keel end. Some ends, as the lower end of F 13, were also sawn flat.

Figure 4.50. Countersunk nail head on the inner face of FR 7.

Figure 4.51. Forward face of F 13, with saw marks and saw return marks.

Finally, score marks were noted on the inner face of replacement half-frame FR 14 and original half-frame FR 24 (fig. 4.52); these marked the location of stringers and other internal timbers that would have been temporarily removed during repairs. Other occasional knife cuts on frames' inner faces are of unknown function.

Surface Treatment

Pitch was preserved on the framing to varying extents and was usually noted on all surfaces. Although generally thinner than elsewhere, the presence of pitch on the outer face of most frames is noteworthy and indicates that the outer face was coated with pitch before it was installed in the planked hull shell.[22] Pitch is generally thicker or better preserved on other faces due to multiple applications.

Figure 4.52. Thin score mark on the inner face of FR 24, near keel end.

[22] This was also the case in the framing of the late fourth- or early fifth-century Yassıada ship (van Doorninck 1976, 124).

Figure 4.53. Steeply-angled pitch drips on the forward face of F 2.

On the inner face, pitch and pitch stain can indicate the location of stringers and other internal timbers. Some of the disused inner face nails had been filled in and covered over with pitch; on replacement frames, as on FR 14 and FR 18, this indicates significant repairs to the ship on several occasions. Old cracks, damage, or holes from wood-boring insects were often filled in with pitch.

Pitch is poorly preserved on the futtocks due to their location within the hull and exposure after sinking. However, pitch drips down the forward face of F 2 reflect the steep angle of this half-frame futtock in relation to the ship's centerline (fig. 4.53).

Plank Seams

During excavation, prior to removal of framing from the wreck, plank seam lines were marked with small, stainless-steel wire pins. These proved quite helpful in matching nails on the framing with those on the planking, especially considering the discrepancies between extant planking fastener holes and those of the framing. The pins were at times misleading, due either to displacement or distortion of the planking.

The pins were often not the only demarcation of plank seam locations. On nearly every frame, one or more plank seam lines could be identified by a pressure mark, pitch stain, or, less frequently, a distinct change in the preservation of the frame's outer surface. Distinct cut marks, as from an adze or chisel, were also noted at one or more plank-seam locations on 19 of the frames (fig. 4.49). These most often occur at areas where one plank has been cut down for a repair and are common at small repairs. These cut marks were noted on several of the replacement frames, again confirming that this ship underwent a series of repair events over its lifetime. Not all of the cut marks, however, are clearly the result of the trimming of planks for repairs; some marks do not seem to occur at an area where planking was cut down and may instead indicate that damage was incurred during the recaulking of the vessel.

Problem Areas and Unidentified Fragments

While most frames may be classified as an original or a repair with relative certainty, there are problem areas. For example, both the keel as well as most of the planking appear to indicate that FR 8 was an original frame. However, score marks and a series of three predrilled and caulked holes on SS 7-1 and SS 8-1, just aft of FR 8, seem to suggest that the frame is a repair. There is a bend in the frame around the turn of the bilge, such that the frame arches forward above this point. In this case, it seems plausible that the pilot holes for FR 8 were drilled in the wrong location, the shipwright having assumed a straighter frame than was the case. These holes were then filled with caulk fibers and redrilled in the proper location. It is noteworthy that the mistakes did not continue above the edge-fastened planking, since this higher area would have been added after the frame was installed and fastened to the planking below the waterline. A similar situation may have occurred at FR 23. Again, all indications are that this frame is original, but for caulked or disused fastener holes on original planks PS 3-3 and PS 4-2. These may simply have been misplaced as FR 23 is both irregular in section and curves significantly along its starboard arm. Two other nails, on PS 3-3, were placed in the right location but, due to splitting and damage, can no longer be located on the frame.

FR 14 was originally considered to be an original half-frame but is problematic. On the basis of the location of nail holes, six planks seem to have been replaced after this frame was already in place, which indicates that this is an original frame. However, caulked or disused holes at this location on original planks SS 10-1 and SS 12-4, and wales SS 11 and SS 13, as well as a second fastener hole on the keel with no match on the frame, are strong evidence that this frame was a replacement. Nails on the inner face reveal that the frame was installed before SST 4 and SST 5 were removed and replaced on at least one occasion; however, there is no evidence on this frame that any of the lower stringers or ceiling had been removed and replaced. In sided dimension, FR 14 is slightly larger than most original half-frames and fits better with replacement half-frames; in addition, it does not exhibit the extensive splitting and cracking seen on the outer face of many of the original frames. Altogether, although questions remain, the evidence indicates that FR 14 was an early replacement.

Table 4.4. Unidentified fragments of framing found around YK 11.

Fragment Number	Wood Species	No. of Pieces	Length Remaining (cm)	Maximum Sided (cm)	Maximum Molded (cm)	Description
UM 27	*Pinus brutia*	1	48	8.1	8	Near end of ship (part of FR 26?)
UM 32	*Pinus brutia*	1	52	9	6.5	Frame end
UM 33	*Acer pseudoplatanus*	1	60	6	8	Floor
UM 34	*Acer pseudoplatanus*	4	75.5	5	7.5	Floor
UM 36	*Pinus brutia*	1	63	6.9	9	Crosses a wale
UM 38	*Pinus brutia*	2	16		8.2	From turn of bilge, near end of ship
UM 43	*Pinus brutia*	1	32	6.1	6.9	Near end of ship, crosses a wale
UM 48	*Pinus brutia*	2	50	7.7	8.3	
UM 51	*Cupressus sempervirens*	1	69.5	9.6	8.4	Top timber?
UM 52	*Pinus brutia*	1	86	10.5	8	Across turn of bilge
UM 53	*Pinus brutia*	1	87	9.2	7.8	Top timber?
UM 55	*Pinus brutia*	1	51.5	7.5	8.2	Frame end
UM 57	*Pinus brutia*	1	14.4	8		
UM 64	*Pinus brutia*	1	41	8.6	9.8	Frame end
UM 99	*Pinus brutia*	1	23.5	5.9	5.8	
UM 104	*Pinus brutia*	1	15	9	8.5	
UM 111	*Pinus brutia*	1	21	9	7.3	
UM 141	*Pinus brutia*	2	33.5	6.3	9.2	
UM 142	*Pinus brutia*	1	17.5	7	7.8	
UM 143	*Fraxinus excelsior*	1	25.5	6.7	7.7	Near one end of ship
UM 144	*Pinus brutia*	1	38.5	7.9	9.5	Near one end of ship
UM 195	*Pinus nigra*	1	17.2		6.3	Crosses keel or wale

Finally, fastening patterns on both FR 15 and FR 20 are consistent with these being original frames. However, at each of these frame locations on the keel, there is a concreted hole with no match on the frame. The purpose of these holes is unclear, but may have served some function in the initial construction of the ship.

In addition to the UM frames that were identified after excavation, there were 22 additional fragments that appear to be part of the ship's framing (or part of the framing of another ship) but which could not be matched to the nails on the YK 11 planking. An overview of these is provided in table 4.4. None of the timbers is original in length, but the original sided and molded dimensions are available in most cases. Most of these fragments are Turkish pine, and all are within the dimension range seen in the extant framing.

THE PLANKING

The planking of YK 11 is in a very good state of preservation. Approximately 50% of the hull planking was preserved, comprising 58 distinct planks in 17 strakes (table 4.5, fig. 4.54). Planking was preserved to the turn of the bilge on the starboard side and to the second wale on the port side. The majority of the planks are complete, and more than half of the extant planks and small replacement or graving pieces are both complete and intact (32 of 58, 55%). The overall condition of these planks is excellent, most exhibiting original surfaces and surface treatment, well-preserved tool marks, and caulking along plank edges. Several planks also retain their original curvature, maintained through storage on custom-built, foam-lined wooden molds constructed at the site prior to removal of each plank from the wreck.

The vast majority of planking is of *Pinus brutia*. Only two pieces are of *Cupressus sempervirens* (Mediterranean cypress), also a softwood. Both of the cypress planks were small replacement or graving pieces (SS 3-6 and SS 7-6).

Table 4.5. Overview of YK 11 planking.

Plank Number	Type	Length (m)	No. of Pieces	Maximum Width (cm)	Minimum Thickness (cm)	Maximum Thickness (cm)
PS 1	Replacement	6.09	2	17.3	2.1	3.1
PS 2-1	Replacement	3.34	1	22.3	2.0	2.7
PS 2-2	Replacement	3.36	1	17.5	1.9	2.5
PS 2-3	Graving Piece	0.37	1	4	2.0	2.4
PS 2-4	Replacement	4.85	1	24	2.1	3.3
PS 3-1	Replacement	2.53	3	23.2	2.0	2.7
PS 3-2	Replacement	5.90	2	24.6	2.3	2.9
PS 3-3	Orig. (Edge-Fastened)	2.90*	1	20.9	2.0	2.4
PS 4-1	Replacement	4.02	4	21.3	2.3	2.8
PS 4-2	Orig. (Edge-Fastened)	3.43*	1	20.7	2.1	2.5
PS 5-1	Replacement	2.98	1	26.7	2.4	3.0
PS 5-2	Replacement	2.62	1	19	2.1	2.6
PS 5-3 (UM 45)	Graving Piece	0.46	2	7.2	2.0	2.4
PS 6	Replacement (?)	1.03*	1	N/A	2.1	2.6
PS 6A (BH 1)	Replacement	0.94	1	13.1	1.9	2.6
SS 1	Replacement	5.92	3	19.9	1.9	2.7
SS 2-1	Replacement	3.54	1	20.5	2.0	2.5
SS 2-2	Replacement	3.48	1	20.6	1.9	2.4
SS 2-3	Replacement	4.66	1	33.4	2.2	2.9
SS 2-4	Graving Piece	0.27	1	5.7	2.0	3.0
SS 3-1	Replacement	4.87	1	31.2	1.9	3.0
SS 3-2	Replacement	3.48	1	18	2.1	2.4
SS 3-3	Graving Piece	0.64	1	7.2	2.2	2.3
SS 3-4	Replacement	1.68	2	13.4	1.8	2.4
SS 3-5	Orig. (Edge-Fastened)	2.73*	1	20.2	2.0	2.3
SS 3-6	Graving Piece	0.52	1	6.4	2.4	2.9

Table 4.5. Continued.

Plank Number	Type	Length (m)	No. of Pieces	Maximum Width (cm)	Minimum Thickness (cm)	Maximum Thickness (cm)
SS 4-1	Replacement	3.49	1	19	1.9	2.4
SS 4-2	Orig. (Edge-Fastened)	3.27*	1	19.8	2.0	2.2
SS 5-1	Replacement	3.30	6	15.6	1.8	2.2
SS 5-2	Replacement	2.04	1	14.8	2.2	2.4
SS 5-3	Graving Piece	0.57	1	5.8	2.1	2.4
SS 5-4	Orig. (Edge-Fastened)	3.87	2	14.9	1.9	2.6
SS 6-1	Replacement	3.49	1	16.3	2.0	2.5
SS 6-2	Replacement	0.68	4	9.5	2.0	2.5
SS 6-3	Graving Piece	0.32	1	3.5	2.3	2.4
SS 6-4	Replacement	1.12	1	10.6	2.0	2.5
SS 6-5	Unclear	0.29	1	2.2	2.2	2.3
SS 7-1	Orig. (Edge-Fastened)	2.22	1	15.7	1.8	2.1
SS 7-2	Replacement	2.00	1	17.2	2.1	2.5
SS 7-3	Orig. (Edge-Fastened)	4.05	2	13.5	1.8	2.2
SS 7-4	Orig. (Edge-Fastened)	4.73*	2	12.8	1.9	2.3
SS 7-5	Graving Piece	0.36	1	9.5	2.5	2.5
SS 7-6 (UM 31)	Replacement	0.69	1	16.2	2.3	2.4
SS 8-1	Orig. (Edge-Fastened)	3.89	1	19.6	1.8	2.2
SS 8-2	Graving Piece	0.39	1	6.1	2.1	2.5
SS 8-3	Orig. (Edge-Fastened)	4.11*	1	14.7	1.9	2.4
SS 9-1	Replacement (?)	1.85	1	16.6	2.3	2.8
SS 9-2	Replacement	1.71	1	11.9	2.5	3.1
SS 9-3	Orig. (Edge-Fastened)	4.97	5	16.8	1.9	2.2
SS 10-1	Original (?)	4.12	1	13.8	1.9	2.5
SS 10-2	Graving Piece	0.43	3	4.6	2.1	2.4
SS 10-3	Graving Piece	0.32	1	6	1.9	2.2
SS 10-4	Original	1.94*	1	12.5	2.0	2.2
SS 12-1	Original (?)	0.95	3	8.7	2.0	2.6
SS 12-2	Unclear	0.51	1	9.3	1.4	1.8
SS 12-3	Unclear	0.53	1	8.6	1.8	1.9
SS 12-4	Original	1.99	1	9	1.7	2.3
SS 12-5	Original (?)	1.84*	6	9.7	2.0	2.5
Average		2.46		14.9	2.0	2.5

* designates lengths that are not original.

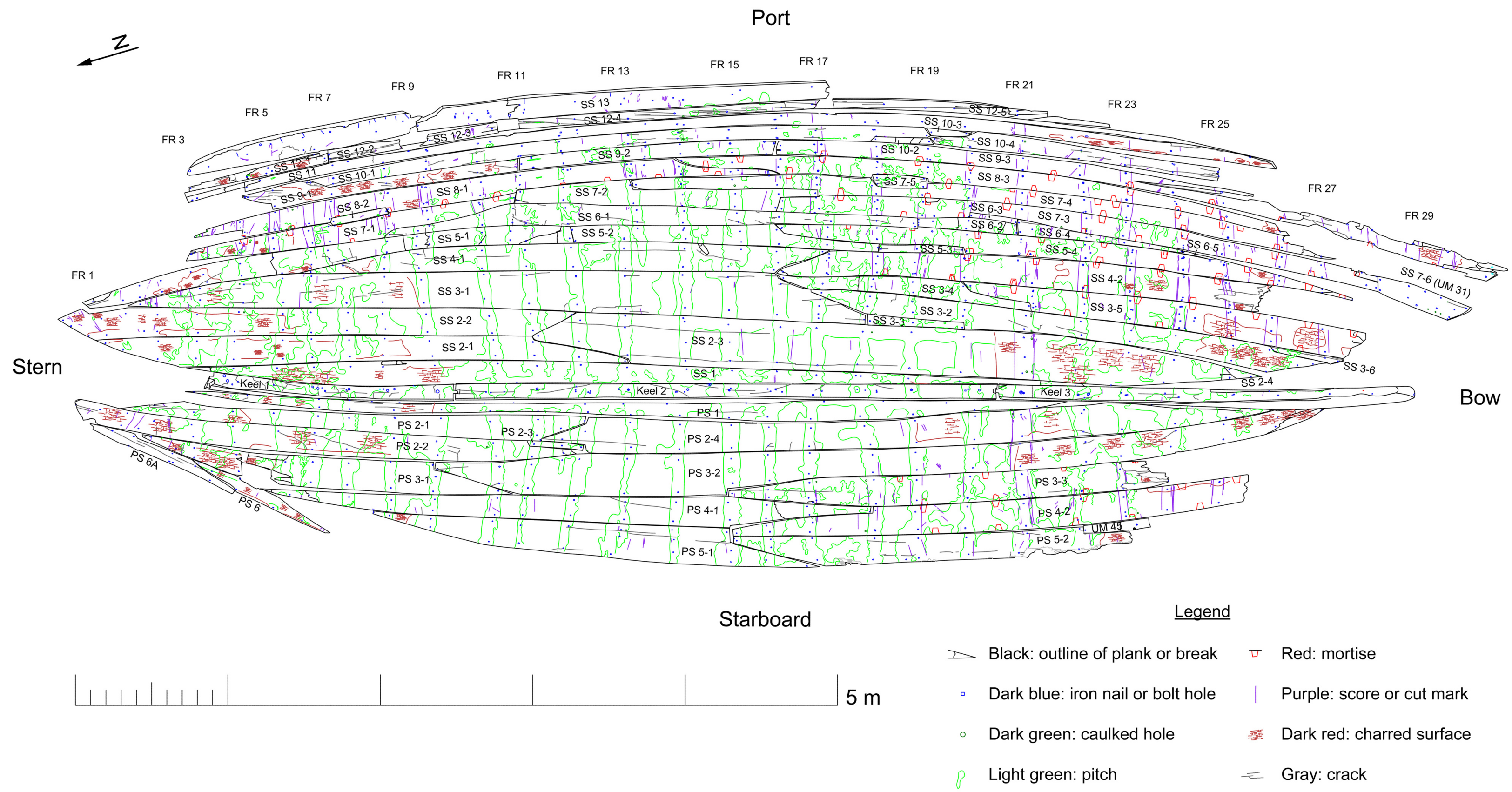

Figure 4.54. YK 11 planking, with surface detail shown.

YK 11 planking includes pieces that were part of the ship's original construction (16 of 58) and pieces that were later repairs or replacements (39 of 58) (fig. 4.18).[23] Whether a plank is an original or repair piece is determined through several factors, the most important being the matching of fasteners on each plank with each extant frame. Both types of planking may be further divided into two subtypes. Original planks include planks edge-fastened with mortise-and-tenon joints and planks above the waterline that were not edge-joined. Repair or replacement planks include both graving pieces which fill a (usually) small gap along one edge of a strake and larger replacement pieces that span the width of an entire strake.[24]

Strakes were labeled from the keel to the top, with port strakes labeled SS 1, SS 2, etc. and starboard strakes PS 1, PS 2, etc.[25] Within each strake, discrete planks or graving pieces were given a separate number based on their position in the strake, moving from inboard to outboard (where necessary) and aft to forward. For most strakes, this was fairly straightforward; for example, plank SS 4-1 was aft of plank SS 4-2. However, four of the strakes, SS 2, SS 3, PS 2, and PS 3, consisted of one wide plank scarfed to two narrower planks at the opposite end, necessitating an odd numbering

[23] Three planks are of indeterminate status. These ratios represent the relative number of distinct pieces rather than the area covered by the repairs or replacement timbers. Furthermore, these do not necessarily represent the original ratio of original-to-repair pieces, as the upper portion of the hull, which is less extensively preserved, is often far less repaired than the bottom of the hull, as is evidenced by the ship's framing.

[24] There are admittedly graving pieces that are somewhat difficult to categorize; SS 2-4, for example, technically covers the width of strake two at its forward tip, but it is classified as a graving piece due to its size and position. SS 6-5, although of unclear status, is a small piece, lacking mortise-and-tenon joints, below the waterline; as such, it is grouped with the graving pieces. It may, however, be a small fragment of an original plank.

[25] Strakes SS 11 and SS 13 are port-side wales. The labeling using PS and SS was begun during excavation in 2008, when the bow and stern had been reversed, hence the association of PS with (what has been found to be) the starboard side, and SS with (what has been found to be) the port side.

system.[26] For example, the aftermost, furthest inboard plank on strake SS 2 was labeled SS 2-1, while the plank outboard of this was SS 2-2 and the wide forward plank SS 2-3 (see fig. 4.54). Graving pieces which spanned a strake seam, such as SS 7-5 and SS 8-2 (both along the SS 7-SS 8 seam), were grouped with one of the strakes along that seam.

Edge-fastened Planking

Small, unpegged mortise-and-tenon joints are present on the ship's original planking below the waterline. These planks were those most easily recognized as original elements of the ship's construction, a designation confirmed through analysis of fastening patterns on associated frames. Eleven such planks were preserved, two on the starboard side, PS 3-3 and PS 4-2, and nine on the port side, SS 3-5, SS 4-2, SS 5-4, SS 7-1, SS 7-3, SS 7-4, SS 8-1, SS 8-3, and SS 9-3. Only two of these planks, SS 7-1 and SS 8-1, are located in the stern, reflecting more extensive repairs in this area, perhaps due to repetitive beaching of the vessel. The edge fastening ceased above strake eight in the stern and strake nine in the bow (with the transition between the two near amidships); both SS 8-1 (stern) and SS 9-3 (bow) have mortise-and-tenon joints along their lower edges but not along their top edges.[27] Otherwise, all other planks with mortise-and-tenon joints have mortises cut along both edges.

<u>Condition</u>

Although most of the edge-fastened planking is very well preserved, only five of the 11 are complete, and only two of these are intact. Breaks on extant planks are

[26] A similar scarfing of two planks to a third at one scarf was noted on the late fourth- or early fifth-century ship at Yassıada (van Doorninck 1976, 121).
[27] The plank directly above SS 9-3, SS 10-4, is an original plank lacking edge fasteners; this proves that the transition away from edge fasteners occurred at this area. Edge fastening ceased in a similar manner on the seventh-century Yassıada ship, with mortises along one edge only (Bass and van Doorninck 1982, 59).

relatively uncommon, with most of the planks either intact (although incomplete) or with small fragments broken off. Planks that are broken are usually in no more than two pieces. Cracking, where present, runs along the wood grain and is often associated with nails; the wood of these planks is usually quite solid.

Most of the damage to these planks is limited to minor surface damage; there is occasional dry rot at frame locations. Damage from *Teredo navalis* was observed on all of the edge-fastened planks, most commonly at broken ends and along edges, especially at mortises. The prevalence of teredo damage at mortises necessitated the odd form of repairs and graving pieces that fill areas cut down between two or more mortises.

Dimensions

With the exception of length, original dimensions are available for all edge-fastened planks. Compression is relatively uncommon, occurring only at some frame positions; these areas were generally avoided when recording dimensions. On average, the edge-fastened planks are 1.9-2.3 cm thick and 13-21 cm in maximum width (average 17 cm). Original lengths are more difficult to ascertain, first because so few of these planks are complete, and second because even complete planks, such as SS 7-1 and SS 7-3, appear to have been cut down for repairs. Preserved lengths are 2.22-4.97 m.

In section, the edge-fastened planks are generally flat on the inner face; edges are either perpendicular or have a very slight bevel to either direction. The lower edge of SS 5-4 has a distinct (0.5-1.0 cm) outward bevel along the aft scarf edge, while the top edge of that plank has a notable inward bevel at the tapered forward tip.

Where discernible, the pith of the original timber is variable, sometimes closer to the inner, sometimes closer to the outer face, with relatively the same probability of either. In most cases, the planks seem not to have been cut from the center of the tree (i.e., the pith is not within the plank); the only exception to this is SS 8-1. Almost all of these original edge-fastened planks were placed so that the direction of growth was toward the ship's bow; a similar orientation was noted on the planking of the Ma'agan Mikhael ship.[28]

Scarfs and Butts

Due to extensive repairs to the ship's planking, scarf ends show a great deal of variation. Curved (S) scarfs, three-planed (Z) scarfs, and butt joints are represented in the edge-joined planking, with one plank, SS 5-4, terminating in a thin, tapering point (drop strake, original form). The forward ends of SS 8-3 and (perhaps) SS 7-4 also taper in this manner but are not fully preserved.

Only one original scarf has been preserved in the edge-fastened planking, the gently-curving S-scarf between SS 8-1 and SS 8-3, located around amidships (FR 14-FR 16); it is 69 cm in length (fig. 4.55). The SS 8-3 tip was nailed to FR 14, while the SS 8-1 tip was just slightly shy of FR 16 for fastening; instead, this tip was fastened to SS 7-4 with a transverse iron nail. SS 8-1 and SS 8-3 were also joined along the scarf edge by a mortise-and-tenon joint along the central (flat) portion of the scarf. SS 4-2 also terminates in a slightly-curving S-scarf at its aft end; however, rough cutting, a lack of

[28] Hillman and Liphschitz 2004, 152.

edge fasteners, and the adjoining plank all indicate that the original aft end of SS 4-2 was roughly cut down to accommodate plank SS 4-1.

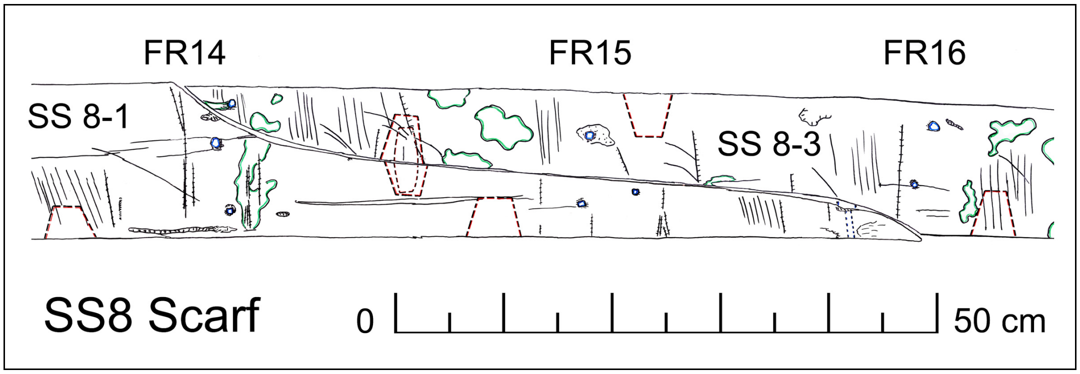

Figure 4.55. S-scarf on SS 8.

Rough, irregular butt joints are present on four of the edge-fastened plank ends. These joints were cut at frame locations and accommodate replacement planks; they are often cut at a slight angle. PS 3-3 is tapered toward its aft end before terminating in a short butt joint. The tapered edges accommodated the surrounding replacement planks; this created irregularities in the seam lines of the starboard side.

Six of the original edge-fastened plank ends comprise a three-planed (Z) scarf but vary greatly in length and angling. The shortest, at the aft end of SS 8-1, spans only two frames (35 cm). Much longer scarfs are present at the aft ends of SS 5-4 and SS 7-4, with each scarf over 1.20 m in length and spanning five frames. The aft scarf of SS 5-4, however, was likely originally much shorter and only covered three frames, prior to the addition of graving piece SS 5-3. In contrast to the smooth lines of the original SS 8 curved scarf, the irregular, clumsy nature of both the butt joints and the three-planed scarfs betray their identity as new cuts to accommodate later repairs.

Strake End Details

There is only one hood end preserved on the original, edge-joined planking, SS 9-3 (fig. 4.56).[29] The hood end is cut with a slight bevel (110°), and the forward end is at an angle of 142° to the lower edge. There are two drilled holes for nails near the edge, and a damaged area that probably held a third iron nail.

Figure 4.56. Forward hood end of original plank SS 9-3.

[29] The forward lower edge tip of SS 3-5 might also be a small part of the hood end; most of this original end was not preserved.

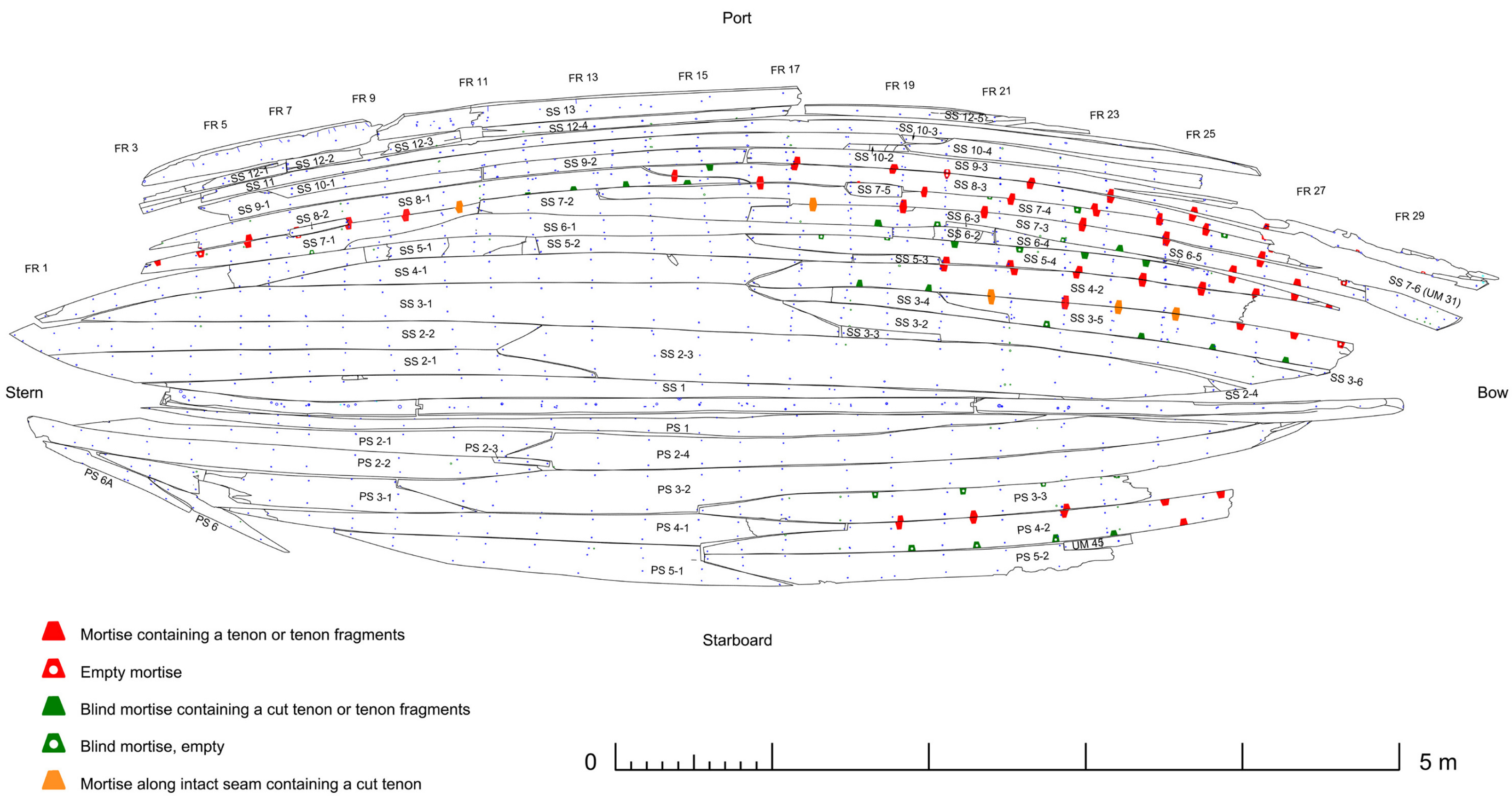

Figure 4.57. YK 11 mortise-and-tenon joints.

Table 4.6. Overview of YK 11 mortise-and-tenon joints.

Description	Number	Percent of total joints (out of 87)
Total number of mortise and tenon joints*	87	100
Mortises with some trace of a tenon (intact, half, fragments)	61	70
Tenons still intact during excavation	6	7
Tenons sampled for wood-species identification	49	56
Mortises with no trace of a tenon	26	30
All blind mortises (including those with cut tenons)	32	37
Blind mortises with no trace of a tenon	18	21
Blind mortises containing a cut tenon	10	11
Blind mortises with part of a tenon that appears broken	4	5
Total number of cut tenons	18	21
Cut tenons along intact (unrepaired) seams	5	6
Cut tenons at which facing plank was not preserved	3	3

*Total includes all evidence of a mortise-and-tenon joint, including blind, cut-down, misplaced, and damaged mortises as well as intact mortise-and-tenon joints along original seams. An intact mortise-and-tenon joint or one at which both halves are preserved to any extent is counted only once.

Mortise-and-Tenon Joints

The 11 extant edge-fastened planks retained evidence of 87 mortise-and-tenon joints (table 4.6, fig. 4.57). Mortises are chisel-cut and 3.3-6.1 cm in width, with an average width of 4.7 cm.[30] Mortises are 0.35-0.6 cm thick, with an average thickness of 0.47 cm.[31] A typical mortise-and-tenon joint is shown in figure 4.58. Depths of mortises vary significantly due to both rough cutting of the mortise as well as the relatively common trimming of plank edges to accommodate repairs; recorded depths range from

[30] Narrower widths are not representative of the original width of the mortise at the plank edge. Rather, such mortises were located along plank edges that had been trimmed. Widths vary along the depth of the mortise due to the angled cuts along the sides.

[31] A mortise thickness of 0.47 cm is surprisingly close to the mortise (and tenon) thickness used in the late fourth-century B.C. shipwreck found at Kyrenia off the coast of Cyprus; these had an average thickness of just 0.55 cm, but tenons were much longer, wider, and fit the mortises more snugly. Steffy 1985, 81.

2.6 to 4.7 cm, with an average depth of 4.0 cm. Despite being nearly twice the size of YK 11, the seventh-century shipwreck at Yassıada, Turkey, exhibited nearly identical dimensions on its mortises, with an average width of 5 cm, depth of 3.5 cm, and thickness of 0.5 cm.[32]

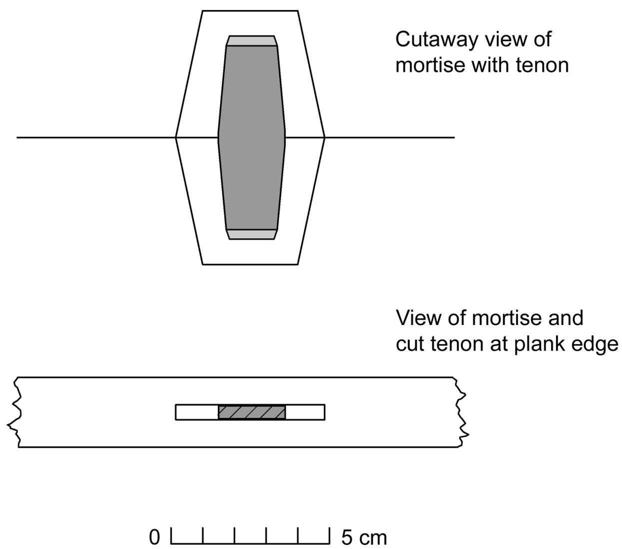

Figure 4.58. Typical mortise-and-tenon joint of YK 11, based on average dimensions. Tenon is shaded in gray.

Although uncommon, broken plank surfaces reveal that the mortises of YK 11 were cut at an angle (fig. 4.59), such that the back wall of the mortise was narrower than the opening along the plank edge. An exposed back wall of a mortise on PS 3-3 further reveals that the mortises were relatively roughly cut, with jagged, irregular back walls. Tool marks at this exposed mortise, combined with what appears to be the profile of a

[32] Bass and van Doorninck 1982, 55.

mortising chisel visible at a break in the top edge mortise of SS 3-5 at FR 27-FR 28, indicate a mortising chisel 0.45 cm thick, beveled to its tip (see App. A). Width of the mortising chisel is somewhat more difficult to ascertain; difficult-to-interpret marks in mortises at exposed or broken areas indicate that it could be as little as 0.5 cm or slightly wider, perhaps 1-2 cm. It is possible that more than one type of chisel was used in cutting these mortises.

Figure 4.59. Exposed mortise along the top edge of SS 7-4. Note angled cuts to edges (arrow).

The spacing between mortises is highly variable, from 28 to 65 cm, with an overall average spacing of 45 cm. When analyzed on the basis of each individual plank seam, average spacing between mortises is smallest along SS 3-5 to SS 4-2 (average 39.5 cm), SS 4-2 to SS 5-4 (41.9 cm), SS 7-3 lower edge (37.5 cm), and SS 7-1 to SS 8-

3 (34.2 cm) seams. Average spacing is greatest along PS 3-3 lower edge (52.3 cm), PS 3-3 to PS 4-2 (52.3 cm), SS 3-5 lower edge (52.7 cm), and SS 7-3 to SS 7-4 (58.3 cm) seams. This suggests that edge fasteners were spaced more closely together around the turn of the bilge, but this does not seem to have been done consistently.

When analyzed by area of the hull rather than by plank seam, spacing between mortise-and-tenon joints is least along the aft one-third of the ship, between FR 1 and FR 13 (average spacing 34 cm). Because mortise-and-tenon joints are only preserved along one seam between FR 1 and FR 13, and this seam is near the turn of the bilge, the short spacing here may not be representative of the stern in general. Spacing increases around amidships to an average of 42 cm between FR 13 and FR 17. Forward of this point, spacing between edge fasteners increases to an average of 47 cm (FR 18-FR 30).

Although little of the original planking is preserved along the bottom of the hull at amidships, there are no edge fasteners between FR 15 and FR 18 on the original planking up to the turn of the bilge. Based on a long stretch of original plank edge along the top edge of PS 4-2 and the lower edge of SS 4-2, it appears that edge fasteners were spaced farther apart around amidships. Without more original planking in this area, however, the edge-fastener spacing patterns remain unclear.

The mortises were cut into the planks without the aid of drilled pilot holes along the mortise edges. Although mortises could be cut more quickly without pre-drilling holes, they were more easily damaged, with the wood to either side of the mortise frequently split (fig. 4.60). Fibrous or irregular edges also indicate that the mortises were chisel-cut without the aid of starter pilot holes.

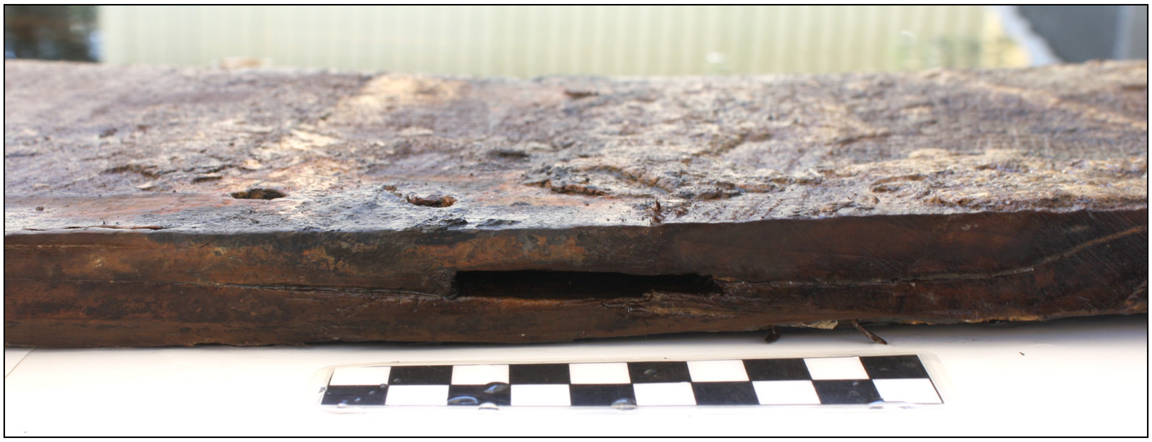

Figure 4.60. Splits from edges of a mortise on the top edge of PS 3-3 at FR 22.

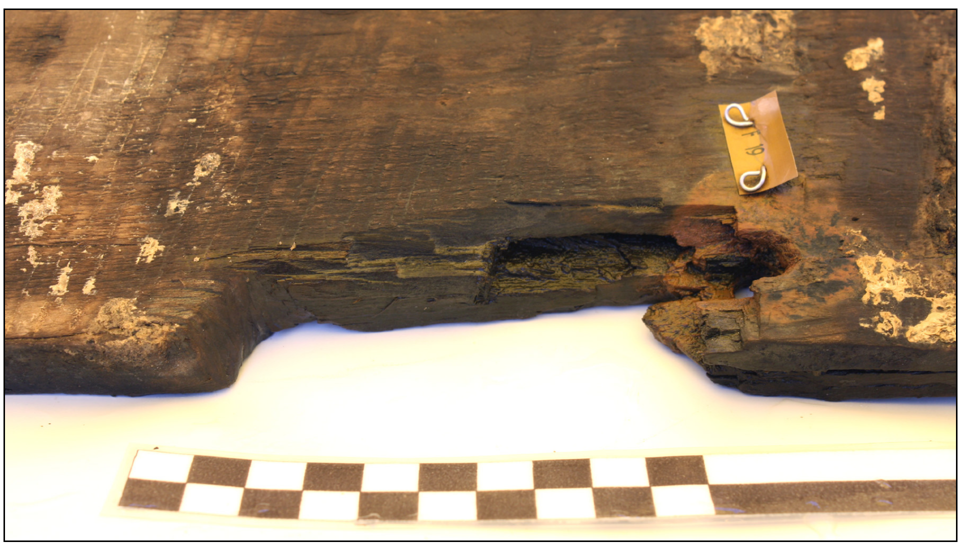

Figure 4.61. Damaged mortise on the top edge of SS 7-3 at F 19. The damaged area was cut out and replaced with thick, grassy caulking.

Due to the large number of replacement strakes and graving pieces, many of the ship's mortise-and-tenon joints were no longer functional by the time the ship was abandoned. On plank seams in which the facing plank was a replacement, the mortises of the original plank were left "blind", either containing a cut or broken half-tenon or fragments of a tenon, or having been filled in with pitch, with or without caulking fibers. Of the 87 mortises identified on YK 11, 32 (37%) were blind, lacking a corresponding mortise on the facing plank (table 4.6, fig. 4.57). Even on seams for which both original planks are preserved, damage, often from *Teredo navalis*, had led to the cutting out of some mortise-and-tenon joints, subsequently replaced with wads of caulking (fig. 4.61) or a graving piece. Mortises were also cut down on the edges of original planks in order to accommodate replacement planks; this has led to some unrepresentative variation in mortise width and depth, noted above. Damage to mortises due to coincidental placement of nails is not uncommon; such damage was also noted in the hull planking of the seventh-century Yassıada ship.[33]

Whenever possible, tenons or fragments thereof were removed from the mortises. Samples of 49 tenons were submitted for wood-species identification; of these, all were oak, with the vast majority (43 of 49, or 88%) being *Quercus coccifera* (Kermes oak). The remaining tenons are either *Quercus cerris* (four tenons) or *Quercus petraea* (Sessile oak, one tenon).[34] Only five intact tenons were recovered from the shipwreck (fig. 4.62); an additional two were complete but not intact. The complete tenons have an average length of 6.4 cm. Measurements were also recorded from 59 additional tenon fragments, including some tenon halves that were wedged tightly in plank mortises and were not removed. These measurements indicate an average width of 2.1 cm, quite narrow in comparison to the mortises, which were on average more than twice as wide

[33] Bass and van Doorninck 1982, 59.
[34] One tenon could only be identified as *Quercus* sp.

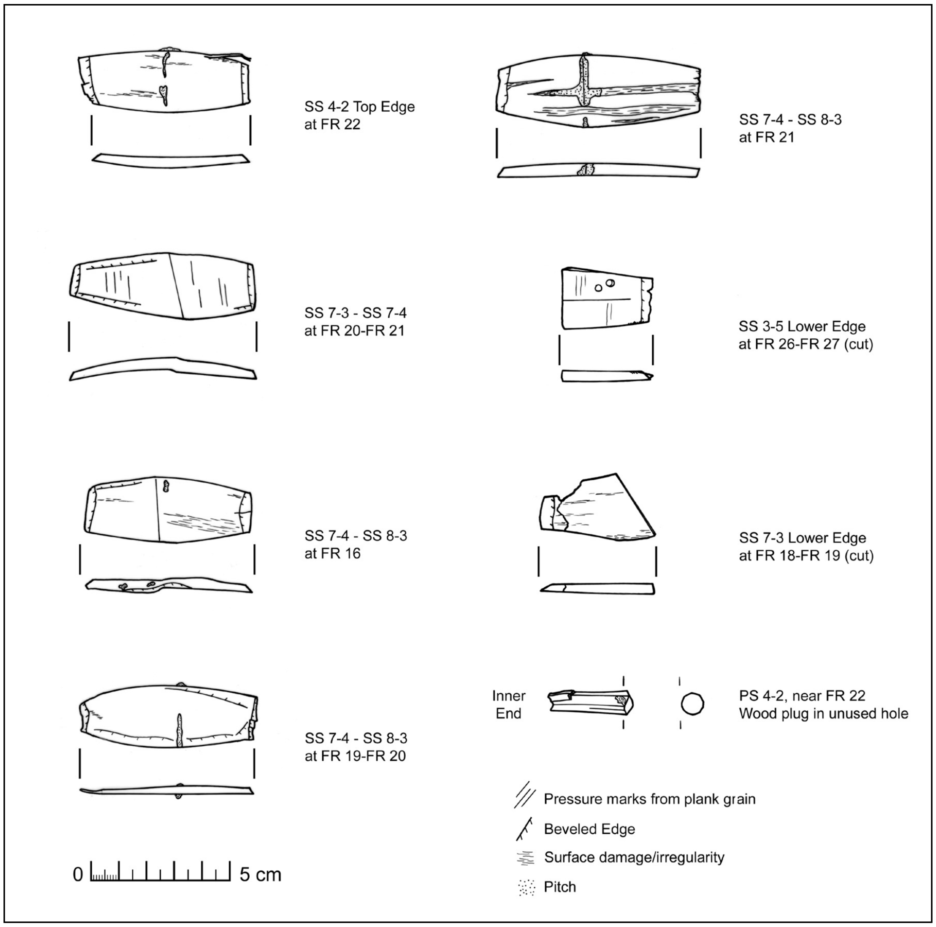

Figure 4.62. Intact and cut tenons from YK 11 edge-fastened planking. The small wood plug on the lower right sealed an abandoned fastener hole.

(4.7 cm).[35] The average half-length of the tenons (that is, the length of the cut or broken half-tenons removed from mortises) is 3.1 cm, again less than the average mortise depth of 4.0 cm. Based on average dimensions, tenons only occupied 32% of their respective mortises (fig. 4.58).[36] The average thickness of tenons, however, is only 0.41 cm, approximately half of a millimeter thinner than the average mortise thickness (0.47 cm).

[35] Loose-fitting tenons were also noted on the seventh-century Yassıada ship's planking (Bass and van Doorninck 1982, 55).
[36] The volume of an average pair of mortises is 14.48 cm^3, while the volume of an average tenon is just 4.63 cm^3.

Thus, while tenons had plenty of play within the mortises in terms of width and depth, they were often wedged tightly in place. Well-preserved mortise-and-tenon joints indicate that much of the remaining space along the sides of the mortise was filled in with pitch and caulk-like fibers.

Figure 4.63. Oblique view of intact tenon at SS 7-3-SS 7-4 seam at FR 20-FR 21. Note beveled tip and narrowing of tenon toward ends.

Tenons are widest around the plank seam and taper toward the ends (average width at ends is 1.5 cm.) They taper slightly in thickness as well, to an average of 0.33 cm near the end; from this slightly diminished thickness, the tenon is then beveled down to a thin tip (fig. 4.63), with bevels on average 0.3 cm in length. In very few cases, this end bevel is omitted and the tenon terminates in a blunt end. On six of the seven complete tenons, the bevels are on the same face.

Tool marks are very rarely preserved on the tenons; preserved tool marks and the tapered form of the tenon both suggest whittling with a sharp knife. Pitch is present in patches on several tenons, usually along the plank seam, but sometimes as sparse patches elsewhere (fig. 4.64). A sharp pressure line or pitch ridge denotes the location of the plank seam on all of the intact tenons. As illustrated in figure 4.62, three of the five intact tenons were bent or distorted along the plank seam.

Figure 4.64. Tenon cut at an oblique angle. From SS 5-4 top edge at FR 20. Note pitch near plank seam edge, bevel at tip, and pressure marks from the plank.

Of the 87 extant mortise-and-tenon joints, 18 (21%) held a tenon (or fragments thereof) that had been cut through along the plank seam. Ten of these were found in blind mortises, indicating that the tenons were cut to facilitate a repair, but five of the cut tenons are located along original, intact seams.[37] It is unclear why such tenons would have been cut, but this may have been associated with recaulking the vessel: the tenons were likely first cut through with a knife before a caulking iron was used to drive waterproofing material into the plank seam. Four of the cut tenons were at an angle within the mortise when cut, as evidenced by their oblique cut line (figs. 4.62, 4.64). The

[37] The remaining three cut tenons are at places where the facing plank was not preserved.

tight fit of the tenons within the mortises (in terms of thickness) complicated their removal and, at times, led to pressure damage on the face of the tenon reflecting the wood grain of the plank, also seen in figure 4.62.

Problem Areas

There are two places in the edge-fastened planking where the mortise-and-tenon joints do not align as expected, both on SS 7-4. On the upper edge of SS 7-4, there are three empty mortises with no match on the facing plank, SS 8-3. These appear to be mistakes, cut either just forward (F 25) or just aft (FR 21-FR 22, FR 22-FR 23) of the functioning mortise (fig. 4.65). Spacing between these blind, misplaced mortises and the functional mortise is 8-12 cm. While the widths and thicknesses of the misplaced mortises are commensurate with those of other mortises, the depths of two of them are much shallower, suggesting the shipwright realized his mistake before completing the mortise to its usual depth. This is not surprising in the mortise at FR 21-FR 22, which may have been re-cut after it was cut too close to the plank's outer face.[38] It is less than half the depth of the functioning mortise (1.6 and 3.5 cm, respectively.) The blind, misplaced mortise at F 25 was only 2.8 cm in depth, while the functioning mortise was about 50% deeper (4.3 cm). The deepest of the misplaced mortises, that at FR 22-FR 23, was filled in with pitch.

[38] If this is indeed the case, then mortises would have first been cut in the top edge of SS 7-4 before being cut in the lower edge of SS 8-3. This seems to contradict the sequence suggested by other evidence along this seam.

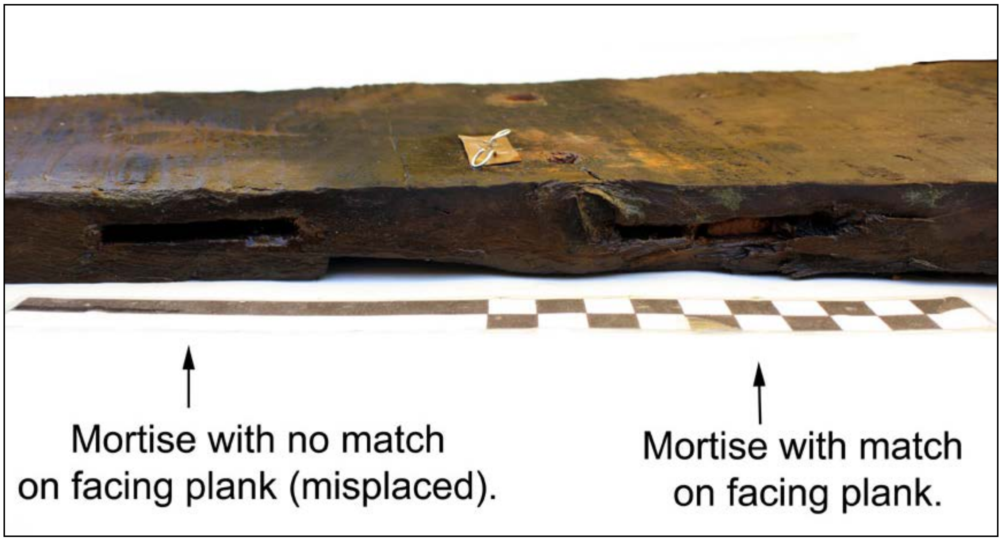

Figure 4.65. Mortises on the top edge of SS 7-4 near F 25.

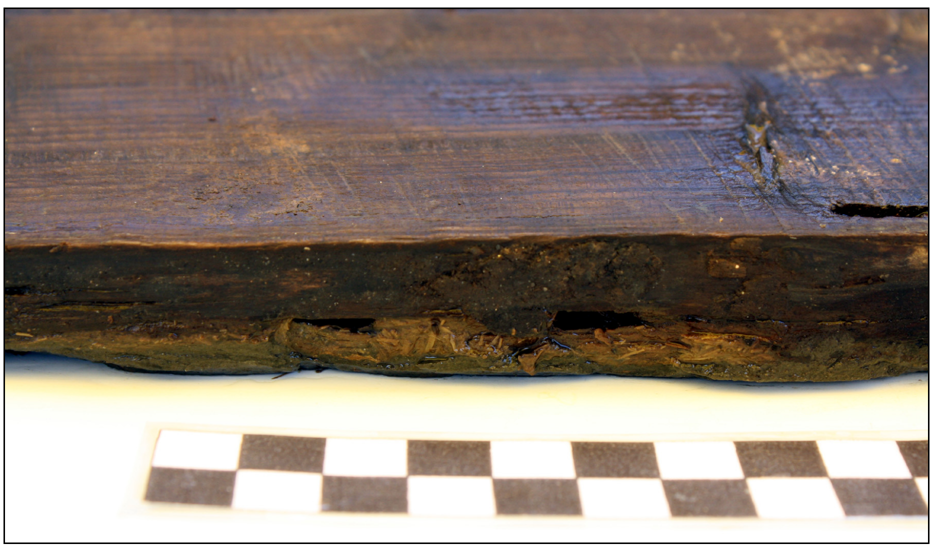

Figure 4.66. Cut and caulked-over tenon on the lower edge of SS 8-1 at FR 13-FR 14. There is no corresponding mortise on the top edge of SS 7-4, also an original plank with mortise-and-tenon joints.

In addition to these blind, misplaced mortises, there are two mortises along the lower edge of SS 8-1 between FR 13 and FR 15 that have no corresponding mortise on the top edge of SS 7-4. In both of these mortises, there is a tenon half that had been cut through and caulked over (fig. 4.66). SS 8-1 is attached to SS 8-3 with a mortise-and-tenon joint along the scarf edge, and all of the lower edge mortises on SS 8-3 have a matching mortise on the top edge of SS 7-4. The most plausible explanation for these two blind mortise-and-tenon joints along an original, intact seam is that the shipwrights, focusing on cutting the mortises that matched SS 8-1 in the top edge of SS 7-1, forgot to cut the mortises along the top edge of SS 7-4 which overlapped with SS 8-1. Upon installing SS 8-1, they realized this mistake and cut off the tenons protruding out of SS 8-1's lower edge then caulked over the disused joint. The transverse nail fastening the tip of SS 8-1 to the top edge of SS 7-4 confirms that SS 7-4 was in place when SS 8-1 was installed.

The missing mortises near the aft end of SS 7-4's upper edge suggest that the mortises were first cut into the lower edge of the plank to be installed, then cut into the plank that was already in place on the ship.[39] The presence of tenons in the blind mortises on SS 8-1's lower edge furthermore suggests that the tenons were fitted into the mortises of the plank to be installed, then guided down into the top edge mortises of the plank that had already been fitted. The misplaced mortises on SS 7-4's top edge, in contrast, could have been cut either before or after the mortises on the lower edge of SS 8-3 were cut; that the mortises were re-cut on the lower rather than the upper plank may simply be due to ease of cutting based on the plank's position.

[39] If the opposite were the case, the shipwrights would have noticed the lack of mortises in the top edge of SS 7-4 when they measured distances for cutting mortises on SS 8-1. In contrast, on the early fifth-century Dramont E ship, the mortises were cut into the top edge of the lower plank before being cut into the lower edge of the next plank to be added (Santamaria 1995, 143).

Frame Locations

Frame locations are usually indicated by one or more of the following features: holes from nails, caulked or pitched holes from abandoned fasteners, pitch lines or stains, score marks, pressure marks, and (less commonly) dry rot.

Figure 4.67. Score marks on PS 3-3 at FR 21. Differentiating between saw marks and score or other cut marks was facilitated through the use of raking light. Score marks here are denoted by arrows.

Score marks along one or both edges of a frame are present at nearly every frame location on the original edge-fastened planking.[40] These score marks seem to have been cut with a scriber or other sharp blade. They can be faint and difficult to identify,

[40] Similar marks were identified on the planking of the seventh-century Yassıada ship (Bass and van Doorninck 1982, 59) and the fifth-century B.C. Ma'agan Mikhael ship (Mor 2004, 167-68).

especially if saw marks run in a similar orientation (fig. 4.67). Some score marks, especially those at charred areas near the ship's extremities, are wider and deeper, possibly cut with a different tool than the thinner score marks (fig. 4.68). Perhaps a different tool was needed on the harder, charred surfaces, or perhaps the nature of the charred wood caused the marks to be better preserved.

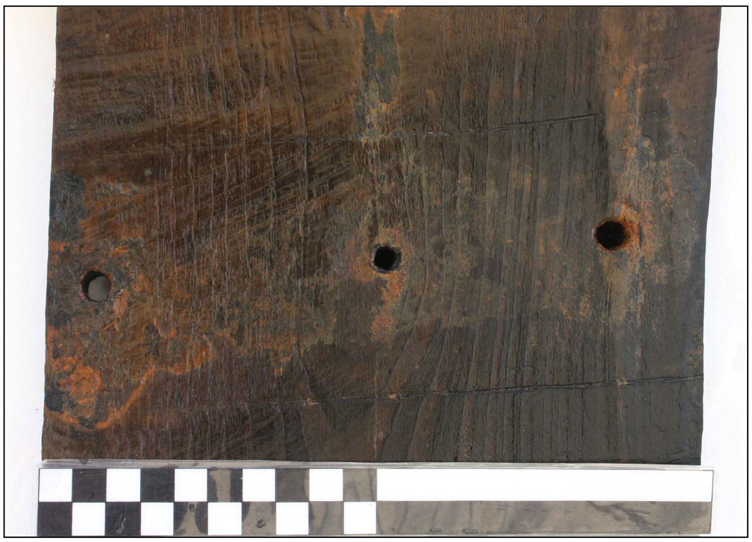

Figure 4.68. Score marks along the forward and aft edges of FR 26 on SS 3-5.

There are several areas where multiple score marks have been cut along one frame edge. These score marks may highlight a discrepancy in placement between an original and a replacement frame. On SS 7-1 and SS 8-1, score marks at an original futtock location are partly obliterated by later adzing, while score marks at the replacement for that futtock, aft rather than forward of the floor, cut across any previously adzed area (fig. 4.69). Comparison of score marks may also indicate whether a framing element had been replaced or not, even though the frame itself is not preserved. This is the case at both FR 20P and FR 24P, which have score marks along frame edges at original planks but none at replacement planks; this suggests that these half-frames were original.

Figure 4.69. SS 8-1 at FR 5-FR 7. The charred inner face of the plank is adzed down at the original location of futtock F 5; note lighter color at adzed area.

Pressure marks at frame locations are relatively uncommon on the edge-fastened planking. These tend to occur toward amidships and along the lower planking rather than at the extremities or above the turn of the bilge. A lack of pressure damage at frames at the ship's extremities might again be related to the charring of plank surfaces here, which has created a harder wood, or may also be due to minimized flexing of the hull at the ends. Although rare, there does seem to be some surface unevenness indicative of dry rot on some of the edge-fastened planks. The relative lack of dry rot might be due to the wood type used; Vitruvius describes pine as a wood that is resistant to rot.[41]

Original Planking above the Waterline: Strakes Ten and Twelve

Original planking above the waterline, lacking edge fasteners, was preserved only on the port side in strakes SS 10 and SS 12. Being so high up on the hull, fewer frames were preserved here; this, combined with a lack of preserved planking above wale SS 13, makes a positive identification of these planks, as either original or repair, more difficult. After analyzing the features of these strakes and matching fastener holes to extant elements of framing, it is clear that SS 10-4 and SS 12-4 were part of the ship's original construction. SS 10-1, SS 12-1, and SS 12-5 are less clear. SS 10-1 has conflicting features, but the preponderance of the evidence seems to indicate an original plank.[42] Although few futtocks are preserved at SS 12-1 and SS 12-5, what little evidence that exists points toward both of these pieces being original. Thus, in total, there are five extant planks above the waterline that are original or likely so.

SS 10-2 and SS 10-3 are graving pieces used to repair damage at the SS 10-1 to SS 10-4 scarf and are discussed below. SS 12-2 and SS 12-3 are the only two pieces in these strakes for which a designation of original or repair is impossible. None of the extant frames is fastened to either of these short pieces, both of which are approximately

[41] Vitr. *De arch* 2.9.12.

[42] SS 10-1 has caulked holes in several locations, suggesting it is original, but lacks some holes (fastener holes?) that are present on framing, which would in contrast suggest that it is a repair. The general wear to this plank, the nature of the fasteners, and the presence of a small repair at its forward end all point toward SS 10-1 being either original or a fairly early repair. If it was original, it may have been scarfed to SS 10-4 with a long, curving S-scarf approximately 70 cm in length, not unlike that seen in the original scarf at SS 8-1 to SS 8-3. Alternately, it may have been a shorter S-scarf, 32 cm in length; note the downward curve at the aft tip of original plank SS 10-4.

50 cm in original length. As part of SS 12, the thin strake of planks that filled the gaps between through-beams, they will be discussed in this section.

UM 110, which was found in close proximity to the broken forward end of SS 12-5, may in fact be a sixth plank in strake twelve. In form, dimensions, and surface detail, it is consistent with a plank that abutted a through-beam, and its in-situ location suggests it abutted the forward face of a through-beam located between FR 23 and FR 24. As such, it will be discussed here; however, because its location and status as original or replacement cannot be confirmed due to a lack of preservation, it will not be conclusively grouped with the ship's planking.

Condition

The original planking above the waterline is in a very good state of preservation. Most of the planks were found in or near their original locations. Wale SS 11 had slipped down behind the top edge of SS 10, exposing this entire edge. Pressure marks from barnacles on the inner face on several planks of SS 12 as well as UM 110 confirm exposure of this part of the hull after it was submerged.

Four of the seven planks, SS 10-1, SS 12-2, SS 12-3, and SS 12-4, are complete (or very nearly so) and intact, while SS 12-1 is also nearly complete but had broken into several pieces. Neither SS 10-4 nor SS 12-5 are complete, both having broken at their forward ends. SS 12-5 exhibits the worst preservation of the original planking above the waterline; the soft wood is structurally weak and has broken or cracked in several areas. The top edge was exposed for some time after sinking, and damage from *Teredo navalis* is evident within breaks.

Figure 4.70. Caulk wad stuffed in split at aft end of SS 12-4, outer face.

Figure 4.71. Gap between SS 12-2 and SS 12-3 for FR 8-FR 9 through-beam; inner face shown.

Most of the other planks of this type are relatively solid; cracking is usually associated with nails, and damage from teredo or gribble may be present in areas that were exposed after sinking. Both SS 10-4 and SS 12-4 have areas of old damage that were either filled in with pitch or stuffed with caulking fibers (fig. 4.70). Splits or cracks that emanate from the blunt-cut ends, often running through a nail hole, are present on each plank in SS 12. Wear or damage on several of the plank ends in this strake seems to be associated with their abutting a through-beam (fig. 4.71).

Dimensions

Although original length is available for five of the seven planks, there is a great deal of variation. Intact plank SS 10-1 is the longest, at 4.12 m in length, while the short planks that comprise SS 12 are 0.51-1.99 m in original length. Original widths and thicknesses are preserved on all of these planks; compression at frame locations was only noted on SS 10-1.[43] Thicknesses were relatively uniform. SS 10 planks are 9-14 cm in width, generally tapering toward the extremities, and 1.9-2.5 cm in thickness. SS 12 planks are both narrower and slightly thinner than other strakes. In width, they are 6.5-9.7 cm (on average 8-9 cm), and slightly thinner than other strakes, with an average thickness of 1.8-2.3 cm. Shorter segments SS 12-2, SS 12-3, and UM 110, which is probably another fragment of SS 12, do not exceed 2.0 cm in thickness and in some areas are as little as 1.5 cm.

Examination of the wood grain shows that the pith of the timber was usually closer to the plank's inner face; there were usually 15 or fewer annual rings visible. SS 12-5 is the only plank on which the pith was closer to the outer face, and the natural surfaces visible on the inner face of the plank confirm that it was cut from near the outer part of a young trunk. With the exception of the natural surfaces on SS 12-5, most of the original planking above the waterline has flat inner and outer faces. The lower edges of all of the planks angle slightly inward, reflecting a gentle curvature to the hull, while

[43] The compressed areas, with unrepresentative thicknesses, were avoided during recording.

most of the top edges have no consistent bevel.[44] The angling is more intense along the lower edges of SS 12-4 and SS 12-5.

Scarfs and Butts

SS 10-1 and SS 10-4 were originally joined with an S-scarf; however, both of the ends of this scarf were cut out and replaced with short graving pieces SS 10-2 and SS 10-3. The aft end of SS 10-1 terminates in a short diagonal scarf that fits into a deep recess cut out of SS 9-1; since SS 9-1 is a repair, however, it is unclear whether this was the original form of SS 10-1's aft end or if it was cut down during a repair.

The planks that comprise SS 12, including UM 110, terminate in butt joints in varying degrees of preservation. SS 12-1 joins SS 12-2 in a butt joint at a very slight angle, while the remaining original ends butted up against through-beams.[45] Based on the one extant fragment of a through-beam, these were recessed to receive the blunt-cut ends of strake twelve, and pressure marks or discoloration on the outer or inner faces of these ends reflect the form of the through-beam (fig. 4.72). Damage at these ends is also relatively common (fig. 4.71).

Frame Locations

The most reliable indicators of frame location on the planks above the waterline are holes from nails, both used and disused. The lack of any nail or indication of a nail, such as iron sulfide staining, at the forward end of SS 12-2 suggests it was held in place by being slotted into the through-beam. Planks tend to be slightly darker at the location

[44] SS 12-1 and SS 12-2 exhibit a consistent slight inward bevel.
[45] There is no timber preserved aft of SS 12-1, so it is unclear what this joined.

of frames, and there is some slight pressure damage, often in the form of muted tool marks, at frame locations.

Figure 4.72. Outer face of UM 110 at preserved (aft?) end. Pressure mark likely reflects the outline of the through-beam, recessed to receive the plank end.

Score marks are relatively rare and very faint; some may have been degraded through exposure. No score marks were found on SS 12-2, SS 12-3, and SS 12-5. They are somewhat more common on SS 10, present at several frame stations, three of which, F 13, F 23, and FR 24, are known to be original.[46] Score marks at futtock locations indicate that the planking above the waterline was installed after the half-frames were in place but before some of the futtocks had been installed. It is unclear why there are score marks along one edge of FR 24; perhaps this frame was installed later than the other half-frames.

[46] Part of a score mark may be preserved along the forward edge of F 19 on SS 10-4, but this may just be an errant tool mark.

Replacement Planks

Disregarding the 12 graving pieces that served to repair areas along plank seams, 28 of the 46 extant planks (61%) were replacements of original planking. These replacement planks include the port and starboard garboards as well as nearly all planks along the bottom of the hull aft of amidships. SS 7-6 (UM 31), a short, recycled plank that probably filled the space between the forward end of SS 7-3 and the stem, is a replacement plank and will be included in this discussion, although its placement in the hull is not absolutely certain. PS 6A, placed by workers into the bulkhead frame and initially labeled BH 1, was later found to be a replacement plank at the stern on the starboard side.

While replacement planks below the waterline were easily identifiable due to their lack of edge fasteners, those above the waterline proved more challenging, especially as fewer elements of framing are preserved here. PS 6 is not extensively preserved, but fastener holes (or lack thereof), a lack of edge fasteners, and general location in the hull all suggest that this is probably a replacement. SS 9-1 was also difficult to categorize; while fastening patterns indicate a replacement, it is an earlier replacement than plank SS 9-2, a recycled plank.

Condition

Most of the replacement planks are in an excellent state of preservation, with original surfaces and very little damage. The original curvature of the planks, especially at the ship’s extremities, has been preserved to some extent. More than half of the replacement planks are both complete and intact. Breaks, although uncommon, are usually at plank tips or somewhere along the scarfs. The wood of these planks is quite solid, although there is some distortion or pressure damage on some of the planks, especially on PS 1, where frames on the starboard side were pressed down onto the top edge of the plank, causing damage. The pressure damage to PS 1 forced the plank out of place, while a line of 21 nails remained, affixing the plank to the keel; as a result, the form of the plank is distorted, with a large part of the lower edge between FR 9 and FR 15 bent upwards. A sharp pressure line from a displaced frame edge was not uncommon on several planks on the port side.

Cracking is usually minor, and tends to follow the wood grain, often running through iron nail holes; transverse cracks near the plank edge reflect compression of planks at frame locations. Orange iron oxide staining at iron nail locations was common and proved difficult to remove in some cases. Although some concretion was present around iron nails, it was generally minor; the garboards are an exception and some areas were obscured by concretion from the rabbet nails. Damage from *Teredo navalis* was limited to those areas that had been exposed. The worst preserved of the replacement planks is PS 6, of which only a small portion was preserved. Damage to the lower edge of PS 6 matches a large hole out of the top edge of adjacent plank PS 3-1 between FR 4 and FR 5; perhaps this contributed to the abandonment of the vessel.

Dimensions

Of the 28 replacement planks, 22 are either complete or, as in the case of PS 3-1, incomplete but with its original length preserved. Original lengths vary greatly, from 0.68 to 6.09 m, with an average length of 3.06 m. The garboards, both of which are approximately 6 m in length, are the longest, while PS 3-2 (5.90 m, although its tip is missing) is nearly as long. Shorter pieces, such as SS 6-2 and SS 7-6, both of which are shorter than 70 cm, were cut to fill in smaller gaps or to repair segments of original planking that were cut out. Four of the five planks for which the length is not original, PS 2-2, PS 3-2, PS 5-1, PS 5-2 and PS 6A, are broken at a scarf, tip, or along a hood end and are therefore relatively close to their original lengths. PS 6 is the only replacement plank for which even an approximate original length is unknown.

Original widths and thicknesses were available for nearly all of the replacement planking, the only exception being PS 6. Original maximum widths are 9.5-33.4 cm, with an average maximum width of 19 cm. The narrowest replacement planks are in strake SS 6 at the turn of the bilge on the port side. The widest replacement planks, SS 2-3 and SS 3-1, are more than 30 cm in maximum width and may in fact be replacing two narrower strakes of original planking. That each of these wide planks has two separate planks scarfed into one end further supports this. Light pressure damage or faint stain lines on the outer face of some original frames may also indicate the location of original plank seams.

Where the planks were not compressed, thicknesses range from 1.7 to 3.6 cm, but are on average 2.1-2.6 cm, at times varying significantly within a single plank. Garboard PS 1 is somewhat thicker than the average replacement plank, especially along its lower edge, while garboard SS 1 is of average plank thickness. Contraction of wood at char-bent areas may have had an adverse effect on plank thickness. There does not seem to be a notable difference in thickness between planks’ upper and lower edges.

In section, planks are generally rectangular or approximately so where sufficiently preserved. Upper and lower edges are usually cut with either no bevel or a very slight bevel, either inward or (less commonly) outward. Although a very shallow bevel may be incidental due to adzing, a more significant bevel probably reflects an effort by the shipwright to smooth the planking interfaces along the hull curvature. The surprisingly slight inward bevel along the lower edge of SS 1 may be intentional or may simply be a result of adzing; there is no clear bevel on PS 1, but this plank is heavily distorted in some areas. Where a plank was cut down for a graving piece, the cut edge usually has a notable outward bevel.

Although most of the planks had a section that was approximately rectangular in form, there are exceptions. At least four planks—SS 5-1, PS 5-1, PS 6 and PS 6A—were found to deviate from this slightly, with the outer face adzed down slightly along some edges in order to smooth the turn of the bilge on the hull exterior. SS 9-2 was originally rectangular but has become slightly bowed, forming a slight concavity on the inner face. This may be due to an excessive absorption of water and could be related to the fact that this was a recycled plank.[47]

Planks were usually cut so that the pith of the timber, or the area closer to the pith, faced inward (21 out of 27 planks). On planks for which the pith or core is visible on the plank, which was only recorded on seven of the replacement planks, the pith is invariably oriented to the inside of the hull. The preference for orienting the pith toward the ship's interior may be associated with a tendency toward cracking along the pith

[47] The warping of pine due to wetting and drying is discussed in Hillman and Liphschitz 2004, 151-52.

during the initial drying of the timber.[48] Even on the widest planks, no more than approximately 60 annual rings could be counted, and darker heartwood, which does not appear in *Pinus brutia* before 80-100 years, was not observed; this lack of heartwood suggests that relatively young trunks not more than 30-40 cm in diameter were used.[49] Even younger trees may have been used for many of the replacement planks, most of which had a maximum of 20-35 annual rings visible.

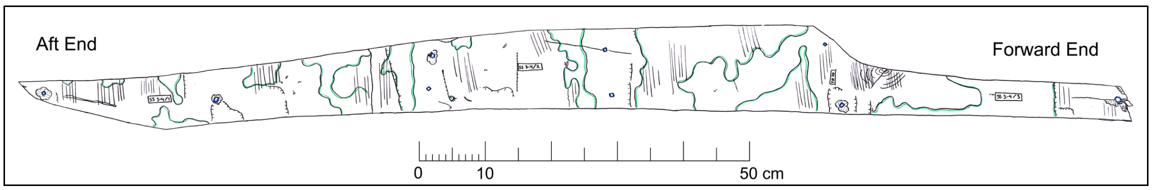

Figure 4.73. SS 3-4 inner face.

The overall form of the replacement planking varies widely, again depending on the form of planking that is being replaced; while some planks have more or less straight edges, others are irregular, clearly cut to fill a gap left by rotting planks that had been pried off or trimmed down. The lower edge of SS 6-1, for example, forms a small dip between replacement plank SS 5-1 and SS 5-2, which was probably a later replacement. SS 3-4 is very clearly a small replacement, custom-cut to fill a gap at the aft end of SS 3-5 (fig. 4.73).

[48] Hillman and Liphschitz 2004, 151.
[49] Hillman and Liphschitz 2004, 150. Use of *Pinus brutia* sapwood was also noted on the Ma'agan Mikhael shipwreck.

Scarfs and Butts

Variety in form is perhaps best exemplified by the array of scarf ends and butt joints on the replacement planking. Preserved plank ends may be grouped into one of seven categories: butt joint, two-planed scarf, tapered, three-planed (Z) scarf, curved (S) scarf, and diagonal scarf; a seventh group includes planks that have a scarf cut along both the top and lower edge at one end, for two separate adjoining planks.

Twelve of the replacement planks terminate in a butt joint at the location of a frame.[50] Such joints are either vertical or at a very slight angle but do not extend beyond the location of the frame over which they are placed. Butt joints seem to have been preferred for narrower planks, and there are no butt joints located below strake five.

The next most common type of scarf is perhaps best described as a two-planed scarf, as it is something like a combination of a diagonal and a three-planed scarf; nine such scarfs were preserved on the replacement planking.[51] These scarfs closely resemble a diagonal scarf which has a short, vertical step near one end (fig. 4.74). The resultant scarf edge could be either convex or concave in general form. This type of scarf allowed the shipwright to create a diagonal scarf at any angle while retaining the ability to attach the scarf ends to the ship's framing. As such, scarf lengths tend to be approximately 30 or 60 cm in length, or covering two or three frame locations, respectively. Nevertheless, two-planed scarfs as short as 19 cm (aft end of SS 9-1) and as long as 80 cm (aft end of

[50] Replacement planks with butt joints include SS 5-1 (forward end), SS 5-2 (aft end), SS 6-1 (forward end), SS 6-2 (both ends), SS 6-4 (both ends), SS 7-2 (aft end), SS 7-6 (UM 31) (aft end), SS 9-1 (forward end), and SS 9-2 (both ends).
[51] Two-planed diagonal scarfs are present at PS 2-1 (forward end), PS 3-1 (both ends), PS 5-1 (forward end), PS 5-2 (aft end), SS 3-1 (forward end), SS 5-1(aft end), SS 6-1 (aft end), and SS 9-1 (aft end).

SS 6-1) were recorded. The narrow forward tip of PS 3-1 was fastened to the plank below with a transverse iron nail.

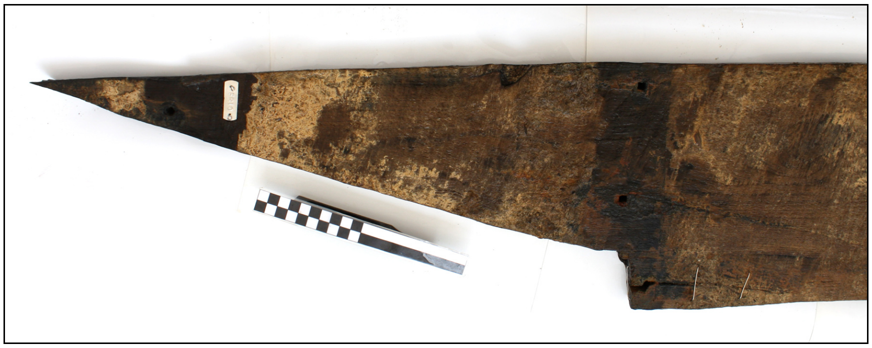

Figure 4.74. PS 3-1 forward scarf.

Nine of the replacement planks end by gradually tapering to a point, not unlike a long diagonal scarf.[52] However, these planks either do not have a clearly-delineated scarf area, as on PS 1 and the forward end of SS 1, or do not join the end of another plank, as along the chine-like edges which outline of the bottom of the hull. The latter include all of the non-garboard planks in this category. These are 0.75-1.04 m in length and usually have a slight inward bevel to the scarf edge. The aft end of PS 5-1 broke along a transverse iron nail that fastened the plank tip to PS 4-1 below.

Only four planks terminate in a three-planed, or Z, scarf, although length and form vary (fig. 4.73, to right).[53] These are 27-64 cm in length and cover either two or three frames, with scarf ends always at frame locations. Four planks possess a curved (S)

[52] Long, tapering ends were recorded on PS 1 (both ends), PS 4-1 (aft end), PS 5-1 (aft end), PS 6A (aft end), SS 1 (both ends), SS 3-1 (aft end), and SS 4-1 (aft end). Technically, both garboards should be considered hood ends, but they are included in this category as there is no clearly-delineated start of a hood end.

[53] These include SS 2-1 (forward end), SS 3-4 (forward end), SS 5-2 (forward end), and SS 7-2 (forward end).

scarf (fig. 4.75).[54] In contrast to the scarf on original planks SS 8-1 to SS 8-3, the curved scarfs of replacement planking are shorter (29-35 cm), only covering two frame locations, again with scarf tips at frames. Diagonal scarfs were only recorded on two of the replacement planks, although neither resembles a typical diagonal scarf.[55] The narrow aft end of SS 3-4 (fig. 4.73, to left) is only 22 cm in length; only one end of this approximately diagonal scarf falls at a frame location. The aft end of SS 3-2, 40 cm in length, more closely resembles a typical diagonal scarf; however, this was originally probably a two-planed scarf whose vertical portion was later cut off and replaced with graving piece SS 3-3.

Figure 4.75. SS 4-1 forward scarf.

[54] PS 6 (aft end), PS 6A (forward end), SS 2-2 (forward end), and SS 4-1 (forward end).
[55] SS 3-2 (aft end) and SS 3-4 (aft end).

Finally, there are five plank ends at which a scarf is cut out of both the top and the lower plank edges, forming a double scarf, which accommodated two separate planks.[56] The clearest example is on the aft end of SS 2-3 (fig. 4.76), in which the plank's top and lower edges form an unbroken, approximately straight seam with the lower edge of SS 2-1 and the top edge of SS 2-2. The double-scarfed planks on the starboard side tend to be less clear-cut; as exemplified by PS 2-2, these usually have one clearly-delineated edge, while the opposite edge is trimmed down to create a subtle, ill-defined diagonal scarf (fig. 4.77). Because these planks are narrower than SS 2-3, and the adjoining planks wider, the smooth seam lines of the port side are not present on much of the bottom on the starboard side. The double scarfs are 33-92.5 cm in length and cover between two and four frames, with scarf ends at frame locations.

Figure 4.76. SS 2-3 aft scarf. "Double" scarf for both SS 2-1 and SS 2-2.

[56] PS 2-2 (forward end), PS 2-4 (aft end), PS 3-2 (aft end), PS 4-1 (forward end), and SS 2-3 (aft end). Technically, the forward end of SS 3-1 also accommodated two planks and one graving piece; however, in form, it closely resembles a two-planed scarf and was therefore included in that category.

Figure 4.77. "Double" scarf at forward end of PS 2-2.

Figure 4.78. SS 2-1 inner face at hood end. Rabbet nails are indicated with arrows.

<u>Strake End Details</u>

Nine of the replacement planks terminate in a hood end, where the plank was fastened to the ship's keel, stem, or sternpost with nails driven from the outer face of the plank (fig. 4.78).[57] The end is cut at a diagonal, either long and shallow for planks lower in the hull (up to 1.08 m in length on the forward end of PS 2-4), or shorter and steeper for planks higher up in the hull (15 cm in length on the forward end of SS 7-6). The

[57] Replacement planks terminating in a hood end include PS 2-1 aft end; PS 2-2 aft end; PS 2-4 forward end; PS 3-2 forward end; SS 2-1 aft end; SS 2-2 aft end; SS 2-3 forward end; SS 3-2 forward end; and SS 7-6 forward end.

hood end is usually cut with a moderate inward bevel, which facilitates a tighter interface with the keel, stem, or sternpost.

Frame Locations

As with other planks, frame locations on replacement planking are most easily identified by the presence of nail holes. In general, these are far less confusing than the mix of nail holes and caulked holes seen on the original planking. Pitch or pitch stain commonly lines frame edges. Frame locations may also be identified through slight pressure marks to the planks' inner faces, relatively common near the ends and on the lower strakes. These subtle marks represent the working of the hull against the frames, while a single, deeper pressure mark to one side or off-center usually reflects the displacement of a frame on the wreck after submergence.

As expected, score marks were far less common on the replacement planks than the original planking, and they are also more poorly preserved, perhaps simply not cut as deeply. Score marks at charred areas are generally better preserved. Score or cut marks along some frame edges were recorded on approximately half of the replacement planks. They were observed at several replacement frames and are best preserved at FR 21, a very late repair (fig. 4.79). Score or cut marks in several areas on both the port and starboard sides at the stern indicate the replacement of multiple frames in this difficult area. A score mark just forward of original FR 20 on SS 2-3 could have been used by the shipwrights to mark where the plank should be char-bent. Score marks on SS 6-4 and SS 9-2 do not match those of neighboring planks, instead flanking the location of disused fastener holes; these score marks are thus further proof that these planks are recycled.

Figure 4.79. PS 3-2 inner face at FR 21. Note clearly-delineated charring and score marks at FR 21.

Figure 4.80. Graving piece PS 2-3 in situ. Note large wad of caulking at the gap between PS 2-3 and the forward end of PS 2-2.

Graving Pieces

The graving pieces are those small repairs that did not span the entire width of a strake; twelve such pieces were identified.[58] These pieces were installed to repair damaged areas along the edges of planks, both original and replacement planks (fig. 4.80). SS 7-5 and SS 8-2 repaired areas of damage along both edges of a seam between two original planks. With the exception of SS 3-6, *Cupressus sempervirens*, all of the graving pieces are *Pinus brutia*.

SS 6-5 is the one plank in this group that may actually be the fragment of an original, edge-fastened plank. It is a narrow sliver of planking at the forward end of SS 6, sandwiched between two original, edge-fastened planks, SS 5-4 and SS 7-3. SS 6-5 is notable for its transverse iron nail at one end, its narrowness (it is greater in thickness than in width), and its very roughly-cut (possibly broken) aft end, cut at a nail. Because the iron nail that edge-fastened the forward tip to the original plank below it is driven at a slight diagonal, there is a possibility that this small fragment was installed as a repair. It is more likely, however, that this was the tip of an original plank at the forward end of SS 6, the remainder of which was replaced. It is included in this group due primarily to its size and function, that is, filling a small gap in planking.

<u>Condition</u>

Eleven of the twelve graving pieces are complete, and ten of these are also intact. The pieces are nearly always in an excellent state of preservation, solid, with little or no

[58] These are PS 2-3, PS 5-3 (UM 45), SS 2-4, SS 3-3, SS 3-6, SS 5-3, SS 6-3, SS 6-5, SS 7-5, SS 8-2, SS 10-2, and SS 10-3. PS 5-3 (UM 45) is probably the forward-most portion of strake PS 5, which filled the cut-out area along PS 5-2's lower edge. Its placement, although very likely, is not certain; however, for this discussion, it is considered part of PS 5.

damage and with original surfaces. Compression and minor surface wear or damage were observed on those graving pieces that repaired original planks.

Dimensions

All of the graving pieces are quite small, often of a narrow, bar-like form, although there is notable variation. Complete pieces range in length from 27 to 64 cm, with an average length of 41 cm. Original widths and thicknesses were available on each of the pieces. Widths range from just 1.2 cm on the narrow tip of SS 6-5 to a maximum of 9.5 cm on SS 7-5, which repaired damage along the edges of two planks. On average, the graving pieces were 2.1-2.4 cm thick, although greater thicknesses, up to 3.0 cm, were noted on SS 2-4 and SS 3-6, the graving pieces functioning as hood ends.

In form, eight of the 12 graving pieces are slender quadrangles that span either two or three frames, much longer than their width and with either approximately parallel top and lower edges, or a slight taper toward one end. SS 2-4, SS 6-5, and SS 10-3 replace the tip of another plank and are therefore approximately triangular as opposed to quadrangular in form. In section, these pieces are approximately rectangular; edges are often straight or, as often in repairs, have a slight inward bevel. There is a notable inward bevel along the top edges of SS 3-3 and SS 6-5. Only one graving piece, SS 7-5, is cut from wood near the pith of the timber; the remaining pieces were cut from an area further from the center of the tree, perhaps from leftover scraps of timber. Eight of the twelve were cut from a plainsawn quarter-log. The pith was oriented closer to the interior of the hull on only five of the planks, in contrast to what is seen on other replacement planks. There are only 10-25 annual rings visible on each graving piece.

Figure 4.81. Graving piece SS 8-2 in situ.

<u>Scarfs and Butts</u>

Most of the graving pieces terminate in a butt-joint, either straight or at a slight diagonal, depending on the form of the plank to be repaired. These have either no bevel or, more often, a slight inward bevel that would facilitate repairing a plank from the ship's exterior. The aft ends of SS 2-4 and SS 10-3 form a short diagonal scarf with the adjoining plank; the forward end of SS 10-3 is cut in the form of the curving tip of an S-scarf. The forward end of SS 6-5 tapers to a thin tip that is fastened to the plank below it with a transverse iron nail. Both SS 7-5 and, to a less notable extent, SS 8-2 terminate in a kind of two-planed scarf, custom-cut to fit recesses on two planks each (fig. 4.81).

Two of the graving pieces, SS 2-4 and SS 3-6, form part of a hood end at the ship's bow; although SS 3-6, as expected, has a slight inward bevel here, SS 2-4 does not. A pressure mark on the inner face of SS 3-6 might indicate the location of the edge of the keel. With the exception of the hood ends and the tapered tip of SS 6-5, all of the graving pieces begin and terminate at a frame location.

Frame Locations

Frame locations on graving pieces are most easily identified through nails and occasional patches of pitch. Otherwise, there are no clear indicators of frame location. Occasional cut marks on these pieces do not seem to line up with any score marks on other planking.

Fasteners

Frames were attached to the planking with short nails driven from outside the hull. The number of nails at each frame station varies, but there are usually between one and three nails, in most cases two, with as many as four or five nails per frame where a frame had been replaced or reinforced. Graving pieces were usually fastened with one nail per frame location. The square nail holes vary slightly in size but are usually 0.5-0.6 cm in sided dimension on the plank's inner face; outer face dimensions, at the base of the nail shank, are larger, usually 0.8-0.9 cm sided.

Pressure marks or concretion outlines on the outer face of planking indicate rounded or slightly angular nail heads, usually 1.8-2.3 cm in diameter. These may be impressed into the plank surface up to 0.1-0.2 cm. Only two nail head concretions were preserved on the outer face of replacement planking; these indicate domed nail heads 0.6-1.1 cm thick. Although easily washed away, grass-like fibers were found surrounding the hole on many of the planks' outer face nails, on both original planks and repairs (fig. 4.82). The frequency of this phenomenon, and the ease with which it could be obliterated in the cleaning process, suggests that all nails were first wrapped with a line of caulk-like grass fibers before being driven into the hull, the rings of fibers acting as a washer to form a tight seal.[59]

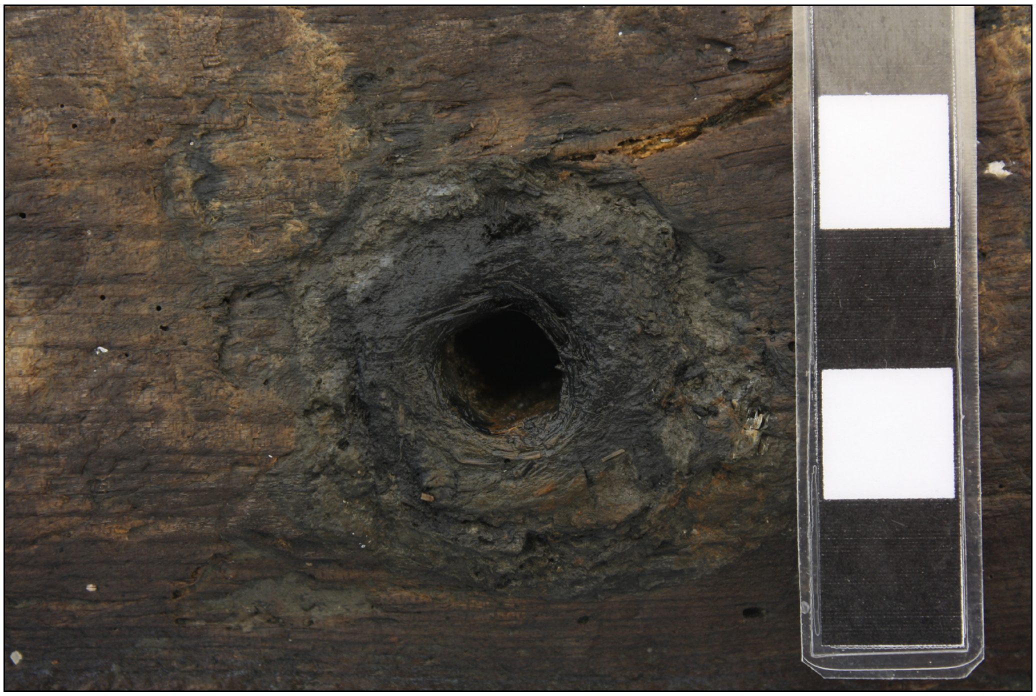

Figure 4.82. Nail on PS 5-1 outer face at FR 15. Note fibers that had been wrapped around the base of the nail shank.

Some (but not all) of the nails were driven through pilot holes; these holes, drilled from the outer face of the planking, are inconsistent in depth, with some but not all drilled holes visible on the inner face of the plank.[60] Pilot holes were relatively common on original planking but less so on replacement planks; only one was observed

[59] This was also noted on some of the nails of the Serçe Limanı shipwreck (Bass et al. 2004, 110).
[60] A round, 1 cm-diameter pilot hole would be heavily obscured by a square shank hole 0.8-0.9 cm in sided dimension. As such, it is quite likely that many shallow pilot holes have left no trace on the extant planking.

on the graving pieces. The pilot holes that extend to the inner face are 0.8-1.1 cm (usually approximately 0.9 cm) in diameter. Some of the nails seem to have veered away from the pilot hole, such that an irregular hole, partly rounded and partly angular, is formed on the plank's inner face. Some nails, perhaps later additions, were clearly not driven through pilot holes.

The shipwrights attempted to minimize the number of holes in the planking by reusing holes from old nails that had been pulled. The replacement nail did not always follow the prescribed path, however, at times creating an oblong or "double" nail hole on the inner face or two nail holes in very close proximity.

When a hole on the plank was abandoned or otherwise disused, it was filled in, either with caulk-like fibers (fig. 4.83) or, in one instance, with a small wood plug (fig. 4.62, lower right) and sealed with pitch. Many such holes could only be identified after nearly all pitch had been removed from the inner face of the planking. Although initially misinterpreted as the location of cleats used in the initial construction of the ship, it is now clear that these filled holes, in most cases, indicate where a frame had been replaced. Abandoned holes were found on nearly all of the original planking and several of the other planks, reflecting multiple significant repairs to the ship.

Abandoned holes are usually at the same location as the replaced frame, but some are located just forward or just aft of the replaced frame. Several of the abandoned nail holes are located along plank edges (fig. 4.84), where the plank had been trimmed down for repairs; this was observed even on replacement planks.

Figure 4.83. Caulked- and pitched-over hole on SS 5-4 between FR 21 and FR 22.

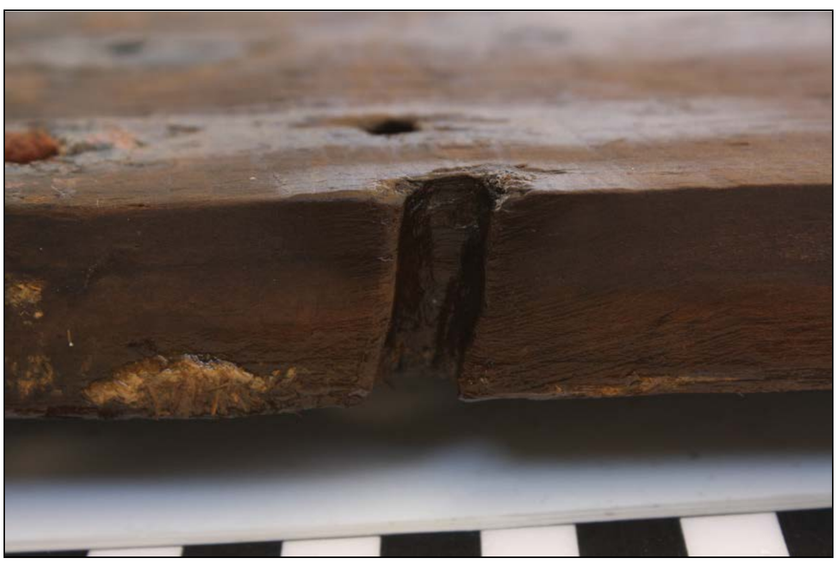

Figure 4.84. Abandoned fastener (?) hole, cut through, along the lower edge of SS 3-5 at FR 24. Note striations within adze marks on plank edge.

Although rare, caulked or disused holes may also indicate the location of a frame-like support piece that was not preserved or a temporary cleat that had been removed; this seems to be the case at FR 19-FR 20 and FR 21-FR 22 on SS 5-SS 7, and FR 13-FR 14 on SS 8-SS 11. Caulked holes with no associated hole or fastener on another plank may indicate a recycled plank, as is the case on SS 9-2, SS 7-6, and perhaps SS 6-4. A few of the caulked holes do not seem to follow any pattern and their function remains unclear.

In addition to nails for frames, the replacement garboards (PS 1 and SS 1) were attached to the keel rabbet with 21 short nails each. Very similar nails fastened the hood ends to the keel rabbet, with two or three small nails per hood end (figs. 4.56, 4.78). These rabbet nails were driven at an oblique angle from the outer face and exited the inner face very near, and sometimes on, the plank's edge. These nails are similar in size and form to the framing nails; square nail holes on the inner face are usually 0.5-0.6 cm sided. Only a few nail-head impressions on the outer face could be measured; these are 1.5-2.1 cm in diameter. Combined with measurements from the keel, these rabbet nails were originally 5.5-8.0 cm in length. As on the other nails, a line of grass-like fibers wrapped around the shank helped seal the nail head against the outer surface of the garboard. On average, garboard nails were spaced 29 cm apart, although there was significant variation in spacing.

When replacing planks, the shipwrights made an effort to place scarf ends at frame locations, no doubt for ease of attachment. This explains some of the oddly-shaped and inconsistent scarfs seen on the ship. However, there are five locations on the extant planking where a plank terminates between frame locations and a transverse iron nail was used to edge-fasten the plank tip to the plank below it.[61] The technique of fastening plank tips with a transverse metal fastener is known from other ships of the Classical period and was used well into the Byzantine period.[62] However, this created a point of weakness in the planks of YK 11; three of the five plank tips fastened in this way had broken the plank at this point.[63]

The square nails used for this purpose were approximately 0.5 cm sided and 3-4 cm in length; where impressions were preserved, nail heads were 1.7 cm in diameter. On the forward tip of SS 6-5, a shallow recess was cut to accommodate the nail head. This nail is also driven at a slight diagonal, closer to the outer face on the top edge of SS 6-5. The nail head at the SS 8-1 forward tip is merely impressed into the plank edge but not countersunk, while there is no trace of a nail head on the PS 3-1 tip. Where sufficiently preserved, the nails appear to have been driven through pilot holes (1.0 cm diameter), no doubt to prevent breakage.

There are two instances where a transverse iron nail was used to attach the tip of a repair to the adjacent plank: at the PS 3-1 forward tip, fastened to the top edge of PS 3-2 at FR 10-FR 11, and the PS 5-1 aft tip, fastened to the top edge of PS 4-1 at FR 7-FR 8. These nails suggest that PS 3-1 and PS 4-1 were replaced at the same time, as were PS

[61] These five nails are found at the following locations: PS 3-1 forward tip into the top edge of PS 3-2 at FR 10-FR 11; PS 5-1 aft tip into the top edge of PS 4-1 at FR 7-FR 8; SS 5-4 forward tip into the top edge of SS 4-2 at FR 27-FR 28 (SS 4-2 is not preserved here); SS 6-5 forward tip into the top edge of SS 5-4 at FR 24-FR 25; and SS 8-1 forward tip into the top edge of SS 7-4 at FR 15-FR 16.
[62] This was noted on some of the scarf tips on the Kyrenia ship (Steffy 1985, 78-81) as well as those of the Nemi ships (Ucelli 1950, 152-53). Similar nails were used on the seventh-century Yassıada ship (Bass and van Doorninck 1982, 59) and the 11th-century Serçe Limanı ship (Bass et al. 2004, 107-8).
[63] The aft tip of PS 5-1 and forward tip of SS 5-4 broke away at these nails and were not preserved. SS 6-5 also broke at the transverse nail, but the delicate tip was preserved.

5-1 and the plank above it (which was not preserved); otherwise, the shipwright could not have driven a transverse nail through the plank tip.

On original planks, transverse nails were found at two of the three known original plank ends: the forward tip of SS 5-4 and the forward scarf tip of SS 8-1, at the SS 8-1 to SS 8-3 scarf. Although there is insufficient preservation to make a definitive statement, the little evidence that is preserved suggests that, as expected in a primarily shell-built vessel, original plank tips were not located at frames, but rather were edge-fastened to lower strakes with nails. It is perhaps noteworthy that the SS 8-1 tip was nailed to the plank below while the mortises just aft of this nail do not have a match on the adjoining plank. Did the transverse iron nail compensate for the lack of mortise-and-tenon joints nearby, or was it standard practice to pin the plank tips in this manner during the ship's construction? Evidence from UM 100 indicates the latter. An unidentified fragment of edge-joined planking, UM 100 was probably part of a scarf end of one of the ship's original planks.[64] The tip was fastened with a transverse iron nail, and an adze or chisel was used to countersink the nail head along the top edge (fig. 4.85). The presence of mortise-and-tenon joints along both edges of UM 100, within 20-30 cm of the transverse nail, indicates that the nail was not used as a substitute for mortise-and-tenon joints or vice versa.

Finally, there is an odd nail that is driven from the outer face of SS 12-1 up through the top edge and into the lower edge of SS 13 between FR 6 and FR 7 (fig. 4.86). This seems to have been done to repair damage to the plank near this edge.

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[64] Although this fragment's correct location remains unknown, its features strongly suggest it was once part of YK 11; it was found just forward of the ship on the port side.

Figure 4.85. Transverse iron nail at the tip of edge-fastened plank fragment UM 100. Note countersinking for nail head.

Figure 4.86. Top edge of SS 12-1 at forward end. An iron nail was driven through the top edge of SS 12-1 into SS 13 to repair damage.

Surface Treatment

Pitch or pitch stain usually covers the inner plank surfaces between frames, and it is therefore a good indication of frame location (figs. 4.80). Where well preserved, it is

0.1-0.3 cm thick; there are thick ridges of pitch, up to 0.5 cm thick, along some frame edges, indicating re-paying of pitch over the hull on several occasions. Hair or small bits of organics were observed in pitch in some areas; hair may have been added to the pitch as a bulking agent, although this was more prevalent on other ships at Yenikapı.[65] Pitch was more common on lower rather than upper strakes and also less common toward the ship's extremities, no doubt a result of prolonged exposure of these areas after sinking and during excavation. Alternately, a lack of pitch toward the extremities might be associated with the charring of planking, as pitch does not adhere as well to these surfaces. Pitch was usually thicker and much better preserved on the outer face of the planks, again reflecting a lack of exposure.[66]

Pitch was rarely preserved under frames, usually having seeped in under frame edges; however, distinct patches of weathered pitch under the frames occur infrequently. Pitch on original planks at original frame locations is significant; this is less common than pitch on the outer face of frames, thus indicating that the outer face of the framing had a layer of pitch applied to it prior to initial installation in the hull.[67] Application of pitch to this surface, rather than to the inner face of planking prior to the installation of frames, would provide the protection of pitch to an area vulnerable to dry rot while keeping other surfaces pitch-free and easier to work with until the construction could be completed, at which point the entire interior of the vessel could be payed with pitch. This

[65] A large lump of pitch found just under the exterior planking of YK 11 had copious amounts of thin but stiff hair throughout; this lump of pitch, however, is not necessarily associated with wreck YK 11.
[66] Significant pitch on the inner face of SS 3-6, found inner face down, again indicates that poorer preservation of pitch is closely linked to exposure.
[67] The outer face of the framing of the late fourth- or early fifth-century Yassıada ship was also pitched prior to its installation (van Doorninck 1976, 124).

pitch at the frame-plank interface is usually poorly preserved, as it would (in theory) only have been applied once.[68]

Figure 4.87. Aft end of PS 1, inner face. Very thick pitch formed a 3 cm-high ridge, sealing the space between PS 1 and the keel. Note wood chips in pitch.

Pitch was generally not well preserved on the garboards, although at the garboard extremities, pitch had pooled in the narrow space between plank and keel, forming a tight seal between the two (fig. 4.87). A pitch line also seems to indicate the location of the keel on some of the hood ends. On SS 2-3, there is less pitch at the location of SST 1, which likely protected part of the plank from a later application of pitch (fig. 4.88). Although faint, pitch stains were preserved at old frame locations on recycled plank SS 9-2.

As noted above, pitch was used to seal up abandoned or disused holes that had been filled with organic fibers, probably caulk fibers and perhaps also sawdust; this was perhaps done inadvertently during the overall application of pitch to the hull. Pitch was

[68] Parts of the outer face of frames may have had additional pitch applied during the replacement of planking.

also frequently found within ancient cracks and areas of damage. Pitch applied over barnacles on the outer face of several repair pieces reveals that these repairs had been in place for at least a season prior to re-pitching and eventual abandonment of the vessel.

Figure 4.88. SS 2-3 inner face at FR 17-FR 19. Note pitch stain between frame stations and lack of pitch stain at SST 1 location (near upper edge).

Figure 4.89. Caulk on lower edge of SS 3-5 at FR 22-FR 23.

Caulking

Caulking was preserved to varying extents on all of the planking, including edge-fastened plank edges; both applied caulking and driven caulking are represented on YK 11. The caulking is composed of short, chopped segments of grass-like fibers heavily intermixed with pitch. Where well-preserved, caulk was usually 0.1-0.2 cm thick, covering the entire edge between inner and outer face; caulk was up to 0.5 cm in thickness in several areas. One or both edges (usually outboard, sometimes also inboard) was lined by a pitch ridge showing where the pitch payed over the outer or inner face of the hull soaked into the plank seam and intermingled with the caulking (fig. 4.89). Caulking was easily washed away, both prior to and during excavation; for this reason it is very rarely preserved where plank seams have opened up or been otherwise exposed, especially at hull extremities. Even on closed seams caulk was often preserved in localized patches; sparse fibers embedded in pitch or areas of pitch stain are all that remain in many areas.

The presence of caulk fibers along edge-fastened seams challenges the conventional belief that caulking was not used in association with mortise-and-tenon edge joinery. That caulking was found to inboard of intact tenons proves that, during the initial construction of the vessel, caulking was applied to edge-fastened plank seams during assembly (fig. 4.90). Pitch was found on several tenons, usually at the plank seam but also in spots throughout, and many of the mortises had pitch and caulking fibers filling the cavity around the tenon. Damaged areas along mortise edges were also filled in with caulk fibers.

Fig. 4.90. Intact tenon on top edge of SS 7-4 at F 21. Note caulk along plank edge, inboard of tenon.

Figure 4.91. Caulk removed from top edge of PS 2-4 at FR 20-FR 21.

In addition to the use of applied caulking along edge-fastened plank seams, there is also ample evidence for the use of driven caulking throughout much of the hull. Where well preserved, caulk fibers were generally oriented perpendicular to the plank seam (fig. 4.91), indicating driven caulking. This orientation of fibers was inconsistent, however, with some caulk patches exhibiting no clear orientation. It seems likely that thick caulking (or wads of caulk fibers) was driven into seam gaps during the addition of graving pieces or replacement planks, or during routine maintenance. Caulk fibers were also used to fill in knot holes, damaged areas, and other irregularities along plank edges, some of which were surprisingly large. A wad of caulking between PS 2-2 and PS 2-3 was 2 cm thick (fig. 4.80), and similar, albeit slightly thinner, lumps were found in several areas.

As noted previously, several of the tenons had been cut through and covered with caulking. Although this was most common at blind mortises, cut tenons include those at which both facing planks were original (fig. 4.92).[69] This occurred even along seams where other tenons remained intact and uncut. The irregularity of the distribution of cut tenons indicates the re-caulking of deteriorated patches rather than a blanket re-caulking of all original, edge-fastened seams. To facilitate the re-caulking of part of an original seam, any tenons in the area were first cut through with a knife. Damage from a caulking iron was noted on the edge fasteners of Yenikapı shipwreck YK 14,[70] but it is unlikely that the cut tenons of YK 11 may be attributed to caulking iron damage. If the YK 11

[69] In order to identify all mortise locations, the caulking and pitch along plank edges were removed during documentation.
[70] M. Jones observed probable caulking iron damage to the coaks of late ninth-century shipwreck YK 14 (Jones 2010).

tenons had been accidentally cut with a caulking iron, one would expect to find at least one tenon that was merely damaged and not completely cut through, and this was not the case. Cutting along the plank seams with a knife or other similar tool may also have served to clear out old waterproofing material prior to the insertion of new caulk.

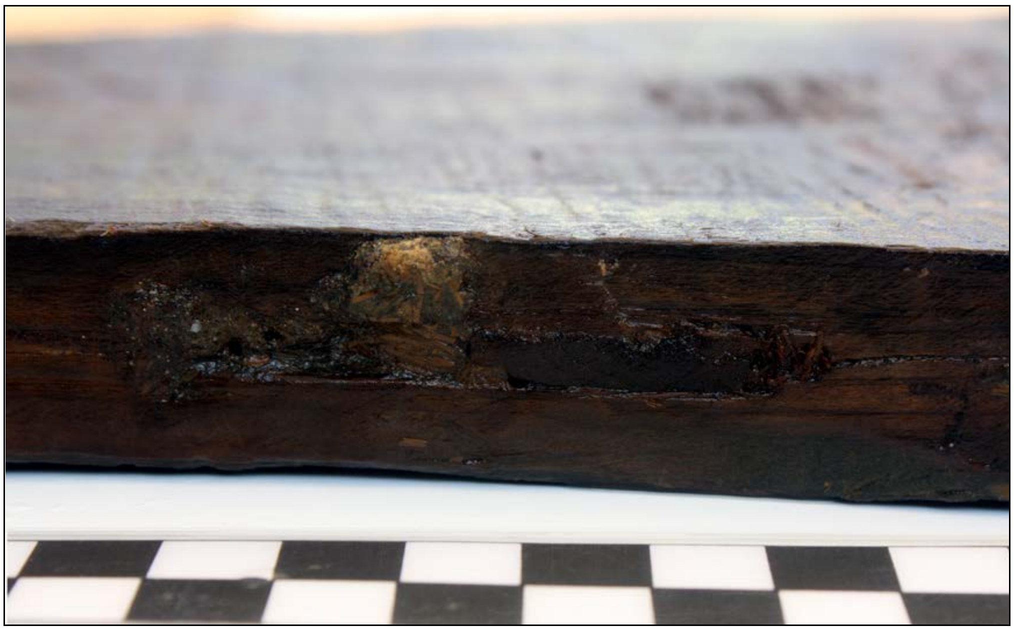

Figure 4.92. Cut tenon on SS 4-2 lower edge at FR 20-FR 21. Note caulk fibers in mortise around tenon.

In overview, there is evidence for the use of both applied and driven caulking in the hull of YK 11. Applied caulking was utilized on edge-fastened plank seams during the initial construction of the hull below the waterline. As planks were repaired and replaced, seams lacking mortise-and-tenon joints became more common and new waterproofing material was driven into such seams with a caulking iron. Tenons along edge-fastened plank seams also requiring renewal were cut through with a knife before fresh caulking was driven into the seam, resulting in the mix of applied and driven caulking, and cut and intact tenons, along some original plank seams.

Tool Marks

Most of the planking consists of plainsawn boards with edges trimmed to form with an adze. Saw marks are quite clear and are usually angled, varying slightly in orientation. They are usually 0.1-0.4 cm apart and are especially deep and more closely spaced at knots. On several planks, deep, arcing scratches probably represent saw return marks, not unlike those observed on the framing (fig. 4.83). Based on the size of the planks, they must have been cut with a large frame saw. The direction of sawing on the planks' inner faces was usually oriented against the direction of growth. More often than not, the plank was oriented such that the growth of the tree was from aft to forward. However, inconsistency here is enough to suggest that this may be merely coincidental. On SS 10-4, the plank was sawn toward the aft end then split along the last 16 cm. This split surface was later trimmed with an adze, but damage due to splitting remained and was filled in with pitch (fig. 4.93).

After the plank was sawn, it was dubbed to form along its edges with an adze, at times roughly (fig. 4.94). Adze marks on edges are usually at a slight angle and may vary in direction, even along the same edge. In well-preserved areas, parallel striations within adze marks reflect the use of a chipped blade.

Figure 4.93. Aft tip of SS 10-4. Note abrupt end to sawing, followed by adzing of the inner face. The plank tip was roughly cut for a repair.

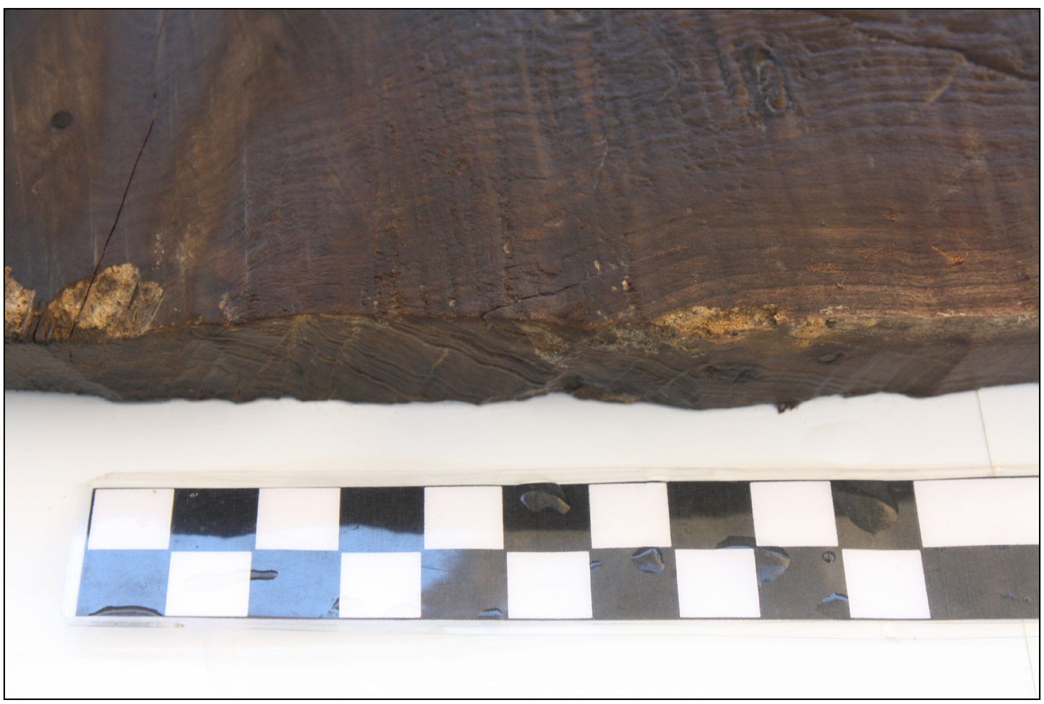

Figure 4.94. Roughly-adzed lower edge of SS 4-2 at FR 16-FR 17.

Although relatively uncommon, adzing is present on the inner or outer face of some planks; tool marks on plank surfaces reflect use of an adze blade 3.5-4.0 cm in width. Planks that are entirely adzed on any face are rare, limited to some graving pieces and smaller planks; on SS 12-5, the choice of dubbing the inner face with an adze was probably dictated by the form of the timber, close to the outer surface of a small trunk.

Patches of surface adzing were frequently observed at charred inner surfaces near the ship's extremities. On some planks, especially graving pieces, the inner or outer face was trimmed with an adze toward one edge, presumably to provide a more flush fit with the adjoining plank or keel. Parts of the outer face of PS 5-1, PS 6, and PS 6A had been trimmed with an adze near one or both edges, which decreased the plank thickness by two to three millimeters (fig. 4.95). The location and inconsistent nature of the adzing indicate that these planks were trimmed in order to smooth the plank seams along the turn of the bilge.[71]

On SS 7-1 and SS 8-1, the inner face of the plank was adzed at the original location of futtock F 5 (fig.4.69); the replacement for this futtock was located aft of this. This adzing may have served to reshape the planks for a better fit or may simply reflect the smoothing of char-bent surfaces. If the former, this area comprises the only preserved evidence of such a procedure on YK 11. The adzing obliterated part of the score marks around the original futtock. An adzed area on the inner face of SS 6-2 likely

[71] Not all planks could be flipped over, and, therefore, the extent to which YK 11 planking was adze-trimmed in this manner is unclear. This is an area for further study, which will be more easily done after conservation and removal of pitch from the planks' outer faces.

represents the location of a support timber that was later removed; a caulked hole at the same area matches fastener holes on SS 5-4 and SS 7-3.

Figure 4.95. SS 5-1 outer face at FR 6-FR 7. Note adzed area near top edge.

For sharply angled cuts at repaired areas, the plank was probably dubbed to form with an adze and, if necessary, finished with a chisel at sharp corners which could not be reached with an adze. Adze marks of this nature were observed on the lower edge of PS 2-4, the top edge of SS 5-2, or the lower edge of SS 9-1. The small area of damage on the top edge of SS 7-3 at F 19 also seems to have been cut out with either an adze or a chisel (fig. 4.61).

A scriber or other sharp tool was used to create the score marks that delineate frame locations on many of the planks. A similar tool may have been used to create a series of short cuts across the outlines of knots and along natural fissures in the wood (fig. 4.96). The function of these cuts is unclear, but they appear to be associated with natural defects in the wood grain; plank PS 3-1 broke along one such grain defect.

Figure 4.96. Small cuts across a grain defect on the outer face of PS 5-1 at FR 14.

Char-bending was extensively used to help attain the desired form of the planks at the complex curves at the ship's extremities; it was observed on nearly every plank at the extremities, including both original and replacement planking.[72] Although the original planks above the waterline were not preserved near the bow or stern, one of these, SS 12-1, had been charred on its inner face. Char-bending was not used for any of the graving pieces and indeed would not have been necessary due to their small size.

Char-bending is characterized by a charring of the plank's inner face, resulting in a surface that is black or darker in color and much harder than the remaining planking

[72] This technique is described in greater detail in Chapter V.

(fig. 4.97). The charring of replacement planks seems to have been much more severe than that seen on the original planking, with charred and crazed surfaces very common (fig. 4.98). Distinct charring was sometimes later trimmed with an adze, perhaps to create a smoother surface; similar adzing was noted on the Kyrenia ship.[73] The charred areas are usually somewhat poorly delineated; in some cases, however, the char-bent area ends in a very distinct line, as on PS 1, PS 2-4, PS 3-2, SS 2-3, and SS 3-1 (fig 4.79). As noted above, a score mark on the inner face of SS 2-3 may have been cut to indicate where the char-bending should commence.

Figure 4.97. Charred areas on the inner face of SS 4-2 at FR 25.

Charred surfaces, with just one exception, started at or near the keel scarfs; that is, planking forward of FR 20 (Keel 2-Keel 3 scarf) and aft of FR 9 (Keel 1-Keel 2 scarf) was char-bent, while the central portion of the ship—that corresponding to the location

[73] Steffy 1985, 84.

of the main, straight part of the keel (Keel 2)—remained uncharred. On this ship, then, the ends of the flat, central Keel 2 served as an indicator to the shipwrights of what portion of planking needed additional shaping. Only on SS 9-1 does the charred surface extend to FR 11, perhaps reflecting more curvature at this part of the hull above the turn of the bilge.

Figure 4.98. Charred inner face of PS 3-1 at FR 3-FR 4.

Unidentified Fragments

In addition to the 11 original edge-fastened planks, five unidentified fragments were found with part of one or more mortises preserved. One of these, UM 29, had broken away from the wreck and been flipped onto its inner face; it was later matched to the broken forward end of SS 9-3, thereby completing the plank. The remaining four fragments are similar to the edge-fastened planking of YK 11 in all ways except wood species, these being of *Cupressus sempervirens* rather than *Pinus brutia* (table 4.7).

Three of these were found in the same general area outboard of the wreck, near the starboard bow; these three may be from the same original edge-joined plank.

Table 4.7. Unidentified fragments (UM) of edge-fastened planking found around YK 11. Length measurements are not original; other measurements are original unless noted otherwise.

Fragment Number	Wood Species	No. of Pieces	Length (cm)	Maximum Width (cm)	Maximum Thickness (cm)	Locus
UM 39	*Cupressus sempervirens*	2	39.2	10	2.1	Starboard
UM 41A	*Cupressus sempervirens*	1	27.5	5.5 (not orig.)	2	Starboard
UM 46	*Cupressus sempervirens*	3	40	8.6	1.9	Starboard
UM 100	*Cupressus sempervirens*	1	37.5	8	2.1	Port

Four unidentified fragments were found around YK 11 that could be part of a strake of planking between two wales (including UM 110, mentioned above) (table 4.8). These fragments are similar to SS 12-2 and SS 12-3 in form, with blunt-cut original ends. All of the planks possess one broken end; therefore, original lengths are unknown. Widths, varying from 6.5 to 9.6 cm, match widths seen elsewhere on SS 12.

In addition to UM 31 and UM 45 (included in the discussion above), there were five unidentified fragments of planking similar to the replacement or graving pieces for YK 11 (table 4.9). This designation is based on form, dimensions and wood type. Four of the five plank pieces are complete (or nearly so) and all are intact; only UM 89 is incomplete. Four of the five, UM 80, UM 89, UM 98, and UM 115, are similar to the slender quadrangular graving pieces, and like those, may have served to repair damage incurred at vulnerable mortises along original plank edges. UM 102, in contrast, seems to be a replacement for a starboard hood end in the ship's stern.

Finally, 31 fragments bore some resemblance to planking, at least in their thickness, but could not be identified as a certain type of plank. These are presented in table 4.10. All are softwoods, either pine or cypress. Some of the smaller pieces could be ceiling planking. As with any of the unidentified fragments, these are not necessarily from YK 11.

Table 4.8. Unidentified fragments of planking found around YK 11, possibly from a strake between two wales. All measurements are original except length.

Fragment Number	Wood Species	No. of Pieces	Length (cm)	Maximum Width (cm)	Maximum Thickness (cm)	Locus
UM 63	*Pinus brutia*	1	41	9.6	3.1	Starboard
UM 68	*Pinus brutia*	1	22	6.5	2.55	Stern
UM 110	*Pinus brutia*	1	35	8.3	2	Port
UM 194	*Pinus nigra*	1	39	7.1	2.1	Starboard

Table 4.9. Unidentified fragments of replacement planking found around YK 11.

Fragment Number	Wood Species	No. of Pieces	Length (cm)	Maximum Width (cm)	Maximum Thickness (cm)	Locus
UM 80	*Cupressus sempervirens*	1	44.8 (orig.)	6.3	2.3	Stern
UM 89	*Pinus brutia*	1	48	5.2	2.6	Stern
UM 98	*Cupressus sempervirens*	1	25.4 (orig.)	3.3	2.3	Starboard
UM 102	*Pinus brutia*	1	61 (orig.)	14.5	2.2	Stern
UM 115	*Pinus brutia*	1	37 (orig.)	5.4	2.8	Unknown

Table 4.10. Other unidentified plank-like fragments found around YK 11.

Fragment Number	Wood Species	No. of Pieces	Length (cm)	Maximum Width (cm)	Maximum Thickness (cm)	Locus
UM 8	*Pinus brutia*	2	53.4	8.6 (not orig.)	2.7	Port
UM 14	*Pinus brutia*	2	73.5	14.3	2.5	Port
UM 17	*Pinus brutia*	1	36	13.3 (not orig.)	2.7	Port
UM 18	*Pinus brutia*	3	26	8 (not orig.)	2.4	Port
UM 24	*Pinus brutia*	1	53	10.2	2.2	Port
UM 41B	*Cupressus sempervirens*	1	50.7	10	2.5	Starboard
UM 42	*Cupressus sempervirens*	3	144	13.5	2.8	Starboard
UM 58	*Pinus brutia*	2	188	20	2.3	Starboard
UM 65	*Pinus nigra*	2	34	10.1	3.1	Starboard
UM 84	*Pinus brutia*	1	38.8	2.4 (not orig.)	2	Stern
UM 85	*Cupressus sempervirens*	1	45	8.4	2.4	Stern
UM 87	*Pinus brutia*	1	40	9.8	2.7	Stern
UM 96	*Pinus nigra*	2	72	12.5 (not orig.)	2.8	Port
UM 101	*Pinus brutia*	1	16.8	5.6 (not orig.)	1.8	Port
UM 112	*Pinus brutia*	1	26	4.8 (not orig.)	2.2	Starboard
UM 133	*Pinus brutia*	1	33	7.9	2.1	Unknown
UM 134	*Pinus brutia*	1	11.6	7 (not orig.)	2.1	Unknown
UM 136	*Pinus brutia*	1	20.5	7.5 (not orig.)	2.1	Unknown
UM 137	*Pinus brutia*	1	12.2	7.7 (not orig.)	2.3	Unknown
UM 138	*Pinus brutia*	1	27.5	8.9 (not orig.)	2.3	Unknown
UM 139	*Pinus brutia*	1	31.5	7	3.2	Unknown
UM 140	*Cupressus sempervirens*	1	34.5	5.2 (not orig.)	2.6	Unknown
UM 145	*Pinus brutia*	4	12.7	9 (not orig.)	1.9	Unknown
UM 146	*Pinus brutia*	1	23	4.2	3	Unknown
UM 147	*Pinus brutia*	2	22	4.1	2.4	Unknown
UM 148	*Pinus brutia*	1	9.3	4 (not orig.)	2.9	Unknown
UM 149	*Pinus brutia*	1	52	5.7 (not orig.)	2.7	Unknown
UM 150	*Pinus brutia*	1	30.5	4.3 (not orig.)	3.3	Unknown
UM 160	*Cupressus sempervirens*	2	21	7.7 (not orig.)	2.9	Port
UM 168	*Pinus brutia*	1	30	4.9	2.2	Port
UM 169	*Pinus brutia*	1	58	9.9	3	Port

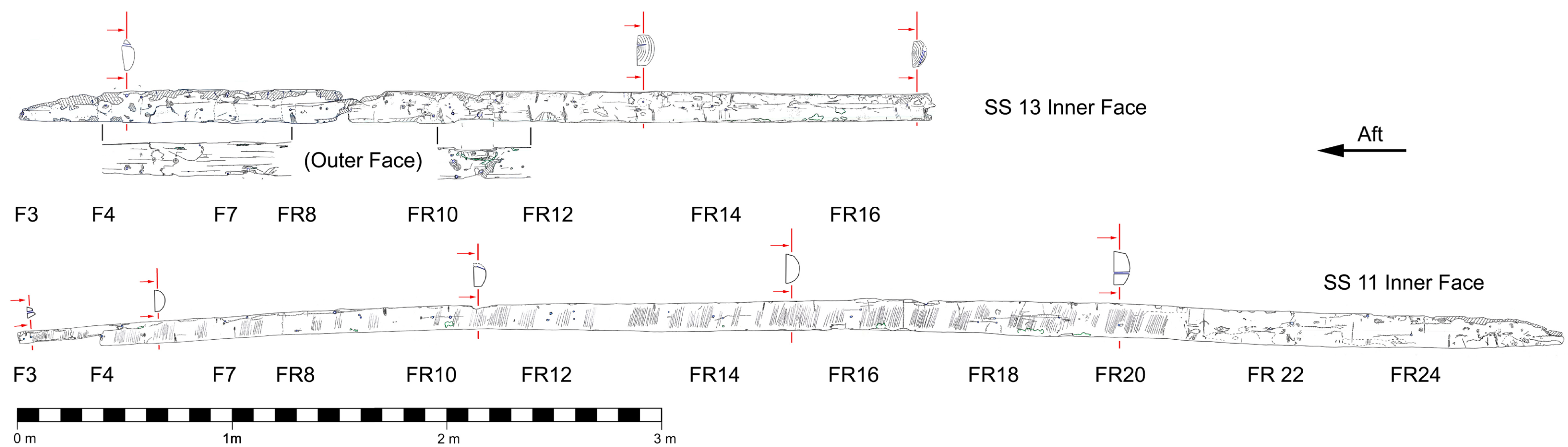

Figure 4.99. YK 11 wales.

THE WALES

In-situ Wales

Two wales were found in situ on the port side, SS 11 and SS 13. The two were separated by SS 12 and at least three (probably four) through-beams (figs. 4.99-4.100). Based on evidence associated with the ship's through-beams and framing UMs, there would originally have been four wales on either side of the ship. Both extant wales are *Pinus brutia*; several other UM fragments of wales or wale-like timbers were found scattered around the wreck site, and all but one are of *Pinus brutia* or, less commonly, *Cupressus sempervirens.*

Dimensions

The preserved length of SS 11, with one original end and one broken end, is 7.24 m, nearly 7 m of which remained intact. Some of its original curvature was preserved. In order to prevent breakage during removal from the wreck, the excavation pit was flooded with enough water to cover the timber so that it could be floated off and placed into a foam-lined crate. Neither end of SS 13 is original, and the extant timber had broken into three pieces; its assembled length is 4.28 m.

Both wales are half-logs with the bark removed from the rounded outer face. The pith of the timber is at times visible along the center of the flat inner face; 20-25 annual rings are visible at the breaks. The upper and lower edges were trimmed down in some (but not all) areas, producing sections that are semicircular or approximately so. SS 11 has a maximum width of 16.5 cm near its forward end; this tapers toward the stern, in the direction of growth, with a minimum full width of 9.6 cm at the start of the aft scarf, at F 4. It is 5 cm in width along the scarf (see below). SS 13, less extensively preserved, has a maximum width of 15.7 cm and seems to taper slightly toward the bow, in the direction of growth, with a minimum width of 13 cm at its broken forward end, at the FR 17-FR 18 through-beam.

Figure 4.100. Part of SS 11 and SS 13 in situ. Holes for through-beams at FR 10-FR 11 and FR 17-FR 18 are clearly visible.

Due to the curvature of the outer face, the maximum thickness of each wale was around the center of the timber's section. This was usually approximately 5-8 cm, slightly less near the SS 11 scarf. Edges, where adzed flat, were usually 2-4.5 cm thick, but many areas, including much of the top edge of SS 11, had a rounded or poorly-defined edge.

<u>Condition and Wale Ends</u>

The two in-situ wales are very well preserved. Although the breaks in SS 11 occur along the aft-end scarf, the most damage to this timber is at its broken forward end, which was exposed and eroded. The wale's lower edge had slipped down behind SS

10-1; as a result, in-situ drawings do not convey an accurate width. There is damage and wear along the top edge of SS 11 at through-beam locations, probably a combination of wear from the through-beam as well as damage from the nails that fastened them having been torn out. Similar damage was seen on the lower and upper edges of SS 13 at through-beam locations. Being higher in the hull, SS 13 was more exposed and thus suffered more extensive damage from teredo and gribble, especially along its top edge. The aft end of SS 13 is especially poorly preserved; however, there is better surface preservation at frame locations, where the wale surface was protected from woodborers. The breaks on SS 13 are located at through-beams.

Figure 4.101. Scarf at aft end of wale SS 11.

The aft end of SS 11 terminates in a flat scarf, 38 cm in length, between F 3 and F 4 (fig. 4.101); the timber to which it was scarfed was not preserved. A similar scarf was observed on the wale of the Serçe Limanı hull, although this was nailed together;[74] there are no nails on the SS 11 scarf that would have edge-fastened it to another part of

[74] Bass et al. 2004, 112.

the wale. The ends of the scarfs are at F 3 and F 4, with futtock nails at each location; a second nail in close proximity on each futtock shows that the timber scarfed to SS 11 was also attached to F 3 and F 4 with nails.

Figure 4.102. Outer face of SS 11 at FR 12. Note clenched nail tip (at arrow) and thick pitch and caulk near top edge.

Table 4.11. Overview of nails fastening framing to wales.

Frame Type	Shank Length (cm)	Shank Dimensions (cm)	Nail Head (cm)	Direction Driven	Description
Half-Frame	10-15	0.6-1.0	2.5-3.0	From interior	All but FR 6 attached to SS 11; only FR 8 attached to SS 13.
Floor futtock, nailed from interior	9-14	0.4-0.8	2.5-2.9	From interior	Just over half of SS 13 futtock nails; one SS 11 futtock nail.
Floor futtock, nailed from exterior	7-10	0.65-0.9	2.0-2.7	From exterior	Almost all SS 11 futtock nails; just under half of SS 13 futtock nails.
Half-frame futtock	10-12	0.4-1.1	2.1-2.6	From interior	All half-frame futtocks originally attached to wales they contacted.

Fasteners

The ship's framing and through-beams were nailed to the wales; an overview of the framing nails is provided in table 4.11. Each half-frame was attached to the wales with an iron nail driven from the hull interior. The nails were driven through pilot holes drilled from the inner face of the frame, usually 1.2-1.3 cm in diameter; these pilot holes at times extended to the inner face of the wale, as on SS 13 at FR 14. The half-frame nails did not extend to the wale's outer face on SS 13. On SS 11, most of the nails did extend through the wale, four of them being clenched over on the wale's outer face (fig. 4.102). Other nails may not have extended far beyond the outer face of the wale or may have been hammered over at the protruding tip but were not impressed into the wale surface.

All of the extant half-frames, with the exception of FR 6, were attached to SS 11; FR 6 does not seem to have extended up to this level, but the top end is damaged.[75] Most of the half-frames do not extend to SS 13; FR 8 terminates over SS 13 and was attached to it. FR 10 and FR 14 seem to have been either cut down or damaged below SS 13. Replacement frame FR 12 extended just to SS 13; while it is not attached to the wale, a shallow recess trimmed out of the wale's inner face accommodated the frame (fig. 4.103).

The floor futtocks were almost always attached to SS 13 but only sometimes attached to SS 11. F 3, F 4, F 7, F 9, and F 19 were attached to SS 11; fastening patterns on the planking indicate an additional eight floor futtocks that crossed SS 11 but were

[75] The following half-frames were attached to SS 11: FR 8, FR 10, FR 12, FR 14, FR 16S, FR 18, FR 20, FR 22, FR 24.

not attached to it. In contrast, all floor futtocks were attached to the extant portion of SS 13, except for F 9, although SS 13 is damaged in this area and evidence of an iron fastener may not have been preserved.[76] There is less consistency in how the floor futtocks were attached to the ship's wales. All but one of the floor futtock nails on SS 11, and just under half of the floor futtock nails on SS 13, were driven from the hull exterior. Some of these nails were driven through a pilot hole 1.0-1.4 cm in diameter; the nails did not extend through the inner face of the floor futtocks.

Figure 4.103. Inner face of SS 13 near lower edge, trimmed down for FR 12 top end.

Just over half of the SS 13 floor-futtock nails and one of the SS 11 floor-futtock nails were driven from the inner face of the ship's framing. Most of the nails driven from

[76] F 13 seems to have been damaged or cut down at its top end, but a fastener at this location on SS 13 suggests it was attached to the wale at some point.

the interior do not extend to the outer face of the wale; for those that do, the hole is relatively small and there is no evidence of clenching. A seemingly disused nail on SS 13 at F 11 may indicate that this futtock was a replacement for an earlier timber.

Half-frame futtocks were attached to wales with nails driven from the interior (table 4.11); only in one case did the nail extend to the outer face of the wale, showing as a small hole here.[77] As on the half-frame nails, the half-frame futtock nails were driven through pilot holes, 1.1-1.3 cm in diameter, drilled from the inner face of framing; in some cases, these drilled holes extended to the inner face of the wale.

Due to insufficient preservation, it is unclear how consistent the half-frame futtocks were in their form and location. F 10, F 12, F 18, and F 22 appear to have been attached to SS 11; F 20, the only in-situ half-frame futtock, did not cross SS 11, and there is no evidence elsewhere on the planking that any of the other half-frame futtocks extended down to SS 11. F 6, F 8, F 10, and F 12 were originally fastened to SS 13. There does not seem to be a nail preserved for a half-frame futtock at FR 14; the second nail here is likely from an original FR 14 that was later replaced, although this is not certain. There is also no evidence for a half-frame futtock located next to FR 16S.

Altogether, the extant fasteners show that all of the half-frame futtocks were attached to the wales they crossed, at least during the initial construction. F 12 was originally fastened to SS 13 while its replacement was not. UM 13 (possibly F 18) seems to follow a similar pattern along its outer face: two nails, driven from the inner face, very

[77] The only area where this half-frame futtock fastening pattern deviates is at F 10, where there are several nail holes on both the inner and outer face of the wale. These seem to be reinforcements, which are reasonable for this half-frame futtock adjacent to a through-beam. The other two outer face holes at F 10 did not extend to the opposite face and had been filled in with caulking or wood fibers and covered over with pitch; their original function is unclear.

likely attached the timber to two wales; the spacing here indicates that a wale (SS 13?) was skipped. Without more than one wale preserved here, however, it cannot be stated whether this was an original timber, thus providing evidence of a half-frame futtock that was not attached to a wale it crossed; the presence of only one nail here on SS 11 would indicate that it was original.

There are several other nails on the wales that do not appear to match the pattern of the ship's framing. A nail forward of F 13 on SS 11 matches a line of fasteners on SS 8, SS 9, and SS 10; this deviates from the typical framing pattern and could be a reinforcement frame timber, not unlike FR 12A on the starboard side (fig. 4.104). Unexplained nail or fastener holes are much more common on SS 13 and may represent top timbers at F 3-F 4, F 6-F 7, F 8-F 9, and F 9-F 10. Multiple nail holes at the F 9-F 10 location on SS 13 suggest that whatever timber was here may have been replaced at some point. None of these nails appears to have been driven from the outer face; nail holes are 0.4-0.6 cm in sided dimension and do not always extend to the outer face of the wale.

There are also six holes on the outer face of wale SS 13 that do not extend to the inner face. Four of these had been filled in, either with wood fibers or caulking. One seems to be a pilot hole that was not used or had been drilled in the wrong location at F 3. The two outer face holes that were not filled in do not seem to have been used and look like holes from nails that had been pulled.

In summary, the framing was attached to wales with nails; for half-frames and half-frame futtocks, these nails were driven from the interior, while floor futtocks were attached with a combination of nails driven from the exterior and interior. Those nails that extended through the outer face of the wale were clenched over or just barely broke the surface. There is no evidence for the use of bolts to fasten the framing to the wales. The nails suggest that F 3, F 9, F 11, FR 12, F 12, FR 14, FR 16S, and FR 18 are all replacement frames.[78]

Figure 4.104. Line of nail holes and pitch outline around a possible reinforcement futtock forward of F 13 on the port side.

Nails were also used to fasten the wales to the ship's through-beams. These nails were driven from the ship's exterior, diagonally through the wale edge closest to the through-beam and into the top or lower face of the through-beam at its central recess. These diagonal edge nails or traces thereof occur at known through-beam locations: along the top edge of SS 11 and lower edge of SS 13 at FR 8-FR 9, FR 10-FR 11 and FR

[78] This aligns with the evidence seen on extant frames F 3, FR 12, F 12, FR 14, FR 16S, and FR 18.

17-FR 18. A similar nail along the top edge of SS 13 at FR 7-FR 8, combined with a pressure mark and caulking outline on the wale's outer face, indicate the presence of a second level of through-beams between the second and third wales.

In addition to these, three nails of this type were observed that do not seem to have been associated with through-beams. Diagonal nails driven through the top edge of SS 11 at FR 4-FR 5 and FR 7-FR 8 cannot have fastened a through-beam, as SS 12 does not have a gap at these locations. A nail of this kind was also noted along the top edge of SS 13 at FR 4-FR 5, but there is no other indication of a through-beam here. The purpose of these diagonal nails remains unknown.

The diagonal edge nails were 0.6-1.2 cm in sided dimension and seem to have been driven through pilot holes, 1.1-1.4 cm in diameter. Based on the depth of the nail in through-beam fragment UM 81, these nails were approximately 8-13 cm in length; the SS 13 nail at the FR 10-FR 11 through-beam was bent within the wale. All of the diagonal edge nails were driven from the outer face; nail-head impressions are 2.0-2.6 cm in diameter and are often associated with damage. The nail heads on SS 13 at the FR 10-FR 11 and FR 17-FR 18 through-beams, and perhaps also on SS 11 at the FR 17-FR 18 through-beam, are partly countersunk (fig. 4.105) to offset the odd angling of the nail head against the curved face of the wale.

Finally, there are 12 nail holes along the top edge of SS 13 between F 4 and F 13, approximately 1-2 cm from the inner face edge of the wale; their function is unknown. These were driven down into the wale, sometimes at a slight oblique angle. These small holes are usually 0.3-0.5 cm in sided dimension and up to 4.8 cm in depth. Concretion or black staining was observed in and around these holes, suggesting they had been in use (fig. 4.106). Only one hole had been filled in with wood fibers and seems to have been abandoned.

Figure 4.105. Countersunk nail head at a through-beam nail. SS 13 at FR 17-FR 18.

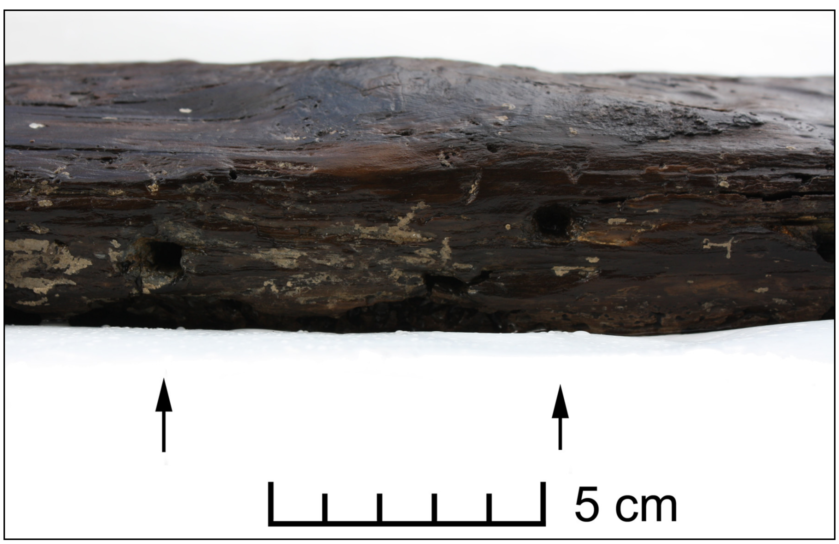

Figure 4.106. Nail holes along top edge of SS 13 near FR 8. The hole on the left (aft) was slightly concreted. The hole on the right had been filled in with wood fibers.

Tool Marks

Both wales were cut from young trunks of *Pinus brutia* that were sawn in half lengthwise, the sawn face corresponding to the wale's inner face. The saw marks are muted on SS 13, but clear saw marks on SS 11 show that the timber was cut against the direction of growth, oriented toward the stern. Forward of FR 21, most of the inner face of SS 11 was adzed rather than sawn, perhaps to remove a charred surface. The top and lower edges of both wales were dubbed with an adze blade at least 3.0 cm in width; adze marks confirm that the aft scarf was also adzed. The outer face was left naturally rounded; bark was perhaps removed with an adze, which was also used to trim down areas where branches had been removed.

There are several areas on SS 13 where the surface was notched or recessed. This includes the inner face at the top end of FR 12, which was cut with a 1.4 cm deep recess to accommodate the frame; this was likely dubbed with a 4.4 cm-wide adze (fig. 4.103). There is also a shallow (0.9 cm deep) notch cut out of the lower edge of SS 13 at the FR 10-FR 11 through-beam; this notch is 17.6 cm along the length of the wale, although the gap for the through-beam in SS 12 is only 14.7 cm wide. The countersinking for outer face nail heads, at two through-beam locations and for a nail driven from the outer face at F 10, was created with a chisel; tool marks suggest blade widths of 1.3 cm and 1.9 cm (fig. 4.107). An area of pitched damage just forward of the through-beam nail on SS 13 at FR 10-FR 11 (around the middle of the outer face) may be a botched attempt at countersinking; if so, the countersinking was done too close to the edge of the through-beam, which could be why the effort was abandoned (fig. 4.107). Cut marks here, at least 1.8 cm in width, seem to have been made with a chisel.

Figure 4.107. SS 13 outer face at FR 10-FR 11. Red arrow indicates rough tool marks that had been pitched over. Note pressure mark and caulk outline at through-beam location (indicated in black).

On SS 11, there are irregular patches of charring along the inner face from the eroded and broken forward end to around FR 21. This charring coincides with the start of adzing on the inner face, indicating that the timber had been char-bent into form then dubbed with an adze to remove some of the rougher surfaces. There is no evidence of similar charring on SS 13, probably due to insufficient preservation.

Caulking and Surface Treatment

Wale edges were caulked in a manner similar to the planking (fig. 4.102), although much of the pitch and caulk had washed away due to exposure. Where well preserved, lumps of pitchy caulk were 0.4-0.8 cm thick and backed by a thick ridge of pitch. Grass-like caulk fibers were oriented perpendicular to the line of the wale and were up to 1 cm in length. Pressure lines along wale edges reflect the displacement of the SS 12 planks. Pitch is generally better preserved than the caulk and often remains after caulk fibers have been washed away. Traces of pitch on the wales' inner and, to a greater extent, outer faces indicate that these had also been payed with pitch.

Caulk and pitch outlines on the outer face of the wales at some through-beam locations indicate that caulking was stuffed into gaps between the wale and through-beam then sealed with pitch.[79] This is best preserved on the lower edge of SS 13 at FR 10-FR 11 but is also seen on the top edge of SS 13 at FR 7-FR 8, the lower edge of SS 13 at FR 17-FR 18, and the top edge of SS 11 at FR 17-FR 18. The well-preserved pitch outline on the lower edge of SS 13 at FR 10-FR 11 matches well with the edges of the gap in SS 12 (w=14.7 cm), suggesting the 17.6 cm wide notch on SS 13's lower edge was cut too wide; the resulting gap would most likely have been filled in with pitch and caulking.

Other Surface Detail

The inner face of SS 13 is generally slightly better preserved at frame locations, even on frames that had been displaced, such as F 4. That this is the case indicates that the ship had been submerged for some time before the wreck was disturbed and many timbers pulled out of place.

[79] This is discussed further in the section on through-beams.

There are no clear score marks of the type seen on planking on the inner face of SS 13, but multiple short cut marks around the top end of FR 14, a probable replacement frame, may have indicated where the frame was to be placed. Although less clear than those on other planks, score marks were noted in several areas on SS 11. They were noted at the edge of frames that are known replacements, including F 3 and FR 16S, as well as along one edge of F 17, a possible replacement. Score or score-like cut marks were also noted along the edge of original framing, including F 23 and FR 24, and on the edge of F 15, F 21, and F 25, none of which was preserved but which fastening patterns indicate were original timbers.

Figure 4.108. Fine wear marks on the outer face of SS 11 between FR 14 and FR 15.

The presence of score marks on the wales at original frame edges is significant and helps elucidate the construction sequence of the vessel. Scoring along edges of original or possibly original frames occurs almost exclusively at floor-futtock locations. The only exception is FR 24, and the faint cut mark here, slightly forward of the frame, may indicate the location of a half-frame futtock or have served another function. Most of the evidence, then, indicates that wale SS 11 had been in place when some of the futtocks were installed but had not been in place when most of the half-frames were installed (see Ch. V, *Construction Sequence*).

Finally, there are fine, vertical wear marks on the outer face of SS 11 at its thickest area between FR 14 and FR 15 (fig. 4.108). The location and orientation of these marks strongly suggest rubbing damage, perhaps against some part of a dock, although it is noteworthy that this was not observed on SS 13.

Table 4.12. Unidentified wale-like fragments found around YK 11.

Fragment Number	Wood Species	Length (cm)	Width (cm)	Thickness (cm)	Locus
UM 26	*Pinus brutia*	22.5	9.7	3.9	Port
UM 28	*Tamarix* (x5)	37.5	10.9	5.3	Port
UM 40	*Cupressus sempervirens*	196.0	14.0	6.3	Starboard
UM 69	*Pinus brutia*	15.9	5.2	4.7	Unknown
UM 72	*Pinus brutia*	49.5	12.8	7.0	Unknown
UM 77	*Pinus brutia*	16.5	7.6	4.2	Unknown
UM 88	*Pinus brutia*	19.5	8.9	4.9	Unknown
UM 92	*Cupressus sempervirens*	33.5	13.3	6.9	Unknown
UM 121	*Pinus brutia*	58.0	10.2	5.5	Unknown
UM 125	*Pinus brutia*	24.0	8.6	5.7	Unknown
UM 126	*Fraxinus excelsior*	22.0	8.8	5.7	Unknown
UM 128	*Pinus brutia*	21.0	11.9	5.0	Unknown

Figure 4.109. Damaged scarf at the end of wale UM 40.

Other Wale Fragments

In addition to SS 11 and SS 13, fragments of several other wales or wale-like timbers were found scattered throughout the YK 11 excavation pit. These 12 timbers were all given UM numbers; dimensions are provided in table 4.12. Nine of the 12 had been removed by museum staff during initial excavation; their find locations within the excavation pit were not recorded. Several of the timbers are very fragmentary and are included here due to a wale-like cross section; they may or may not be wale fragments.

The UM that was most likely a wale of ship YK 11 is UM 40; it was found just outboard of the ship on the poorly-preserved starboard side, toward the bow. It rested upon its inner face, but barnacle pressure marks throughout this face indicate that it had been exposed underwater for some time before it was displaced. Although UM 40 is a half-log of *Cupressus sempervirens* rather than *Pinus brutia*, several features match those seen on SS 11 and SS 13. It is 1.96 m in length and comparable to the YK 11 wales in width and thickness. Both ends were broken, but the end toward the bow had part of a flat scarf preserved, very similar to that seen at the aft end of SS 11 (fig. 4.109).

Diagonal nail holes along one edge of UM 40 indicate two possible through-beam locations; large areas of damage here were probably caused by the tearing out of the nails that secured the wale to the through-beam. Like the YK 11 wales, UM 40 has several frame fasteners that appear to have been abandoned, indicating frame repairs.

Although much shorter and of unknown provenience within the excavation pit, UM 121 provides an example of an original wale end. This wale was part of a longer half-log of Turkish pine; only 57.5 cm of its length was preserved, and in width and thickness it is similar to the slightly smaller aft end of SS 11, just before the scarf. A diagonal edge nail and a pressure mark along one edge indicate the location of a through-beam. At this wale fragment's original end, the timber is beveled along the outer face over a length of 4 cm to a thin tip (fig. 4.110). A nail was driven into the wale just before the start of the bevel to fasten the timber to the stem or sternpost. A triangular notch, approximately 4 cm per side and 1.5 cm in depth, accommodated the nail head, of which no trace was found. The nail was driven through a 0.9 cm-diameter pilot hole. It is interesting that this wale end was located just 30 cm from a through-beam, which perhaps supported one of the decks.

The remaining wale timbers are very fragmentary; none is more than 50 cm in length. They are 7.6-13.3 cm in width and 3.9-7.0 cm in thickness, similar to the dimensions of the in-situ wales. All had a wale-like, approximately semicircular, section with one naturally rounded face; the pith was located along or near the opposite face. All but two are softwoods, primarily Turkish pine but also Mediterranean cypress; the odd wood-species identification for UM 28 (tamarisk) and UM 126 (ash) may indicate that these timbers are not wale fragments.

Figure 4.110. Original end of wale(?) UM 121.

Table 4.13. Evidence for YK 11 through-beam placement.

	FR 23-FR 24, SS 11-SS 13	FR 17-FR 18, SS 11-SS 13	FR 10-FR 11, SS 11-SS 13	FR 8-FR 9, SS 11-SS 13	FR 7-FR 8, Above SS 13
Hole Size (cm)	Unknown	8.5	13.6	Est. 9.6	Est. 10
SS 11 Evidence	Nail near top edge; wear.	Diag. nail through top edge, damage.	Damage to top edge, traces of iron fastener.	Diag. nail near top edge, damage.	[Not applicable]
Through-beam strake (SS 12, SS 14) evidence	Possible gap between SS 12-5 and UM 110?	Gap between SS 12-4 and SS 12-5.	Gap between SS 12-3 and SS 12-4.	Gap between SS 12-2 and SS 12-3.	[SS 14 not preserved]
SS 13 Evidence	[SS 13 not preserved]	Nail through lower edge; break here.	Nail through lower edge; pitch/caulk outline, pressure mark on outer face; break here.	Nail through lower edge; break here.	Nail through top edge; pitch line and pressure mark on outer.
Other Notes	Location aligns with mortises in forward S-Blocks.	Forward of mortises in central S-Blocks.		Location aligns with mortises in aft S-Blocks.	Evidence on SS 13 only.
Suggested Beam Function	Forward deck support?	Mast-partner through-beam.	Structural support.	Bulkhead attachment.	Stern deck support?

THE THROUGH-BEAMS

Although none of the YK 11 through-beams was preserved in situ, evidence on adjacent planks indicates the presence of several such timbers; this evidence is summarized in table 4.13. The form and method of attachment of the through-beams, as suggested by the planking and wales, was confirmed by the one probable fragment of a through-beam found near the ship, a displaced timber that was cataloged as UM 81.

Evidence for Through-beams on YK 11 Wales and Planking

The clearest evidence for the presence of through-beams may be found along strake SS 12 on the port side, where gaps in the planking accommodated the through-beams. Well-defined gaps are clearly visible at FR 10-FR 11 and FR 17-FR 18 (fig. 4.100). Based on the finished (albeit damaged) forward end of SS 12-2 and aft end of SS 12-3, there was another gap between FR 8 and FR 9. A fourth through-beam was postulated between the broken forward end of SS 12-5 and the aft end of the proposed original location of displaced timber UM 110, although this remains uncertain; however, evidence from SS 11 seems to confirm a through-beam in this location.

Several types of evidence for the location of through-beams were preserved on the wales, including nails, notches or wear to wale edges, and caulk, pitch, and pressure lines on the outer face. The through-beams were locked in place with nails driven diagonally inward through the wale edges and into the top or lower face of the through-beam. These are preserved as diagonal fastener holes that emerge through the wales' inner face near or along the edge (fig. 4.111). Some nails have been torn out, and at other locations, all that remains is a patch of iron staining to indicate the previous presence of an iron nail. Due to damage, it is unclear whether the shipwright fastened each through-beam with two nails (one per wale), or whether, in some cases, only one nail was used; UM 81 seems to indicate the latter (see below). The through-beams were not attached to SS 12; these planks were too weak to provide any structural support and served merely to fill the empty spaces between through-beams and wales.

Figure 4.111. Wale SS 13 inner face at FR 10-FR 11 through-beam. Note nail hole near lower edge and shallow notch along edge.

There was a shallow notch, 0.9 cm in depth, cut out of the lower edge of SS 13 at the FR 10-FR 11 through-beam (fig. 4.111).[80] Otherwise, the wale edges are usually worn or damaged at the location of through-beams. Pressure marks along the outer face were caused by some through-beam edges. A well-preserved line of pitch and caulking fibers along the wale's outer face denotes the original chamfered form of the through-beam at the lower edge of SS 13 at FR 10-FR 11 (fig. 4.107). Although this is above the waterline, the caulking of this seam indicates the shipwright's desire to waterproof the area. Traces of similar pitch and pressure lines are also seen on the top edge of SS 13 at FR 7-FR 8, the lower edge of SS 13 at FR 17-FR 18, and the top edge of SS 11 at FR 17-FR 18. The pitch line and iron fastener on the top edge of SS 13 at FR 7-FR 8 are the

[80] The fourth- or fifth-century Fiumicino 1 ship also had rectangular notches on the wale edge, associated with iron nails that likely fastened through-beams in place (Boetto 2008, 38-9).

only indications of a second level of through-beams, between the second and unpreserved third wales (fig. 4.112).

Figure 4.112. Wale SS 13 top edge at FR 7-FR 8. Iron nail hole and pitch outline (red arrow) indicate a through-beam at this location.

Pressure marks and discoloration on the inner and outer faces of planks in SS 12 suggest that the through-beam was notched on the sides to accommodate the plank ends (fig. 4.72); this served to hold the ends of SS 12 in place on the through-beam rather than to lock the through-beam in place on SS 12. This notching of the through-beam to accept the ends of SS 12 accounts for the lack of fasteners on some ends of SS 12, notably the aft end of UM 110 (SS 12-6?), the forward end of SS 12-2, and the aft end of SS 12-5.

The pressure marks, lacking sharp angles, also indicate a through-beam with rounded or chamfered edges.

Through-beam Fragment UM 81

Only one part of a through-beam, UM 81, was found in the YK 11 excavation pit (fig. 4.113). This cypress timber was almost certainly one of YK 11's through-beams, since the characteristics of this timber match very closely the characteristics of the through-beams that have emerged from the study of the wales and SS 12. UM 81 was part of a large group of UM timbers that had been removed from the wreck area by museum staff before the INA team began work on the wreck; it is therefore of unknown provenience, but a worker noted that it came from a group of timbers found around the stern. Based on the angle and location of notches, it would have either been from the starboard bow or port stern; the latter is far more likely, as the port stern is a well preserved area in the aft 1/3 of the ship, while the starboard bow was only preserved to near the turn of the bilge.

The outboard projecting end of through-beam UM 81 is original; the timber had broken approximately 12 cm inboard of the hull planking and the remainder was not preserved. It is intact but incomplete, preserved for a length of 34.5 cm; it is 8.1-9.7 cm in sided dimension and 9.4-10.1 cm in molded dimension, tapering slightly toward its outboard end. Staggered notches are cut on each face to accommodate the wales and side planking; at notched areas, the beam is 7.4 cm sided and 8.1 cm molded. The staggering of the notches indicates that this through-beam was from near the ship's extremities. The notches are 1.0-1.7 cm in depth, which corresponds to the typical 1-2 cm of pressure damage at the ends of SS 12.

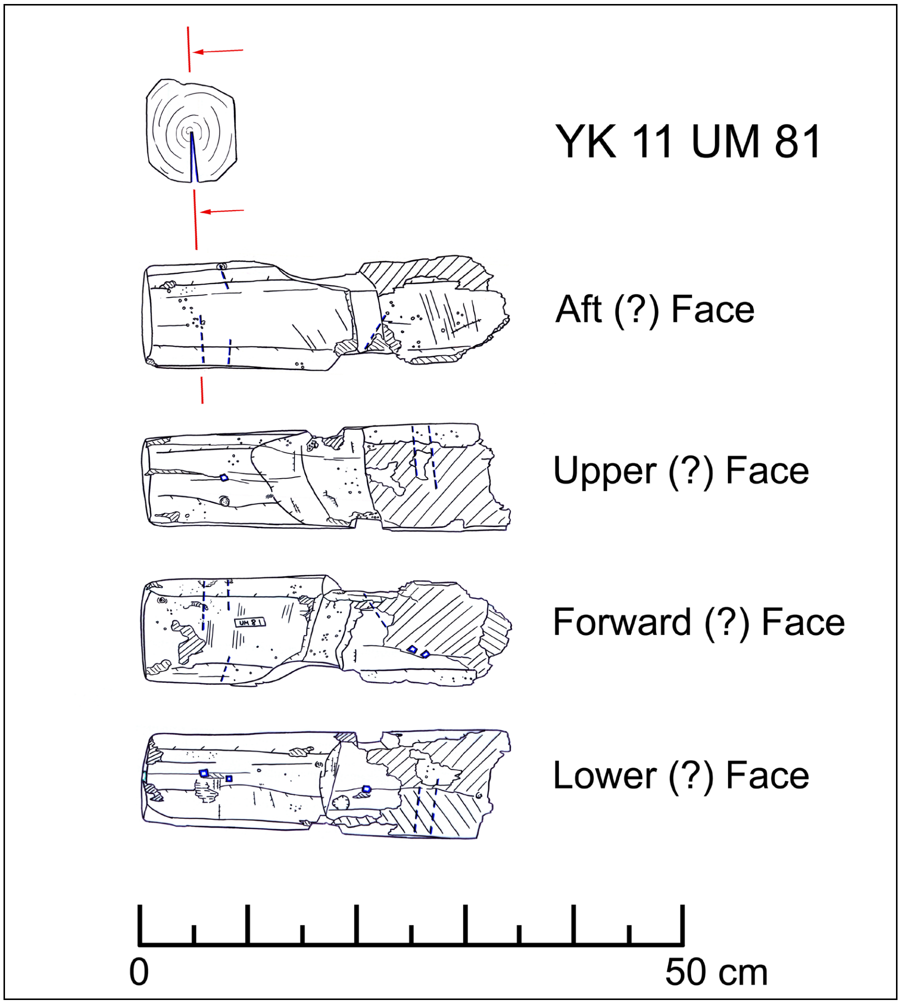

Figure 4.113. Through-beam fragment UM 81, likely part of YK 11.

The beam was cut from the center of a small cypress trunk with approximately 20 annual rings visible. Edges were cut with a chamfer or naturally rounded, which matches the pressure marks and pitch outlines observed on SS 12 and the wales. A through-beam end was also found in situ on the late 10th-century merchantman YK 5 at Yenikapı; like UM 81, the YK 5 through-beam was also chamfered along its edges.[81]

The outboard end of UM 81 was sawn flat, and the recesses for planking were cut with a chisel. Although most of the original surface treatment was not preserved, a small patch of pitch at the original end suggests that at least the outboard part of the timber had been pitched, which again confirms the evidence noted on the wales.

Several nail holes were observed on the through-beam. A nail on the lower face in the notched area, driven diagonally from outboard, would have secured the through-beam to the lower wale; a similar nail was not observed on the top face, which seems to prove that, in some cases, one nail was deemed sufficient to lock the through-beam in place. Two nails were found on one side (forward?) of UM 81, inboard of the planking; perhaps these were used to secure part of a bulkhead or inner partition, or indicate that a futtock or top timber was attached to the through-beam. Three other nails were found outboard of the planking, two on the lower face and one, apparently an old, disused nail hole, on the top face; these are of unknown function, but perhaps were used in some structure to support the quarter rudder.

The staggering of the side notches makes it clear that UM 81 was not the mast-partner through-beam (FR 17-FR 18). Furthermore, the lack of a nail hole in the notch on the top face of UM 81 indicates that it was also not the SS 11-SS 13 through-beam at either FR 8-FR 9 or FR 10-FR 11, since there was a nail driven through the lower edge

[81] The YK 5 through-beam was also cut with notches, but only on the forward and aft faces. It was found between a wale and a plank that was recessed along its lower edge to accommodate the through-beam rather than sandwiched between two wales, as on YK 11.

of SS 13 at each of these locations. It may have been the through-beam above SS 13, where upper edge pressure and wear marks 9.5 cm in width (fig. 4.112) fit the sided dimension of UM 81. However, without the third wale preserved, it is impossible to say for sure.

Combining the size of the gaps in the through-beam strake SS 12 (table 4.13) with a minimum notch depth of one cm on each side produces a hypothetical sided dimension of 10-15 cm. The width of SS 12 at through-beam locations is 7.6-9 cm which, combined with a 1 cm recess on each edge, produces a molded dimension of approximately 9.5-11 cm. These dimensions overlap with those of UM 81, although UM 81 seems to be at the narrow end of the range in sided dimension. Combining UM 81 with evidence seen on the planks and wales indicates a through-beam attachment as illustrated in figure 4.114.

Through-beam Location and Function

In addition to the through-beam locations noted in table 4.13, there are additional diagonal nails on wale edges that do not seem to be at through-beam locations. These are forward of F 4 and between FR 7 and FR 8 along the top edge of SS 11; however, SS 12 runs uninterrupted through these areas, and there is furthermore no other indication (other than a diagonal nail) of a through-beam. There is also a diagonal nail along the top edge of SS 13 between FR 4 and FR 5; in the reconstruction, the quarter rudders have been mounted on a hypothetical through-beam at this location. Other through-beams may have been located between the second and third wales; due to damage along the top edge of SS 13 and no planking preserved above this point, this remains unclear.

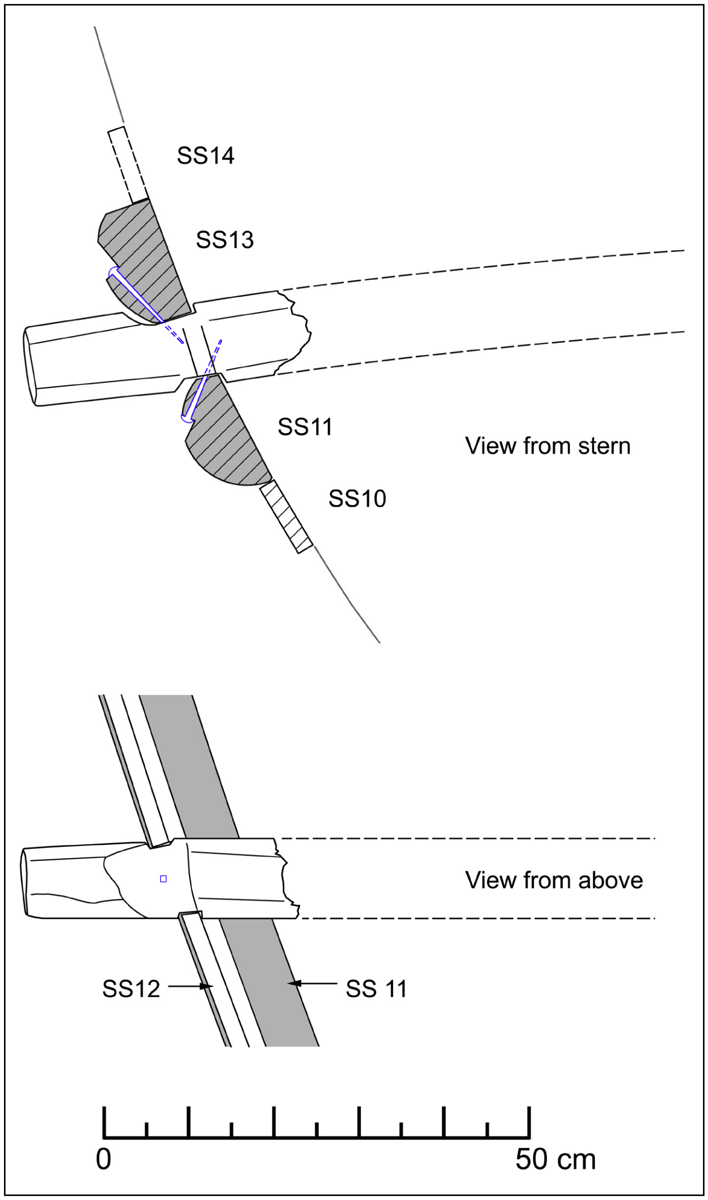

Figure 4.114. Likely attachment of the YK 11 through-beams.

Each of the through-beams would have served a specific function, based on its location in the hull. The through-beam at FR 23-FR 24, the forward-most through-beam for which any evidence was preserved, may have supported a forward deck. It is aligned with the mortises in the forward pair of stanchion blocks.

The FR 17-FR 18 through-beam would have served as the ship's mast-partner beam; the position of this through-beam, just forward of amidships, was the primary reason that the bow and stern were reversed from their initial designation in 2008. The gap in SS 12 for the mast-partner at FR 17-FR 18 is slightly smaller than other gaps in SS 12, which may indicate deeper notching or, less likely, a smaller beam.[82]

The three through-beams in the stern could have served multiple purposes. The spacing between the FR 8-FR 9 and FR 10-FR 11 through-beams (between the first and second wales) is approximately 65 cm; similarly-spaced through-beams on the seventh-century Yassıada ship were interpreted as part of the support frame for the quarter rudder.[83] However, these through-beams appear to be too far forward to have served that purpose on YK 11. The FR 10-FR 11 beam was probably 15 cm in sided dimension based on the gap in SS 12, larger than that for other beams. In the reconstruction, this through-beam provides structural support to the hull and a secure point of attachment for the lower halyard block. The lower beam at FR 8-FR 9 aligns approximately with mortises in the aft pair of stanchion blocks and is just aft of the bulkhead partition; it has been reconstructed as a support for the latter.

The upper-level through-beam at FR 7-FR 8 (SS 13-SS 15) likely supported the stern deck. Based on a fastener hole on the top edge of SS 13 at FR 4-FR 5, a second upper-level through-beam is suggested in the YK 11 reconstruction; the quarter rudders were likely attached to this through-beam.

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[82] The central through-beam on the seventh-century Yassıada ship was 32 cm sided and 19 cm molded, much larger than any through-beam of YK 11 (Bass and van Doorninck 1982, 52; van Doorninck 1967, 40, 68).
[83] Bass and van Doorninck 1982, 52-3.

STEMSON AND STERNSON

Two keelson-like central longitudinal timbers were preserved in situ on YK 11, one near the bow, the stemson, and the other near the stern, the sternson.[84] These notched timbers, although keelson-like in form, did not extend the entire length of the vessel and are therefore not parts of a true keelson. Instead, the central portion of the ship, between FR 10 and FR 21, is strengthened longitudinally with a pair of closely-spaced stringers flanking the ship's centerline.

Sternson KS 1

The sternson and stemson on YK 11 are very different in form and dimensions. The sternson, KS 1 (so labeled due to its similarity in form to a keelson), was a substantial timber, not unlike similar timbers recorded on shipwrecks at Tantura.[85] KS 1 was fashioned from a recycled keel of Turkish pine (fig. 4.115). It was notched to fit over frames between FR 2 and FR 9; it covers the entire length of Keel 1 and extends aft two additional frames and would thus have provided valuable internal support to the transition between the sternpost and the flat portion of the keel. It is complete but not intact, having been broken into three pieces and badly distorted by compression damage (fig. 4.116). It is 2.05 m in length, 9.5-13.5 cm in molded dimension at unnotched areas and 9.6-10.9 cm in sided dimension, widest at its inner face. These measurements exclude those areas that are notably affected by compression.

[84] According to Pomey et al. (2012, 261), Steffy suggested use of the term central longitudinal timber for similar pieces. "Sternson" and "stemson" were used here to avoid confusion with the central stringers of YK 11.

[85] Similar timbers were found on Dor 2001/1 (1 timber, in the stern) and Tantura F (2 timbers, one at either end). Mor and Kahanov 2006, 279-80; Barkai and Kahanov 2007, 24.

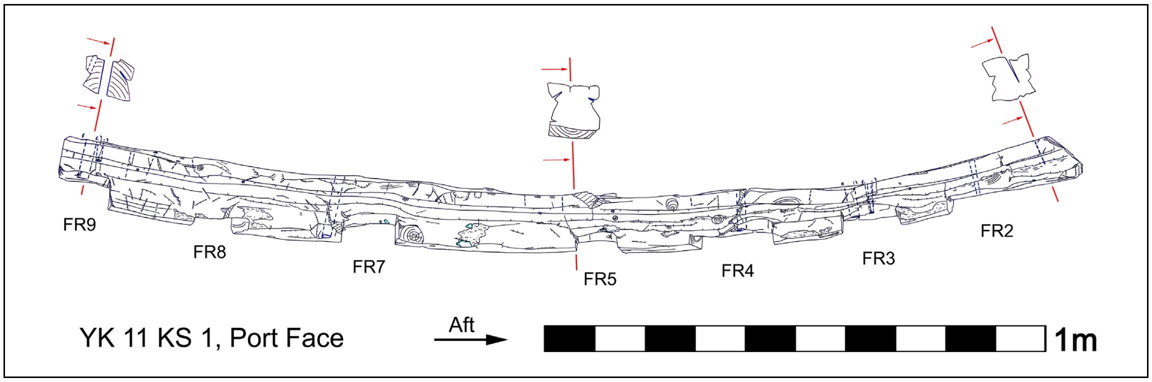

Figure 4.115. YK 11 KS 1 (sternson), port face.

Figure 4.116. Sternson KS 1 in situ. Note compression over frames.

Perhaps the most notable feature of KS 1 is that it was fashioned from a recycled, worm-damaged keel timber from another ship, albeit one with similar construction features as YK 11. As such, it has rabbets cut along the sides (fig. 4.117), nails within the rabbets that fastened the garboards to the keel, and nails and faint pressure marks from the original framing on KS 1's inner face. Detail on the inner face indicates a framing pattern of alternating floors and paired half-frames. Relatively closely-spaced garboard nails on the sides may indicate that, as on YK 11, this other ship's garboards were replaced at some point. The size of KS 1 is comparable to that of the YK 11 keel, although it has been cut down along its outer face; the width and depth of the rabbet, as well as the thickness of that portion of the keel above the back-rabbet line, are also comparable. The overall curvature of the timber, paralleling the curvature of Keel 1, indicates that this was not the flat portion, but rather a curved transitional piece, of another ship's keel. In sum, the detail on KS 1 indicates that it was originally the curved portion of the keel of a ship of very similar construction, and perhaps also form, as YK 11; the primary difference between this keel and the keel timbers of YK 11 is in its wood type (pine), the YK 11 keel timbers being of oak.

KS 1 is in a relatively good state of preservation; its most significant damage is breakage, cracking and distortion resulting from compression of the timber over the framing. It is broken into three pieces and has additional cracking, often at YK 11 frame locations. Compression damage is worst at the unsupported aft end, aft of FR 2. The keel timber that was modified to form KS 1 was already extensively damaged by teredo and gribble along its outer face. Although much of this damaged portion had been cut off, traces remain on KS 1 (fig. 4.118). Despite the distortion and ancient damage, surfaces were usually very well preserved, especially along the outer face. There is more wear along the inner face, both due to its previous use as keel, as well as its exposure within the hull both during use and after abandonment.

Figure 4.117. Forward end of sternson KS 1. Note rabbet from former use as a keel.

Figure 4.118. Sternson KS 1 outer face at FR 3-FR 4. Note teredo and gribble damage from its previous use as a keel.

The aft end of KS 1 was cut at an angle but is heavily worn and has been damaged, perhaps during excavation. It does not appear to have rested upon a frame, but ended aft of FR 2; perhaps it made contact with the endpost, as did a similar timber on

Dor shipwreck 2001/1.[86] The forward end, much better preserved, was cut flat, probably with an adze; it rested upon FR 9, which likely protected it from further compression damage.

Figure 4.119. Sternson KS 1 inner face at forward end. Note bolt hole and secondary nail hole.

KS 1 was attached primarily through two bolts that extended through frames and keel at the Keel 1 scarf ends, at FR 4 and FR 9. The cavity left by the bolt is 1.7-1.8 cm in diameter on the outer face and a smaller diameter of 1.2-1.6 cm on the inner face; at FR 9, the bolt hole is slightly angular in section on the inner face, which is also seen in the bolt-end assemblies recovered from the seventh-century Yassıada shipwreck.[87] A countersunk area 3.7 cm in diameter around the hole on the inner face probably represents the size of the washer placed over the bolt-end assembly and is again

[86] Mor and Kahanov 2006, 279.
[87] Bass and van Doorninck 1982, 256-58.

comparable in size to washers found on the seventh-century Yassıada ship (fig. 4.119). There is no indication of washer size on the FR 4 bolt. No evidence remains of the key or of the tip of either bolt. The reliance on bolts as the principal means of attachment greatly facilitated the framing repair process, since the bolts could be removed and replaced fairly easily, and the drilled holes reused.

Two additional nails were added to secure KS 1 to the inner face of FR 3 and FR 9, perhaps to tighten a loosened fit (fig. 4.119). The inner face was chiseled out around the FR 3 nail head, allowing the nail head to be countersunk into the surface. Only one other nail was used on KS 1, and this fastened the bulkhead frame to KS 1's inner face; it did not extend to the outer face. Several other nail holes on the inner face of KS 1 were disused and probably represent nails from the timber's original function as a keel as well as nails that had been extracted when the sternson was, out of necessity, removed in order to replace framing. The nails used were of the same type as those seen elsewhere on YK 11, short nails, approximately 8 cm in length, with square, 0.45-0.6 cm shanks and 2.4-2.8 cm-diameter heads. Some of the nails were driven through pilot holes, 1.1-1.5 cm in diameter. Large drilled holes near FR 3 and FR 7 may represent the location of bolts from this timber's previous use.

KS 1 was cut from a relatively young trunk of Turkish pine, seemingly curved along its length. Surfaces appear to have been dubbed with an adze; this is best preserved on the outer face, where tool marks indicate a blade up to 5 cm in width (fig. 4.118). The outer face notches were first sawn along the edges then trimmed to form with an adze or chisel, although some notches appear to be entirely cut by adze or chisel.

Some of the notch edges were cut at a significant angle; the reason for this is unknown. The notches are 1.9-5.0 cm in depth, usually 2.5-3.5 cm; the notches vary in length from 9.7 to 17 cm, variable depending on the type of frame covered and angling of notch edges. A long notch, 26 cm in length, runs from FR 2 to the aft end of KS 1. There was no notch cut for either of the FR 6 half-frames, and pressure damage on the inner face of FR 6 and the outer face of KS 1 (less intense) suggests this was not because the frame was too small in molded dimension to necessitate a notch. The width of KS 1's FR 4 notch (17 cm) and the presence of two abandoned nails on Keel 1 at this location suggest that replacement floor FR 4 may have replaced two original half-frames, which would have been consistent with the framing pattern of the ship.

Very little pitch was preserved on KS 1, but traces on each face indicate that the entire timber had been pitched at some point. It is unclear when this timber was added and whether it was itself a replacement for an original timber. It was only attached to repair frames, but that does not mean that KS 1 was not part of the ship's original construction. The presence of similar timbers on other ships of this period strongly suggests that this or a very similar timber was present from the beginning.

Stemson UM 47

UM 47, the stemson, was so different from the sternson that it was initially not recognized as an in-situ element of the ship's construction but mistaken for a displaced frame and therefore labeled as an unidentified member (fig. 4.120). It was found resting on FR 21-FR 23 and notched to fit over FR 22; its aft end fit into the notched inboard edge of CST 1.

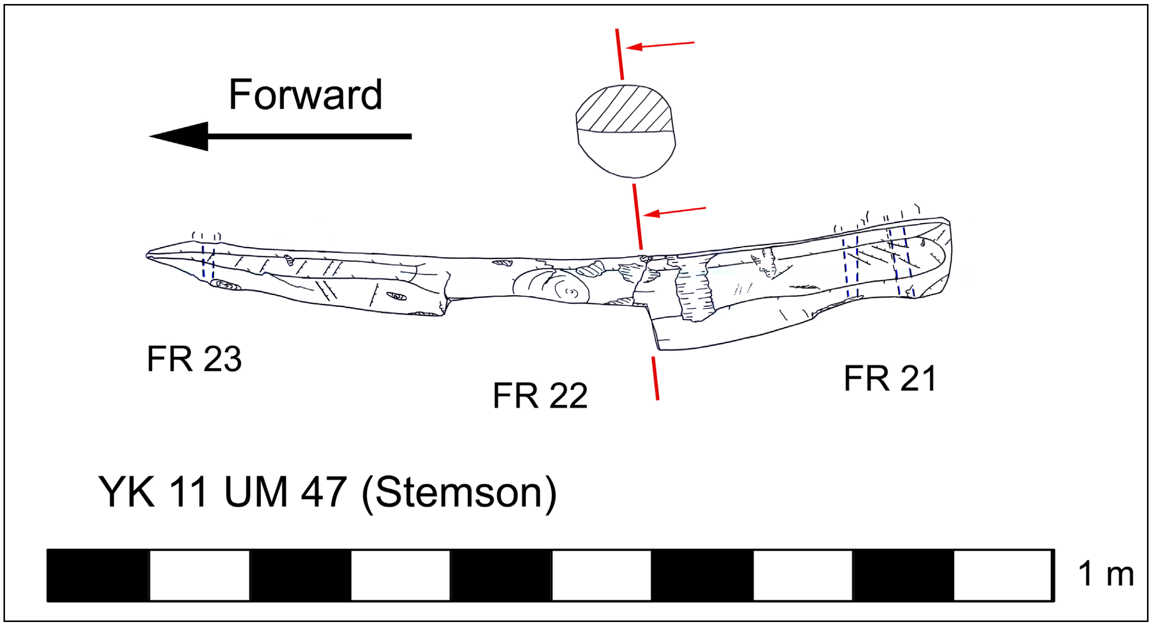

Figure 4.120. YK 11 UM 47 (stemson).

Rather than a worn, recycled pine keel, UM 47 is a pristine, custom-made timber cut from *Ulmus campestris.* Although broken at the FR 22 notch, it is otherwise in excellent condition, with solid wood structure and well-preserved surfaces. There is some pressure damage at the FR 21 location (fig. 4.121). The timber is complete and is 80 cm in length. It is 8.2-9.5 cm in sided dimension and 3.7-9.3 cm molded, tapering toward its forward end. Much of the inner and outer faces are naturally rounded surfaces with bark removed. It was cut from the center of a large elm branch with 12 tree rings visible. Where not naturally rounded, inner face edges were chamfered with an adze to remove sharp edges.

Figure 4.121. Aft end of stemson UM 47, from outer/aft. At FR 21.

The forward end is adzed down along its inner face to a thin tip. The aft end, in contrast, is sawn flat to form a blunt end that was fit into notches on the central stringers; the fine, closely-spaced saw marks (fig. 4.121) suggest a different saw than that used for the planks, perhaps a much smaller hand saw. Both ends were located at frames which aided its preservation. Other than the sawn aft end, all other surfaces and chamfers, where not natural, were trimmed with an adze (blade width 3.0 cm). The notch on the outer face for FR 22, up to 4.6 cm in depth, was 19.5 cm in length and was cut with an adze or chisel at least 2.5 cm in width.

UM 47 was attached to framing with three nails, one at FR 23 and two at FR 21. One of the nails at FR 21 was a short nail driven near the starboard edge; it does not extend to the outer face of FR 21 and seems to be a secondary nail driven to reinforce the primary fastener. It was nevertheless driven through a large predrilled hole, 1.9 cm in diameter, that did not extend to the outer face; a nail head, 3.0 cm in diameter, was countersunk into the inner face. The primary fastener on FR 21 and the nail at FR 23 were both driven through large drilled holes, 1.5-1.8 cm in diameter, showing on both inner and outer faces. Each nail, sided 1.1-1.2 cm on the inner face, is larger than usual and extends through the frames into Keel 3. Nail heads are 2.5-3.1 cm in diameter. The confusion of nails on FR 23, an original frame, probably indicates that the stemson had been removed and reinstalled at some point.

The large drilled hole at the primary FR 21 fastener seems to indicate that UM 47 was attached to the original FR 21 and Keel 2-Keel 3 scarf with a bolt. Once the frame was replaced and the bolt no longer fastened the frame to the keel, but merely served to bolt the two keel timbers together (see section on frames, above), UM 47 was fastened to the replacement frame and the keel with a long iron nail driven through the predrilled hole that previously held a bolt. This was obviously too loose a connection and a secondary nail was added accordingly (fig. 4.122).

The small size, different wood type, and excellent condition—all at odds with what is seen on KS 1—seem to point toward UM 47 being a secondary or replacement timber; however, the confusion of drilled holes for fasteners, and the presence of a secondary nail, suggest otherwise. On Tantura F, the stemson and sternson were more comparable in size.[88] Was UM 47 a small, secondary element to a more substantial stemson that was not preserved? There is no inner face fastener on FR 24-FR 26 to suggest that this is the case. Furthermore, if KS 1 is any indication, a timber of that kind would have been fastened with bolts, and the only evidence of a bolt forward of FR 23 is around FR 29. It seems likely, therefore, that there was no longer stemson, comparable to the sternson, at the bow of YK 11, and the small but sturdy elm timber UM 47 instead served merely to provide longitudinal rigidity to the Keel 2-Keel 3 scarf which was otherwise held by its own thickness.

Figure 4.122. Aft end of stemson UM 47, from inner. At FR 21.

THE CEILING

A significant portion of the ceiling of YK 11 was preserved and consists of three types of timbers: stringers, common ceiling, and sills, that is, crenelated planks that

[88] Barkai and Kahanov 2007, 24.

prevented foreign objects from falling into the bilges. All of these timbers were relatively lightly fastened to the ship's framing with short nails.

Stringers

Ten stringers were preserved on YK 11, most of them in their original locations (fig. 4.123, table 4.14).[89] One central stringer, CST 1, was located just to starboard of the keel and inboard of the stanchion blocks; as such, it may be considered a limber strake. Unmatched nails on the framing indicate the location of a similar stringer just to port of the keel, although this was not preserved. Outboard of the keel area, five strakes of stringers were preserved on the port side, each strake composed of one or two stringers. The topmost of these, SST 5, is a clamp, that is, a slightly thicker stringer located approximately opposite the wale SS 11. Due to poorer preservation along the ship's starboard side, only one strake of stringers, consisting of two stringers scarfed together, was preserved.

Stringers were labeled by location and strake; the central stringer was labeled CST 1, while the stringers to the port and starboard sides were labeled SST and PST, respectively, due to the initial reversal of the bow and stern during excavation. Each strake was numbered consecutively from inboard to outboard; for those strakes having two stringers, the stringer was numbered consecutively from aft to forward following a hyphen. For example, the forward stringer of the third strake up on the port side was labeled SST 3-2.

[89] These were labeled PST 1-1, PST 1-2, CST 1, SST 1-1, SST 1-2, SST 2, SST 3-1, SST 3-2, SST 4, and SST 5.

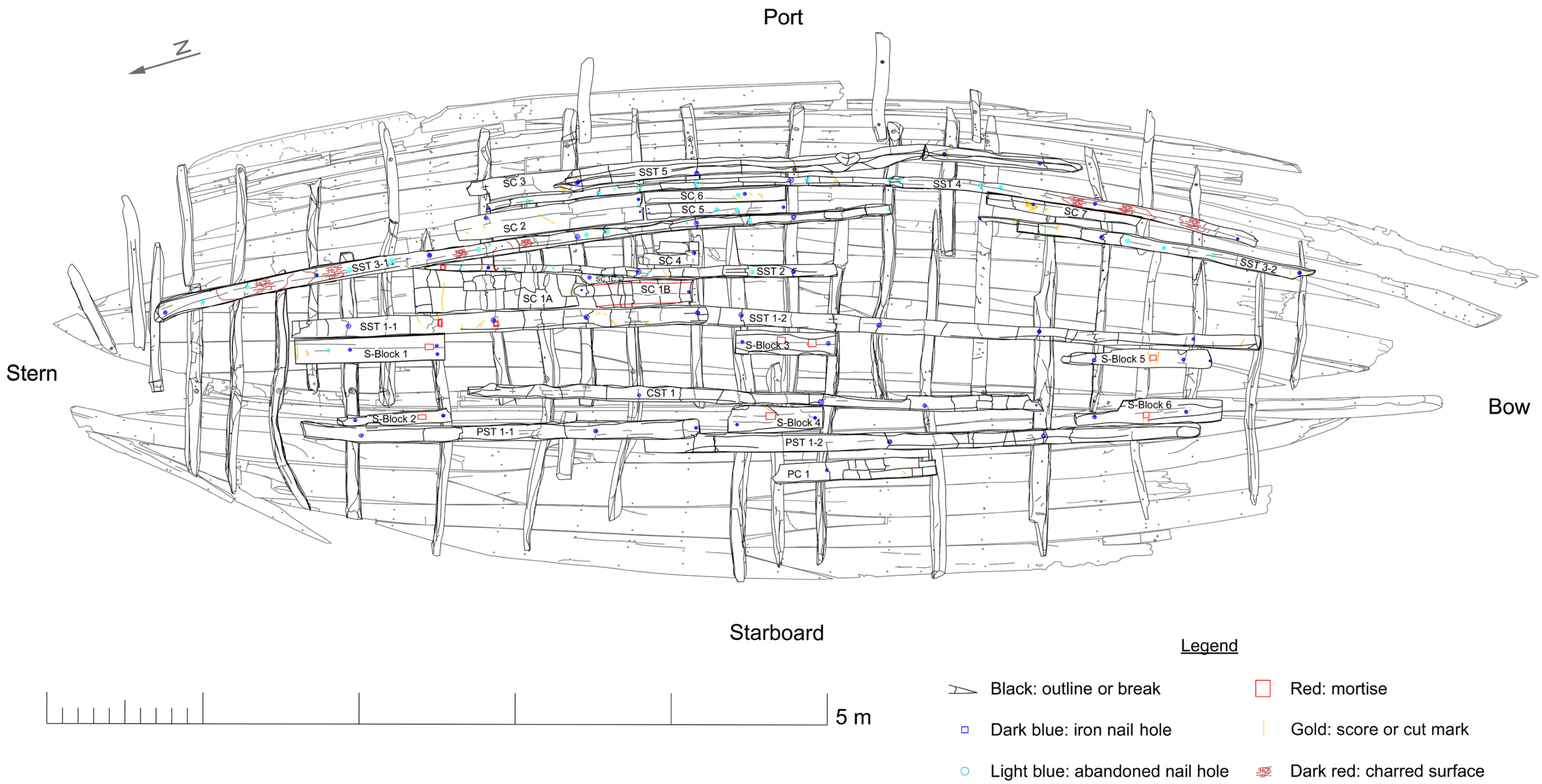

Figure 4.123. YK 11 in-situ stringers, common ceiling, and stanchion blocks. Plank and frame outlines are also indicated.

Table 4.14. Overview of YK 11 in-situ stringers.

Stringer Number	Wood Species	No. of Pieces	Length (m)	Maximum Width (cm)	Maximum Thickness (cm)	No. of Nails
PST 1-1	*Pinus brutia*	5	2.57*	12.8	5.0	3
PST 1-2	*Pinus brutia*	5	3.59	12.8	6.5	3
CST 1	*Pinus brutia*	17	3.86	11.1	4.6	4
SST 1-1	*Pinus brutia*	12	2.7*	13.0	4.4	4
SST 1-2	*Pinus brutia*	13	3.9	13.2	5.2	5
SST 2	*Cupressus sempervirens*	17	2.7*	10.5	3.4	8
SST 3-1	*Cupressus sempervirens*	8	4.84	12.2	4.4	23
SST 3-2	*Cupressus sempervirens*	8	2.3*	10.3	3.5	6
SST 4	*Cupressus sempervirens*	21	5.09*	11.2	3.5	16
SST 5	*Pinus brutia*	7	3.4*	14.5	6.5	7

* denotes an incomplete timber.

Condition

Like the exterior planking, the stringers were fashioned from flexible softwoods, both Turkish pine (6) and Mediterranean cypress (4) (table 4.14). Although very well preserved in most aspects, several of the stringers are heavily distorted in form, having suffered significantly from compression damage. The stringers were pressed down over the frames, resulting in cracks, breaks, and an undulating form along the length of the stringer (fig. 4.124). In addition to the breaks and cracks, deep pressure marks, some sharply delineated, indicate some frame locations on the stringers' outer face. Although most of this damage was likely incurred after sinking, there is evidence that similar pressure damage, although far less intense, was incurred during the ship's working life: a crack on the inner face of SST 3-2 at FR 21 is similar to those caused by pressure damage, but had been filled in with pitch (fig. 4.125).

Figure 4.124. Forward portion of SST 1-2 in situ. Note distortion and cracking at frame locations.

Figure 4.125. Pitched crack on the inner face of SST 3-2 at FR 21.

None of the stringers was intact, all having broken into five or more pieces, as many as 21 pieces for SST 4. Breaks and cracks are either transverse (at pressure-damaged areas) or run along the wood grain. The thick, viscous mud which adhered to the stringers' outer face after excavation was left in place during transport from Istanbul to Bodrum in order to provide added support for the weak stringers; removal of this mud during cataloging necessarily led to the further separation of some pieces. Aside from the cracks, breaks and distortion due to pressure damage, the wood of these stringers remains quite solid. Surfaces are very well preserved, with tool marks often clearly visible. Damage is relatively minor on the inner face and consisted primarily of small scrapes and gouges.

Dimensions

All of the stringers were cut from relatively young trunks of small diameter; the pith of the timber used was invariably oriented toward the exterior of the hull. The pith is visible along the flat-sawn outer face of several of the stringers; on SST 5, a small portion of the pith had dropped out of the outer face. Knots, some quite large, were very common throughout all surfaces of the stringers. Each of the stringers exhibits 20-30 annual rings, clearly visible at breaks. Sectional form varies significantly depending on the size of the timber from which the stringer was fashioned. Natural surfaces, with only the bark removed, are common, resulting in semicircular (half-log) sections in narrower areas; wider areas, in contrast, were trimmed flat on the inner face, with a natural, rounded surface or a flat, adzed chamfer between the inner face and the edges of the stringer. Either method resulted in a lack of sharp edges which might be broken or damaged by movement of cargo within the hull. This form also resulted in thinner edges with a maximum thickness usually around the center of the stringer.

Outside of compressed areas at frame locations, widths and thicknesses are representative of the stringers' original size. Widths range from 5.5 to 14.5 cm, with an average maximum width of 12.2 cm. Edges are, on average, 1.3-3.7 cm thick, while maximum thickness, around the center of the stringer's section, averages 2.9-4.7 cm. Clamp SST 5 was slightly larger than the other stringers in both thickness and maximum width, reflecting its importance and function, perhaps serving as a shelf clamp for through-beams. Only three of the stringers, PST 1-2, SST 1-2, and SST 3-1 are complete, with a fourth stringer, CST 1, nearly so; these range in length from 3.59 to 4.84 m. Incomplete stringers range in length from 2.30 to 5.09 m, with an average preserved length of 3.5 m.

Figure 4.126. SST 1 scarf in situ, at FR 14.

Figure 4.127. Inner face of PST 1-2 scarf end.

<u>Scarfs and Ends</u>

Strakes PST 1 and SST 1 both consist of two stringers that are scarfed together with a carefully-crafted, flat vertical scarf 29-33 cm in length (which could correspond roughly to either one Roman or Byzantine foot); a single nail is driven through each scarf, fastening the stringers to FR 14 (figs. 4.126-4.127). In each scarf, the aft stringer (1-1) overlaps the forward stringer (1-2). Other than for PST 1 and SST 1, there is no evidence of scarfing on any of the stringers. Although SST 3 consists of two separate stringers, the ends of SST 3-2 are broken, and there is a gap between the broken aft end of SST 3-2 and the original forward end of SST 3-1, which is roughly cut.

Original ends of stringers that did not terminate in a scarf were cut in a variety of forms. The forward ends of PST 1-2 and SST 1-2 increase significantly in thickness toward the tips which are adzed to a blunt finish (fig. 4.128); this may have been influenced by the natural form of the timber. The aft end of SST 2, in contrast, tapers to a thin, narrow tip, further weakened by the presence of a deep mortise on the inner face (fig. 4.129). Both the aft end of SST 3-1 and the forward end of SST 4 are of average thickness, cut at a slight diagonal and beveled toward the inner face. All of these original ends fall at frame locations, which would have prevented damage to the stringer tips from cargo or foot traffic.

Figure 4.128. Forward end of SST 1-2. Note naturally rounded inner face and adzed edge.

Figure 4.129. Tapered aft end of SST 2. Note mortise on inner face.

Figure 4.130. Recessed aft end of CST 1.

In contrast, the original ends of CST 1, the limber strake, did not terminate at frames. Both ends are curiously cut with recesses along the lower (inboard) edge at the aft end (fig. 4.130) and along both edges at the forward end. The lower edge recess at the forward end accommodated stemson UM 47. The other recesses at CST 1 ends are of unknown function.

Figure 4.131. CST 1 inner face at FR 19. Note recess along inboard edge and deep pressure mark from nail head.

<u>Fasteners</u>

The stringers were attached to the ship's framing with iron nails driven from inside the hull; all of these have corroded, leaving a black sludge of iron sulfide. The fasteners were widely spaced, on average 90 cm between nails, with approximately one nail every third frame, although this pattern was inconsistent.

Figure 4.132. Countersinking around nail at FR 16 on SST 5. Note small barnacle in countersunk area.

The square holes left by the nail shanks are 0.5-1.2 cm in sided dimension on the inner face and slightly smaller, only 0.4-1.0 cm, on the outer face. The nails were driven through pilot holes, usually 1.0-1.2 cm in diameter, in some cases up to 1.5 cm; in most cases, these pilot holes did not extend to the outer face of the stringer. Pressure marks from nail heads that were hammered into the inner face are usually 2.0-2.5 cm in diameter; these pressure marks can be quite deep (fig. 4.131). On SST 5's inner face, a chisel was used to countersink two of the nail heads (fig. 4.132).

All five stringers in strakes PST 1, CST 1, and SST 1 have a relatively small number of nails (not more than 5 each), all of which were used to fasten the stringers to framing. In contrast, all of the remaining stringers have multiple abandoned fastener holes, usually the same number or far greater than the number of used fastener holes, the latter clearly identifiable through the presence of concretion and black staining as well as a matching concreted nail hole on the respective frame (fig. 4.133). On SST 4, there are more than twice as many empty or disused nail holes as used nail holes. The presence of these abandoned nail holes offers proof that these stringers were pried out of place, without doubt to permit the extensive repairs to the ship's framing, then later reattached.[90] That many such abandoned holes were found between frame locations shows that the stringers were not always reattached in precisely the same position; such was the case on SST 2, SST 3-1, SST 3-2, and SST 4.[91] The great number of disused holes on SST 4, combined with two disused nail holes at FR 10 at this location, indicates that SST 4 was pried out of place then reinstalled on at least two occasions.

Figure 4.133. Inner face of SST 4 at FR 16. Note difference between used (to left) and disused (to right) nail holes.

[90] Similar disused fastener holes were noted on the single preserved stringer of late 10th-century shipwreck YK 1 from Yenikapı and may well indicate a similar situation. Like YK 11, extensive repairs had been carried out on the framing of YK 1, including the addition of secondary futtocks at the location of the stringer.

[91] It is noteworthy that this was the case for SST 2, in which mortises had been cut, presumably to support a through-beam or other transverse timber. Had the stringer been shifted in its position, which appears to be the case, these mortises would no longer line up with the timbers they were supporting. Perhaps these mortises had been abandoned in favor of those on SST 1-1 (in a similar location) after a repair; alternately, perhaps the SST 2 mortises were cut after the stringer's position had changed. Preservation of the ship's interior structure would appear insufficient to permit a resolution of this question.

Figure 4.134. Outer face of SST 5 at FR 12, with broken aft end. Both nail holes were started from the same hole on the stringer's inner face. One of the nail holes is disused.

Does the lack of disused holes on PST 1, CST 1, and SST 1 mean that these stringers had not been removed and were, therefore, replacements for earlier stringers? Not necessarily; there were only two disused nails on SST 5, and both had been driven through the same inner face pilot hole as a used nail when the stringer was replaced. They are only identifiable as disused nails since, in each pair, one of the nails bent slightly upon insertion, creating two nail holes on the stringer's outer face at each of the frames in question (fig. 4.134). If indeed SST 5 is a shelf clamp, as seems to be indicated by both its location and the cut recess near the mast-partner through-beam, its position in the hull could not be altered. It appears, then, that stringers for which a position was delineated by one or more other timbers were replaced in their exact original location, and the old pilot holes were reused. CST 1, with its multiple recesses, would have had a prescribed position and, theoretically, may have been removed and replaced without any apparent disused fastener holes. Surface damage around the nails on the inner face of CST 1 strengthens this claim, but it cannot be stated with certainty. The four stringers in strakes PST 1 and SST 1 would have been more flexible in their position, and a corresponding lack of surface damage to the inner face suggests that PST 1-1, PST 1-2, SST 1-1 and SST 1-2 were all replacements.

On SST 3-1, there are several nails lacking a nail-head impression and not extending to the stringer's outer face. Some of these are for the attachment of the bulkhead frame between FR 8 and FR 9; an abandoned fastener hole here proves that, as expected, the bulkhead was also dismantled and later reassembled to facilitate repairs to the ship's framing.

There are a great number of nail holes on the inner face of the ship's framing that were disused, as well as many for which timbers were not preserved. It is not clear, however, which of such nails were for stringers and which were for common ceiling. Nail holes on the inner face of the ship's framing indicate the presence of a second central stringer, just to port of the ship's centerline; this, with limber strake CST 1, would have been part of the ship's mast-step assembly. The symmetry seen in the scarfs of SST 1 and PST 1 was very likely reflected elsewhere, and it is reasonable to suppose that stringers extended up the starboard side of the vessel much as they do the port side. SST 2 would likely have extended farther toward the bow, while the gap between SST 3-1 and SST 3-2 was much smaller, although probably not nonexistent.

Tool Marks

All of the stringers were sawn along their outer face, most likely with a frame saw (fig. 4.135). In eight of the ten stringers, sawing was oriented against the direction of growth on the tree. On SST 1-2, the outer face was sawn to a point near the aft end, after which the wood was roughly split (fig. 4.136). The outer faces of PST 1-1 and SST 1-1 were both sawn from aft to forward, after which the forward portion (approx. 30 cm) was trimmed with an adze to form a flat vertical scarf. On SST 3-1, SST 4, and SST 5, the outer face was sawn, but an area at the end of the sawn portion was trimmed with an adze. This adzed area on SST 3-1 and SST 4, 31 and 24.5 cm, respectively, is substantial, but, probably due to breakage, only 5.5 cm of the adzed portion is preserved on SST 5. That such adzed areas were only preserved at stringer extremities seems to indicate that the broken aft end of SST 5 was relatively close to the original end of the stringer.[92]

In many areas, the natural, rounded surface of the timber was preserved along the stringer's inner face, the bark having been removed with an adze. Where cut, inner faces and edges were shaped with an adze (figs. 4.128, 4.137); blade widths of 3.2-4.3 cm, most often approximately 4.0 cm, were recorded. Striations within blade marks reflect cutting with a chipped blade. Recesses or mortises were cut with chisels of varying size, approximately 2.0-2.2 cm for mortises in the inner face of SST 1-1 and SST 2. A larger blade, probably an adze, up to 3.1 cm in width, was used to cut the recesses along the edges of CST 1. The countersinking on the inner face of SST 5 was created with a

[92] Perhaps the original end of SST 5 was located at FR 11.

narrower, tapered chisel, 1.2 cm in width at the tip, up to 1.5 in width further up on the blade.

Fig. 4.135. Wood borer damage on the outer face of SST 4. Note saw marks and, at frame location, pressure damage.

Figure 4.136. Split aft end of SST 1-2, outer face. Arrow indicates end of sawing.

Fig. 4.137. Tool marks from a chipped adze on the inner face of SST 3-1. Near forward end.

Knife cuts or score marks are rare on the stringers, although a score mark indicates the edge of one (possibly both) of the mortises on SST 1-1. A sharp tool, perhaps a scriber, was used to carve a graffito into the inner face of SST 4 near F 17, below the location of the mast-partner through-beam (fig. 4.138). This graffito might represent the word *ἅλα*, a variant of the word *ἅλας*, which means "salt" or, by extension, "seawater," the latter meaning appearing more likely in view of the inscription's context.[93] Upon reconstruction of the ship, the graffito was found to be located approximately halfway between the calculated waterline of the empty hull and the

[93] van Doorninck 2012, pers. comm; Ciccolella 2013, pers. comm.

estimated load waterline. The graffito thus seems to have served as an indicator of the ship's waterline; as such, it may have aided the crew in the lading of the vessel.

Figure 4.138. Graffito cut into the inner face of SST 4 at F 17. White outline added for emphasis.

Figure 4.139. Mortises on the inner face of stringer SST 1-1 at FR 9-FR 10.

Mortises and Notches

Two quadrilateral mortises were chiseled out of the inner (top) faces of both SST 1-1 and SST 2, both at approximately the same location, near FR 9 and FR 10. On SST 1-1, the mortises are 2.2-3.0 cm in depth and 2.8-4.7 in sided dimension (fig. 4.139). The mortises on SST 2 are slightly shallower, just above 1 cm in depth, and smaller as well, just 2.7-3.0 cm in sided dimension. The edges of the mortises are worn, and SST 2 is broken at each mortise. There is no pressure damage on the inner face indicating that a timber might have been seated here.

A score mark indicates the aft edge of the FR 9 mortise on SST 1-1, reflecting the importance of the placement of this mortise along the length of the vessel; this indicates that the mortise may have held a stanchion or other such timber supporting a transverse rather than longitudinal timber, most likely the through-beam near FR 9. SST 2's mortise at FR 9 probably also held a stanchion supporting the through-beam here, and both of the stringers' FR 9 mortises align very roughly with mortises on the aft pair of stanchion blocks as well. These mortises may alternately be associated with the ship's bulkhead. The mortises on both stringers at FR 10, however, fall aft of the FR 10-FR 11 through-beam location, and the function of these mortises remains unclear.

CST 1, SST 3-2, and SST 5 all have recesses or notches cut out of one or more edges. These are most pronounced at CST 1, which has four deep recesses along the inboard edge (figs. 4.130-4.131) and one along the outboard edge. These recesses appear to have accommodated other timbers, only one of which, UM 47, was preserved. The inboard edge recess at FR 19 may have accommodated the end of the ship's mast step, which would have been fitted between the two central stringers or limber strakes. The other recesses on CST 1 are of unknown function.

There is a shallow notch, 0.9 cm in depth, cut from the outboard edge of SST 3-2 at its aft end; due to a lack of preservation of the aft end, only 2.7 cm of this notch is preserved. There is also a shallow recess cut out of the top (outboard) edge of SST 5 that corresponds to the location of the mast-partner through-beam. This recess, perhaps both chiseled and adzed, is 15.5 cm in length and 1.3 cm in depth at the stringer's outer face, notably deep toward the inner face (fig. 4.140). It does not seem to show any signs of wear and thus may have been trimmed away to merely accommodate, rather than support, the mast-partner through-beam; as such, it remains unclear whether SST 5 is a clamp or, more specifically, a shelf clamp.

Figure 4.140. Upper edge of SST 5 at F 17. Edge is cut down, possibly for mast-partner through-beam.

Surface Treatment and Other Surface Detail

Traces of pitch were found on all of the stringers, although it was very poorly preserved. It was most common on the outer face at frame locations, most of which seems to have been transferred from the framing; however, patches of pitch and pitch stain that were not at frame locations prove that the entire outer face of the stringers was payed with pitch. Faint traces of pitch were often visible on the stringer edges; it was very rarely noted on the inner face, however, and what spots of pitch are preserved appear to be drips rather than a uniform coating. Perhaps the top faces of the stringers were left free of pitch in order to avoid creating a sticky surface. The pitch within the wide crack on SST 3-2, however, seems to suggest otherwise, and it is possible that a thin coating of pitch on the inner face of stringers was simply not preserved. A small lump of pitch was also found inside one of the SST 1-1 mortises.

Figure 4.141. Marine growth and barnacle on the outer face of SST 1-2 at FR 14-FR 15.

Shells from barnacles and oysters and other marine growth were noted on many of the stringers. That such growth was present on the outer face of some of the lowest stringers in the hull (fig. 4.141) indicates that the hull sat abandoned for some time, filling slowly with water, before it had become fully inundated and choked with mud which would have prevented such growth. This again confirms the slow but steady demise of this abandoned vessel. Evidence of char-bending was found on SST 3-1 and SST 4. On each, the blackened portion of the inner face (fig. 4.142) appears to have facilitated a twist in the stringer toward the ship's extremities (near the stern on SST 3-1 and near the bow on SST 4). A charred portion of SST 5 was found along the stringer's lower (inboard) edge (fig. 4.143); both the location and intensity of the charring suggest that this may have been an area that had been burned in a forest fire or otherwise unintentionally. Pre-felling damage to the wood is also visible on SST 4, on which some areas of the outer face are riddled with damage from wood-boring insects (fig. 4.135).

Figure 4.142. Inner face of SST 3-1 at aft end. Note charring of inner face.

Figure 4.143. Charred lower edge of SST 5.

Unidentified Stringer Fragments

Eight fragments of stringers or other components of similar form were found scattered throughout the excavation pit; these are presented in table 4.15. They were identified as stringer fragments based primarily on their cross-sectional form and dimensions; none of the fragments comprises an original end.

Table 4.15. Unidentified stringer or stringer-like fragments found around YK 11.

Fragment Number	Wood Species	No. of Pieces	Length (cm)	Maximum Width (cm)	Maximum Thickness (cm)	No. of Nails	Locus
UM 15	*Pinus brutia*	1	45	6.3	2.9	2	Port
UM 16	*Pinus brutia*	3	80	12.5	4.7	3	Port
UM 70	*Pinus brutia*	1	21.7	5.6	2.8	1	Stern
UM 74	*Pinus brutia*	2	25.5	9.3	3.4	0	Stern
UM 76	*Pinus brutia*	3	41	10.7	3.3	1	Stern
UM 107	*Pinus brutia*	1	10.6	9.0 (not orig.)	3.6	0	Port
UM 122	*Pinus nigra*	2	28	6.3 (not orig.)	2.8	1	Unknown
UM 123	*Pinus brutia*	5	65	11	2.5	1	Unknown

Table 4.16. Overview of YK 11 in-situ common ceiling.

Ceiling Number	Wood Species	No. of Pieces	Length (m)	Maximum Width (cm)	Maximum Thickness (cm)	No. of Nails
PC 1	*Acer pseudoplatanus*	11	1.06*	13.7	2.2	1
SC 1A	*Pinus brutia*	23	1.14	28	2.6	1
SC 1B	*Fagus orientalis*	13	0.76	17.8	2.6	2
SC 1C	*Cupressus sempervirens*	2	0.27	6.3	2.2	1
SC 2	*Cupressus sempervirens*	1	1.22	19.5	2.9	5
SC 3	*Acer pseudoplatanus*	1	0.73*	16.6	2.3	1
SC 4	*Quercus cerris*	5	0.40*	15.2	2.5	1
SC 5	*Cupressus sempervirens*	3	0.91	11.2	2.9	6
SC 6	*Cupressus sempervirens*	1	0.92	9.5	2.8	2
SC 7	*Cupressus sempervirens*	4	1.01	8.8	2.1	2

* denotes length measurements that are not original.

Common Ceiling

Ten planks of common ceiling were preserved on YK 11 (table 4.16). Most of these were located on the port side between FR 9 and FR 16, just forward of the bulkhead, where they alternated with stringers (figs. 4.123, 4.144). The orientation of the ceiling ran parallel to the centerline of the ship; there is no evidence of transverse ceiling. Only one ceiling plank, PC 1, was preserved on the starboard side, outboard of PST 1, and one, SC 7, on the port side toward the bow, between SST 3 and SST 4. The planks were numbered PC (for starboard ceiling) and SC (for port ceiling), with consecutive numbers starting in the stern and moving up and forward in the hull. SC 1, a poorly preserved area of ceiling, was found to be three separate planks, later labeled SC 1A, SC 1B, and SC 1C. Like the stringers, the common ceiling rested atop frames, to which the ceiling was very lightly nailed. As illustrated in figure 4.144, the boards were carefully cut to fill gaps between stringers.

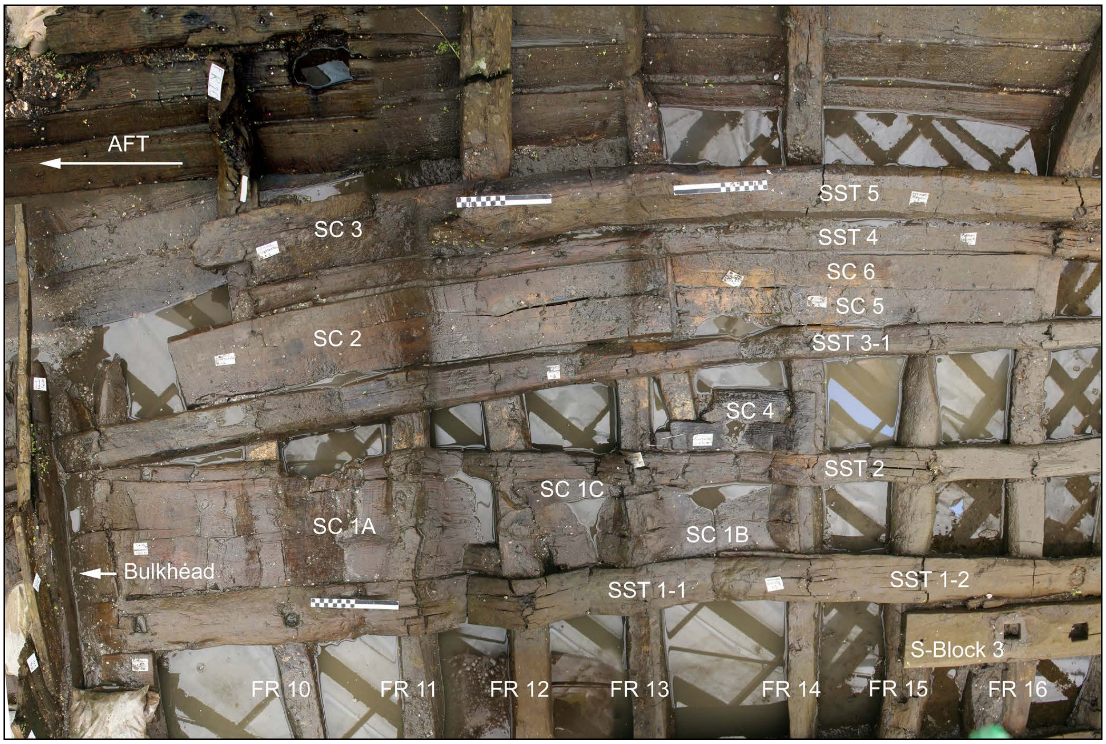

Figure 4.144. Photomosaic of port-side ceiling, forward of the bulkhead. SST 5 has slipped downward. Scale shown is 20 cm.

<u>Condition</u>

The variation in size, shape, and wood species all indicate that the ceiling was cut from a wide variety of scrap timber, some of which had been recycled. Half of the common ceiling is of Mediterranean cypress, while the remaining five planks are of sycamore maple (2), Turkish pine (1), Turkey oak (1), and Oriental beech (*Fagus* *orientalis,* 1). While most of the planks are relatively, and some very, well preserved, those pieces of ceiling along the bottom suffered from the distortion and breakage common to YK 11 stringers (fig. 4.145). Like the stringers, some of the more distorted ceiling was held together by a layer of viscous mud, and many fragments separated upon removal of this mud during cataloging. Three of the planks are intact, while the others are broken into two or more pieces, up to 23 pieces in the case of SC 1A.

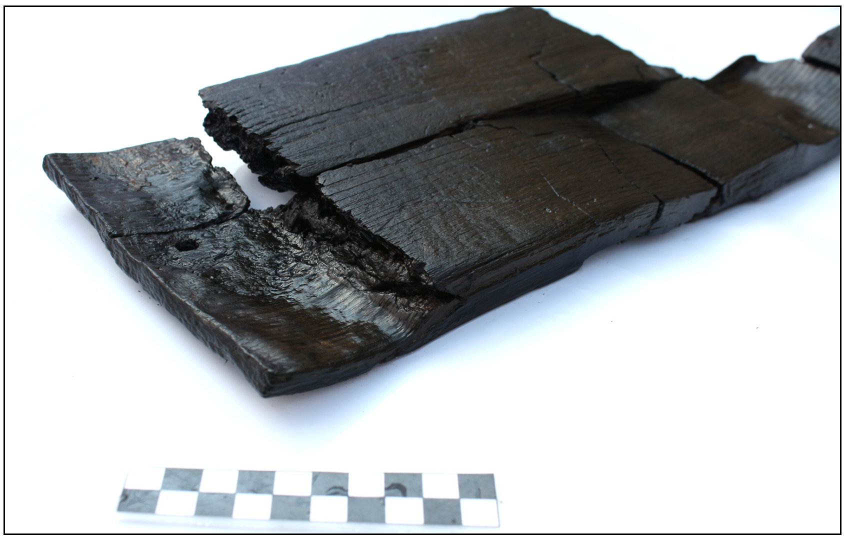

Figure 4.145. Outer face of SC 4 at forward end. Ceiling plank is compressed at FR 14.

SC 1B is by far the worst preserved, in part due to its location, but primarily due to the wood used: beech was very poorly preserved in this area at Yenikapı, the wood being weak in structure and having a soft and easily damaged surface. The maple and oak planks, PC 1, SC 3, and SC 4, are also weak and their surfaces frequently marred by pressure damage from sediment or other timbers. The cypress planks, in contrast, are the best preserved, having a firm structure and well-preserved surface detail.

Dimensions

Despite the damage, seven of the ten ceiling planks were either complete or nearly so, and two of these are both complete and intact (table 4.16). The complete planks range in length from 0.76 to 1.22 m, 96 cm on average. SC 1C is a small, nearly complete piece (with a broken tip) that is just 27 cm in length; this approximately triangular piece was custom-cut to fill a gap between SC 1B and SST 2 (fig. 4.146).

Figure 4.146. SC 1C outer face. Edges are beveled to fit with SC 1A and SC 1B.

Representative thicknesses were available at one or more points on each piece of the common ceiling; maximum thicknesses range from 2.1 to 2.9 cm, with an average thickness of 2.5 cm, surprisingly the same or even slightly thicker than much of the exterior hull planking. In contrast, compressed areas at frame locations, where most severe on PC 1, SC 1A, SC 1B, and SC 3, may be less than 1 cm in thickness. Widths varied depending on the size of the gap that the ceiling planks were designed to fill;

original widths of 2.1-28 cm were recorded, with an average maximum width of approximately 15 cm. SC 5, SC 6, and SC 7, all cypress, appear to be more standardized; these narrow, rectangular planks have a maximum width of 8.8-11.2 cm and a length of 91-101 cm. UM 19, a similarly-shaped pine plank found wedged under SST 5, is probably also a ceiling plank of the same type (fig. 4.147).

Figure 4.147. Narrow ceiling planks SC 6 and UM 19, inner face.

<u>Original Ends</u>

Most of the ceiling was rectangular or approximately so in form, with straight edges and flat, blunt-cut ends, usually sawn and located over frames. These include PC 1, SC 2, SC 4, SC 6 and SC 7; SC 5 was similar in form, but with a shallow recess along the lower edge. The aft end of SC 2 was not located at a frame, but its location just above the turn of the bilge, and perhaps also its proximity to the bulkhead partition, protected the end from damage from foot traffic. The original forward end of SC 3 is squared, but there is a deep recess along the lower edge near the broken aft end.

SC 1A, SC 1B, and SC 1C form an odd scarf over FR 12 (fig. 4.148). In this transition, the forward end of SC 1A forms a fork to accommodate a matching projection cut from the aft end of SC 1B. The inboard projection in the forked end of SC 1A is broken, and the preserved outboard projection is cut down to accommodate the short diagonal aft end of SC 1C. This odd configuration is unique and seems to have been made to precisely fill the angled gap between stringers. The other original ends of SC 1A (aft end) and SC 1B (forward end), like the other ceiling, was cut flat. The aft end of SC 1A abutted the bulkhead frame aft of FR 9.

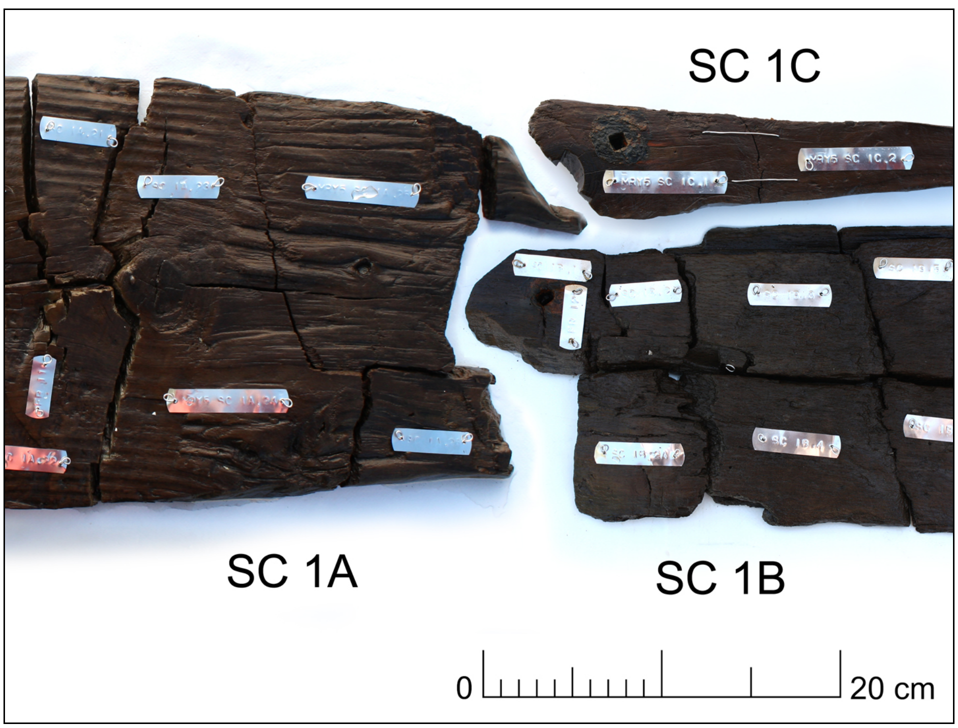

Figure 4.148. Scarf between SC 1A, SC 1B, and SC 1C.

Figure 4.149. Aft end of SC 2. Note inward bevel to edges.

In section, the bar-like pieces of ceiling, SC 5, SC 6, SC 7, and UM 19, are slightly trapezoidal, with edges beveled so that the inner face is slightly wider than the outer face. Alternately, the edges of SC 2 are significantly beveled so that the inner face is 2-3 cm narrower than the outer face (fig. 4.149). However, other evidence reveals that some of these ceiling planks were removed and replaced upside down, which suggests these bevels are merely incidental. The only evidence of an edge intentionally cut at an angle to fit the edge of another plank is in the SC 1 transition, where SC 1A and SC 1C were both cut with a chamfer to ensure a better fit, and the inboard edge of SC 1C was also cut with a chamfer to better match the edges of SC 1B (fig. 4.146). Most other common ceiling had a section that was either approximately rectangular or too badly compressed to identify any edge beveling. Unlike those on the stringers, inner face edges remained sharply angled rather than rounded.

Figure 4.150. Groove cut along top (outboard) edge of SC 1B.

SC 1B, a recycled piece, has a unique section. A deep, narrow groove, 2.0-2.5 cm in depth and 0.5-0.6 cm in width, was cut along both the upper and lower edges (fig. 4.150).[94] Although the form is now badly damaged and compressed, with many of the edge fragments broken away along one or both edges (fig. 4.151), it was originally a fine piece of craftsmanship. It is much more delicate than anything seen on YK 11, and it may have been recycled from another ship or, more likely, from the *opus intestinum*, the interior woodwork, of some structure in Constantinople. A tongue-and-groove joint such as this was observed on the carbonized planks of a shuttered shop door at Herculaneum.[95]

[94] In addition to this groove, a thin, shallow band runs parallel to the top edge on part of the outer face, 1.5-2.3 cm from the edge. It is unclear whether this is some kind of decoration or if it is a result of enhanced compression at the grooved area.
[95] Ulrich 2007, 182-84. These planks were 16-24 cm in width, comparable to SC 1B (17.3-17.8 cm).

Figure 4.151. Outer face of recycled ceiling plank SC 1B, forward end. Note deep groove along damaged edges and compression damage at end.

Fasteners

The common ceiling was very lightly fastened to the ship's framing with small nails, similar to those used for the planking, framing, and stringers. Nails were driven from the inner face, and the square holes left by the nail shanks are 0.5-0.9 cm, usually 0.7 cm, sided on the inner face, and slightly smaller on the outer face, usually 0.5-0.6 cm. Nail heads often left a pressure mark or an outline in concretion on the inner face and range from 1.7 to 2.3 cm in diameter, although nail-head impressions up to 2.5 cm in diameter were observed. Most, but not all, of the nails were driven into pilot holes drilled from the ship's interior. These usually do not extend to the outer face of the ceiling and show some variation in size, from 0.7 to 1.2 cm, although 0.9 to 1.1 cm is most common.

Figure 4.152. Nail holes in SC 6 inner face. The nail hole on the left is disused.

Five of the ceiling planks, PC 1, SC 1B, SC 1C, SC 3, and SC 4, were fastened to framing with one nail each. Four of the planks, SC 2, SC 5, SC 6, and SC 7, as well as UM 19, have multiple fastener holes, some of which were in use when the ship sank and some of which had already been abandoned; the presence of disused fastener holes is due to the removal and reinstallation of common ceiling in the process of framing repair. As on the stringers, the abandoned holes are easily identified through their lack of concretion and black staining (fig. 4.152). On SC 5 and SC 7, there are abandoned fastener holes between frame locations, suggesting that the ceiling had been shifted from its original location upon reinstallation.

The abandoned fasteners seem to have been of the same size and form as those that were in use, although on both SC 5 and SC 7 the drilled pilot holes at the nails that were in use were notably smaller in diameter than those at the abandoned nails (0.7-0.9

cm versus 1.2 cm). On SC 2 and SC 7, the disused nail holes have a pressure mark from the nail head on their outer, rather than inner, faces, revealing that some of the reused ceiling had been flipped over before it was reinstalled.

Only one plank, SC 1A, was not fastened in place, nor could it have been at its broken forward tip, as there is no corresponding nail on the frame at this location. There is, however, an abandoned fastener hole near the aft end, suggesting this piece, like many of the others, had been pried out of place and reinstalled. SC 1A would have been held in place by SC 1C at its forward end and, perhaps, was wedged into place forward of the bulkhead, which prevented this unfastened ceiling plank from floating away after sinking.

There is other evidence of the common ceiling having been removed, replaced, and shifted, such as nails on frames that have no match on the ceiling that covers them (PC 1, SC 1A). A lack of common ceiling between SST 1 and PST 1, especially between FR 11 and FR 14 on the port side, where there is no evidence of fasteners, may reflect the location of removable limber boards. Otherwise, the prevalence of nails on the inner face of framing throughout the ship, both used and disused (pitched, in some cases), suggests extensive ceiling, either stringers or common ceiling, in areas where the timbers were not preserved and furthermore reveals that the majority of these pieces were fastened in place, albeit lightly.

Tool Marks

Without exception, all of the common ceiling was fashioned from sawn boards that had been adzed along their edges or, in the case of recycled timber SC 1B, left in their previous form. The pith of the tree is usually around the center of the plank, although it could be facing the interior or exterior of the hull. On three of the ceiling planks, all of which were fairly narrow, the pith is closer to the top (outboard) edge than the center of the plank, with 15-20 annual rings present on each plank.

Flat-cut ends are usually sawn, and the fine, closely-spaced striations on the forward end of SC 6 suggest cutting with a finer saw than the larger frame saws that were used to create the wide, flat inner and outer faces. On both faces, SC 1A was sawn to a point near the forward end, then split for the remaining distance; this split surface was then trimmed with an adze along the outer face, while the inner face remained untrimmed.

On SC 2 and SC 5, parts of the outer face were trimmed with an adze, presumably to provide a better fit against the framing (fig. 4.153). On SC 2, this area helped accommodate the replacement FR 12, which was slightly larger than the average frame in molded dimension. The adze used in this area was notably wide, 5.5 cm, while other adze-trimmed areas suggest use of an adze closer to 4 cm in width. Recesses or notches along ceiling edges and at the carefully crafted SC 1 transition were likely adzed, with blade widths up to 2.1 cm recorded (fig. 4.154). No score marks were recorded on the common ceiling, but a series of thin, deep, knife-like cuts or sharp abrasions were noted on the inner face of SC 7, around F 21; the cause of this is unclear but could be associated with movement of cargo (fig. 4.155).

Figure 4.153. Roughly-adzed area on outer face of SC 2 at FR 12. Note pressure mark and pitch stain at frame location.

Figure 4.154. Adzed forward end of SC 1A.

Figure 4.155. Cut marks or deep abrasion to SC 7 inner face at F 21.

Figure 4.156. Pitch on inner face of SC 3.

Other Surface Detail

Pitch was generally not well preserved on the common ceiling. When present, it was usually found on the outer face in small patches or as a vague, yellowish stain (fig. 4.153). Some areas of pitch on the outer face had been transferred from the inner face of framing. There are some small patches of pitch on the edges and, more rarely, the inner face; there is an extensive area of pitch on the inner face of SC 3 (fig. 4.156), but it is unclear whether all of the common ceiling was pitched on the inner face, or if this area, above the turn of the bilge, was pitched for a certain reason. The former seems more likely, although perhaps the pitch was tempered with some other material to prevent it from being too sticky on the interior of the cargo hold.

The oddly-cut SC 1 transition and adzed or chiseled notches along the edges of SC 3 and SC 5 cause these planks to deviate from the standard rectangular form of the common ceiling. On SC 3, there is a long recess in the lower edge, 5.1 cm in depth and 11.5 cm in length, at the plank's aft end; it was originally longer as the plank is broken at this end. A second, shallow notch along the top edge, 8-9 cm in width and approximately 1 cm in depth, may have served to fit the ceiling over a frame. A dogleg along the lower edge of SC 5, 0.7 cm in depth, may have been cut to fill a narrowing in SST 3-1 at the same location, but this is speculative. The function of these notches remains unclear.

Table 4.17. Unidentified fragments with characteristics of common ceiling.

Fragment Number	Wood Species	No. of Pieces	Length (cm)	Maximum Width (cm)	Maximum Thickness (cm)	No. of Nails	Locus
UM 9	*Pinus brutia*	9	131	22.5	2.3	2	Port
UM 19	*Pinus brutia*	1	89.5 (orig.)	9.4	2.5	4	Port
UM 60	*Cupressus sempervirens*	1	50 (orig.)	6.8	2.8	2	Starboard
UM 61	*Pinus brutia*	1	67 (orig.)	11.2	2.2	4	Center
UM 73	*Pinus brutia*	1	75	6.8	2.3	2	Unknown
UM 135	*Pinus brutia*	1	14.8	7.9	2.2	0	Unknown

Unidentified Fragments of Common Ceiling

In addition to the in-situ ceiling planks, six unidentified fragments may be pieces of common ceiling; these are presented in table 4.17.[96]

Sills

The final component of ceiling are the sills, crenelated planks custom-cut to fit over the framing, forming a cover that prevented foreign matter from falling between frames into the bilges.[97] Pieces serving a similar function were found on the late 10th-century shipwreck YK 1 from Yenikapı, but these were located at the turn of the bilge;[98] the YK 11 sills, in contrast, were located around the first wale, near the load waterline, reflecting the more extensive nature of the ceiling planking on this vessel.

[96] These UM ceiling planks were categorized as such due to one or more features that indicated ceiling rather than planking; due to similarities between the common ceiling and planking of YK 11, it is possible that some of the UM timbers grouped with planking are actually fragments of common ceiling.
[97] These timbers are described as sills on the basis of their similarity to timbers used in Basque shipbuilding; see Appendix E.
[98] The YK 1 pieces were small plank-like fragments placed between frames rather than a crenelated timber covering multiple frames.

Only two sills have been identified, UM 6 and UM 12 (fig. 4.157).[99] Both had been slightly displaced and were thus grouped with the jumbled layer of UMs that covered the wreck. They were found above SST 5, between FR 12 and FR 14. Both were cut from Turkish pine, each having 10-15 annual rings visible. The pith was closer to the upper face of the sills, and areas of naturally-rounded surface with bark removed on both sills' bottom faces indicate cutting from near the outer surface of relatively young pine trunks.

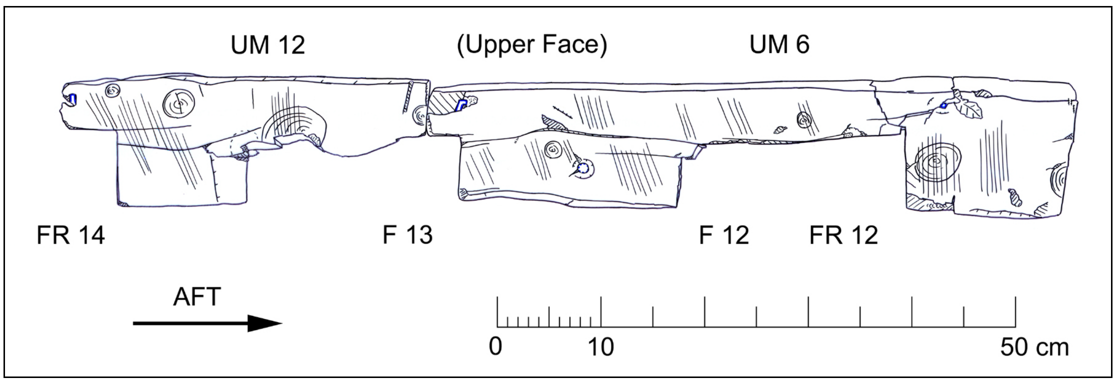

Figure 4.157. Upper face of sills UM 6 and UM 12, reassembled. Frame stations are noted.

The sills are very well preserved, with original surfaces, a solid wood structure, and very little damage. However, both have broken along the wood grain, with an additional transverse break on UM 6; all breaks are associated with the deep recesses cut into the sills' outboard edges. Although neither is intact, UM 6 is complete; it is 63 cm in length. UM 12 is incomplete but, based on tapering to its forward end, may be close to

[99] Although UM 61 is very similar in form, the spacing of the recesses and of the nails suggests this is more likely a piece of common ceiling.

its original length at 35.5 cm. Sill widths and thicknesses are original due to a lack of damage and distortion. Maximum width is 11-13 cm, and thickness is 1.9-2.5 cm. The most characteristic features of these sills are the deep recesses cut along the outboard edges. These recesses are 5-8 cm in depth and allowed the sill to be fitted over frames; variation in depth probably reflects that seen in the molded dimensions of the frames covered. At the recessed areas, the width of the sills drops to 4.3-7.4 cm.

Original ends were cut flat, presumably to form butt joints with other sills, as in the join between UM 6 and UM 12. They did not always terminate at frame locations. The outboard edges of both sills were beveled in several areas, ostensibly to accommodate the angling of the hull planking, although this was not consistent. The inboard edges vary in angle and exhibit signs of wear.

Both UM 6 and UM 12 were fashioned from sawn planks that were adzed along their edges. Part of the lower face of UM 6 was also trimmed with an adze. The ends were sawn flat, from two different directions on the aft ends of both UM 6 and UM 12. On UM 12, the narrow original end was sawn from two directions, and a small unsawn portion was snapped off.

The deep recesses along the outboard edges were adzed or chiseled. On UM 6, angled tool marks reflect use of a sharp blade at least 2.0 cm in width. On UM 12, the FR 14 recess is carefully cut, while the recess at F 13 and an unpreserved timber just forward of this is very roughly cut at a knot with a 1.3 cm-wide chisel (fig. 4.158). Part of this edge also seems to have been split along the wood grain.

The sills were attached to both framing and stringer SST 5 with short nails of the same general type used to fasten planking and ceiling. The square shanks are 0.5-0.65 cm in sided dimension, and nail-head impressions, where preserved, are 1.9-2.1 cm in diameter. Only one nail was observed in a pilot hole, 0.9 cm in diameter.

Figure 4.158. Upper face of UM 12, showing roughly chiseled recess at timber forward of F 13.

UM 12 was attached with one nail only; the nail was driven diagonally through the top face of the sill, exiting through the edge between the bottom and outboard surface, into the inner face of FR 14. UM 6 was attached in a similar fashion to F 13 (fig. 4.159) and also had a nail driven straight through the sill near the aft end, presumably into the top edge of stringer SST 5, which was not preserved here. In addition to the diagonal nail, UM 12 retained traces of two other nails along the roughly-cut recess forward of F 13 (fig. 4.158). There were also traces of a third nail at the FR 12 recess on UM 6; this may be what remains of a nail that attached the sill to the original frame FR 12. There is also a fourth nail hole on UM 6, disused and located between FR 12 and FR 13. Due to its proximity to the outboard edge, it was probably never used to attach this sill to any timber, and it may be evidence that this sill was fashioned from an old, recycled piece of common ceiling or exterior planking.

Figure 4.159. Diagonal nail (at arrows) at forward end of UM 6, at F 13.

There are traces of pitch and pitch stain on the bottom of the sills, but none remaining on the top face, likely due to exposure. This contrasts somewhat similar ceiling components on YK 1, which retained areas with thick pitch. However, these YK

1 pieces, small filling planks rather than crenelated sills as on YK 11, were located lower in the hull, around the turn of the bilge, where dripping pitch likely pooled.

Overview of Ceiling

That the sills were located so far up in the hull suggests that the interior below that point was covered in ceiling, both stringers and common ceiling. This indicates that the well-preserved area of ceiling between FR 9 and FR 16 on the port side is representative of the entire hull, or at least the central portion or cargo hold. Although extensive, the ceiling is not interlocked or beveled to create a tight seal, and would have been somewhat uneven due to the difference in thickness between the stringers and common ceiling. Therefore, although the ceiling protected the framing and added some degree of longitudinal support to the hull, it probably was not designed to equip the hull to carry a loose bulk cargo such as grain, although the latter may well have been carried in sacks.[100] There is no evidence of transverse ceiling, seen on other roughly contemporaneous ships at Yenikapı and elsewhere, notably at Serçe Limanı,[101] but loose limber boards may have been utilized in the area around the keel aft of amidships. Most of the ceiling, however, seems to have been lightly fastened to the ship's framing.

[100] Rougé 1966, 78.
[101] Bass et al. 2004, 118-19.

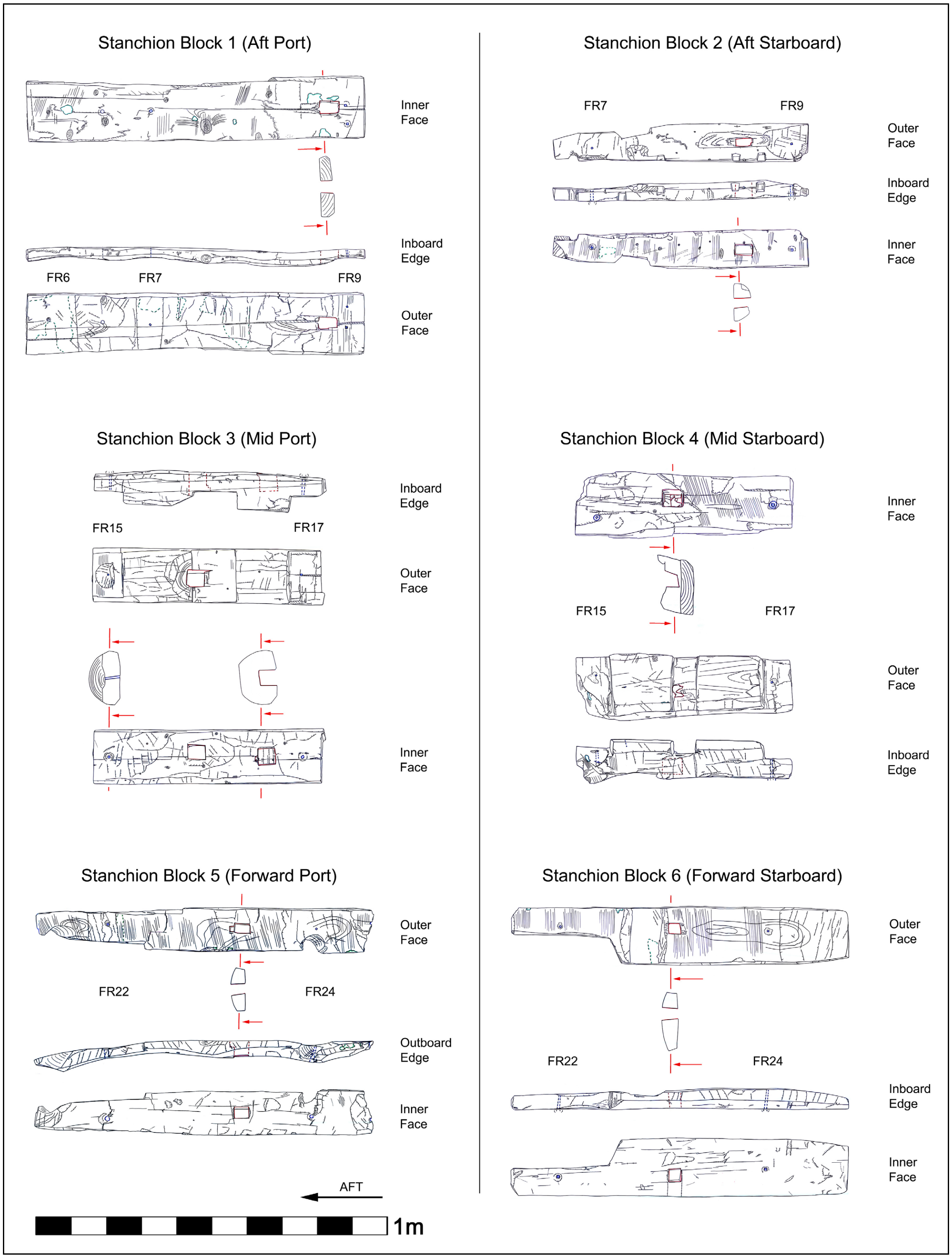

Figure 4.160. YK 11 Stanchion Blocks.

Table 4.18. Overview of YK 11 stanchion blocks.

Stanchion Block No.	Wood Species	Length (cm)	Maximum Sided Dimension (cm)	Maximum Molded Dimension (cm)	Locus
S-Block 1	*Cupressus sempervirens*	96.5	17.6	4	Aft Port
S-Block 2	*Cupressus sempervirens*	73.2	11	5	Aft Starboard
S-Block 3	*Cupressus sempervirens*	66.5	15.6	10.6	Mid Port
S-Block 4	*Pinus nigra*	62	18.4	10.8	Mid Starboard
S-Block 5	*Pinus brutia*	96	12.8	4.8	Forward Port
S-Block 6	*Pinus brutia*	95.8	16.5	5.1	Forward Starboard

THE STANCHION BLOCKS

Six approximately rectangular timbers having a deep mortise in the inner (upper) face were labeled Stanchion Blocks (S-Blocks) 1-6 (table 4.18, fig. 4.160). These were found in their original location, attached to the framing, in pairs flanking the ship's centerline, outboard of the central stringers. These three pairs were located in the stern near the bulkhead partition (FR 7-FR 9), around amidships (FR 15-FR 17), and near the bow (FR 22-FR 24). The pair around amidships, S-Blocks 3 and 4, were notched on the outer face to fit over the framing.

While their exact function is unclear, these timbers probably held stanchions (not preserved) that supported some kind of longitudinal timber or structure at or near deck level, perhaps the *xylokastron* or tabernacle, which provided additional support to the ship's mast.[102] Very similar, albeit slightly larger, timbers have been found on

[102] Basch 1991b, 5.

contemporaneous shipwrecks, such as the late fifth- or early sixth-century Dor 2001/1 wreck and the eighth-century Tantura F wreck, although the timbers are transverse rather than longitudinal in orientation.[103] These are described as "mast-step sisters" or "lateral sisters" and are located only at the central part of the ship; they are thus classed as part of the mast-step assembly.[104]

Figure 4.161. Aft end of S-Block 1, outer face. Note trimming of outer face for frame, compression at frame location, and saw marks and splitting at end.

Condition

The stanchion blocks were identified as softwoods: cypress (S-Blocks 1, 2 and 3), Turkish pine (S-Blocks 5 and 6), and European black pine (*Pinus nigra*, S-Block 4). The stanchion blocks are all in a very good state of preservation; all are complete, and all but one, S-Block 5, are intact. Most of the stanchion blocks are solid timbers with

[103] Mor and Kahanov 2006, 281; Barkai and Kahanov 2007, 24-6.
[104] Mor and Kahanov 2006, 275; Barkai and Kahanov 2007, 24.

original, relatively undamaged surfaces. Cracking is usually minor and does not threaten the integrity of the timbers, except on badly split S-Block 1; surface damage is usually shallow. Compression damage is rare, although it is notable on S-Blocks 1 and 4 (fig. 4.161). On S-Block 4, pressure damage has caused significant distortion to the aft end, although the timber remains intact (fig. 4.162). Part of the pith has dropped out of the inner face here as well; a deep diagonal cut across the inner face near the mortise could have caused this.

Figure 4.162. Distorted aft end of S-Block 4.

Dimensions and Form

The stanchion blocks vary in form and, as a result, dimension. Due to their excellent preservation, original dimensions are available for each timber. S-Blocks 3 and

4, both notched to fit over frames FR 15-FR 17, are very similar and seem to constitute a separate subgroup (fig. 4.160). These two are 66.5 and 62 cm in length and 16 and 18 cm in width, respectively. They are up to 10.6 and 10.8 cm in molded dimension between frames and up to 6.0 and 8.5 cm molded at recessed areas over frames. Both were cut from the central part of a small trunk, such that the pith of the timber is visible (fig. 4.163), with approximately 50 annual rings observed. Parts of the outer face are naturally rounded, reflecting use of a trunk 15-20 cm in diameter. Outer face edges round to the sides either through natural surfaces or a cut chamfer. Inner face edges are usually angular, although the inner-inboard edge of S-Block 3 was also cut with a chamfer.

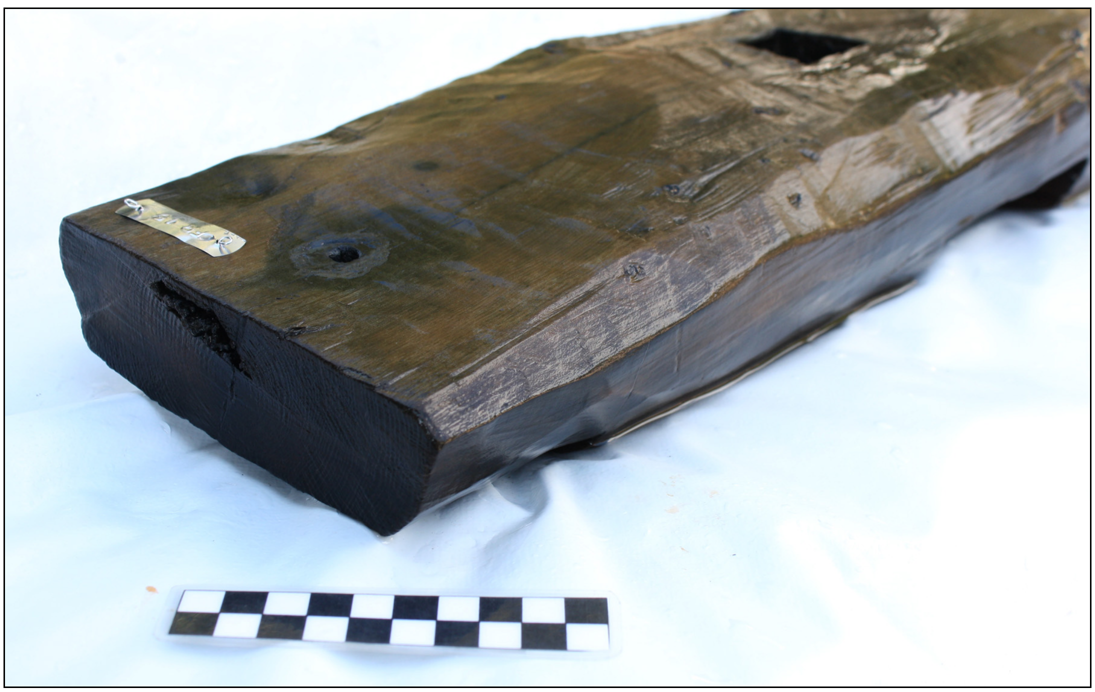

Figure 4.163. Aft end of S-Block 3.

The remaining four stanchion blocks are not notched to fit over frames. Three of the four are approximately 96 cm in length, while S-Block 2, a recycled timber, is just 73 cm long. Widths vary significantly, ranging from 5.6 to 17.6 cm, with an average maximum width of 14.5 cm. Thicknesses are more uniform, from 2.8 to 5.1 cm.

In form, S-Blocks 5 and 6 are quite similar; both are stringer-like in section, with a naturally rounded inner face (fig. 4.164) and a flat outer face, and both narrow toward the aft end through bevels cut along the edges (see below). They were cut from the outer portion of a sawn log, with only 15-25 annual rings visible, the pith oriented toward the exterior of the hull. Areas of the outer face of both timbers were trimmed with an adze to accommodate one or more frames. In section, the edges are beveled such that the outer face is slightly narrower than the inner face.

Figure 4.164. Mortise at S-Block 6 inner face. Note naturally rounded surface, score marks at mortise edges (arrows).

Figure 4.165. Notches on recycled timber S-Block 2.

S-Blocks 1 and 2, near the aft bulkhead compartment, are both of cypress but are dissimilar in form. S-Block 1 is approximately rectangular, although a splintered dog-leg along the outboard edge could be intentional or could just reflect damage or very rough cutting. Parts of the outer face are naturally rounded, while the inner face edges are angular. The outer face may have been trimmed down for FR 9. S-Block 2 was fashioned from a recycled timber; several disused sockets and a disused fastener hole were observed, and the timber's original function remains unknown (fig. 4.165). Much of the outer face is a naturally rounded surface, while inner face edges are irregularly chamfered. Inboard and outboard edges do not exhibit a significant bevel on either timber. On both S-Blocks 1 and 2, the pith is not present but would have been closer to the interior of the hull; 45-50 annual rings are visible on each, and natural surfaces on S-Block 1 indicate a trunk 18 cm in diameter.

Figure 4.166. Aft end of S-Block 2, showing inner face.

Finished Ends

Most of the stanchion block ends have been sawn flat; in at least three cases, the ends were sawn first from one direction, then from another direction, with the small area between the two saw cuts snapped off (figs. 4.161, 4.163). While most ends are blunt-cut, the aft ends of both S-Block 2 and S-Block 5 have wide chamfers to transition from the inner face to the flat-cut end (fig. 4.166). Likewise, the aft end of S-Block 6 is cut flat with an adze, with a wide chamfer cut to one of its corners. The outer face of S-Block 6 is also trimmed with an adze, gradually decreasing the timber in molded dimension toward its forward end; this does not, however, seem to be associated with a frame, and the reason for this trimming is unclear. The forward end of S-Block 5 is the only end which is not cut flat; rather, this end is roughly adzed down to a thin, ragged edge (fig. 4.167). This edge cuts through a nail hole of unclear function, located between frames.

The ends of S-Blocks 3 and 4 are located at frames. On S-Blocks 1 and 2, the forward ends terminate at a frame while the aft ends fall between frame locations. On S-Blocks 5 and 6, neither end terminates at a frame location.

Figure 4.167. Forward end of S-Block 5. Note rough adzing and cut-through nail hole.

Fasteners

The stanchion blocks were attached to framing with two nails each, one nail for every other frame. The only exception to this pattern is S-Block 1, which was attached with three nails, one at FR 7 and two at FR 9. The nails used to attach the timbers were driven from the inner face, where square holes are usually 0.7-0.8 cm sided; on the outer face, the holes are slightly smaller, usually approximately 0.5 cm sided. Nail-head impressions or outlines from concretion are 1.8-2.3 cm in diameter. Some of the nails were driven through pilot holes 1.0-1.2 cm in diameter, but these do not extend to the outer face of the timber.

Four of the six timbers have one disused fastener hole, varying in size, shape, and location. The disused fastener hole on S-Block 1 is an empty drilled hole, 1.0 cm in diameter, between frame locations. The disused fastener hole on recycled S-Block 2 is a diagonally drilled hole that served some unknown function in the timber's original use (fig. 4.165). The small abandoned nail hole on the outer face of S-Block 4 looks like an old, square nail that had been extracted. The large, black-stained nail hole, cut through on the ragged forward end of S-Block 5, was noted above (fig. 4.167).

Figure 4.168. Rough edges of mortise on outer face of S-Block 4.

Figure 4.169. Outer face of S-Block 2 at mortise.

Mortises

The most characteristic feature of the stanchion blocks is their mortise. Each stanchion block, with the exception of S-Block 3, possesses one mortise that extends to the outer face. On S-Block 3, there are two mortises; the forward mortise does not extend to the outer face and may have been cut in the wrong location, while the aft mortise does extend to the outer face and aligns with the mortise on S-Block 4. On S-Block 4, the broken and irregular outlines of the mortise on the outer face suggest it was cut from the inner (upper) face and merely broke through the outer face incidentally (fig. 4.168). Other mortises appear to have been cut from both the inner and outer faces, and chisel marks to one side of the mortise reveal that the mortises on S-Blocks 2, 3, and 5 were started off-center on the outer face (fig. 4.169).

Mortises are approximately square or rectangular and vary slightly in dimension. They range in length from 3.7 to 6.1 cm (average 5.1 cm) and in width from 3.1 to 5.0 cm (average 4.0 cm). Their depth corresponds to that of the timber and ranges from 3.4 to 7.1 cm. The largest mortises are those that extend to the outer face on the central pair of stanchion blocks; these are 6.1 cm in length and 4.8 and 5.0 cm in width.

All of the mortises were cut with a chisel, at times roughly, with blade widths of 1.5 and 2.0-2.3 cm reflected in cut marks (fig. 4.169). The outer face is usually more roughly cut than the inner face. Score marks along both the forward and aft edges of the mortises on S-Blocks 5 and 6 (fig. 4.164) reveal the significance of the longitudinal location; these mortises align with the probable location of a forward through-beam. Faint score marks were also noted near the edges of the mortise on S-Block 2, but were not preserved on any of the other stanchion blocks. Perhaps the longitudinal position of the mortises was less important on the central pair of stanchion blocks, or perhaps the score marks were simply not preserved on these timbers.

There is some minor surface wear around the mortises of S-Blocks 3 and 4, but there is no indication of the form of the stanchion or other timber that may have been inserted into these mortises. That all of the functional mortises extended through the outer face (at least to some extent) reflects the use of a stanchion with a tenon at its lower end. The deep diagonal cut mark across S-Block 4 (fig. 4.162) may have been made to adjust the height of such a stanchion. There is no evidence of pressure damage on the framing to suggest that any part of these stanchions extended below the outer face of the stanchion blocks.

Figure 4.170. Sawn outer face of S-Block 5. This face is adzed down at FR 22. Note large knot hole near end.

Tool Marks

The stanchion blocks were fashioned with the use of an adze, saw, several chisels, and a drill. The inner face of S-Blocks 1, 2, and 4, and the outer face of S-Blocks 5 and 6, were sawn; most of the blunt-cut ends were also sawn. Remaining surfaces and any chamfers were either naturally rounded, with bark removed (figs. 4.164, 4.165, 4.167, 4.169), or were trimmed with an adze. Tool marks suggest the use of one or more chipped blades with widths of 3.5-4.5 cm. The outer face of S-Block 2 was roughly split near its aft end. The sawn outer faces of both S-Blocks 5 and 6 were adzed down at some frame locations (fig. 4.170).

Score marks were used both to designate the longitudinal position of the mortises on S-Blocks 5-6 and to indicate the location of the outer face notches for framing on S-Blocks 3 and 4. Their precise placement on S-Block 4 (fig. 4.171) indicates the importance of fitting these timbers over framing, locking them in place longitudinally;

that the score marks are less precise or inconsistent on S-Block 3 probably reflects a recutting of the notch in order to accommodate replacement frame FR 16S.

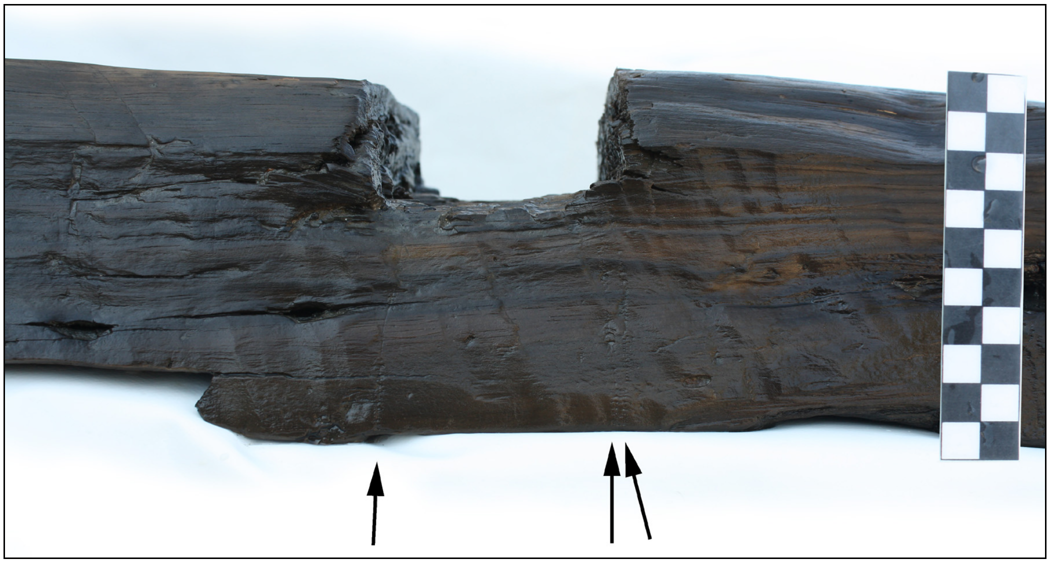

Figure 4.171. Score marks on the inboard edge of S-Block 4.

Chisels were used in several areas of the stanchion blocks, most notably the cutting of mortises (mentioned above). The deep notches for framing on S-Blocks 3 and 4 were cut with a combination of saw, chisel, and adze. The chisels used here were 3.0-4.0 cm in width. Narrower chisels, 1.9-2.5 cm in width, and a saw were used to cut the smaller sockets along the edges of S-Block 2. An area around the FR 15 nail is also chiseled or adzed out of the outer face of S-Block 3 (fig. 4.172). A chisel or an adze, at least 2.5 cm in width, was used to cut notches along the inboard edge of S-Block 6 and outboard and perhaps inboard edges of S-Block 5. These notches are of unclear function, but may be associated with stemson UM 47.

Figure 4.172. Outer face of S-Block 3 at aft end (FR 15). Note cut-down area around nail.

Other Surface Detail

Very little pitch was preserved on the stanchion blocks. It is usually present in small spots or areas of staining on the outer face and edges. It is less common on the inner face, although several patches of thick pitch were preserved on the inner face of S-Block 1, and pitch staining was observed within this timber's mortise.

There is also a pressure mark on the inner face of S-Block 1, indicating the location of the bulkhead frame, which rested atop this timber. That a similar pressure mark was not observed on S-Block 2 does not necessarily mean that there was not a similar frame on the starboard side, but may merely indicate that the pressure mark on the port side was created after the ship had become buried.

S-Blocks 5 and 6 were fastened over original frames and thus may have been part of the original construction of the ship. Both S-Blocks 1 and 2 were attached to replacement framing and had thus either been removed and reinstalled at some point or were not original to the construction of the ship. The latter is more likely the case for S-Block 2, a recycled timber, while the former is more likely for S-Block 1, as suggested by its worn surface and abandoned fastener hole. S-Blocks 3 and 4 were both attached to one original floor and one replacement floor; they must therefore have been removed and reinstalled at some point, or were replacement timbers.

Function of the Stanchion Blocks

The stanchion blocks may be roughly grouped into two categories: those notched over frames (S-Blocks 3 and 4), and those that were not notched over frames. Care was taken in notching S-Blocks 3 and 4 so that the timbers would be locked in place longitudinally and thus be more secure. The latter group, with S-Blocks 1, 2, 5, and 6, were nailed to framing but not locked in place as securely.

Score marks aligned with the edges of the mortise on S-Blocks 5 and 6, and possibly also S-Block 2, indicate the importance of the longitudinal location of these mortises, and the mortises in the fore and aft pair of stanchion blocks align with through-beams. This is not the case with the central pair of stanchion blocks. A longitudinal structure elevated on stanchions between FR 9 and FR 23 is thus suggested, with one or both ends secured to through-beams. Stanchions mounted in the robust, securely-positioned central pair of stanchion blocks would have added additional support to this structure, which would have served to provide lateral support to the mast. This is most likely the *xylokastron* or tabernacle seen in the depictions of sailing vessels of seventh-century date (see Ch. VI); while it may have been more complex on larger ships, a simple pair of fore-and-aft timbers, not unlike the central stringers but at deck level, may have sufficed for a ship of this size.

THE BULKHEAD

Part of a bulkhead partition, which separated an enclosed stern area from the rest of the ship, was preserved on the port side. This bulkhead consists of a slotted "frame", BH FR 1, into which four separate planks, BH Plank 2-BH Plank 5, were inserted; most of these pieces are Turkish Pine (*Pinus brutia*). These were found in situ on the wreck on the port side (fig. 4.173).[105] An additional bulkhead frame UM found just aft of the in-situ bulkhead, UM 157, bears similar characteristics to BH FR 1, but the curvature and form of this piece differ somewhat. Its correct location has not been identified.

Bulkheads were identified on other ships at Yenikapı, notably YK 3 (10-11th century), YK 12 (9th-10th century), and YK 14 (9th-10th century).[106] However, the base for these bulkhead partitions is a slotted frame or futtock rather than a separate timber, independent of the ship's framing, as on YK 11. Perhaps the partition on YK 11 was an afterthought rather than a feature integrated into the ship's structure. Alternately, this difference may reflect the structural importance of stringers on YK 11, which would have been interrupted by the placement of partitions in the later ships.

[105] BH Plank 1 is a small exterior plank that had been placed in the bulkhead frame by workers upon its excavation. Although it was initially considered part of the bulkhead and photographed as such in situ, it was later found to be part of the ship's starboard planking and relabeled PS 6A.
[106] For YK 3 and YK 12, Kocabaş 2008, 114, 123, 159. For YK 14, Jones 2010.

Figure 4.173. Bulkhead components in situ, viewed from stern. Plank PS 6A, to left of bulkhead planks, was erroneously placed in the bulkhead frame by workers. UM 157 is on its side, aft of the bulkhead (toward foreground), between FR 5 and FR 8.

Bulkhead Frame BH FR 1

The frame-like timber into which the planks of the bulkhead were fitted was originally labeled “BH FR” and was relabeled “BH FR 1” in light of UM 57. BH FR 1 (identified as *Pinus brutia*) was found in situ, resting on KS 1, S-Block 1, SST 1-1 and SST 3-1 on the port side of the ship. Early 2006 photos show that SST 4 had extended across the top face of this frame near its outboard end. This timber was located between FR 8 and FR 9; this was somewhat surprising, as it was expected that the bulkhead partition would have been located at a frame for added support. Indeed, wear on the inner face and distortion of S-Block 1 indicate the location of BH FR 1. The location of the bulkhead frame between FR 8 and FR 9 corresponds to the likely location here of a through-beam between SS 11 and SS 13.

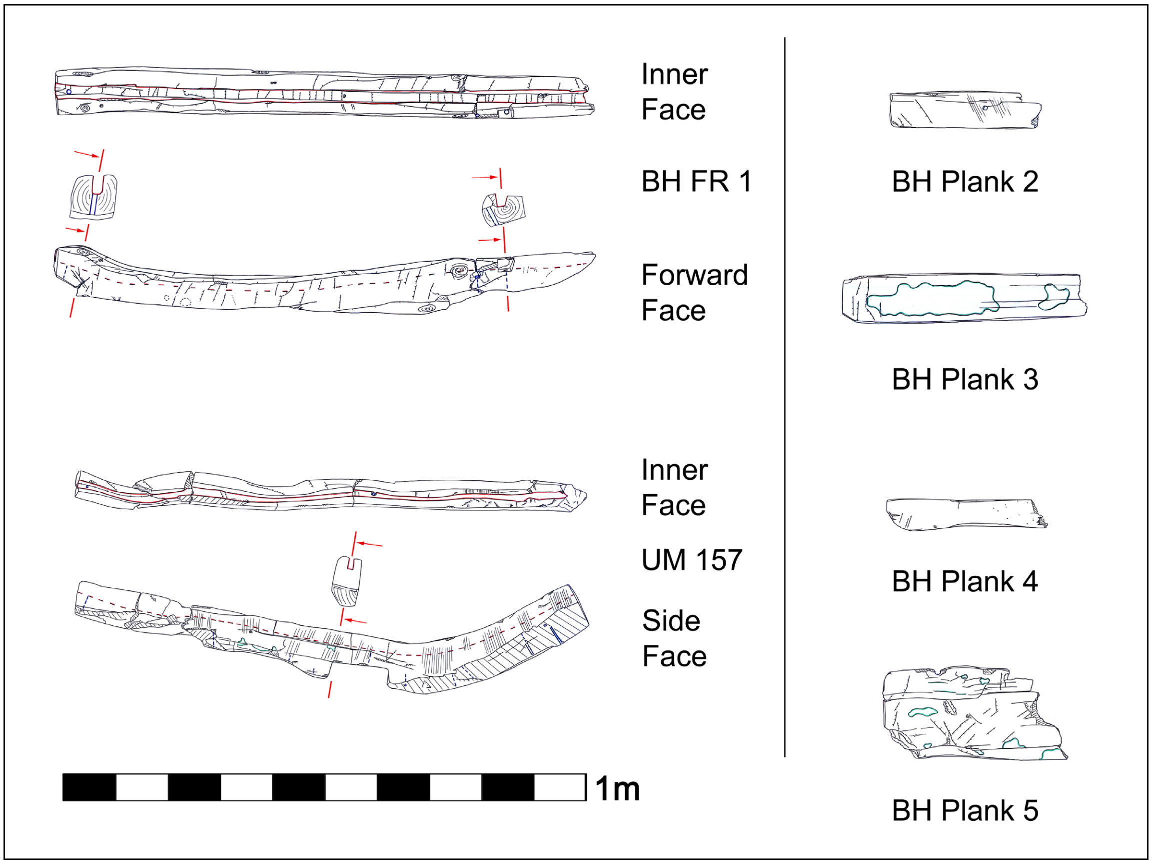

Figure 4.174. Components of the YK 11 bulkhead. Forward face of bulkhead planks is shown.

BH FR 1 is complete timber, 1.04 m in length (fig. 4.174). It is 6-10 cm in molded dimension and 7-9 cm sided. The frame is in an excellent state of preservation; it is complete but not intact, having broken at the nail that attached BH FR 1 to stringer SST 3-1. It exhibits very little damage; surfaces are well preserved with detail such as tool marks clearly visible in most areas. Because the frame was located between FR 8 and FR 9, it was not supported from below except at stringers, sternson KS 1, and stanchion blocks, resulting in some pressure damage and distortion where the bulkhead frame was pressed down over these timbers over time. This resulted in the break at SST

3-1 and in pressure cracking and damage at KS 1. Such pressure damage occurred despite the outer face of BH FR 1 being cut down to accommodate these timbers. The outer face has an adzed or chiseled recess at the location of KS 1; this recess is up to 1.3 cm in depth (fig. 4.175). At SST 3-1, a 14.5 cm-long area on BH FR 1's outer face (more than wide enough for SST 3-1) is trimmed down with an adze; this recess is approximately 1 cm in depth, but is less distinct than the KS 1 recess. The outer face also seems to have been trimmed down lightly with an adze at the location of SST 1-1.

Figure 4.175. Notched outer face of BH FR 1 at sternson KS 1.

BH FR 1 was cut from a large branch of Turkish Pine; approximately 15 annual rings are visible. Much of the inner face is naturally rounded, reflecting the original outer form of the tree, but with bark removed; part of the outer face edge is also rounded off through natural chamfers reflecting the form of the tree. Outer, forward and aft faces were cut flat with an adze having a 3.5 cm blade.

The frame was attached to the sternson KS 1 and stringer SST 3-1 with a single iron nail each. Evidence from both BH FR 1 and the timbers to which it was attached reveal that the bulkhead frame had been installed, then removed for the replacement of frames, then reinstalled in approximately the same position. In its original installation, it was still only attached with 2 nails. Whether this timber or other parts of the bulkhead were original elements of the ship's construction remains unknown, but it is possible that this was not the case.

The nails were driven through pilot holes. The outer part of the 1.1 cm-in-diameter pilot hole for the nail that fastened the bulkhead frame to KS 1 was filled with bits of shell and sediment. Damage just inboard of this hole shows that the nail which attached BH FR 1 to KS 1 was driven at an angle, breaking out part of the outer face and leaving the pilot hole empty at the outer face (fig. 4.175). Other, unexplained and disused nail holes on the inner face of sternson KS 1 may represent the original bulkhead nail. At KS 1, BH FR 1 only covers half of the timber's inner face. Another nail on the inner face of KS 1 at this location, but to starboard of the inboard edge of BH FR 1, provides evidence for a second bulkhead frame on the starboard side of the ship. The nail for KS 1 was driven from within the inner face slot of BH FR 1; a small pressure mark on one side of the slot wall might represent the edge of the nail head.

The second nail was driven through a shallow pilot hole that did not extend to the outer face of the bulkhead frame. This nail was driven from the forward face of BH FR 1 down into the inner face of stringer SST 3-1 (fig. 4.176). The timber broke at this nail. The original second nail on the bulkhead frame was much more carefully driven, through a drilled hole set in a chiseled recess. This chiseled recess, cut with a chisel not more than 2.5 cm wide, is set into the naturally-rounded, inner-forward edge of BH FR 1. The recess is 2.5 cm in length and 2.1 cm in height, with a depth of 2.2 cm. It suggests an original nail head not more than 2.5 cm in diameter. The original nail here seems to have corresponded to an abandoned nail hole on the inner face of stringer SST 3-1, suggesting that the original position of the bulkhead partition was very close to its replaced position, assuming of course that the stringer SST 3-1, which was also removed and repositioned, did not change location significantly. Traces of pitch found within the 0.9 cm-in-diameter pilot hole of this abandoned fastener hole on the bulkhead frame are the only remains of pitch on the timber.

Figure 4.176. Nails N2 and N3 on BH FR 1. N3, a disused nail, is in a chiseled recess.

Figure 4.177. Chiseled slot on inner face of BH FR 1.

The most significant characteristic of BH FR 1 is the chiseled slot running the entire length of the timber (fig. 4.177). This slot is cut into the inner face of BH FR 1 and served as a base for the planks that comprise the bulkhead wall. The slot is usually 2.0-2.1 cm in width at its base (or deepest area). The depth of the slot is variable, from 2.0 to 3.0 cm depending on the depth of some of the chisel cuts, but is usually approximately 2.5 cm deep. The depth increases to 3.7 cm near the keel end. The slot was cut with a chisel, fairly smoothly along the walls, but roughly at the base of the slot, where the wood between the walls seems to have been roughly chopped out with a chisel probably 2.0 cm in width. That the slot runs along the entire length of the timber lends some support to the theory that the bulkhead partition continued on to the starboard side of the ship.

Table 4.19. Overview of YK 11 bulkhead planks. Length measurements are not representative of the original size.

Plank Number	Wood Species	Length (cm)	Maximum Width (cm)	Maximum Thickness (cm)	No. of Pieces
BH Plank 2	*Pinus brutia*	29.0	7.0	2.0	1
BH Plank 3	*Pinus brutia*	47.2	9.5	2.3	1
BH Plank 4	*Pinus brutia*	31.0	5.9	1.8	1
BH Plank 5	*Fraxinus excelsior*	35.3	17.2	2.2	3

Bulkhead Planks

Five planks were found resting in the BH FR 1 inner face slot; these were numbered BH Plank 1-BH Plank 5 (from outboard/port to inboard/keel) (figs. 4.173-4.174). BH Plank 1 was later found to be part of the ship's planking, mistakenly placed in the bulkhead frame by workers during excavation; the other planks were in their original location, slotted into the bulkhead frame. Measurements for each plank are provided in table 4.19. Planks 2 through 4, like the bulkhead frame, are of Turkish pine; BH Plank 5 is of European ash. The planks are of relatively consistent thickness, usually 1.8-2.1 cm, which would fit well within the BH FR 1 slot. Widths vary, from a maximum of 5.9 cm (Plank 4) to a maximum of 17.2 cm (Plank 5). Lengths vary as well and are not original; only the planks' inboard ends are preserved. Preserved lengths are 29-47.2 cm, approximately 35 cm on average.

The bulkhead planks are all approximately rectangular in form, although the port or outboard (upper) end is consistently broken. Two of these planks, Plank 2 and Plank 5, have old, disused fastener holes, suggesting they are recycled; they are perhaps old pieces of ceiling planking. Planks 3 and 5 were adzed down on the forward and aft faces near the lower end, presumably to help the plank fit better into the BH FR 1 slot. Planks 3 and 4 are cut along the lower-outboard corner, either flat-cut (Plank 3) or rounded (Plank 4), which may indicate a diagonal orientation within the frame or may simply reflect the curvature of the hull here. Planks 2 and 5 are damaged at the lower corner, with significant compression and distortion on Plank 5.

Plank 5 is the only bulkhead plank that was broken. This is the only bulkhead plank not of pine, and the wood type used might have affected the structural integrity of the piece. As found, the top edge of Plank 5 extended beyond the keel end of the bulkhead frame (fig. 4.173).

Bulkhead Frame UM 157

In addition to the bulkhead frame and four planks found in situ, UM 157 was found just aft of the bulkhead and is almost certainly part of a separate bulkhead frame (fig. 4.174). This UM is also complete but not intact, having broken into four pieces. It is similar to BH FR 1 in molded dimension (5.5-9.5 cm), but is somewhat narrower in sided dimension (only 5-6 cm, in contrast to 7-9 cm on BH FR 1, although this is due in part to compression.) It is also slightly shorter (98 cm) and has a much more pronounced curvature than BH FR 1. It was found lying on its side over S-Block 1 and stringer SST 1-1, just to port of the keel, between FR 5 and FR 8 (fig. 4.173). The side was pressed down over these in-situ timbers, and this resulted in significant compression damage to the timber.

The main feature by which UM 157 may be identified as part of a bulkhead frame is the deep slot along the inner face (figs. 4.174, 4.178). This slot is heavily damaged due to compression of the timber's sided dimensions, such that the width of the slot is now only 1.1-1.2 cm at its widest places. The depth of the slot, however, is at 1.8-3.2 and usually 2.2 cm much more comparable to that of BH FR 1. Also, as on BH FR 1, there are recesses cut into the outer face of UM 157, presumably to accommodate internal timbers such as stringers and stanchion blocks. Three such recesses are present; all are slightly different in form, with the deepest a rectangular recess, 11 cm in length and 3.6 cm in depth.

Figure 4.178. Sectional view of bulkhead frame UM 157, at a break. Note slot on inner face and recess on outer face. Inner face to left.

UM 157 is of European ash rather than pine. Furthermore, it seems to be a recycled frame, based on nine disused nail holes on the outer face that do not appear on the inner face. Only two nails on UM 157 were in use, one at an end and the other around the center of the timber. The central nail is located at the deep rectangular recess on the outer face. Both nails were driven from the inner face, within the slot.

The timber was cut in a different manner than BH FR 1, on which all faces were adzed; instead, UM 157 was cut in a manner similar to the YK 11 ship's framing. One face was sawn flat, and the pith is oriented along this face. Other faces were adzed, with some areas having a naturally rounded form or chamfer. Traces of pitch were found on both sides as well as within the chiseled slot near one end. Both ends are cut flat.

Based on the curvature of this timber, this was probably a bulkhead frame from a narrower point in the hull than where the in-situ bulkhead is preserved. The sharp curve almost certainly represents the turn of the bilge, which seems to preclude its association with the in-situ bulkhead. It seems more likely to be from an area farther aft from the original bulkhead, which fits with its find position. The deep rectangular recess seems to fit with SST 3-1, but it does not match any fastener on this stringer. The form, method of fastening, and inner face slot all point to this timber as a bulkhead frame on YK 11, and the use of a recycled ash frame is in keeping with the general philosophy of the YK 11 shipwrights. It is even possible that UM 157 was one of YK 11's original half-frames, but this can probably never be proved.

Construction Notes

In conclusion, the stern bulkhead partition of YK 11, located on the port side of the vessel between FR 8 and FR 9, was built primarily of pine (with one ash plank). It consists of thin planks, usually approximately 2.1 cm in thickness, slotted into a frame which was very lightly fastened to other internal elements of the ship, the sternson KS 1 and a stringer. Nails toward the starboard edge of KS 1's inner face, and the open slot on the keel end of the bulkhead frame, suggest that a matching bulkhead frame was located on the starboard side of the ship, and that the bulkhead extended across the hull, as expected. A through-beam located here was probably used as a surface onto which the upper parts of the bulkhead were secured.

The bulkhead planks, as found, were in a slightly diagonal orientation to the bulkhead frame. This orientation fits with the curved lower corner of Plank 4 and the flat-cut corner of Plank 3. Such an orientation, however, leaves triangular gaps between the planks (Plank 2-Plank 3 and Plank 3-Plank 4.) An upright orientation for the planks would be more likely based on the adzing of the keel ends on Planks 3 and 5. An upright orientation, however, does not seem to fit together very well (or perhaps this is a result of compression damage). Reassembling the planks in either orientation provided no conclusive evidence of either a vertical or a diagonal orientation, although the former seems more probable. Either way, several of the original planks were not preserved.

Another wall to the bulkhead is suggested by the presence of UM 157, a displaced bulkhead frame. The correct location of this bulkhead partition is unclear but seems to have been aft of the in-situ bulkhead.

OTHER UNIDENTIFIED FRAGMENTS

In addition to the unidentified fragments of framing, planking, wales, and ceiling mentioned above, many other unidentified fragments, which do not appear to have been parts of the YK 11 hull, were found scattered throughout the excavation pit. These include elements of rigging that may have been used in association with YK 11 or other ships in the area (presented in Ch. VI); oar- or pole-like fragments, probably used by smaller ships or boats; and fragments of timber that lack sufficient detail and may not be categorized or identified.

Figure 4.179. İvgin excavating oar UM 30, found upright just aft of YK 11. May 27, 2008.

Unidentified Oar- or Pole-like Fragments

Twelve unidentified fragments found in and around YK 11 are likely the remains of devices that had been used to propel smaller watercraft after YK 11 had become inundated (table 4.20). These are most often pole- or handle-like objects of rounded or oval section, 3.7-6.3 cm in diameter. Frequently, these are minimally-worked objects from which the bark had been removed. Nearly half of these objects were found upright in the viscous mud surrounding the shipwreck (fig. 4.179). This orientation confirms the shallow nature of the area as well as its continued use by smaller vessels, most likely fishing boats.

Only one of these fragments, UM 49, is complete and may therefore represent a tool handle rather than a punting pole; it is 1.12 m in length. UM 21, found within the ship toward the bow, has a squared section and a whittled collar near its broken end (fig. 4.180). Due to its form, this fragment may more likely be a stanchion; however, there is no preserved evidence of a flange as would have been necessary for its use with the YK 11 stanchion blocks.

Finally, five of these fragments appear to represent part of an oar, including oar blades, a counterweight near the handle, and a transitional fragment between the oval shaft and the blade or counterweight. All five are *Fagus orientalis* (Oriental beech), which Theophrastus notes does not decay in water;[107] however, the beech timbers found around YK 11 were somewhat poorly preserved and frequently compressed. The most extensively-preserved oar is UM 30, on which the entire oar blade and a large part of the shaft is preserved (fig. 4.181). The UM 30 oar blade is triangular in section, up to 4.8 cm thick along the thicker edge and up to 2.5 cm along the thinner edge. Based on its form, perhaps UM 30 was the quarter rudder used by a small boat when sailing. In contrast, compressed oar blade UM 93 seems to have had a more uniform section, although it is now not more than 1.1 cm in thickness due to severe compression (fig. 4.182).

[107] Theophr. *Hist. pl.* 5.4.4.

Table 4.20. Pole, oar, or handle-like UMs found around YK 11.

Fragment Number	Wood Species	No. of Pieces	Preserved length (cm)	Maximum handle width or diameter (cm)	Description
UM 21	*Ulmus campestris*	1	58.5	4.4	Object with one original end; squarish section. Pole or stanchion? Found within ship.
UM 30	*Fagus orientalis*	2	114.5	4.6	Oar with blade and part of shaft. Blade width 8.7 cm, thickness 4.8 cm. Found upright in mud aft of ship.
UM 37	*Acer pseudoplatanus*	1	60.0	3.7	Pole or shaft? Found upright in mud aft of ship. (Intrusive modern piece?)
UM 49	*Quercus coccifera*	6	112.0*	6.3	Complete pole or shaft. Found across starboard planking.
UM 62	*Pinus brutia*	1	32.5	5.9	Minimally worked; found outboard of starboard stern. Pole?
UM 93	*Fagus orientalis*	1	25.0	N/A	Compressed oar blade, width 11.7 cm, compressed thickness 1.1cm. Found upright in mud aft of ship.
UM 94	*Fagus orientalis*	1	21.5	5.9	Possibly same oar shaft as UM 113. Found near UM 95 oar, to starboard of ship.
UM 95	*Fagus orientalis*	1	96.0	N/A	One end of an oar (near the handle?), with stars inscribed on one face. Maximum width 10.2 cm. Found upright in mud to starboard of ship.
UM 113	*Fagus orientalis*	1	14.0	5.2	Possibly same oar shaft as UM 94. Locus unknown. Transition from shaft to blade. Max. width 6.0 cm.
UM 154	*Quercus cerris*	1	38.0	4.0	Minimally worked branch with one original, beveled end. Pole or shaft? Locus unknown.
UM 156	*Pinus nigra*	2	38.2	4.2	Minimally worked branch with one original but damaged end. Pole or shaft? Found within ship.
UM 171	*Pinus nigra*	1	61.5	6.2	Minimally worked branch with one worn original end. Pole or shaft? Found upright in mud outboard of starboard stern.

* denotes original length measurement.

Figure 4.180. Whittled collar near broken end of UM 21.

Figure 4.181. Oar UM 30, found upright in mud aft of YK 11.

Figure 4.182. Oar blade UM 93.

Figure 4.183. UM 95, part of an oar (near handle?). Pentagrams are highlighted for emphasis.

UM 95 may be the counterweight of an oar near the handle (fig. 4.183). It also has a triangular section but differs from the section of UM 30 and does not seem well-suited to an oar blade. The UM 95 section reaches 6.7 cm in thickness and 10.2 cm in width. If this is the handle rather than the blade of an oar, it was being used upside down in order to push or punt the ship through a shallow, marshy area, perhaps in order to preserve the more delicate blade at the opposite end. Two nearly complete pentagrams and two lines of a third were inscribed on this piece near its broken end (fig. 4.183, detail).

Other Unidentified Fragments with No Classification

About one quarter of the UM timbers found scattered across the YK 11 excavation pit could not be grouped with any particular category, due either to insufficient preservation or simply a lack of detail. These 47 fragments are presented in table 4.21.

Table 4.21. Unidentified fragments with no classification, found near YK 11.

Fragment Number	Wood Species	No. of Pieces	Preserved Length (cm)	Locus
UM 2	*Pinus brutia*	3	90.5	Port stern
UM 4	*Pinus brutia*	1	46.0	Port stern
UM 10	*Pinus brutia*	6	137.0	To port, amidships
UM 23	*Pinus nigra*	1	79.5	Forward of amidships
UM 44	*Pinus nigra*	1	38.0	Starboard bow
UM 54	*Quercus cerris*	1	33.5	To starboard, amidships
UM 56	*Cupressus sempervirens*	1	34.5	To port, aft of amidships
UM 59	*Pinus brutia*	1	25.5	To starboard, aft of amidships
UM 67	*Pinus brutia*	1	21.5	Unknown (stern?)
UM 71	*Ulmus campestris*	1	35.0	Unknown (stern?)
UM 75	*Pinus brutia*	1	24.8	Unknown (stern?)
UM 82	*Cupressus sempervirens*	1	27.0	Unknown (stern?)
UM 83	*Cupressus sempervirens*	1	30.7	Unknown (stern?)
UM 86	*Pinus brutia*	1	30.5	Unknown (stern?)
UM 90	*Fagus orientalis*	1	21.0	Unknown (stern?)

Table 4.21. Continued.

Fragment Number	Wood Species	No. of Pieces	Preserved Length (cm)	Locus
UM 91	*Ulmus campestris*	1	15.8	Unknown (stern?)
UM 103	*Pinus brutia*	1	17.3	Aft of amidships
UM 105	*Pinus brutia*	2	18.8	Near mast-partner beam
UM 114	*Fagus orientalis*	1	6.0	Unknown
UM 116	*Cupressus sempervirens*	1	34.0	Unknown
UM 118	*Ulmus campestris*	1	33.0	Unknown
UM 119	*Quercus cerris*	1	27.0	Unknown
UM 120	*Quercus cerris*	1	37.0	Unknown
UM 124	*Quercus cerris*	1	11.9	Unknown
UM 127	*Pinus brutia*	1	13.6	Unknown
UM 129	*Fagus orientalis*	1	23.5	Unknown
UM 130	*Fagus orientalis*	1	13.3	Unknown
UM 131	*Quercus cerris*	2	18.8	Unknown
UM 132	*Pinus brutia*	2	25.5	Unknown
UM 152	*Pinus brutia*	2	50.0	Toward bow
UM 155	*Pinus nigra*	1	30.0	Forward of amidships
UM 161	*Quercus cerris*	1	13.0	Aft of amidships
UM 163	*Pinus brutia*	1	26.0	Forward of bulkhead
UM 164	*Acer pseudoplatanus*	1	30.8	Port side
UM 166	*Pinus brutia*	1	26.5	Amidships
UM 167	*Pinus brutia*	1	20.8	Forward of ship
UM 170	*Pinus nigra*	1	88.0	Under hull, starboard
UM 172	*Pinus nigra*	2	10.7	Under hull, starboard
UM 173	*Quercus cerris*	2	80.0	Under hull, port
UM 174	*Quercus coccifera*	1	47.2	Under hull, starboard
UM 187	*Quercus coccifera*	3	37.5	Under hull, port
UM 188	*Quercus cerris*	1	13.9	Under hull, port
UM 191	*Quercus cerris*	1	19.2	Under hull, port
UM 193	*Pinus nigra*	1	10.0	Under hull, port
UM 196	*Pinus nigra*	2	23.5	Under hull, starboard
UM 198	*Ulmus campestris*	1	21.4	Under hull, port
UM 199	*Ulmus campestris*	1	34.5	Under hull, port
UM 200	*Cupressus sempervirens*	1	67.2	Toward bow
UM 201	*Cupressus sempervirens*	1	20.6	Toward bow

CHAPTER V

THE CONSTRUCTION OF YK 11

AND TRANSITIONAL SHIPBUILDING IN THE MEDITERRANEAN

CONTEMPORANEOUS SOURCES

Over the course of the first millennium A.D., shipbuilding in the Mediterranean gradually developed from what may best be termed a shell-based to a skeleton-based concept. The distinction between the two was first proposed by Olof Hasslöf, who used a ship's construction sequence as the basis for a designation of either a "shell-construction technique" or a "skeleton-construction technique."[1] In the former, which is often commonly referred to as shell-first shipbuilding, the hull's form is derived primarily from its exterior planking; in the skeleton-construction, or frame-first, technique, the hull's form is derived primarily from its internal framework.[2]

The transition between the two was both gradual and complex. Lucien Basch notes that, on many ships, "…an absolute distinction between the 'shell' and 'skeleton' techniques is as convenient as it is artificial."[3] Furthermore, in studying the history of naval architecture, the development of structural method and the form of the ship are of the utmost importance; determining whether a vessel is built shell-first or skeleton-first is just one element of the study.[4] Basch therefore proposed the concept of "active" and "passive" framing: the form of "passive" framing is determined by planking, which it

[1] Hasslöf 1963, 163-66.
[2] Hasslöf 1972, 42-72; Hocker 2004a, 6.
[3] Basch 1972, 34.
[4] Basch 1972, 52.

serves merely to reinforce, while “active” framing controls the form of the planking in addition to reinforcing it.[5] Building on this previous work, Pomey suggested a more comprehensive approach, emphasizing that both the concept as well as the realization or processes of construction be analyzed.[6] In a similar vein, Hocker proposed three specific aspects that should be considered in the analysis of a hull: design, assembly sequence, and structural philosophy.[7] He specified that design is usually, but not always, tied to assembly sequence and defined structural philosophy as “…the way in which the shipwright intends the component timbers of the hull to distribute the different working stresses the vessel can be expected to encounter.”[8] With these three aspects in mind, Hocker suggested that use of the terms “shell-based” and “skeleton-based,” rather than “shell-first” or “frame-first,” is a better expression of the complexity behind these concepts.[9]

Much has been written—and continues to be written—on the transition from shell-based to skeleton-based shipbuilding in the Mediterranean, and this transition is yet to be fully understood. Recent work has proposed that the transition may have developed differently in certain geographic areas.[10] Furthermore, the date by which truly skeleton-based vessels were being built is under debate. For many years, the early 11th-century ship at Serçe Limanı, Turkey, lacking plank-edge fasteners, was considered to mark the

[5] Basch 1972, 15-6.
[6] Pomey 1988, 400-5; Pomey 2004, 25-9.
[7] Hocker 2004a, 6.
[8] Hocker 2004a, 6-7. This seems to correlate to Pomey’s “structural concept”, which he considers as part of the overall concept of a vessel (Pomey 2004, 26).
[9] Hocker 2004a, 6.
[10] Rieth 2008; Pomey et al. 2012.

end of the transition;[11] some ships from the Tantura Lagoon in Israel, however, have recently been proposed as the earliest skeleton-based vessels, pushing this date back to the fifth or sixth century A.D.[12]

As will be shown, Yenikapı YK 11 is a ship that was built according to a strong shell-based philosophy while incorporating a combination of both shell-first and skeleton-first construction techniques. The shell-based tradition is most evident below the waterline, while above the waterline, skeleton-first techniques prevailed. Such a combination of traditions is mentioned by Hasslöf in reference to northern European shipbuilding and is evident in the construction of the seventh-century Yassıada ship.[13] YK 11's construction developed out of a Graeco-Roman tradition, the core elements of which may be clearly seen in the shell-based, fourth-century B.C. ship at Kyrenia off the north coast of Cyprus: a wineglass-shaped hull, edge-fastened planking, and a framing pattern of alternating floors and paired half-frames.[14] All three elements may be observed on YK 11 as well as on three other roughly contemporaneous shipwrecks that simultaneously reflect a gradual development toward skeleton-first construction. Two of these, Dramont E (early fifth century A.D.) and Saint-Gervais 2 (seventh century A.D.), were found off the southeast coast of France; the third, Yassıada 1 (early seventh century A.D.), was found on the west coast of Turkey.[15]

[11] Bass et al. 2004, 123, 157-61; Steffy 1994, 91.
[12] These include wreck A at Tantura, of late fifth- or early sixth-century date (Kahanov and Royal 1996, 23; Kahanov 2001, 268), and Dor 2001/1, of early sixth-century date (Mor and Kahanov 2006, 285-88).
[13] Hasslöf 1972, 57-60; Bass and van Doorninck 1982, 70-2, 82-3.
[14] Steffy 1985, 77-86.
[15] YK 23, a late eighth-century shipwreck excavated at Yenikapı, is likewise a further step in this progression, being edge-fastened with coaks rather than mortise-and-tenon joints. It has not yet been fully documented, however, and remains to be conserved and published.

These three ships, similar to YK 11 in construction technique as well as function (each being a small- to medium-sized merchantman), are described in more detail below. In addition to these, several wrecks at Tantura Lagoon, Israel, ranging in date from the fifth to ninth centuries A.D., offer valuable comparanda, and those that appear to belong to a similar tradition as YK 11 are also presented in more detail below. Table 5.1 provides a list of shipwrecks mentioned in the text, including their location and date.

Table 5.1. List of shipwrecks mentioned in Chapter V.

Shipwreck	**Location**	**Date (A.D. unless noted otherwise)**	**Works cited in Ch. V**
Anse des Laurons 2	Martigues, France	Third-fourth cent.	Gassend et al. 1984; Guibal and Pomey 1998
Bataiguier	Agay, France	Tenth cent.	Joncheray 2007
Bozburun	Southwest Turkey	Late ninth cent.	Harpster 2005a; Harpster 2005b; Harpster 2009
Dor 2001/1	Tantura Lagoon, Israel	Early sixth cent.	Kahanov and Mor 2009; Mor 2010; Mor and Kahanov 2006
Dor D	Tantura Lagoon, Israel	Fifth-sixth cent.	Kahanov and Royal 2001; Kingsley 2002; Royal and Kahanov 2005
Dramont E	Saint-Raphaël, France	425-455	Santamaria 1995
Dramont F	Saint-Raphaël, France	Late fourth cent.	Joncheray 1975a; Joncheray 1977
Fiumicino 1	Rome, Italy	Fourth-fifth cent.	Boetto 2000; Boetto 2008; Scrinari 1979
Grado	Gorizia, Italy	Second cent.	Beltrame and Gaddi 2007
Herculaneum	Naples, Italy	First cent.	Steffy 1999
Kinneret	Sea of Galilee, Israel	First cent.	Steffy 1987
Kyrenia	Cyprus	Fourth cent. B.C.	Steffy 1985
La Bourse	Marseilles, France	190-220	Gassend 1989; Gassend et al. 1982
Ma'agan Mikhael	Med. Coast, Israel	Fifth cent. B.C.	Hillman and Liphschitz 2004; Mor 2004
Madrague de Giens	Hyères, France	First cent. B.C.	Guibal and Pomey 1998; Pomey 1988; Pomey 1998
Pantano Longarini	Sicily	Early seventh cent.	Kampbell 2007; Throckmorton and Throckmorton 1973
Parco di Teodorico	Ravenna, Italy	Fifth cent.	Medas 2001; Medas 2003

Table 5.1. Continued.

Shipwreck	Location	Date (A.D. unless noted otherwise)	Works cited in Ch. V
Pisa D	Pisa, Italy	Late fifth cent.	Bruni 2000; Camilli and Setari 2005
Pointe de la Luque B	Marseilles, France	Third-fourth cent.	Clerc and Negrel 1973; Guibal and Pomey 1998; Negrel 1973
Port Berteau II	Charente-Maritime, France	600	Rieth 2000; Rieth et al. 2001
Port-Vendres 1	Port-Vendres, France	400	Liou 1974
Saint-Gervais 2	Fos-sur-Mer, France	Seventh cent.	Jézégou 1983; Jézégou 1989; Jézégou 1998
Saint-Gervais 3	Fos-sur-Mer, France	Second cent.	Liou et al. 1990
Serçe Limanı	Southwest Turkey	11^{th} cent.	Bass et al. 2004
Tantura A	Tantura Lagoon, Israel	Fifth-sixth cent.	Kahanov 2001; Kahanov and Breitstein 1995; Kahanov and Royal 1996; Kahanov et al. 2004; Wachsmann and Kahanov 1997
Tantura B	Tantura Lagoon, Israel	Early ninth cent.	Kahanov 2000
Tantura E	Tantura Lagoon, Israel	Seventh-ninth cent.	Israeli and Kahanov 2012; Pomey et al. 2012
Tantura F	Tantura Lagoon, Israel	Eighth cent.	Barkai 2009; Barkai 2010; Barkai and Kahanov 2007
Yassıada 1	Bodrum, Turkey	Seventh cent.	Bass and van Doorninck 1982; van Doorninck 1967
Yassıada 2	Bodrum, Turkey	Late fourth or early fifth cent.	Bass and van Doorninck 1971; van Doorninck 1976
Yenikapı YK 1	Istanbul, Turkey	Late tenth cent.	Pulak 2007a
Yenikapı YK 3	Istanbul, Turkey	10^{th}-11^{th} cent.	Kocabaş 2008
Yenikapı YK 5	Istanbul, Turkey	Late tenth cent.	Pulak 2007a
Yenikapı YK 6	Istanbul, Turkey	10^{th}-11^{th} cent.	Kocabaş 2008
Yenikapı YK 7	Istanbul, Turkey	10^{th}-11^{th} cent.	Kocabaş 2008
Yenikapı YK 9	Istanbul, Turkey	10^{th}-11^{th} cent.	Kocabaş 2008
Yenikapı YK 12	Istanbul, Turkey	Ninth-tenth cent.	Çelik 2007; Kocabaş 2008; Özsait Kocabaş 2012
Yenikapı YK 14	Istanbul, Turkey	Late ninth cent.	Ingram and Jones 2011; Jones 2010
Yenikapı YK 15	Istanbul, Turkey	Eighth-ninth cent.	Kocabaş 2008
Yenikapı YK 17	Istanbul, Turkey	Eighth-ninth cent.	Kocabaş 2008; Türkmenoğlu 2012
Yenikapı YK 23	Istanbul, Turkey	Late eighth cent.	Ingram and Jones 2011
Yenikapı YK 24	Istanbul, Turkey	Late tenth cent.	Ingram and Jones 2011

The Early Fifth-Century Shipwreck at Cap Dramont, France (Dramont E)

Wreck E found off Cap Dramont near Saint-Raphaël, France, was first identified in 1965 and excavated between 1981 and 1991.[16] A *terminus post quem* of A.D. 425 is based on associated coins and other artifacts.[17] The wineglass-shaped hull as reconstructed is 14.1 m in length and 6.15 m in beam, with a cargo capacity of approximately 42 tons.[18] In addition to the underwater study, sections of the hull were cut out and studied in a laboratory in order to better understand aspects of the ship's construction.[19]

Most of the ship's bottom was preserved as well as a large part of the starboard side. The flat portion of the keel, preserved in its entirety, was joined to the sternpost and to a transitional piece at the bow with keyed hook scarfs.[20] Along the flat portion of the ship's keel, the inner face edges are chamfered to receive the garboard planks; toward the extremities, this chamfer transitions into a rabbet, reflecting the steeper angling of planks joining the keel.

The pine planking of Dramont E was edge-fastened with mortise-and-tenon joints spaced 10-14 cm.[21] These joints were usually locked in place with small pegs, but this was not consistent; on several joints, the lower portion of the tenon, fitting more snugly in its mortise, was pegged in place while the upper portion, in a wider mortise, was not. The thick garboards were joined to the ship's keel with larger mortise-and-

[16] Santamaria 1995, 11, 21-5. A detailed report on the wreck was published by Claude Santamaria in 1995.
[17] Santamaria 1995, 116.
[18] Poveda 2012, 332; Santamaria 1995, 175-78.
[19] Santamaria 1995, 142.
[20] Santamaria 1995, 133-39.
[21] Santamaria 1995, 143-44, 181.

tenon joints spaced 26-31 cm apart; twists and bends in the garboard were achieved with the aid of char-bending.[22] Planks were joined with diagonal scarfs, locked into place with pegged mortise-and-tenon joints as well as transverse iron nails.[23] Two large, pine half-log wales were preserved on the starboard side; unlike those of YK 11, the Dramont E wales were edge-fastened to the planks, again with pegged mortise-and-tenon joints.[24] Despite the consistent edge fastening of planking and wales, caulking was observed within several plank seams; Santamaria notes that this helped compensate for slight irregularities along these seams.[25]

The ship's framing followed an alternating pattern of floors and paired half-frames; at the very stern, two pairs of half-frames were used instead, reflecting the steep angling of frames at the ship's extremities.[26] The use of compass timbers for the ship's framing resulted in some areas where the frame did not exactly fit the shape of the planking; to compensate for such gaps, small shims were sometimes inserted between framing and planking. Futtocks were usually adjacent to but not attached to floors and half-frames; in one exceptional case, a futtock was scarfed to a floor.[27] Only five floors were attached to the ship's keel, with large iron bolts.[28]

The Dramont E stringers, like those of YK 11, were lightly fastened to the ship's framing, attached to every third or fourth frame with iron nails.[29] A pair of central

[22] Santamaria 1995, 143.
[23] Santamaria 1995, 146.
[24] Santamaria 1995, 148, 187.
[25] Santamaria 1995, 149-50.
[26] Santamaria 1995, 150-60.
[27] Santamaria 1995, 154.
[28] Santamaria 1995, 154-60.
[29] Santamaria 1995, 160-61.

stringers ran down the center of the ship and formed a foundation for the ship's substantial mast step; these central stringers, slightly thicker than the other stringers, were attached to every second or third frame with iron nails. Nineteen strakes of stringers were preserved on the starboard side, with some strakes consisting of multiple stringers scarfed together. A large portion of the ship's mast step and the heel of the mast were also preserved.[30]

In his detailed study, Santamaria notes that nearly all of the pegs that locked the mortise-and-tenon joints were driven from the interior; exceptions were only noted at the extremities where the steep angle of the planking prevented this.[31] He found that this was also the case at the location of frames that had been bolted to the keel, thus confirming that these frames could not have served as control frames, but were simply bolted to the keel to reinforce the ship's structure.[32] Thus, Santamaria concludes that ship Dramont E was built according to a shell-based tradition, the frames being inserted after the planking had been assembled. Other features that support this conclusion are the use of edge fasteners throughout the planking and wales, the attachment of garboards to the keel, the use of diagonal scarfs, the lack of attachment between elements of framing, and the use of char-bending to achieve curves in the planking.[33]

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[30] Santamaria 1995, 161-71.
[31] Santamaria 1995, 143.
[32] Santamaria 1995, 179.
[33] Santamaria 1995, 179-80.

The Seventh-Century Shipwreck at Saint-Gervais, Fos-sur-Mer, France (Wreck 2)

Wreck 2 at Saint-Gervais, France, at the mouth of the Rhône River, has been dated to the seventh century.[34] The ship is estimated to have been 15-18 m in length and 6 m in beam; the depth of the hold was 2 m and it had a 40-50 ton capacity.[35] A large part of the bottom of this ship was preserved; part of the port side was also preserved, having broken away from the ship at the turn of the bilge.[36] Only a very small portion of the ship's keel was preserved, in the stern, where a sternson was bolted to it through floors and one half-frame.[37] Garboard planks were fastened to the keel with iron nails; the average spacing between these nails, 15 cm, is approximately half that of the 29 cm-average spacing on the YK 11 keel.[38]

This ship's substantial framing followed the traditional pattern of alternating floors and paired half-frames.[39] On three of the preserved floors, a separate chock of wood was added to the frame to compensate for a gap between the floor and keel, not unlike the chocks seen on the fourth-century B.C. Kyrenia ship.[40] Two of the pairs of half-frames were held together with a transverse iron fastener.[41] The original framing pattern was very consistent, with an average frame spacing of 25 cm. However, the framing was "doubled-up" with six frame-like timbers that provided additional support

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[34] Jézégou 1983, 5-6; Jézégou 1989, 139; Jézégou 1998, 350. The ship was discovered in 1978 in the course of construction work near Fos-sur-Mer, France. A salvage excavation was carried out by Marie-Pierre Jézégou of DRASM (Direction des Recherches Archéologiques Sous-marines) in the summer of 1978 and continued to some extent in December 1979 (Jézégou 1983, 14-5, 32).
[35] Jézégou 1983, 55-9; Jézégou 1989, 139.
[36] Jézégou 1983, 26-7.
[37] Jézégou 1983, 31-3; Jézégou 1989, 139.
[38] Jézégou 1983, 46.
[39] Jézégou 1983, 33-6; Jézégou 1989, 139.
[40] Jézégou 1983, 33-5; Steffy 1985, 84-5, 93.
[41] Jézégou 1983, 156; Jézégou 1989, 140. It is unclear whether the fastener is a nail or a bolt. Either way, a single fastener would be a weak method of maintaining the frames at the proper attitude.

between frame stations, perhaps after the original construction; these did not extend to the ship's keel.[42]

At the stern, the keel, five frames (four of them floors) and the sternson were fastened together with large bolts. Elsewhere in the hull, most of the floors and half-frames were attached to the keel with iron fasteners.[43] Jézégou has suggested that, for the area covered by the stemson (which was not preserved), some of the timbers were also fastened together with bolts. The sternson and the ship's floors at the location of both stemson and sternson were notched, locking these timbers in place longitudinally and laterally.[44]

The ship's planking was 2.5-3.0 cm thick and was fastened to framing with a combination of treenails and iron nails, the latter being more prevalent below the waterline.[45] The planking of this ship is noteworthy for its paucity of mortise-and-tenon joints; according to the publications, these unpegged joints are sparse, irregularly spaced and include "blind" mortises with no mortise on the facing plank.[46] The Saint-Gervais 2 tenons were 8.8 cm in length and 2.8 cm in width, just slightly larger than those of YK 11.[47] Two wales reinforced the side of the hull, above the turn of the bilge, but were not

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[42] Jézégou 1983, 33, 61.
[43] Jézégou 1983, 46; Jézégou 1989, 140. Jézégou (2012, pers. comm.) has indicated that these were likely nails rather than bolts.
[44] Jézégou 1983, 38-9, 46.
[45] Jézégou 1983, 36-7, 48; Jézégou 1989, 139.
[46] Jézégou 1983, 46-7; Jézégou 1989, 140.
[47] Pomey et al. 2012, 265. The 10 x 6.5 x 0.6 cm dimensions provided by Jézégou (1983, 47) likely refer to the size of the mortises rather than the tenons.

integrated into the ship's planking; rather, they were treenailed and nailed to the ship's framing through the exterior planking.[48]

Finally, the Saint-Gervais 2 hull exhibited a traditional mast-step assembly, in which a mast step (partially preserved) rested on a pair of central stringers.[49] These central stringers were nearly twice as large in molded dimension as sided; therefore, they would have added significant longitudinal strength to the hull. However, this orientation affected their stability, necessitating a small wooden brace between the two timbers, at the location of the mast step.[50]

In her analysis, Jézégou suggests that this ship represents an early form of skeleton-based construction, in which two-thirds of the frames were erected before any of the planks were installed.[51] This interpretation is based primarily on the paucity of edge fasteners on planking and the attachment of most of the frames to the ship's keel, but it also takes into account the size of the framing relative to the ship, the size and nature of the sternson in relation to the ship's keel, and the presence of shims filling gaps between planking and framing in several areas.[52] Many similar details, however, may also be observed on the YK 11 hull, which, as will be shown, was built with a combination of techniques but had a strong shell-based tradition as its foundation.

[48] Jézégou 1983, 48-9; Jézégou 1989, 141.
[49] Jézégou 1983, 38-9.
[50] Jézégou 1983, 50.
[51] Jézégou 1983, 159-61; Jézégou 1989, 141-43. This claim of skeleton-based construction on the Saint-Gervais 2 ship continues to be repeated by scholars to the present, although with some reservation (Pomey 2004, 33; Pomey et al. 2012, 264-66).
[52] Jézégou 1983, 119-21.

The Seventh-Century Shipwreck at Yassıada, Turkey (Wreck 1)

The seventh-century Yassıada shipwreck (Yassıada 1) was excavated between 1961 and 1964.[53] The ship sank with its cargo of wine some time after A.D. 625.[54] Another shipwreck located in close proximity was excavated some years later and dates to the late fourth or early fifth century A.D. (Yassıada 2).[55] The seventh-century ship is estimated to have been 20.5 m in length and 5.2 m in beam; the depth of hold was 2.25 m, and it had a carrying capacity of 50-60 tons.[56] A large part of the port side of the ship was preserved, including part of the ship's sternpost; nothing remained of the bow.[57] The ship had become flattened out along the seabed, and only timbers that were supported by and buried in sand were preserved.

Like the YK 11 ship, the Yassıada 1 hull was held together entirely with iron nails, iron bolts, and small, unpegged mortise-and-tenon joints.[58] The ship's straight keel, much larger than that of YK 11 but of very similar proportions and form, was attached to the sternpost with a bolted keyed hook scarf.[59] The garboard planks were

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[53] Bass and van Doorninck 1982, 2-5; Throckmorton 1964, 13-71. This ship is one of several wrecks discovered by Peter Throckmorton with the aid of Turkish sponge divers in the late 1950s; the wreck was found in the Aegean, just west of the Bodrum peninsula. The ship was excavated under the directorship of George F. Bass for the University Museum of the University of Pennsylvania; Frederick H. van Doorninck, Jr., assistant director, studied the hull remains for his Ph.D. dissertation at the University of Pennsylvania (Bass and van Doorninck 1982, 8-31; van Doorninck 1967).
[54] Bass and van Doorninck 1982, 145-46, 163-65.
[55] Bass and van Doorninck 1971; van Doorninck 1976; Hocker 2004a, 7.
[56] Bass and van Doorninck 1982, 84-6.
[57] Bass and van Doorninck 1982, 32-4.
[58] Bass and van Doorninck 1982, 55.
[59] Bass and van Doorninck 1982, 58.

attached to the keel primarily with iron nails, although one mortise-and-tenon joint was noted between the keel and garboard.[60]

The thin pine planking, on average 3.5 cm thick, was edge-fastened with small, unpegged, widely-spaced mortise-and-tenon joints up to the ship's waterline.[61] These joints were spaced 35-50 cm toward the stern, but were spaced farther apart, up to 90 cm, toward the center of the ship.[62] Planks were joined with diagonal scarfs, at times with a mortise-and-tenon joint; other scarf tips were fastened to adjacent planks with transverse iron nails.[63] On the side of the hull, large, half-log wales were integrated into the planking but were not edge-fastened.[64] These wales were first nailed to the framing then bolted in place with the framing and clamp strakes, with bolts every fourth or fifth frame.[65]

The framing of the ship was very poorly preserved; the several preserved fragments did not include any frame ends.[66] However, extensive score marks as well as fastening patterns on planking indicate the locations of frames, and the preserved portion of the keel reveals that approximately every fourth frame was bolted to the keel (a total of five floors).[67] Most other frames were fastened to the keel with a long iron nail. Based

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[60] Bass and van Doorninck 1982, 59; van Doorninck 1967, 88 note 5. The spacing of the nails, 30 cm, is very close to the spacing of the rabbet nails on the YK 11 garboards.
[61] Bass and van Doorninck 1982, 55, 59; van Doorninck 1967, 90. Mortise size was 5 cm wide, 3.5 cm deep, and 0.5 cm thick, very close to the size of the YK 11 mortises. The Yassıada tenons were less than 3 cm in width.
[62] Bass and van Doorninck 1982, 55.
[63] Bass and van Doorninck 1982, 59.
[64] Bass and van Doorninck 1982, 61.
[65] Bass and van Doorninck 1982, 61.
[66] Bass and van Doorninck 1982, 59.
[67] Bass and van Doorninck 1982, 60.

on the construction of a physical model, a framing pattern that includes short floors, long floors, and half-frames has been suggested.[68]

No trace of a keelson was preserved but its presence has been assumed.[69] Several ceiling timbers were identified, consisting of rough half-logs.[70] Based on its location, the preserved fragment of a large through-beam is likely the mast-partner beam, and two other proposed through-beam locations, toward the stern, probably supported the ship's quarter rudder.[71] Mortises cut at certain locations on the ship's ceiling probably held both upright and diagonal stanchions to support deck beams; fragments of timbers notched to fit over the ceiling align with these mortises and are likely the remains of hanging knees that also supported the deck beams.[72]

Steffy states that the Yassıada 1 ship was built according to a strong shell-based tradition, but one which was combined with skeleton-first techniques above the waterline;[73] a very similar technique was used for YK 11. According to Steffy, the ship's planking below the waterline was assembled before any frames were installed.[74] He bases this sequence on the presence of diagonal scarfs, the avoidance of stealers, and the use of mortise-and-tenon joints along plank edges. The frequency of score marks at frame edges is also cited as an indication of shell-based construction below the waterline.

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[68] Bass and van Doorninck 1982, 73.
[69] Bass and van Doorninck 1982, 60, 77.
[70] Bass and van Doorninck 1982, 60.
[71] Bass and van Doorninck 1982, 52.
[72] Bass and van Doorninck 1982, 62.
[73] Bass and van Doorninck 1982, 70-2, 82-3.
[74] Bass and van Doorninck 1982, 70-1.

Shipwrecks of the Tantura Lagoon, Israel, Fifth to Eighth Centuries

At the eastern end of the Mediterranean Sea, several shipwrecks found in Israel's Tantura Lagoon, 30 km south of Haifa, have provided some significant contributions to the study of transitional shipbuilding and seem to indicate an early abandonment of the use of edge fasteners.[75] Three of these shipwrecks, Dor D, Tantura A, and Tantura F, exhibit some noteworthy similarities to the YK 11 hull. Dissimilar to YK 11, Dor 2001/1 (early sixth century) and Tantura E (seventh to ninth century) are characterized by a flat bottom and hard chine.[76] Rieth has argued that such angular, flat-bottomed ships, the first to truly exhibit a skeleton-based approach in construction, reflect a development from a riverine tradition.[77] Nevertheless, the mast-step assembly of Dor 2001/1 is similar to that of YK 11.[78]

The Tantura hull most similar to YK 11 in construction, Dor D, is perhaps the most poorly preserved. Of probable mid-fifth- to mid-sixth-century date, it is a fragmentary group of 14 hull planks; framing or keel timbers were not preserved.[79] These planks, like those of YK 11, were edge-fastened with unpegged mortise-and-tenon joints in which the tenons are much narrower than the mortises.[80] Furthermore, the shipwrights used char-bending to achieve curves in the ship's planking toward the

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[75] Kahanov 2003, 49.
[76] Both ships exhibited framing patterns similar to that of YK 11. The skeleton-based construction of Dor 2001/1 has been discussed in detail in Mor and Kahanov 2006, Kahanov and Mor 2009, and Mor 2010; in order to support the claim of a skeleton-based construction, a two-meter section of the hull was cut out and analyzed in 2005 (Kahanov and Mor 2009, 22). Tantura E, on which a bulkhead support was preserved, was excavated in 2006-2008 and has not yet been published in detail (Israeli and Kahanov 2012, 43-6; Pomey et al. 2012, 260-62, 270-71).
[77] Rieth 2008, 66-7.
[78] Mor and Kahanov 2006, 279-81.
[79] Kahanov and Royal 2001, 257; Royal and Kahanov 2005, 311.
[80] Kahanov and Royal 2001, 262 table 4; Kingsley 2002, 19.

extremities.[81] Diagonal scarfs and score marks strongly suggest a shell-based building tradition.[82]

The Tantura A shipwreck has been dated to the late fifth or early sixth century based on radiocarbon dating and cargo analysis.[83] This is the wreck of a small merchantman with an estimated original length of around 12 m and a beam of 4 m.[84] Thin pine planking, butt-jointed at frame locations, was charred toward the extremities, reflecting a use of char-bending in obtaining the desired plank shape.[85] Although the planking was not disassembled, the archaeologists could not find any mortise-and-tenon joints along the exposed plank edges.[86] The ship's framing, although of an unclear pattern, was attached to planking and the keel with iron nails.[87] Based on the use of iron nails, butt joints at plank ends, the presence of caulking along plank seams, and the lack of mortise-and-tenon joints along exposed plank edges, Kahanov and Royal have identified Tantura A as one of the earliest examples of skeleton-based hull construction in the Mediterranean.[88] There were, however, multiple repairs noted to the ship's planking.[89]

Finally, Tantura F, dated to the eighth century, was estimated to have been 15 m in length.[90] This ship, despite a structure very similar to that of YK 11, is lacking in edge

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[81] Kingsley 2002, 8 fig. 15, 19.
[82] Kahanov and Royal 2001, 258, 261 table 3.
[83] Kahanov et al. 2004, 113; Pomey et al. 2012, 259.
[84] Kahanov and Royal 1996, 22-3.
[85] Kahanov and Royal 1996, 22; Wachsmann and Kahanov 1997, 6; Kahanov 2001, 267-68; Kahanov et al. 2004, 117.
[86] Wachsmann and Kahanov 1997, 5.
[87] Kahanov and Breitstein 1995, 10; Kahanov and Royal 1996, 22; Kahanov 2001, 267-68.
[88] Kahanov and Royal 1996, 23; Kahanov 2001, 268.
[89] Kahanov and Royal 1996, 22; Kahanov et al. 2004, 117-18.
[90] Barkai and Kahanov 2007, 21; Barkai 2009, 25.

fasteners and exhibits some characteristics of a skeleton-based construction. The ship's keel, slightly smaller than that of YK 11, was also joined to posts or transitional pieces with keyed hook scarfs.[91] Most (but not all) of the frames, following an alternating pattern of floors and paired half-frames, were fastened to the keel with iron nails.[92] The Tantura F half-frames extended across the width of the keel, in some cases just beyond; some half-frames were scarfed, but not fastened, to each other.[93] Futtocks, however, were fastened to floors with one or two transverse iron nails.[94] Although the thin planks of *Pinus brutia*, 2.5 cm thick, do not appear to have any edge fasteners, there were traces of "some kind of fire treatment" (char-bending?) observed.[95] The planks were fastened to framing with iron nails and usually terminated in butt joints at frame locations, although one diagonal plank scarf was reported.[96] Similar to YK 11, the ship's internal longitudinal structure and mast-step assembly include a substantial stemson and sternson, a pair of central stringers down the center, and a mast step notched over frames but not nailed in place.[97] Although the fact that some frames are not attached to the keel and the presence of a diagonal scarf argue against Barkai's claim that this is a skeleton-based construction,[98] the scarfing of some half-frames over the keel and the nailing of futtocks to floors support this claim.

[91] Average dimensions for the keel are provided as 9.5 cm sided and 16 cm molded (Barkai and Kahanov 2007, 22-3).
[92] Barkai and Kahanov 2007, 23; Barkai 2010, 99, 104 fig. 3. Eight of the frames that crossed the keel were not fastened to it.
[93] Barkai 2009, 25-6, fig. 1; Barkai 2010, 99.
[94] Barkai 2009, 26.
[95] Barkai and Kahanov 2007, 24.
[96] Barkai 2010, 99.
[97] Barkai and Kahanov 2007, 24-6.
[98] Barkai 2009, 26-7.

Other Shipwrecks

Many other shipwrecks of third- to ninth-century date exhibit construction detail that has aided in the interpretation and reconstruction of the YK 11 hull. Several of these wrecks, in addition to the Saint-Gervais 2 and Dramont E shipwrecks, have been found off France's Mediterranean coast. The third- or fourth-century Anse des Laurons 2 shipwreck is notable for the preservation of part of its deck and other elements of the ship's upper works.[99] Its large mast step, notched over frames, was recessed to fit over a pair of central stringers.[100] Wreck B at Pointe de la Luque, also of third- or fourth-century date, retained a sternson, bolted through frames to the keel, and a mast step resting on a pair of central stringers.[101] The planking was edge-fastened with pegged mortise-and-tenon joints; the garboard was joined to the keel in a similar manner, but, toward the extremities, the mortise-and-tenon joints were abandoned in favor of iron nails driven through the garboard edge into the keel.[102]

Wreck F at Cap Dramont sank in the late fourth century; this small vessel, up to 12 m in length, had been carrying a cargo of pine resin in amphoras.[103] Although locked in place with pegs, the planking's tenons were smaller than their mortises, and the joints were relatively widely spaced.[104] Joncheray also notes the presence of mortises lacking a tenon and mentions one plank that had no mortises, both of which might indicate

[99] Gassend et al. 1984; Guibal and Pomey 1998, 160-61.
[100] Gassend et al. 1984, 100.
[101] Clerc and Negrel 1973, 66-7; Negrel 1973, 62-3; Guibal and Pomey 1998, 160-61.
[102] Negrel 1973, 60.
[103] Joncheray 1975a; Joncheray 1977.
[104] Joncheray 1975a, 123; Joncheray 1977, 5-6.

repairs.[105] Part of the hull of wreck 1 at Port-Vendres, France, dated to around A.D. 400, was raised to the surface for study during a salvage excavation in 1974.[106] This ship had been in use for the better part of a century by the time it sank, and numerous repairs were noted in its hull.[107] Although the ship's planks were edge-fastened with pegged mortise-and-tenon joints, the presence of caulking was noted along plank edges.[108]

The Port Berteau II ship, dated to A.D. 600, is that of a riverine vessel that had capsized on the Charente River, near the Atlantic coast of France; as a result, only portions of the hull above the waterline were preserved.[109] Although its form and suggested building tradition are very different from those of YK 11, its upper works, including through-beams, deck beams, and fore and aft decks, help to inform the reconstruction of YK 11.[110]

Several ships of comparable date to YK 11 have been excavated in Italy. Fiumicino 1, from Rome's *Portus Claudius* and of probable late fourth- or early fifth-century date, was a towed boat for use on the Tiber River.[111] This ship was built with mortise-and-tenon joints, most of which were locked in place with pegs, but many of which were pegged on one side only (as on Dramont E), or were lacking pegs on both sides.[112] Wales were integrated into and edge-fastened to planking, and many frames were not attached to the keel, reflecting a shell-based tradition despite weakened edge

[105] Joncheray 1975a, 123; Joncheray 1977, 6.
[106] Liou 1974, 414-7, 428.
[107] Liou 1974, 427-28.
[108] Liou 1974, 422.
[109] Rieth et al. 2001, 42-5.
[110] Rieth 2000, 227-28; Rieth et al. 2001, 52-61, 66-9.
[111] Boetto 2000, 99, 101-2; Boetto 2008, 51-8; Scrinari 1979, 37-9.
[112] Boetto 2000, 100; Boetto 2008, 39-40.

fasteners. As with YK 11, the construction is obscured by the presence of numerous repairs.[113]

The small, fifth-century Parco di Teodorico shipwreck, found near Ravenna, was built using unpegged mortise-and-tenon joints; although lacking the wineglass form, this ship may nevertheless provide an interesting parallel to YK 11 once it is fully published.[114] Also awaiting full publication, late fifth-century Wreck D at Pisa, having capsized upon sinking, provides a rare glimpse at the upper portions of a merchant vessel.[115] Although its method of construction remains unclear, the ship's remains include fore and aft decks with hatchways and a row of heavy through-beams between half-log wales. Finally, the early seventh-century shipwreck at Pantano Longarini, Sicily, although badly damaged during a drainage project, comprises the stern end of a large coastal barge, perhaps originally over 30 m in length.[116] Like YK 11, the ship found at Pantano Longarini had a framing pattern of alternating floors and paired half-frames, planks edge-fastened with unpegged mortise-and-tenon joints, through-beams, and half-log wales.[117]

In addition to the seventh-century shipwreck at Yassıada, several ships excavated and studied in Turkey by INA archaeologists illustrate the gradual change in Mediterranean shipbuilding that occurred in the first millennium A.D. The fourth- or fifth-century Yassıada ship (wreck 2), with a wineglass-shaped hull and planking edge-

[113] Boetto 2000, 101; Boetto 2008, 47-8.
[114] Medas 2001; Medas 2003.
[115] Bruni 2000, 48-51; Camilli and Setari 2005, 76-7.
[116] Throckmorton and Throckmorton 1973; Kampbell 2007, 65-7.
[117] Throckmorton and Throckmorton 1973, 244, 263. According to the authors, the structure of through-beams and wales acted as a box girder and strengthened the hull longitudinally.

fastened with pegged mortise-and-tenon joints, reflects the early stages of this transition: only a few frames are fastened to the keel, and the tenons, although pegged in place, are both shorter and narrower than their mortises.[118] The midship frame, installed after only five strakes of planking, seems to have acted as an "active" or control frame to some extent.[119] As on the Pointe de la Luque B ship, the garboards, toward the extremities, were attached to the ship's spine with iron nails rather than mortise-and-tenon joints.[120]

A late eighth-century ship analyzed by INA at Yenikapı, YK 23, exhibits a wineglass-shaped hull and a framing pattern of alternating floors and paired half-frames, not unlike YK 11; however, YK 23 was built of oak, with planks edge-joined with coaks rather than mortise-and-tenon joints.[121] The late ninth-century Bozburun ship, which also had a wineglass-shaped hull and oak planking edge-joined with coaks, exhibited a framing pattern of L-shaped floors with one long and one short arm that alternated in orientation.[122] Its mast step, like that of YK 11, rested on a pair of central stringers.[123] Harpster has argued that several frames, including the midship and tail frames, were erected prior to the installation of planking.[124] Several of the shipwrecks excavated at Yenikapı and studied by INA, YK 1, YK 5, YK 14, and YK 24, also had oak planking

[118] van Doorninck 1976, 122, 124.
[119] van Doorninck 1976, 126-27.
[120] Bass and van Doorninck 1971, 30; van Doorninck 1976, 120. Along the flat portion of the keel, the garboards were attached with pegged mortise-and-tenon joints.
[121] These details were observed during the winter-spring 2008 study of the wreck during its removal from the construction site; a detailed post-excavation analysis of this ship has not yet been completed.
[122] Harpster 2005a, 7, 219-36, 426-27; Harpster 2005b, 89-91.
[123] Harpster 2005a, 349-50, 444.
[124] Harpster 2009, 5-14.

edge-joined with coaks and L-shaped floors that alternated in orientation, but with a flat-floored, rather than wineglass-shaped, hull.[125]

Finally, the early 11th-century shipwreck excavated by INA and Texas A&M University at Serçe Limanı, Turkey, has generally been regarded as the final stage in the transition from shell-based to skeleton-based ship construction in the Mediterranean, although this is now being challenged by the finds at Tantura Lagoon. This ship, with a boxy hull and L-shaped frames, lacked edge fasteners.[126] Based on Steffy's analysis, several of the frames, of predetermined shape, were erected prior to any planking and therefore served as "active" or control frames.[127]

CONSTRUCTION OF YK 11

A synthesis of the timber catalog presented in Chapter IV and a summary of the ship's construction and other features facilitate the comparison between this ship and other late Roman and Byzantine vessels. A brief summary of the YK 11 catalog is presented in table 5.2. As will be demonstrated below, ship YK 11 was primarily a shell-based hull built with a combination of shell-first and skeleton-first techniques.

An Overview of YK 11

Although this was a small ship, just over 11 m in length, the paucity of substantial, interlocking fasteners is noteworthy. The ship was fastened with iron nails of varying size and, below the waterline, with small, thin, unpegged tenons. Iron bolts were

[125] Liphschitz and Pulak 2009, 166-68; Pulak 2007a, 208-13; Ingram and Jones 2011, 14. The study of one of these, YK 14, forms the basis of Michael Jones' forthcoming dissertation.
[126] Bass et al. 2004, 86, 93, 123, 153, 167.
[127] Bass et al. 2004, 157-61.

only found in four locations on the extant hull, all of which were along the keel of the ship. No bolts were found on the wales or in the central, flat portion of the keel, between FR 9 and FR 21. At nails, pilot holes were drilled in many of the timbers on both the interior and exterior of the hull to counter the tendency of the iron nails to bend upon insertion. The shipwrights of YK 11 also wound grass-like fibers around the shanks of the nails driven from the hull exterior; these fibers acted as a seal to prevent leakage.[128]

Table 5.2. Summary of the YK 11 Catalog.

Keel	Tripartite, of *Quercus cerris*; sided 9.3-12.2 cm, molded 16.0-22.2 cm.
Planking	Primarily of *Pinus brutia* with two small replacement pieces of *Cupressus sempervirens*; average thickness 2.0-2.5 cm; edge-joined with unpegged oak tenons below the waterline; 39 of 58 planks were later repairs or replacements; repair planks lack edge fasteners; two half-log pine wales preserved on port side, 5-8 cm thick.
Frames	Primarily of *Pinus brutia* (70%), also of *Acer pseudoplatanus, Fraxinus excelsior*, *Pinus nigra, Quercus cerris, Tamarix* (x5), and *Ulmus campestris*; framing pattern of alternating floors and paired half-frames, with unconnected futtocks extending up the sides; all framing attached to keel with iron nails or iron bolts; average room and space, ca. 31 cm; floors 7.4-9.9 cm sided, 7.4-12.3 cm molded; half-frames 7.3-9.1 cm sided, 7.1-9.9 cm molded; futtocks 6.5-9.9 cm sided, 6.3-12.1 cm molded; frames attached to planks with short iron nails.
Interior scantlings	Stemson of *Ulmus campestris*, nailed to framing; sternson of *Pinus brutia,* bolted through frames to keel; ten stringers in seven strakes, of *Pinus brutia* and *Cupressus sempervirens*, average thickness 2.9-4.7 cm; ten common ceiling planks, of *Cupressus sempervirens, Acer pseudoplatanus, Pinus brutia*, *Quercus cerris*, and *Fagus orientalis*, average thickness 2.5 cm; two sills of *Pinus brutia*, blocking open spaces between frames; six stanchion blocks in three pairs along ship's centerline, of *Cupressus sempervirens, Pinus brutia,* and *Pinus nigra*; bulkhead partition consisting of a slotted frame, attached to sternson and ceiling, with four planks, all elements of *Pinus brutia*, with one plank of *Fraxinus excelsior*; through-beam of *Cupressus sempervirens*, found loose, notched for and nailed to wales.

[128] This was also noted on some of the nails of the Serçe Limanı shipwreck (Bass et al. 2004, 110).

Based on the strength of the joints and the nature of the timbers, the ship's spine—the keel timbers, stem, and sternpost—were the primary elements of longitudinal stiffness in the YK 11 hull. The extant keel timbers, all of oak, were probably the largest timbers of YK 11. The keel is larger in molded dimension than sided, with an average size of 12 cm sided by 20 cm molded in the flat central portion (Keel 2).

The three parts of the keel and the sternpost were locked together with intricate keyed hook scarfs, 24.3-26.5 cm in length, held in place with a wooden key. Iron bolts, probably forelock bolts, were added to reinforce these scarfs and lock them in place with the frames, stemson, and sternson; these bolts were not strictly necessary to hold the scarfs together. Combining the molded dimensions of the keel, frames, and sternson, bolts were at least 39-44 cm in length. No part of the sternpost was preserved, but a keyed hook scarf would have joined this timber to the keel based on the aft end of Keel 1, a short, slightly-curving transitional timber. Keel 3 appears to be a longer transitional timber between the flat part of the keel and the stem; how it was scarfed to the stem remains unclear, but a large drilled hole, presumably for a bolt, at its broken and eroded forward end may have been part of this joint.

In addition to the keel timbers, a stemson (UM 47) and sternson (KS 1) provided internal support at the joints between the various parts of the ship's spine. Both were notched to fit over framing and fastened to the frames and keel at the aforementioned keyed hook scarfs; the primary fasteners (the bolts) were lightly reinforced with short nails driven from the interior that did not extend to the outer face of the frames. The larger of the two, sternson KS 1, itself a recycled pine keel, is just slightly smaller in dimension than the YK 11 keel timbers; it was notched over frames from FR 2 to FR 9, thus providing additional support for the two aft hook scarfs along the ship's spine. UM 47, a much smaller elm timber, was also notched over frames but only covered the scarf between Keel 2 and Keel 3. The location and nature of the stemson and sternson confirm that these were additional support for the ship's spine rather than themselves a primary focus of longitudinal stiffness, as seems to be the case on ships in which the stemson, sternson, or keelson is larger in section than the ship's spine, as on the Serçe Limanı and Saint-Gervais 2 ships.[129]

The ship's thin planking consisted primarily of sawn boards of Turkish pine, on average 2.0-2.5 cm in thickness. Grass-like caulking and pitch along plank edges ensured watertightness and compensated for small gaps along seam edges.[130] Although the presence of caulking is often used to claim a skeleton-based construction, it has notably been found on other edge-fastened, shell-based vessels, including the Port-Vendres 1 (A.D. 400) and Dramont E (early fifth century) ships.[131] With only rare

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[129] For Serçe Limanı, Bass et al. 2004, 164; for Saint-Gervais 2, Jézégou 1983, 75. Although smaller than the ship's keel, stemson or sternson timbers on the Pointe de la Luque B (Negrel 1973, 63), Fiumicino 1 (Boetto 2008, 45-6), and Port-Vendres 1 (Liou 1974, 426-27) shipwrecks were also bolted to the ship's keel. Stemson or sternson timbers on Dor 2001/1 (Mor and Kahanov 2006, 275, 279-80) and Tantura F (Barkai and Kahanov 2007, 22-4) were larger than the keel but were not securely bolted to it.

[130] In some areas, this waterproofing material was added to the seam before it was assembled, and may therefore be described as applied rather than driven caulking. The grassy material appears to be the same, though, and the term caulking is here used of the waterproofing material on the edge-fastened edges as well as on those edges lacking mortise-and-tenon joints.

[131] Liou 1974, 422, fig. 7; Santamaria 1995, 149-50. According to Santamaria, the caulking on the Dramont E ship also helped compensate for irregularities along plank seams. In contrast, Pomey et al. (2012, 297) claim that caulking indicates a skeleton-based construction. Steffy notes that "Mortise-and-tenon construction did not permit driven caulking…" (Bass and van Doorninck 1982, 72). However, there is evidence on the late ninth-century shipwreck YK 14 from Yenikapı that caulking was driven along edge-fastened edges (Jones 2010). It is also noteworthy that, although caulking was not observed, a caulking iron was found on the seventh-century Yassıada ship (Bass and van Doorninck 1982, 248-49). Given this evidence, and the presence of caulking on many other edge-fastened ships at Yenikapı, the presence of caulking as proof of a skeleton-based construction should be reconsidered.

exception, the plainsawn planks of YK 11 were not adzed to form.[132] Yet the planks were altered to achieve, to some extent, the desired form: the prevalence of char-bending at the ship's extremities, on both original and replacement planking as well as some stringers, betrays the importance of this technique in both the construction and repair of the ship.

The application of heat is a simple method for obtaining a curve in thin planking.[133] It is furthermore the cheapest method and the technique least wasteful of materials; it also enhances rather than detracts from the strength of the wood.[134] Vitruvius notes that wood could be both hardened and strengthened by fire, which made it more resistant to decay.[135] The blackened or, in many areas, charred surfaces resulting from char-bending, then, were probably not viewed as detrimental.

In char-bending, the wood is plasticized and allowed to bend through an application of both water and heat, facilitating the formation of complex curvatures without cracking or breaking.[136] The simplicity of this technique is well-illustrated in figure 5.1, which shows workers bending and twisting a plank in an early 20th-century shipyard along the Weser River in northern Germany. In the photograph, a weight clamped to the end of the plank pulls the end downward over a metal rack, which acts as a fulcrum. On the other side of the metal rack, a worker grasps the plank with one arm,

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[132] An overview of the tools used in the construction of YK 11 is provided in Appendix A.
[133] Gianfrotto and Pomey 1981, 271.
[134] Peck 1957, 1.
[135] Meiggs 1982, 350; Vitr. *De arch.* 1.5.3.
[136] Modern guidelines on the practice suggest the timber should be seasoned to obtain a moisture content of 12-20% (Peck 1957, 6, 10-1). Drier wood may also be bent if water is added during the heating process, as seen in figure 5.1. The duration of time that a plank should be held over the fire varies depending on the curve to be achieved, the thickness of the timber, the moisture content of the wood, and the wood species.

and with the other gently twists the plank by means of a hand-held lever clamped to the plank. A second worker maintains sufficient moisture throughout the process with a wet rag or sponge on a stick. Many of the YK 11 planks retained some of their original twist and curvature; these complex curves have been preserved in storage by means of custom-built molds designed by Sheila Matthews. The curve, twist, charred or blackened surface, and, on some planks, sharply-delineated char line, could perhaps have resulted from the simple method illustrated in figure 5.1.

Figure 5.1. Workers char-bending a plank in an early 20th-century shipyard along the Weser River in northern Germany. Photo Deutsches Schiffahrtsmuseum; used with permission.

Char-bending continues to be used in traditional shipbuilding in areas such as Indonesia and Pakistan.[137] Evidence of char-bending has been noted on several shipwrecks, including the Kyrenia, Dramont E, Dor D, YK 14, and YK 23 ships, among others.[138] It was also cited in the construction of the hull of Tantura A and perhaps also Tantura F as well as YK 17, although these ships are lacking in edge fasteners.[139]

Did Late Roman and Byzantine shipwrights conceive of this technique as a means by which planks could be formed, or did they simply view it as a way to prevent plank breakage? If the former, the fact that char-bending was used in tandem with edge fasteners on several ships may suggest that, at least for complex curves, the shipwrights realized that small, weak tenons or coaks were not enough to achieve or hold the desired form. Likewise, this technique may also be taken as an indication that, even during repairs, at which point all of the framing was present within the ship, the YK 11 shipwright conceived of the planking as something that was to be independently formed without complete reliance on the ship's internal structure. In short, on YK 11, the char-bending seen on the original plank above the waterline and on repair pieces may indicate that the presence of framing prior to the installation of planking does not necessarily indicate a purely skeleton-based concept.

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[137] Hawkins 1982, 54, 92; Greenhill 1957, 115; Kahanov et al. 2004, 117. According to Pulak (pers. comm.), this method is still used in the construction of wooden boats in Bodrum, Turkey.

[138] Steffy (1985, 84, 94; 1999,403) notes that the charring observed on the Kyrenia hull may more likely be the result of a process to eradicate termites; however, he also mentions that the charred areas were trimmed with adzes, as is seen on YK 11. For Dramont E, Santamaria 1995, 143; for Dor D, Kingsley 2002, 8 fig. 15, 19. Although not yet studied in detail, Yenikapı shipwreck YK 23, of probable late eighth-century date, exhibits char-bending of planking toward the ship's bow; these planks are edge-fastened with coaks rather than mortise-and-tenon joints (Ingram and Jones 2011, 13-4). Late ninth- or early tenth-century shipwreck YK 14 at Yenikapı also exhibits evidence of char-bending (Jones 2010).

[139] Kahanov and Royal 1996, 22; Kahanov et al. 2004, 117; Barkai and Kahanov 2007, 24; Kocabaş 2008, 171, 174; Türkmenoğlu 2012, 124. Charred plank and stringer surfaces were also noted on the Tantura E ship (Israeli and Kahanov 2012, 45).

Originally, the ship's planking was edge-fastened with unpegged mortise-and-tenon joints below the waterline. The average tenon, just 2.1 cm wide, was fitted into a mortise with an average width of 4.7 cm. As a result, mortise-and-tenon joints on plank edges were somewhat lacking in rigidity; several of the tenons had been cut through at an angle that indicated that the tenon was not straight in the mortise.[140] Despite the flexibility along the length and width of the mortise, tenons fit quite snugly within the mortises in terms of thickness. The spacing of the mortise-and-tenon joints was highly variable, but averaged approximately 45 cm center-to-center; a similarly wide spacing of edge fasteners was observed on the Yassıada 1 and Pantano Longarini ships.[141] On YK 11, edge fasteners seemed to be spaced more closely around the turn of the bilge, but reliable patterns are unattainable due to the ship's extensive repairs.

The only remaining original scarf, on strake eight on the port side, was a curved (S) scarf with a central mortise-and-tenon joint; one of the scarf tips was also edge-fastened to the plank below with a nail (fig. 4.55). On the basis of this scarf and another unidentified (UM) fragment, it may be assumed that this type of scarf is typical of the original edge-fastened planking, indicating interlocking planks in each strake.[142]

[140] The cutting of the tenon, however, may have caused it to become angled in its mortise.
[141] Bass and van Doorninck 1982, 55; Throckmorton and Throckmorton 1973, 263.
[142] This is similar to the diagonal or curved scarfs observed on the Kyrenia, Yassıada 2, Dramont E, and Fiumicino 1 ships, although the mortise-and-tenon joints on those ships were pegged and used more extensively (Steffy 1985, 78-81; van Doorninck 1976, 121; Santamaria 1995, 141 fig. 139, 146; Boetto 2008, 39-40, fig. 14). On the Yassıada 1 ship, some diagonal scarfs have iron nails that were driven from both the upper and lower edges, indicating a preassembly of planks in some strakes; other scarfs were simply joined by an unpegged mortise-and-tenon joint along the scarf edge (Bass and van Doorninck 1982, 59).

Therefore, below the waterline, the thin planks with loose, unlocked mortise-and-tenon joints made some small contribution to overall longitudinal hull strength.[143] This contribution, however, was diminished over time, as edge-fastened planks were replaced by planks lacking edge fasteners. Furthermore, interlocking scarfs were replaced by crudely-cut butts or other forms whose primary goal was to fill gaps left by rotting and worm-eaten timber rather than form a solid, continuous strake of planking.

The lower edge of both garboards and the hood ends of planks were fitted into a shallow rabbet cut on either side of the ship's keel; the planks were then secured with short nails (up to 8 cm long) driven from the hull exterior. The spacing of these nails was highly variable but averaged 29 cm.[144] Mortise-and-tenon joints were not used in the attachment of the garboards to the keel. On average, garboards were only slightly thicker than other planks, up to 3.6 cm in some areas. Both garboards, however, had been replaced during the life of the ship; it is noteworthy that the replacement garboard planks were also nailed into the keel rabbet in the same manner as the original garboards, even though they could have been attached only to the framing, in place at the time of the repair. The garboard planks of the Serçe Limanı ship, in contrast, were fastened solely to framing and not to the ship's keel.[145]

Above the waterline, edge fastening was abandoned and planks were fastened to half-frames, futtocks, or top timbers. Four pine and, perhaps, cypress wales girded the hull on either side. Unlike the wales on the Saint-Gervais 2 ship, which were attached to

[143] Similarly weak tenons were observed on the seventh-century ships at Yassıada (Bass and van Doorninck 1982, 55-6, 82), Saint-Gervais 2 (Jézégou 1983, 47; Pomey et al. 2012, 265), and Pantano Longarini (Throckmorton and Throckmorton 1973, 263).
[144] This is much wider than the 15 cm nail spacing on the Saint-Gervais 2 garboards (Jézégou 1983, 46).
[145] Bass et al. 2004, 86.

the exterior of the hull planking,[146] the substantial YK 11 wales were in line (at their inboard faces) with the ship's planking but not edge-fastened to it. As on the Yassıada 1 ship, the two extant YK 11 wales were installed with the narrower end (the direction of growth) oriented in opposite directions.[147] Only two wales were partly preserved, both on the port side of the ship; these alternated between strakes of planking. Both were cut from half-logs of Turkish pine, up to 16.5 cm in diameter. One of the wales, SS 11, was scarfed near the stern, where it had tapered to only 10 cm in width; the relatively weak flat scarf spanning two frames on this wale, fastened only to frames and not to the other part of the wale (which was not preserved), reflects the shift to skeleton-first techniques above the waterline. Only one strake of planking between wales was preserved, strake SS 12 on the port side. This strake was slightly thinner than other planks (average thickness 1.8-2.3 cm) and served to fill the gaps between through-beams between the first and second wales. Although the through-beams were notched to receive the SS 12 strake ends, it remains unclear whether this strake was installed before or after the second wale was fitted in place.

Based on evidence on the wales and one preserved fragment of a through-beam, YK 11 had at least five through-beams: one toward the bow, one just forward of amidships (serving as a mast-partner beam), and three toward the stern at two different levels. The through-beams occupied the entire area between wales and were notched on all faces to receive the adjacent planks and wales. Iron nails, 8-13 cm in length, were driven from the exterior through the edge of one or both wales into the through-beam,

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[146] Jézégou 1983, 37.
[147] Bass and van Doorninck 1982, 78-9.

locking it in place. Any gaps around the edge of the through-beam were almost certainly packed with caulk fibers and sealed with pitch. Gaps in strake SS 12 and between the first two wales indicate through-beams 10-15 cm in sided dimension and approximately 10 cm in molded dimension. These through-beams, locked in place between the substantial wales, provided transverse strength to the hull and tied the wales together, thus integrating key elements of longitudinal strength above the waterline.[148]

Within the hull, longitudinal strength was enhanced through a series of pine and cypress stringers. From FR 10 to FR 21, between the stemson and sternson, a pair of central stringers nailed to the inner face of the ship's frames on either side of the keel provided a boundary for the ship's removable mast step. (The mast step and the port central stringer were not preserved on YK 11.) This configuration is described as an element of Pomey's Roman Imperial tradition.[149] There is no evidence of the use of braces to tie the pair of central stringers together, and the stringers themselves were not rabbetted to receive the mast step.[150] The recess along the lower or inboard edge of the preserved central stringer indicates that the mast step, although not preserved, originally extended to just aft of FR 19; deeply impressed or countersunk nail heads on FR 14-FR 18 suggest a mast step approximately 1.5 m in length. The mast step, which would not

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[148] The structure of wales and through-beams is cited as a significant source of longitudinal strength on the Port Berteau II ship (Rieth et al. 2001, 56).

[149] Pomey et al. 2012, 237. Ships with a similar configuration include the Anse des Laurons 2 (Gassend et al. 1984, 100), Port-Vendres 1 (Liou 1974, 423-26), Pointe de la Luque B (Clerc and Negrel 1973, 66-7), Dramont E (Santamaria 1995, 160-63), Saint-Gervais 2 (Jézégou 1983, 38-9, 76), Tantura F (Barkai and Kahanov 2007, 24-6), Dor 2001/1 (Mor and Kahanov 2006, 280-81), and Bozburun (Harpster 2005a, 349-50, 444) ships. On other ships, the central stringers may be referred to as "sister keelsons"; on YK 11, however, they are similar to the other stringers in most regards and were therefore labeled as such.

[150] Braces between the central stringers were found on the La Bourse (Gassend et al. 1982, 20-1, 110), Anse des Laurons 2 (Gassend et al. 1984, 100), Port-Vendres 1 (Liou 1974, 423-24, fig. 8), and Saint-Gervais 2 (Jézégou 1983, 50) ships.

have been fastened in place, would have been locked in place longitudinally through notches over the framing; it would have been held in place laterally by the pair of central stringers.

In addition to the pair of central stringers, five additional strakes of stringers were attached to the ship's framing along either side. The lowest strake consists of two stringers scarfed together with a flat vertical scarf. Stringers are usually 3-5 cm in thickness, almost always thicker than the ship's planking. However, the stringers were very lightly fastened to the framing with short iron nails, 8-9 cm in length; even the longest stringers did not have more than 5 or 6 nails holding it in place, thus diminishing their contribution to longitudinal hull strength somewhat. The uppermost stringer, slightly thicker than other stringers, is located approximately opposite the first wale and may therefore be a clamp.

Finally, an additional longitudinal support to the ship's structure is suggested. While no fragments of such a timber were preserved, two robust stanchion blocks, notched to fit precisely over frames FR 15-FR 17, had mortises cut into their top faces, which did not align with a through-beam. The stanchions placed in these mortises must have supported longitudinal rather than transverse timbers, and such a longitudinal structure would have added lateral support to the mast. In theory, the ends of these longitudinal timbers may have been attached to the FR 10-FR 11 and FR 23-FR 24 through-beams, themselves supported by stanchions mounted in pairs of stanchion blocks at these locations.

Transverse support in the YK 11 hull is provided by the ship's framework, which follows the alternating pattern of floors and paired half-frames that characterizes shell-built vessels from the Hellenistic period to the eighth century A.D.[151] If, as evidence suggests, floor FR 4 was a replacement for an original pair of half-frames, this alternating pattern ran unbroken from FR 2 in the stern to FR 26, the last preserved frame in the bow.[152] Floors span the bottom of the ship with tips extending to the turn of the bilge, while half-frames cover the keel and one side of the ship up to the level of the first or second wale. These frames are elongated up the side of the hull through the use of futtocks placed adjacent to, but not fastened to, their respective floor or half-frames, overlapping by the width of one or more planks.

The ship's framing was attached to planking with short iron nails (approximately 7 cm long) driven from the hull exterior; treenails were not used.[153] Half-frames and their futtocks were attached to the wales with longer iron nails, 10-15 cm in length, driven from the interior, while floor futtocks were attached to wales with a single nail from either the exterior or interior. The iron nails driven from the exterior did not extend to the frame's inner face except on rare occasion, usually where frames were steeply angled near the ship's extremities. Every extant floor and half-frame was attached to the spine of the ship with one or more long iron nails, perhaps better labeled as spikes, 14-17

[151] Steffy 1991, 3. The pattern of alternating floors and paired half-frames is seen on merchantmen as early as the late fourth century B.C. on the Kyrenia ship (Steffy 1985, 84) and as late as the eighth century A.D. on Yenikapı shipwreck YK 23. Use of this pattern continued in the construction of galleys until at least the late 10th century based on Yenikapı galleys YK 2 and YK 4.
[152] The interruption of this pattern at the very stern (FR 1-FR 2) probably reflects the shipwright's desire to avoid the use of chocks in association with floors; such chocks were observed on the Saint-Gervais 2 ship (Jézégou 1983, 33). The presence of two pairs of half-frames in the stern followed by a regular pattern of floors and paired half-frames was also observed on the early fifth-century Dramont E shipwreck (Santamaria 1995, 150).
[153] This was also the case on the Yassıada 1 ship (Bass and van Doorninck 1982, 55-6).

cm in length, none of which extended to the outer face of the keel; bolts were used in the attachment of FR 4, FR 9, FR 21 (in the initial construction), and perhaps FR 29 (not preserved). Based on the pair of half-frames at FR 16 and iron fasteners preserved on the keel at other half-frame locations, both lower ends of each half-frame pair were attached to the keel.[154] The frames are quite substantial in comparison to the ship's planking, with a maximum average sided dimension of about 9 cm and a maximum average molded dimension of about 10 cm, with some variation depending on the type of frame and whether or not it was a replacement. These dimensions are significant, considering the keel is just 3 cm larger in its maximum sided dimension.[155]

Other extant elements of YK 11 did not provide any longitudinal or transverse strength to the hull but rather were elements of the ship's interior. These include the common ceiling and the sills. The common ceiling, laid over and lightly fastened to the ship's framing, filled gaps between stringers and provided a platform for cargo, safe from the moisture of the ship's bilge. The sills, located around the first wale, blocked the gaps between frames, thus preventing foreign objects from dropping into the bilge under the level of stringers and ceiling.[156] The location of these sills, combined with the extent of preservation of the stringers and common ceiling, indicates a central hold area that was fully internally planked to the load waterline.[157] The attention paid to the ship's lading is further emphasized by the presence of a graffito carved into a stringer just

[154] On the Yassıada 1 ship, one component of one of the half-frame pairs does not seem to have been fastened to the keel (Bass and van Doorninck 1982, 60).
[155] Similarly large framing was noted on the Saint-Gervais 2 ship (Jézégou 1983, 81).
[156] The crenelated timber found on the early ninth-century shipwreck Tantura B was of a similar function (Kahanov 2000, 153).
[157] Stringers extending far up the side of the hull were also noted on the Saint-Gervais 2 (Jézégou 1983, 40-1, 77-8) and Yassıada 1 ships (Bass and van Doorninck 1982, 60-1).

forward of amidships that seems to indicate the ship's approximate waterline; it was located between the calculated waterline of the empty hull and the estimated load waterline.

Finally, a bulkhead partition near the ship's stern created a compartment separated from the main hold, perhaps for valuables or other necessary items of equipment.[158] Evidence for a bulkhead partition was observed on the Tantura E ship and on other ships at Yenikapı, including YK 3, YK 12, and YK 14, of 9th- to 11th-century date.[159] There is no evidence that this area on YK 11 would have been used for cooking. Separate onboard-cooking facilities were found on the Yassıada 1 ship but would be unexpected on a small coaster such as YK 11.[160] Perhaps the ship carried a brazier for cooking meals on shore; one such brazier was found on the 9th- or 10th-century YK 12 shipwreck at Yenikapı.[161] An intact and nearly complete bronze lamp or incense hanger found in this area on YK 11 was probably used on the ship; it had dropped down between the frames and thereby escaped salvage. The bulkhead partition was relatively flimsy, both lightly fastened and resting atop the sternson, stringers, and stanchion blocks.[162] Although it is only partly preserved along the port side, evidence suggests it extended across the starboard side as well. The through-beam near FR 8-FR 9 likely

[158] A displaced bulkhead frame, UM 157, may represent part of a second bulkhead partition aft of the in-situ bulkhead; the correct location of UM 157 has not been identified.
[159] For Tantura E, Israeli and Kahanov 2012, 45; for YK 3, Kocabaş 2008, 159; for YK 12, Kocabaş 2008, 114, 123; Özsait Kocabaş 2012, 115; for YK 14, Jones 2010. The base for these bulkhead partitions is a slotted frame or futtock rather than a separate timber, independent of the ship's framing, as on YK 11.
[160] Bass and van Doorninck 1982, 87-120.
[161] Çelik 2007, 224; Kocabaş 2008, 112-14.
[162] Distribution of artifacts and the bolting of frame B-29 to the keel indicate a much stronger bulkhead partition on the fourth- or fifth-century Yassıada ship (Bass and van Doorninck 1971, 33-4).

provided support for the upper portion of this partition, and the stern cabin's wooden roof was likely the aft deck platform used by the helmsman.

There are several other elements of the ship that must have existed but for which no direct evidence was found. This includes the ship's mast, mast step, and yard; quarter rudders; fore and aft decks; and cleats for tying off lines. These may have been stripped off of the ship to be recycled elsewhere; this is almost certainly the case for valuable removable timbers like the mast, mast step, and quarter rudders. There is no evidence for the existence of a bilge pump; none of the frames was tailored to accommodate one, as has been observed on other roughly-contemporaneous ships, such as the Port-Vendres 1, Dramont E, and Saint-Gervais 2 ships.[163]

The entire hull was payed with pitch on both the interior and exterior; pitch ridges on planks at frame locations indicate several applications. Pitch was a known deterrent to shipworms,[164] and it also sealed the hull to prevent leakage along plank seams. Theophrastus notes that pitch from a coastal pine such as *Pinus halepensis*, although less fragrant than that of a mountain pine, was superior.[165]

Evidence of Economizing

Pomey stresses that, in order to understand a vessel's construction, one must consider its concept, or principles of construction, in addition to the processes, or

[163] Liou 1974, 423-26 fig. 10; Santamaria 1995, 173-74; Jézégou 1983, 51, pl. 9. The framing was also cut down or interrupted for a bilge sump on the fourth-century B.C. Kyrenia ship (Steffy 1985, 96) and the fourth- or fifth-century A.D. Yassıada ship (van Doorninck 1976, 128). Water was likely bailed by hand on YK 11. Perhaps the lack of a bilge pump on this ship contributed to the need for extensive repairs along the ship's bottom.
[164] Theophr. *Hist. pl.* 5.4.5.
[165] Theophr. *Hist. pl.* 3.9.2. Analyses of four samples of YK 11 pitch by Edith Stout and Sarjit Kaur of the Amber Research Laboratory at Vassar College indicate that the pitch of YK 11 was made from extracts of *Pinus halepensis*; this is surprising considering the ship was found in Constantinople, and *Pinus halepensis* is native to mainland Greece and areas westward of Greece (Meiggs 1982, 44).

methods of construction.[166] How the shipwright conceived of the ship, then, greatly influenced how he built it, and numerous factors affected this. While the function of the ship and experience of the shipwright are, as noted by Pomey, significant factors affecting the construction, Steffy notes that, for a cargo ship, economics were the predominant non-physical factor.[167]

A merchantman like YK 11 was designed to transport cargo in a manner that maximized the profit of the ship's owner.[168] The analysis of YK 11 reveals a hull built and repaired in a manner that made optimal use of available resources. The shipwright economized wherever possible, as is evident through both the materials selected as well as the extent and nature of repairs.

Choice of Materials

The materials chosen for the construction and repair of ship YK 11 reflect a careful use of available resources. First, the naturally rounded surfaces, often with patches of bark or cambium, indicate an effort to minimize timber wastage and reduce labor costs; this is especially true of the frames, which are almost always grown curvatures. Using compass timber is perhaps the best option for curved timbers such as frames; even though it requires a great deal of skill by the shipwright, such grown curvatures are less likely to split or become deformed.[169] Like the rough, natural frames of the first-century A.D. Kinneret boat, found in the Sea of Galilee, the YK 11 floors and half-frames were frequently twisted, with an arm angling either forward or aft of an

[166] Pomey 2004, 25-9. This is similar to Hocker's (2004a, 6) concept of design, assembly, and structural philosophy.
[167] Steffy 1994, 10.
[168] Steffy 1994, 10.
[169] Gianfrotto and Pomey 1981, 270.

exact perpendicular to the ship's keel.[170] If the interpretation of some caulked fastener holes at original half-frame FR 8 presented in Chapter IV is correct, the twisted forms caused some difficulty during the initial construction. The large wales were crafted from long trunks that were sawn in half and only minimally worked on the outer face.[171] The use of widely-spaced, loose-fitting mortise-and-tenon joints also helped to reduce labor costs.[172]

Second, selected timber appears to include pieces that were perhaps not of the highest quality. Damage from wood-boring insects, incurred during the life of the tree, was observed on several timbers, especially frames and stringers. Fire scarring was noted on seven of the ship's extant frames (approximately 20%); that this was noted on both original and replacement timbers indicates a continued use of timber with a flawed surface, although it should be noted that the fire scarring does not seem to have detracted from the timber's functionality.

Third, the salvage and reuse of discarded timbers is another way in which the YK 11 shipwright economized in the ship's construction: several of the ship's components are timbers recycled from elsewhere. The best example of this, and the most substantial recycled timber on the ship, is sternson KS 1. This timber was originally part of a keel for a ship with similar construction features as YK 11, namely an alternating pattern of floors and half-frames, and garboards nailed into a shallow rabbet. Once KS 1 had reached the end of its former life, most of the damage to the heavily worm-eaten outer

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[170] Steffy 1987, 327.

[171] The use of undressed half-logs for wales and ceiling is described as an economizing measure on the Yassıada 1 ship (Bass and van Doorninck 1982, 83-4).

[172] The use of similar mortise-and-tenon joints is also seen as an economizing choice on the Yassıada 1 ship (Bass and van Doorninck 1982, 84).

face was trimmed off with an adze and the piece was then re-cut with notches that accommodated the frames of YK 11. SS 6-4, SS 7-6 (UM 31), and SS 9-2 were used elsewhere before being recycled as replacement planks on YK 11. Stanchion block 2 was also recycled, but the original function of this intricately notched timber remains unknown. Finally, the fine carpentry work along the slotted edges of common ceiling SC 1B is incongruous with the other timbers on this ship, and this piece may represent the discarded interior woodwork of a building in Constantinople.

Last, the use of cheap iron fasteners could be viewed as a form of economizing; the shipwrights relied mainly on iron nails of varying lengths and minimized the use of iron bolts.[173] Although iron was typically used in ship construction by the seventh century, it had significant drawbacks.[174] As late as the late fourth century A.D., Vegetius recommended the use of bronze rather than iron fasteners for warships for, although iron is cheaper, it corrodes quickly in moist conditions.[175] On YK 11, perhaps worn-out fasteners contributed to the need for some of the many repairs.

In summary, the YK 11 hull was well built with an intelligent and economical use (and reuse) of available resources. As such, Steffy's description of the Kinneret

[173] As a contrast to YK 11, the framing of the fourth-century B.C. Kyrenia ship was attached to planking with long copper nails, double-clenched over the frame's inner face (Steffy 1985, 84). The use of short iron nails, rather than longer clench nails, is noted as an economizing measure on the Yassıada 1 ship (Bass and van Doorninck 1982, 84). Many of the later merchant ships at Yenikapı, of ninth-century date or later, were fastened with a combination of both treenails and iron nails, often with an emphasis on the former.

[174] Parker 1992, 27.

[175] Veg. *Mil.* 4.34.

boat's shipwright is equally applicable to the shipwright of YK 11: "…a master craftsman whose efforts produced something substantial from something inferior."[176]

Repairs

A ship, in and of itself, was a valuable asset. In the *Life of St. John the Almsgiver*, patriarch of Alexandria in the early seventh century, a ship-owner whose son was killed and the entire cargo lost in a shipwreck is consoled by the fact that the ship itself was saved.[177] According to the *Rhodian Sea-Law*, even an old ship, with its tackle, was valued at 30 *solidi* per 1,000 *modii* (approximately 6⅔ tons); a new vessel was worth 50 *solidi* per 1,000 *modii*.[178] Thus an aging vessel such as YK 11 was worth the care and cost to repair it, even on multiple occasions. That this ship was eventually abandoned as a derelict is a true testament to the extent of the repairs and the limits to which this hull had been pushed.

The planking of YK 11 was heavily repaired. Excluding the small, patch-like graving pieces, 28 of the 46 extant planks were later repairs, installed to replace rotting and worm-eaten timbers. Although the upper strakes are those less frequently repaired, and also less extensively preserved, it may be assumed that about half of the ship's total planking had been replaced by the time the ship was abandoned. In addition to the planks that were replaced, twelve graving pieces were added to patch small areas of rot or damage along plank edges or at strake ends, including planks that had already been replaced.

[176] Steffy 1987, 327.
[177] *John Alms.* supplement of Leontius 26.
[178] *Rhodian Sea-Law* II.16; Jones 1964, 868. Calculations for tonnage are based on the average ton of wheat equal to approximately 150 *modii* (Rickman 1980, xiii; Plin. *HN* 18.12.66).

Many of the graving pieces were installed to repair areas at or between mortise-and-tenon joints on original planking; such areas appear to have been especially susceptible to shipworm damage. In one area on plank SS 7-3, a damaged mortise-and-tenon joint was chiseled out and replaced with a large wad of caulk fibers and sealed with pitch. Such simple repairs are far different from the elaborate system of "patch tenons" installed on the ships at Kyrenia (fourth century B.C.), Herculaneum (first century A.D.), or Grado (second century A.D.) during repairs to planking.[179] The shipwrights of YK 11 did not bother to recreate the mortise-and-tenon joints in the replacement planking, perhaps realizing that such joints were prone to shipworm damage. The additional labor required for creating a "patch tenon" may also have been deemed excessive for a joint that had become functionally obsolete by that stage in the life of the ship.

The extent of repairs to the ship's planking below the waterline resulted in many abandoned mortise-and-tenon joints. These include joints that were cut out and replaced by a graving piece, "blind" mortises, in which an original plank edge has mortises (empty or containing a cut tenon) while the facing plank edge does not, and cut tenons, in which joints along an original, intact seam are cut through, perhaps in the process of recaulking the ship.

The replacement of so many of YK 11's frames, predominantly floors but also several half-frames, is unexpected. The evidence, primarily the comparison of fastening patterns on the planking, keel, and framing, indicates a series of major repairs rather than

[179] Steffy 1985, 85 fig. 9, 97-8; Steffy 1999, 397-98; Beltrame and Gaddi 2007, 144.

one massive overhaul. Such repairs could not have been simple and necessitated the repeated removal and reinstallation of many of the hull's interior timbers, including the stemson, sternson, stringers, common ceiling, and bulkhead. All of these bear evidence of having been removed and reinstalled; two pieces of common ceiling were flipped over and reinstalled upside down, which likely went unnoticed due to the size and form of these pieces.

In most areas, the YK 11 shipwrights chose to replace frames that had become worn, rotten, or otherwise damaged instead of merely adding reinforcement pieces, which was the case on the Saint-Gervais 2 ship.[180] Of 34 extant frames, only 18 were installed during the initial construction of YK 11.[181] In addition to the removal and replacement of old frames, a short, frame-like repair piece (FR 12A) was added to the starboard side to provide a surface onto which plank ends could be fastened; a similar piece was identified on the Dramont E wreck.[182]

The replacement of FR 21 seems to have been done by a different shipwright, as this frame differs from the other framing of the ship in several aspects.[183] It is larger in sided dimension than any other frame, larger even than the ship's keel. It is also the only floor that is distinctly notched for futtocks at either end. Finally, although it is located at a keel scarf (Keel 2-Keel 3), it is not bolted through the scarf. Rather, it appears that the original floor was removed and the original scarf bolt replaced with a shorter bolt; the replacement floor (FR 21) was then roughly cut down on one face to accommodate the

[180] Jézégou 1983, 33, 61.
[181] The total here excludes reinforcement piece FR 12A as well as two frames whose status as original or replacement remains unclear.
[182] Santamaria 1995, 146.
[183] Steffy (1999, 400) came to a similar conclusion for one replaced frame from the Kyrenia ship.

end of this bolt. Thus, the original configuration, of a strong, bolted joint between the keel, floor, and stemson, was replaced by a much weaker repair consisting of a bolted keel scarf, independent of the stemson and floor that were simply nailed onto the keel's inner surface.

Although the replacement floor at FR 21 was a substantial timber, the means of attaching it to the keel weakened the hull at a key location. Perhaps this repair was carried out as a stopgap measure, while the ship was away from its home port. It is reminiscent of a repair described by Plutarch, who states that "…sailors, when their rudder has been shattered, try to fit and fasten other timbers in its place, striving to meet their needs, not well, indeed, but as best they can."[184] While this reference is relatively early, a later reference to repairs carried out at sea appears in the *Miracles of St. Artemios*, probably compiled in the seventh century. In Miracle 27, Theoteknos, a shipbuilder traveling from Constantinople to Gaul, noticed some problem with the ship's keel and dived under the ship to repair it.[185]

The extensive repairs to YK 11 are perhaps the most characteristic element of this hull. A failure to recognize the repairs as such would alter the interpretation of the remains, skewing them toward a skeleton-based rather than shell-based technique. This underscores the importance of excavation, disassembly, and thorough analysis of ship timbers, with an emphasis on fastening patterns, where feasible. Without such analysis, definitive statements on the construction of any vessel are significantly weakened.

[184] Plut. *Vit. Brut.* 46.4.

[185] *Artemios* 27. Theoteknos' repair seems to have been more than a crudely-executed stopgap measure; it is described by Saint Artemios as "…a fine piece of work."

Altogether, the evidence of economizing and the extent of repairs to this small merchantman reflect the philosophy of the shipwright and the ship's owner. Contemporaneous literary sources affirm the value of a ship, irrespective of cargo, and provide examples of repair to aging vessels. Such examples are also abundant within the archaeological record, where repairs are not uncommon, although they are rarely documented to the extent seen in YK 11. Overall, this heavily-repaired, economically-built yet seaworthy hull is a fitting reflection of the socio-economic milieu of early seventh-century Constantinople. The ship continued to operate despite a contracting economy and political uncertainty, perhaps helping supply the city of Constantinople in times of dire need. Eventually, after a long life of service, the ship, having been stripped of any useful timber, was abandoned.[186]

Overview of YK 11 Wood Species

YK 11 was built predominantly of softwoods, specifically Turkish pine and Mediterranean cypress; the wood species used are detailed in Appendix B (fig. 5.2).[187] Certain types of ship timbers, including the hull planking, wales, and stringers, consisted entirely of such woods. In comparing the types of wood used in ship construction in the Mediterranean, pine and cypress stand out as commonly used for ships' planking. Pine planking was identified on the late fourth-century B.C. shipwreck at Kyrenia[188] and was used on many ships following a similar building tradition, including the La Bourse,

[186] Steffy's (1987, 327) description of the Kinneret boat is perhaps also fitting for YK 11: "What was left was the remains of a tired old hull, no longer of use to carpenters and too saturated with pitch to make good firewood."
[187] All wood-species identification was carried out by Dr. Nili Liphschitz of the Institute of Archaeology, the Botanical Laboratories, at Tel Aviv University.
[188] Steffy 1985, 87.

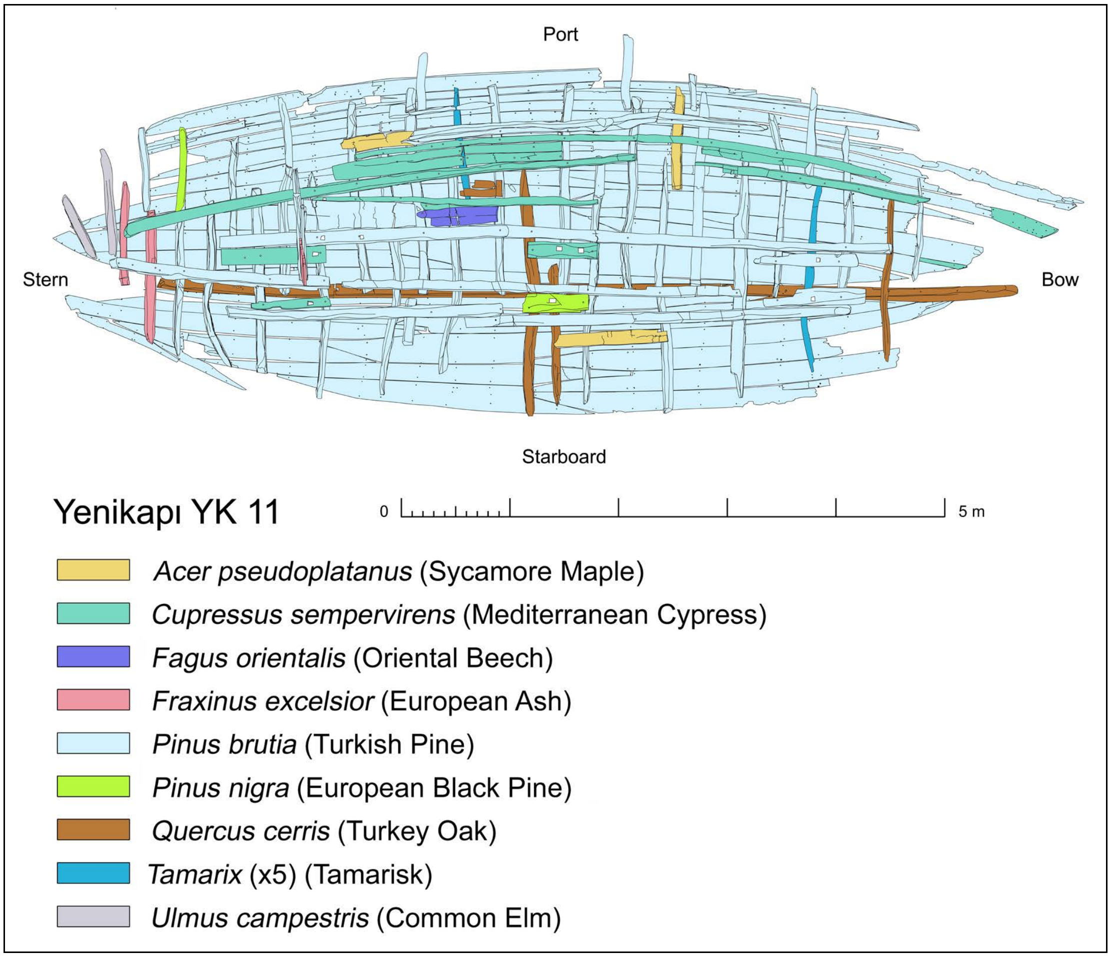

Figure 5.2. Overview of wood species used in YK 11 (identifications by Nili Liphschitz).

Saint-Gervais 2 and 3, Dramont E, and Yassıada 1 ships, all of which had mortise-and-tenon joints along plank edges.[189] Pine or cypress planking was also used in several ships stated to demonstrate skeleton-based construction, such as the Serçe Limanı, Dor 2001/1, Tantura A, Tantura B, and Tantura F ships.[190] In contrast, of the six merchant

[189] Gassend 1989, 117; Liou et al. 1990, 232; Jézégou 1983, 43; Santamaria 1995, 181-87; and Bass and van Doorninck 1982, 55. The Yassıada 2 ship (Bass and van Doorninck 1971, 33) and the Pantano Longarini ship (Throckmorton and Throckmorton 1973, 244, 249) were built with cypress planking.
[190] Bass et al. 2004, 102; Mor and Kahanov 2006, 275; Kahanov and Royal 1996, 22; Kahanov 2001, 267; Kahanov 2003, 49-51; Barkai and Kahanov 2007, 24.

ships documented by INA at Yenikapı, all but YK 11 were built with oak planking, and all of these were edge-joined with coaks rather than mortise-and-tenon joints.[191] The ninth-century ship found at Bozburun, with oak planking, was also edge-joined with coaks.[192] While oak planking with mortise-and-tenon edge joinery is a known combination, as for example on the Fiumicino 1 ship, it is rare.[193]

The framing of YK 11 showed some variation in wood species. During the initial construction, the shipwrights crafted floors and half-frames of oak, pine, and tamarisk. Original futtocks included those of sycamore maple, pine (both *Pinus brutia* and *Pinus nigra*), tamarisk, and elm. During later repairs, however, shipwrights overwhelmingly preferred Turkish pine, with only two other woods, ash and elm, represented in just three timbers, these being shorter timbers near the ship's stern (FR 1, FR 2, and FR 3).

Pine or cypress framing is not unknown on Mediterranean ships of the first millennium and has been found on the Kyrenia, Yassıada 2, and Serçe Limanı ships.[194] Hardwoods such as oak or elm, however, seem to have been preferred on the Madrague de Giens, Parco di Teodorico, Fiumicino 1, Yassıada 1, and Saint-Gervais 2 ships.[195] Oak framing was also identified in the other five merchantmen documented by INA at Yenikapı.[196] A combination of oak and pine framing was identified on the Saint-Gervais 3, Anse des Laurons 2, and Bozburun shipwrecks.[197]

[191] These are shipwrecks YK 1, YK 5, YK 14, YK 23, and YK 24. Liphschitz and Pulak 2009, 166-68.
[192] Harpster 2005a, 10; Harpster 2005b, 93.
[193] Casson 1995, 213; Boetto 2008, 36-8. The Fiumicino 1 ship also had pine and cypress planking.
[194] Steffy 1985, 87; Bass and van Doorninck 1971, 33; Bass et al. 2004, 88;
[195] Guibal and Pomey 1998, 163; Medas 2003, 45; Boetto 2008, 43; Bass and van Doorninck 1982, 55; Jézégou 1983, 42.
[196] These are shipwrecks YK 1, YK 5, YK 14, YK 23, and YK 24.
[197] Guibal and Pomey 1998, 163; Harpster 2005a, 10; Harpster 2005b, 93.

Considering the variation in wood species based on form or size, in addition to the attempts at economizing seen elsewhere in the hull, it seems likely that the variety of woods identified in the framing of YK 11 reflects timber availability rather than the shipwright's preference for a particular wood species. The increase in Turkish pine in the ship's repairs, and a lack of both oak and tamarisk repairs, is notable but does not necessarily reflect construction and repair in two different geographic areas.[198]

Finally, most of the ship's interior structure over the frames, including the stringers, stanchion blocks, and sternson, consists of softwoods: Turkish pine, black pine, and cypress. Pine and cypress stringers were also noted on the Saint-Gervais 2 and Yassıada 1 ships.[199] While small cypress timbers, such as graving pieces or common ceiling, may have been cut from scraps of wood in the shipyard, it is interesting that four of the long stringers—up to 5.09 m in length—were also cut from this wood which, in Constantinople, may have been imported.[200] The importation of cypress is unsurprising, as cypress was prized for several of its qualities.[201] However, the use of an imported wood for sizable timbers is incongruous on a ship otherwise characterized by economizing measures. Perhaps the shipwrights were utilizing lengths of cypress that were leftover from the construction of another ship, or perhaps cypress was indeed locally grown in Constantinople during the sixth and seventh centuries. Altogether,

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[198] The use of tamarisk during the initial construction is also somewhat curious; tamarisk was not known for its qualities in shipbuilding and was not held in high regard by Theophrastus (*Hist. pl.* 5.4.8).
[199] Jézégou 1983, 43; Bass and van Doorninck 1982, 55.
[200] Davis 1965, 1:76-8. Although Rival (1991, 17) states that it could be found in Thrace, the map provided suggests a distribution farther south, along the Mediterranean coast (Rival 1991, 18 map 1). It is unclear whether or not cypress would have been locally grown in Constantinople in the sixth and seventh centuries.
[201] Vitr. *De arch.* 2.9.12; Theophr. *Hist. pl.* 5.4.2.

based on the identified wood species, it is quite possible that YK 11 was built in or near Constantinople, the Empire's primary center for shipbuilding.[202]

Construction Sequence

Despite the extensive repairs, the initial construction sequence of this vessel may be partly determined. The most helpful details in determining this sequence are the presence of score marks on the interior of the hull planking and the location of mortise-and-tenon joints. The score marks were created as guidelines, which first indicated the intended location of a frame and facilitated its exact placement through the process of adjusting the frame to fit the planking.[203] The presence of score marks at an original frame indicates that the planks bearing these marks had been assembled before the frame was installed. However, the absence of score marks at an original frame is not necessarily evidence to the contrary, as these marks may have been omitted for several reasons, especially at futtocks or top timbers that were located adjacent to frames that had already been installed; the absence of score marks may also be attributed to a lack of preservation.

The planking and framing of YK 11 had been extensively repaired, and score marks were used both during the initial construction and the replacement of some frames. Replacement planking was only scored if and when a frame spanning it was also replaced; such score marks occurred only rarely. Nevertheless, the presence of score marks on both original as well as replacement planking diminishes the value of these marks somewhat. In order for the score marks to make a reliable contribution toward an

[202] Makris 2002, 97.
[203] Bass and van Doorninck 1982, 71; Mor 2004, 168.

understanding of the ship's initial construction, one must differentiate between score marks on original versus replacement planking, as well as score marks at original versus replacement frames.

The presence of mortise-and-tenon joints in close proximity to an original frame is another good indication that planking had been assembled before the frame was added. Steffy notes that, based on practical experience, a mortise 1.5 cm from a frame edge was very difficult to cut into a plank if frames were pre-erected.[204] Because mortise-and-tenon joints were used only during the initial construction, these are perhaps a better indicator of construction sequence than the score marks, which could have been created during initial construction or during a later repair. However, because the mortise-and-tenon joints can be widely spaced, both the presence of mortise-and-tenon joints and an analysis of score marks proved valuable in interpreting the construction sequence of the hull (table 5.3).

Table 5.3. Evidence for the early stages of the construction of YK 11.

Frame	Highest plank installed before frame	Evidence	Notes
FR 1	Unknown		Repl.(?) half-frame. All orig. planking has been replaced here.
FR 2	Unknown		Repl. half-frame. All orig. planking has been replaced here.
FR 3	Unknown		Repl. floor. All orig. planking has been replaced here.
FR 4	SS 8-1(?)	Score marks, mortise-and-tenon joint	Repl. floor. Assembly sequence is based on the theory that this floor replaced a pair of half-frames.
FR 5	Unknown		Orig. floor. All orig. planking has been replaced here.

[204] Bass and van Doorninck 1982, 71.

Table 5.3. Continued.

Frame	Highest plank installed before frame	Evidence	Notes
FR 6	SS 8-1	Score marks	Orig. half-frame.
FR 7	Unknown		Repl. floor. All orig. planking has been replaced here.
FR 8	SS 8-1	Score marks, mortise-and-tenon joint	Orig. half-frame.
FR 9	Unknown		Repl. floor. All orig. planking has been replaced here.
FR 10	SS 8-1	Score marks	Orig. half-frame.
FR 11	Unknown		Repl. floor. All orig. planking has been replaced here.
FR 12	SS 8-1	Mortise-and-tenon joint	Repl. half-frame.
FR 13	Unknown		Repl. floor. All orig. planking has been replaced here.
FR 14	SS 8-3	Score marks	Repl. half-frame.
FR 15	PS 3-3?	Possible(?) short score mark on PS 3-3	Orig. floor. Nearly all orig. planking has been replaced here.
FR 16	SS 8-3	Mortise-and-tenon joint	Orig. half-frame on starboard, repl. half-frame on port.
FR 17	SS 5-4	Score marks	Repl. floor. Score marks are present on original planks but not on replacements.
FR 18	SS 9-3	Score marks	Repl. half-frame.
FR 19	SS 5-4	Score marks from original floor	Repl. floor.
FR 20	SS 9-3	Score marks, mortise-and-tenon joint	Orig. half-frame.
FR 21	SS 5-4	Score marks from original floor	Repl. floor.
FR 22	SS 9-3	Score marks	Orig. half-frame.
FR 23	SS 7-3	Score marks, mortise-and-tenon joint	Orig. floor.
FR 24	SS 11	Score marks	Orig. half-frame.
FR 25	SS 7-3	Score marks	Orig. floor.
FR 26	SS 9-3	Score marks, mortise-and-tenon joint	Orig. half-frame.
FR 27	SS 7-3	Score marks, mortise-and-tenon joint	Floor not preserved, but fasteners suggest it was original.
FR 28	SS 9-3	Score marks, mortise-and-tenon joint	Half-frame not preserved.

Evidence for the Construction Sequence

Isolating original floors at original planks reveals that all of the planking covered by original floors FR 23 and FR 25 had been installed prior to the installation of these floors; this includes the planking up to SS 7-3, which includes the turn of the bilge. What amount of the planking had been built up prior to installation of the other original floors, FR 5 and FR 15, remains unclear as almost all of the planking at these locations had been replaced; however, a faint, possible score mark on original plank PS 3-3 at FR 15 seems to indicate that planking had been assembled to at least the third strake before floors were installed near amidships. Although not preserved, FR 27 appears to have been an original floor based on the nail holes on extant planking; if so, planking was assembled to SS 7-3, through the turn of the bilge, before that floor was installed.

The construction sequence at replacement floors is more difficult to interpret. Score marks just forward of replacement FR 19 on SS 4-2, surrounding a disused fastener hole, are likely the score marks from the original floor and therefore indicate that this floor had also been installed after the planks had been assembled to at least plank SS 5-4. Although FR 21, at the Keel 2-Keel 3 scarf, is also a clear replacement, its sided dimension is significantly larger than that of any other floor, even larger than that of the keel. However, score marks at the FR 21 location on original planks PS 3-3, PS 4-2, and SS 4-2 indicate a frame 7.5 cm sided, at locations where the replacement frame FR 21 is 10-14 cm sided. Thus, the score marks on these original planks almost certainly represent the original floor,[205] indicating that the planking had also been assembled up to

[205] It is very unlikely that the 7.5 cm-sided floor represented by these score marks was itself a replacement.

at least SS 5-4 before FR 21 was installed and bolted through the keel scarf. This further reinforces the fact that a bolted frame does not necessarily indicate an "active" or control frame but may equally reflect a desire to reinforce the hull.[206] Although not certain, the fact that score marks at FR 17 are present only on original planking and not on replacement planking suggests that the planking had been assembled to SS 5-4 prior to the insertion of FR 17.

Score marks and, in some cases, mortise-and-tenon joints at the locations of the original half-frames indicate that the edge-fastened planking (up to strake eight aft of amidships and strake nine forward of amidships) had been built up prior to the installation of half-frames FR 6, FR 8, FR 10, FR 20, FR 22, and FR 26. Analysis of score marks at replacement frames FR 4, FR 14, and FR 18 indicates that the original frames at these locations were likely also installed after the edge-fastened planking had been assembled.[207] Although the score marks are unclear, the presence of mortise-and-tenon joints on the lower edge of SS 8 at port-side replacement half-frames FR 12 and

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[206] Basch 1972, 16; Pomey 2004, 31; Pomey et al. 2012, 298. Bolted floors that reinforced the hull but were not control frames were found on the Madrague de Giens (Pomey 1998, 66-7), Dramont E (Santamaria 1995, 159-60, 179), and Yassıada 1 shipwrecks (Bass and van Doorninck 1982, 60, 82-3). Contrary to this, the bolting of certain frames to the ship's keel was taken as proof that they were installed prior to the assembly of the planking in the La Bourse ship (Gassend 1989, 117). The proximity of the frames to the keel, the bolts connecting the keel, frames, and sternson, and the attachment of the garboard to the keel—by means of iron nails rather than mortise-and-tenon joints—were cited by Jézégou (1983, 153-55) as proof that the bolted floors were erected prior to planking in the Saint-Gervais 2 ship.

[207] There is evidence that floor FR 4 was installed to replace a pair of half-frames (see Ch. IV, The Frames, Framing Pattern.) In this location, score marks on original planks indicate that the original half-frame was installed after the planking had been assembled to SS 8. At FR 14, the score marks on SS 8-1 indicate a half-frame just under 7 cm in sided dimension, while the replacement half-frame is 10 cm sided in this location, thus indicating that the score marks are from the original half-frame and that this was installed after planking had been assembled. At FR 18, the naturally twisted replacement half-frame does not follow the score marks on original planks, which align better with the original, disused nail holes, again suggesting the score marks, continuing up to the waterline, are from the original half-frame. At each of these three locations, score marks were found on the original planks but were not found on replacement planks.

FR 16 reveals that, even at what is likely the midship frame, nearly all of the edge-fastened planking had been assembled before the original half-frames were installed.[208] The presence of a mortise-and-tenon joint on SS 9-3 at FR 28 (not preserved) also indicates that planking was assembled to this point before the frame was added.

There are usually no score marks on the wales at original half-frames, indicating that the wales were put into place after the half-frames had been installed. The only exception to this is at original half-frame FR 24, where score marks on both SS 11 and SS 10 suggest that this half-frame was installed fairly late. Perhaps the shipwrights chose to tailor this half-frame to the form produced by the wale at this complex curve toward the ship's stem, a form which may have been difficult to predict considering the width of the first wale at this end.[209]

Summary of the Construction Sequence

Based on the evidence presented above and summarized in table 5.3, planking details from the forward half of the ship provide the best indication of the earliest stages of construction. If results from the bow are applied to the stern, it appears that the edge-fastened planking was assembled at least to the fifth strake before any of the floors were installed. The only possible exception could be FR 15, around amidships, but there is

[208] It is perhaps also noteworthy that the scarf tip on the only remaining original scarf on the edge-fastened planking, on SS 8-1 at FR 16, falls just short of the frame location and is instead fastened to the plank below it with a transverse nail rather than to the frame. At FR 16, there is only one edge-fastened plank above SS 8-3, SS 9-3, and this plank had been cut down here; it is thus unclear whether planking had been assembled to SS 8-3 or SS 9-3 before FR 16 was added, although the latter seems more probable.

[209] As on the Yassıada 1 ship, the wales were installed with growth oriented in alternating directions (Bass and van Doorninck 1982, 78-9). On YK 11's first wale, the direction of growth was from forward to aft, so this wale was widest and thickest, and thus most difficult to bend, at the forward end, near FR 24.

some evidence, albeit weak, for the assembly of at least three strakes before this floor was added.[210]

Floors FR 23, FR 25, and FR 27 were installed after planking had been assembled up to SS 7-3, through the turn of the bilge. Was this also the case for FR 17, FR 19, and FR 21? If all floors were installed at the same stage, the answer is yes. However, because these floors (FR 17, FR 19, and FR 21) only span up to SS 5-4 (just below the turn of the bilge), it remains unclear whether the planking was assembled only to SS 5-4 or to SS 7-3, as was the case farther forward. Logically, the former seems more likely, as the central floors would provide a framework to support the assembled planks as the turn of the bilge was planked; if this was the case, the floors were installed in two stages rather than one. However, there is no clear evidence for either, and what might today seem more logical does not necessarily apply in transitional ship construction.[211]

The situation with the half-frames is much clearer: nearly all half-frames were installed after the edge-fastened planking had been fully assembled, up to SS 8 in the stern and SS 9 in the bow.[212] It is noteworthy that the shipwrights do not appear to have installed any of the half-frames immediately after the floors, although they could easily have done so. The half-frames could have been nailed to the assembled planking below

[210] FR 15 remains relatively unclear due to the extensive replacement of planking at this location.
[211] As Hocker (2004b, 72) notes, "…modern ideas of what is easier or harder do not always apply to ancient craftsmanship."
[212] The only half-frames that remain unclear are FR 1 and FR 2, in the very stern of the ship, due to the replacement of planking here.

the turn of the bilge, thus providing a framework for planking above strake seven.[213] That the shipwrights chose to delay the installation of the half-frames until the planking had been assembled betrays the strength of the shell-based concept in the design and construction of the YK 11 hull below the waterline, even through the turn of the bilge. As shown in table 5.3, nearly all of the half-frames were installed at the same time, that is, after the edge-fastened planking had been assembled and before the wale was installed. The only possible exceptions are FR 1 and FR 2, which remain unclear, and FR 24, which was installed after the wale and SS 10 were in place.

The construction sequence after the installation of the half-frames is obscured to some extent by diminishing preservation. Once the half-frames had been installed, the first wale was added, attached to the half-frames with nails driven from the interior, and the planking between SS 8/SS 9 and the wale (SS 11) was nailed to the half-frames from the exterior. Due to the difficulty in positioning such a substantial timber as SS 11, it is probable that this was installed before SS 10 or, in the stern, SS 9; however, there is no direct evidence for this.

Due to the paucity of clear score marks on the upper strakes and wales, it is unclear whether futtocks were added before or after the first wale had been installed. Based on score marks at original futtocks F 13 and F 23, the latter appears more likely, but the futtocks may have been installed in multiple stages. Most of the floor futtocks do not appear to have been attached to the first wale (SS 11), and for those that were attached (F 3, F 4, F 7, F 9 and F 19), nails were driven from the exterior of the hull in

[213] A similar method was followed at the midship half-frame on the Yassıada 2 ship (van Doorninck 1976, 126-27).

all but one futtock (F 19). Perhaps one or more futtocks near the aft end of SS 11 were installed before the wale was added, so that the wale could be better secured at its weak aft end scarf.

Once the first wale and futtocks had been installed, the lower level of through-beams was added and locked in place with the second wale. The filler strake between wales may have been installed before the second wale was added, as the pieces of the filler strake fit into notches on the through-beams. However, these notches seem to be fairly shallow, which may indicate that the filler strake was added after the second wale was already in place; this would have greatly facilitated the fitting of the second wale. The second wale was attached to nearly all of the futtocks, with some nails driven from the interior and some from the exterior. Top timbers were then installed, forming a framework for the remaining wales and strakes, which were not preserved.

In overview, applying the results from the forward port quarter of the vessel to the entire hull, planks were assembled at least to the turn of the bilge prior to the installation of floors, and to strakes eight or nine (near the waterline) prior to the installation of half-frames.[214] Because the mortise-and-tenon joints with which the planks were assembled were weak, relatively widely spaced, and not locked in place with transverse pegs, it seems logical that one or more control frames aided in the shaping of the vessel. Traditional Greek shipbuilding methods indicate that a mold or a control frame would be most likely located near the center of the ship and around the transition to the bow and stern; according to Basch, in Mediterranean shipbuilding, the

[214] A similar method was found to be optimal in building the model of the Yassıada 1 ship (Bass and van Doorninck 1982, 73-4, 83).

midship frame often serves as a mold that is later incorporated into the final construction.[215] Such seems to have been the case on the Yassıada 2 ship, where the midship frame (a half-frame) was installed after as few as five strakes of planking, serving as an "active" frame for the upper strakes.[216]

There is no evidence to support the use of a control frame in the construction of YK 11. On the contrary, the presence of score marks along the edges of original frames and the presence of mortise-and-tenon joints in close proximity to the frame location rule out the presence of a control frame for the entire vessel forward of FR 15, near amidships (FR 16). There are also no score marks on the keel to indicate a control frame; however, the inner face of the keel was finished with an adze, and it is possible that score marks or other guidelines were adzed off or had otherwise worn off.[217]

There is a possibility that, instead of a control frame, a mold or temporary frame was used to guide the form of the hull planking. A disused nail hole on the keel at FR 15, a floor that in all other respects appears to be original, could be evidence of a temporary frame used in the construction of the ship.[218] Two other caulked holes along this line, on SS 7-4 and SS 8-1, could be further evidence of a temporary mold here, but are equally (and perhaps more) likely to be disused fastener holes from a replaced futtock; because F 15 was not preserved, it is impossible to tell. Two caulked holes, at FR 21-FR 22 on SS 5-SS 7, are better evidence of the use of a temporary support or cleat at complex

[215] Basch 1972, 35; Damianidis 1998, 218-19.
[216] van Doorninck 1976, 126-27.
[217] The keel of the 10th-century Bataiguier wreck, found off the coast of France, was clearly marked with an engraved symbol (Joncheray 2007, 220-21), and similar markings have been found on the keels of other ships at Yenikapı, including galley YK 4.
[218] A small, concreted oval hole was also found on the keel at the location of FR 20 but has no match on the frame; this half-frame also appears to be original.

curves.[219] A short, frame-like support piece was used to aid in the assembly of edge-fastened planking on the fifth-century Dramont E ship, although it was not removed after construction.[220] Something similar to YK 11's short, frame-like support piece FR 12A could very likely have been used in the initial construction and removed once the hull was built.

Based on the above information, the following sequence is proposed for the extant timbers. For steps at which there may be more than one interpretation of the assembly sequence, alternate scenarios are provided. Due to diminished preservation of the upper portions of the hull, the sequence following Step 5 is less reliable.

1. Keel timbers, stem and sternpost were assembled; scarfs were held in place with a rectangular wooden key but not yet bolted together.
2. A mold may have been added near amidships (FR 15?), but there is no clear evidence for this here.
3. Preserved score marks and mortise-and-tenon joints indicate that planking was assembled along the bottom of the ship, at least to strake five, just before the turn of the bilge. The floors in the central portion of the hull were then added, nailed to the keel (from interior) and planking (from exterior). The edge-fastened planking was then continued to strake seven, through the turn

[219] Other areas with a line of disused fasteners include FR 19-FR 20 on SS 5-SS 7 and FR 13-FR 14 on SS 8-SS 11; however, both of these include holes on repair planks and thus do not represent temporary supports used in the initial construction of the ship. These are likely unpreserved elements of framing that do not fit the otherwise regular framing pattern.
[220] Santamaria 1995, 146.

of the bilge, and the remaining floors, those toward the bow and stern, were then added. In this scenario, floors were installed at two different stages. Alternately, edge-fastened planking may have first been assembled to the lower portion of strake seven before any floors were installed. In this scenario, all floors were installed during the same stage.[221]

4. Preserved score marks and mortise-and-tenon joints indicate that the edge-fastened planking was continued to strake eight in the stern and strake nine in the bow (between the waterline of the empty hull and the load waterline).
5. Nearly all of the half-frames were installed (with the exception of FR 24), nailed to the keel (from interior) and planking (from exterior).
6. The stemson and sternson were added, bolted through frames and the keel scarfs at FR 4, FR 9, and FR 21. While this may have occurred later in the construction of the ship, this is the earliest point at which this could have occurred.
7. Some (but not all) futtocks were installed, likely including F 3, in view of the location of the wale scarf. The first wale was then installed, nailed to half-frames from the interior and to some of the futtocks from the exterior.
8. Planking strakes nine (the aft portion, lacking mortise-and-tenon joints) and ten were installed, filling the gap between the edge-fastened planking and the

[221] In theory, all of the ship's edge-fastened planking (to strakes eight/nine) may have been assembled before any element of framing was installed. While there is no evidence that this occurred, there is no evidence to the contrary. If this was indeed the case, Steps 3 through 5 would be merged into two steps: assembly of edge-fastened planking, followed by installation of framing. Although this sequence seems unlikely based on the nature of the YK 11 edge fasteners and Steffy's experiences in building the model of the Yassıada 1 hull (Bass and van Doorninck 1982, 73-4, 83), it cannot theoretically be ruled out.

first wale. While far less likely, this could conceivably have occurred before the first wale was installed; if so, this would be included in Step 7.

9. Score marks indicate that half-frame FR 24 and the remaining floor futtocks were installed after the hull planking was completed up to the first wale.
10. Through-beams were placed at four locations (FR 8-FR 9, FR 10-FR 11, FR 17-FR 18, FR 23-FR 24) above the first wale.
11. The second wale was installed (SS 13) and nailed to most of the futtocks from either the interior or exterior. Gaps between the through-beams were filled with short strakes of planking fastened to futtocks and half-frames with nails driven from the exterior. This conceivably might have been part of Step 10, but this is unlikely.
12. Through-beams were locked in place with long nails driven through the edge of adjacent wales.
13. Half-frame futtocks and, perhaps, top timbers were installed, providing a framework for wales and strakes above the second wale. The futtocks may have been installed in multiple stages.
14. Additional through-beams were placed at one or more locations along the upper edge of SS 13.
15. The remaining two wales (strakes 15 and 17) and the caprail were installed; the second level of through-beams was locked in place with long nails driven through the edge of adjacent wales. Additional strakes between wales and the caprail were installed, nailed to pre-erected framing.

16. Stringers and stanchion blocks were installed on top of framing.
17. Common ceiling was lightly fastened to the framing, filling gaps between the stringers.
18. The bulkhead partition was added at FR 8-FR 9. Sills were added above the top level of stringers.

Once the hull was completed to step 18, other hull components, which did not survive, would have been added. These include stanchions in the stanchion blocks, longitudinal timbers supported by the stanchions which provided lateral support for the mast, the mast step, the vertical support post forward of the mast, and partial decking at the bow and stern. The mast, quarter rudders, and other removable elements of the ship's rig and equipment would have been added once all other components of the hull were completed.

The hull would also have been payed with pitch on the exterior and on much of the interior; this occurred in several stages on the interior. Evidence indicates that the frames' outer faces were coated in pitch prior to installation in the planked shell;[222] the interior of the ship also seems to have been payed with pitch after the assembly of planks and frames but before the addition of stringers. Pitch was reapplied on the interior and exterior on several occasions. Applied caulking would also have been included within plank seams during the initial assembly of planking; this waterproofing material would

[222] This was also the case on the framing of the Yassıada 2 ship (van Doorninck 1976, 124).

have been renewed throughout the life of the vessel, either with driven caulking or, during the replacement of planks, applied caulking.

Altogether, the initial construction of YK 11 relied on a combination of both shell-first and skeleton-first techniques. Shell-first techniques dominate, primarily in the hull below the waterline. Planks, formed to some degree through char-bending, were edge-fastened with loose mortise-and-tenon joints. The presence of score marks and the location of mortise-and-tenon joints indicate the assembly of planks before most, if not all, frames were installed. A mold may have been used around amidships, but there is no clear indication that this occurred. Garboard edges were nailed to the ship's keel, and elements of the ship's framing were not attached to each other. Finally, the use of curved (S) scarfs in the planking both below and above the waterline betrays the shipwright's conservatism and a shell-based approach toward shipbuilding.[223]

Skeleton-first techniques are also well-represented, especially above the waterline, where edge fastening with mortise-and-tenon joints was abandoned. The weak scarf on the first wale (SS 11) required the pre-erection of certain futtocks. Below the waterline, all of the floors and half-frames were attached to the ship's spine, without exception; however, this attachment was usually relatively weak, using only iron nails. Bolts were only used at four frames, FR 4, FR 9, FR 21, and probably FR 29, which was not preserved.

Thus, in its design and initial construction, YK 11 reflects both shell-first and skeleton-first techniques, but its underlying philosophy is predominantly shell-based.

[223] Bass and van Doorninck 1982, 70-1.

The mix of techniques was continued through the numerous repairs to the vessel. Below the waterline, repairs did not utilize mortise-and-tenon joints, and butt joints and scarf tips were placed at frame locations, at times resulting in awkward or crudely-cut scarf forms. However, the shipwright also fastened the edges of the replacement garboard to the keel and continued to use the technique of char-bending to achieve curves in replacement planking. That FR 21 was removed from the keel bolt assembly during a late repair is an indication that the shipwright performing this repair did not consider a strong, interconnected framework to be an essential contribution to hull strength.

RECONSTRUCTION OF YK 11

Due to the extent and degree of preservation of the lower portions of the ship's hull, the wineglass-shaped form of the vessel to above the turn of the bilge could be reconstructed with relative certainty. The data obtained with the aid of a Total Station in 2008 proved less useful than anticipated due to the displacement of many frames and the splaying of planks.[224] As a result, the ship's lines were reconstructed based primarily on the form of the ship's keel and framing, recorded in 1:1 scale drawings during the post-excavation documentation of the ship's timbers.

Lines were created with the aid of Rhinoceros modeling software. The form of the keel was used as the basis of the reconstruction. Comparison of this form with the extant planking revealed very slight, post-depositional hogging of the central portion of the keel (Keel 2). The well-preserved port garboard aided in correcting this hogging as

[224] This data, however, was indispensable in creating the site plans for the wreck.

well as properly aligning the hook scarfs that joined the three elements of the ship's keel together. Although the ship's sternpost was not preserved, the curvature preserved in the hood ends of the stern planking aft of FR 4 allowed the profile to be extended with relative accuracy to just aft of FR 1. The preservation of Keel 3 to FR 27, and the identification of two UM timbers as the forward hood ends of strakes seven and nine (around the waterline), likewise provided a guide to the curvature of the ship's stem to well forward of the first preserved frame (FR 26). These curves at bow and stern were continued upward, approximately two meters at the stern and a little over one meter at the bow, to form the ship's endposts. The resultant profile is very similar to the gently-curving hull form reflected in roughly contemporaneous iconography.[225]

Using the form of the keel timbers and the extended curvatures noted above, the ship was reassembled by placing outlines of the ship's frames at their original positions within the port half of the hull. Many of the frames, especially the floors, were affected by compression damage and cracking, which had caused the floors to flatten slightly and the half-frames to become distorted. Much of the distortion, however, could be digitally corrected through closing the wide cracks on the inner faces of framing. In addition to this distortion, the use of primarily grown curvatures for the frames commonly resulted in hollows or irregular curves in the frame outlines. For this reason, every floor and half-frame was aligned in order to obtain the most accurate progression of forms possible. While a small number of frames proved problematic and could not be sufficiently

[225] Thus, the gentle curves seen in some of the iconography may not be a mere oversimplification of hull form, but may accurately reflect the form of some contemporaneous vessels. A ninth-century image illustrating the sermons of Gregory of Nazianzus (Grabar 1943, pl. LXXIII no. 1, from the Bibliotheque Ambrosienne of Milan, M. 35, 677) and the fifth- or sixth-century graffito from Corinth (Basch 1991a, 17, fig. 8; reproduced here as fig. 6.15) are especially noteworthy.

corrected (due in part to the irregularities of the natural form), the majority of frames aligned quite well. Once aligned, the irregularities due to the use of grown curvatures could also be correctly identified and smoothed out where necessary.

The alignment of the floors, half-frames, and futtocks along the reconstructed profile of the ship provided an accurate framework for the vessel at areas where framing was preserved. The curvature of the two half-frame futtocks preserved along the ship's side (F 12 and F 18) was extended up just slightly to produce the estimated height of the vessel's sheer line. Continuing the curvature of this sheer toward the ends was somewhat arbitrary due to the lack of upper-level framing preserved in these areas, but was drawn to reflect the curving sheer seen in the contemporaneous iconography.[226] Once this hypothetical sheer was established, the outlines of the extant framing could be extended upwards along a reasonable curvature to reach the sheer. Thus, the form of the hull where framing was not well preserved, as at the very ends of the vessel and above the first or second wale, could be reconstructed to produce the likely original form of the entire port side of the YK 11 hull.

Once the three-dimensional form of YK 11 had been created based on the extant hull remains, the ship's lines were generated by cutting through this form with waterlines, buttock lines, station lines, and a diagonal (fig. 5.3). Due to the ship's extensive preservation, waterlines were spaced just 25 cm apart; five waterlines were created. The hull was cut with three vertical planes, spaced 50 cm, to create the ship's

[226] The iconography tends to exaggerate this curvature, but nevertheless usually reveals a curving sheer, more lively at the stern than at the bow. Examples may be seen in Omont 1929, pl. CIV; Weitzmann 1979, 405 no. 361, 427 no. 385; and Weitzmann 1980, fig. 8a.

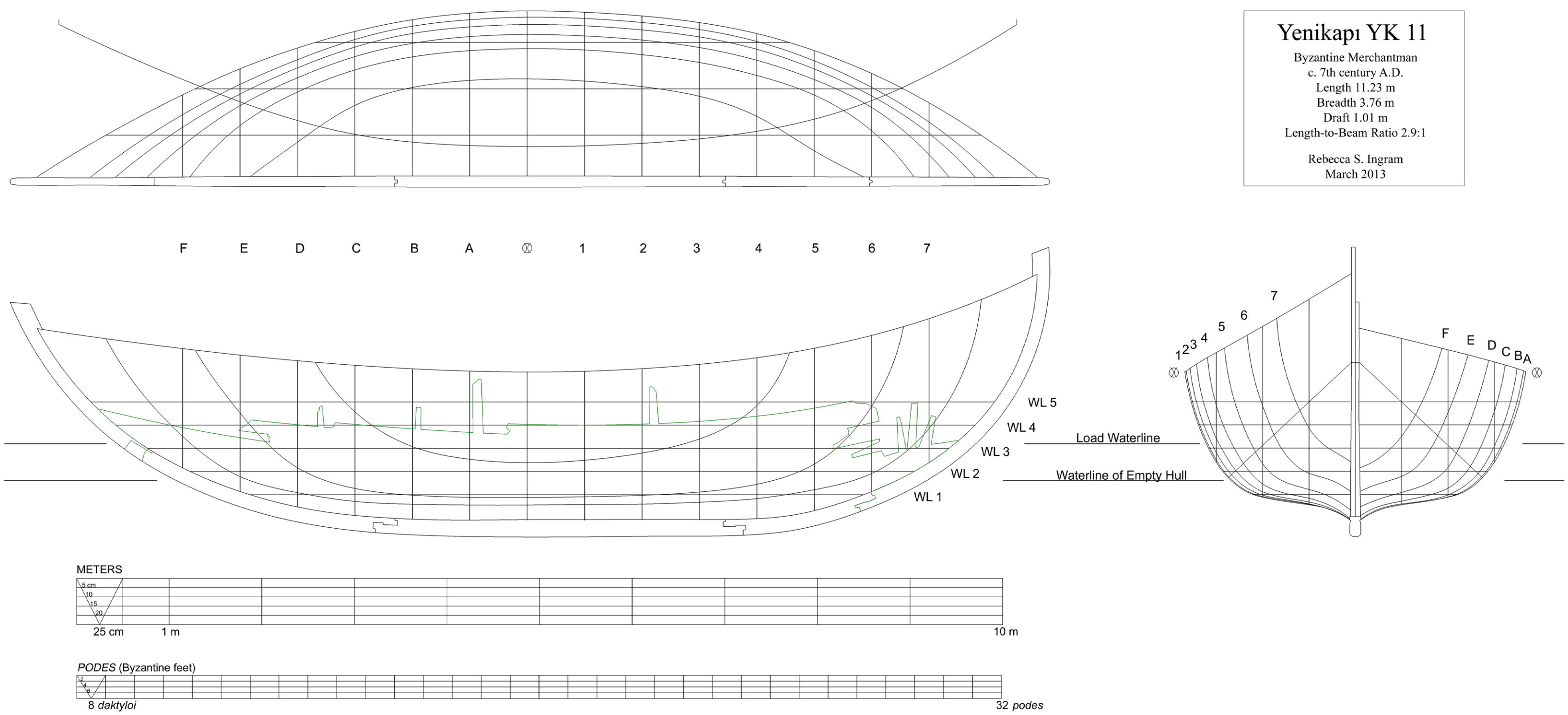

Figure 5.3. The YK 11 ship's lines. The green outline in the sheer view indicates extent of preserved material. Lines are shown in the traditional manner and represent the inner surface of the planking (Steffy 1994, 15).

buttock lines. From the midship frame (FR 16), station lines were evenly spaced at 62 cm intervals, approximately twice the average room and space.[227] The diagonal was placed such that it would cut through the ship close to perpendicular to the turn of the bilge near amidships, just below the second waterline; it was placed at an angle of 46.5° to the ship's centerline. The cross sections of the hull in figures 5.4 and 5.5 show the ship's preserved timbers at FR 16 (midship frame) and FR 9, respectively.

The principal dimensions of the hull are presented in table 5.4; weights and proportions are given in table 5.5. The flat portion of the keel is short, and the stem and stern curve gently into the endposts. Nevertheless, the central cargo hold was quite full at the load waterline, as reflected in the waterplane coefficient of 0.74, just slightly higher than the 0.7 of the 11th-century Serçe Limanı ship.[228] The fullness of the hull is also seen in the length-to-beam ratio of 2.9:1. The midship section, at the half-frame pair FR 16, is located very near the center of the ship.[229] Due to its wineglass-shaped bottom, the midship coefficient of just 0.68 highlights the relative inefficiency of this type of hull in terms of cargo capacity. However, the block and prismatic coefficients, 0.44 and 0.65 respectively, and the gently curving lines of this ship indicate a hull that, despite its fullness at and above the load waterline, would have been relatively sleek and swift, both desirable qualities in regions plagued by piracy.

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[227] Because the station lines were evenly spaced at this interval, they correspond roughly to half-frame locations, deviating only toward the extremities. Labeled station lines correspond roughly to YK 11 frame locations as follows: midship bend – FR 16; A – FR 18; B – FR 20; C – FR 22; D – FR 24; E – FR 26; F – FR 27-FR 28; 1 – FR 14; 2 – FR 12; 3 – FR 10; 4 – FR 8; 5 – FR 6; 6 – FR 3-FR 4; 7 – FR 1.
[228] Bass et al. 2004, 169, table 10-2.
[229] The midship section of the Yassıada 1 ship, in contrast, was located well aft of amidships in the vessel's reconstruction (Bass and van Doorninck 1982, 85).

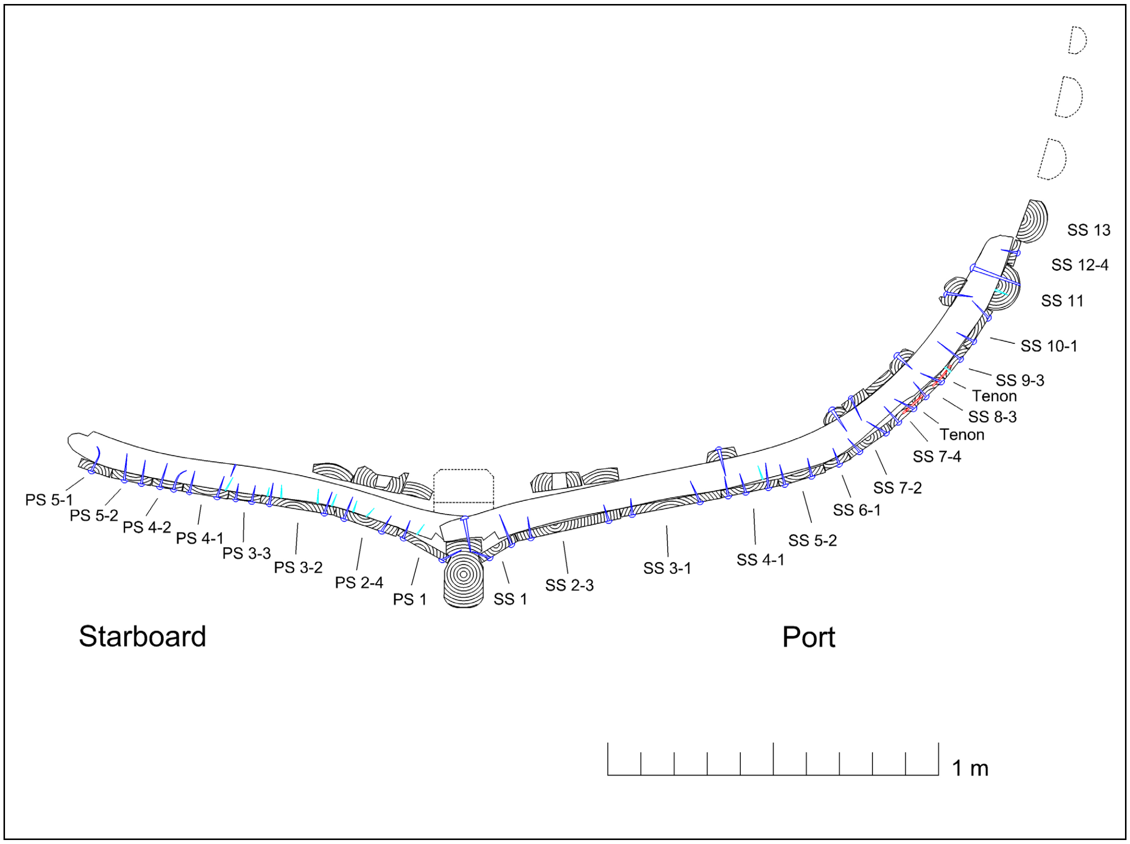

Figure 5.4. Section of the reassembled hull remains at FR 16 (midship frame). The starboard half-frame is original; the port half-frame is a replacement. Iron nails are shown in dark blue, abandoned nail holes in light blue, and mortise-and-tenon joints in red. Approximate wood grain, based on post-excavation documentation, is shown. Dashed lines indicate areas that were not preserved (mast step, upper wales, and caprail). Some stringers and stanchion blocks do not rest on the frames due to the larger molded dimension of floors forward and aft of FR 16.

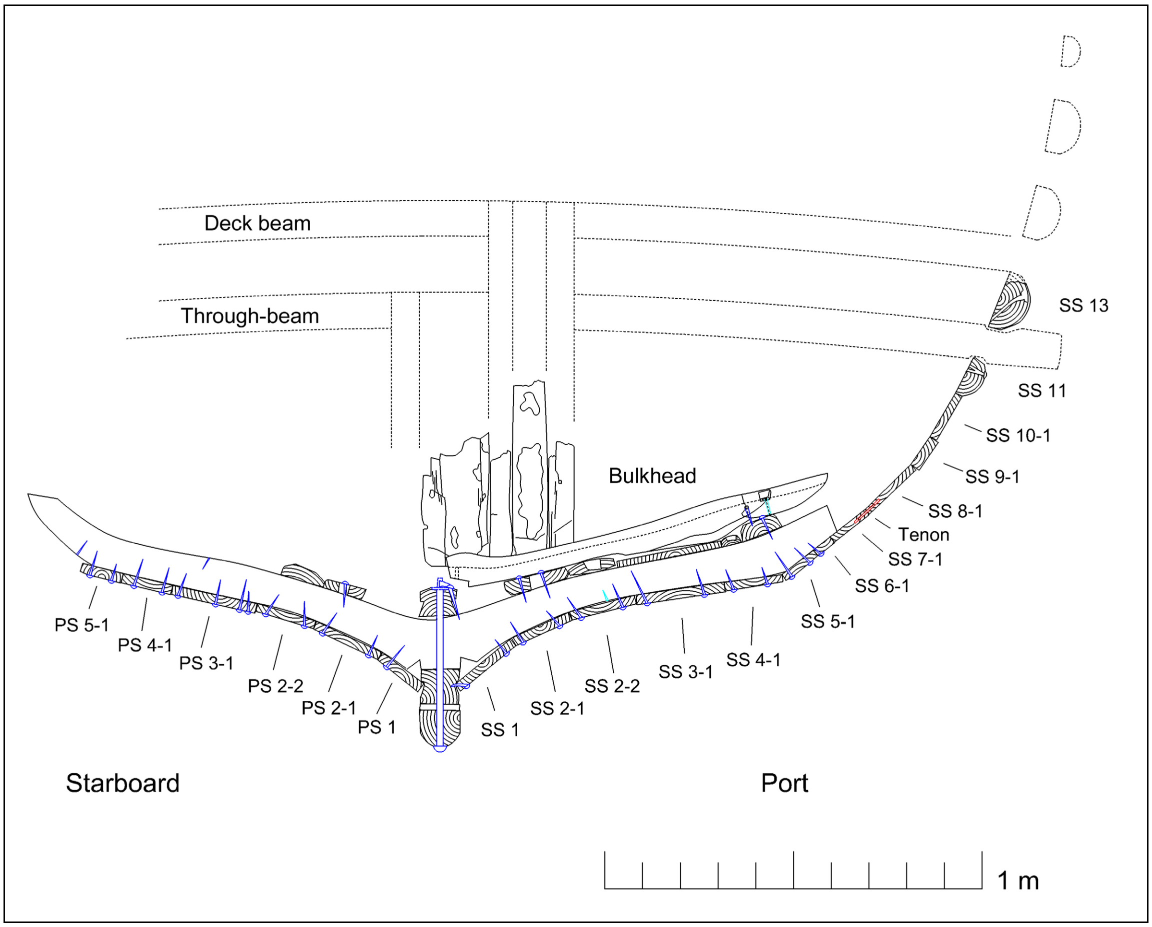

Figure 5.5. Section of the reassembled hull remains at replacement floor FR 9 (at Keel 1-Keel 2 scarf). Iron nails and bolt are shown in dark blue, abandoned nail holes in light blue, and mortise-and-tenon joints in red. Approximate wood grain, based on post-excavation documentation, is shown. Dashed lines indicate areas that were not preserved. In this reconstruction, the central bulkhead planks have been interrupted for the attachment of the lanyard from the halyard block to the deck beam.

Table 5.4. Principal dimensions of YK 11.

Category	Meters	Byzantine Feet[230]
Overall hull length	11.23	35.96
Length between perpendiculars	10.80	34.58
Length on load waterline (overall)	9.27	29.68
Length on load waterline (molded)	8.79	28.15
Length of keel (flat portion)	3.92	12.55
Breadth, maximum	3.76	12.04
Breadth, molded	3.68	11.78
Breadth, molded at load waterline	3.22	10.31
Draft at full load	1.01	3.23
Draft, molded	0.84	2.69

Table 5.5. Weights and proportions of YK 11.

Displacement at load waterline (LWL, 5 cm above WL 3 in ship's lines)	11.36 metric tons
Freeboard at LWL (est.)	0.77 m
Estimated weight of hull and its gear	3.5 metric tons
Estimated tonnage	7.86 metric tons (approx. 1,200 *modii)*
Length/beam ratio (topside)	2.9:1
Length/beam ratio (load waterline)	2.7:1
Waterplane area	20.82 m^2
Waterplane coefficient	0.74
Midship coefficient	0.68
Block coefficient	0.44
Prismatic coefficient	0.65

Due to the curving lower profile of this ship, traditional formulae for determining displacement proved ineffective.[231] However, because the ship was reconstructed using three-dimensional modeling software, an accurate volume of the ship could be attained

[230] The Byzantine foot used here is equal to 31.23 cm (Schilbach 1970, 16).
[231] Bass and van Doorninck 1982, 86.

at any location. The weight of the empty hull and its gear was estimated at 3.5 metric tons; the level at which the hull displaced an equivalent weight in seawater was found to be approximately 15 cm above the lowest waterline in the ship's lines (WL 1).[232] The waterline of the empty hull is marked on the ship's lines. The "seawater" graffito carved into stringer SST 4 (see Ch. IV, *Stringers*) was located between the waterline of the empty hull and the load waterline. The upper limit of the edge fastening of planks on YK 11 also corresponds roughly to the area between the waterline of the empty hull and the load waterline.

Cutting through the hull at what is presumed to be the load waterline (located 5 cm above the third waterline in the ship's lines, just below the lowest through-beam) produced a displacement volume of 11.08 m^3.[233] A submerged hull volume of 11.08 m^3 displaces 11,357 kg of saltwater or 11.36 metric tons. Subtracting the estimated weight of the hull and its gear, 3.5 tons, indicates a cargo capacity of approximately 7.86 metric tons. The estimated weight of the empty hull was calculated on the basis of the approximate actual (for preserved timbers) or likely (for timbers that were not preserved) volume of the components multiplied by the density of the type of wood that was used or would most likely have been used; the estimated weight for the various types of components is provided in table 5.6.

[232] This is based on a weight of 1,025 kg per cubic meter of saltwater.
[233] This includes the volume of the keel and planking below the load waterline.

Table 5.6. Estimated weight of the YK 11 hull components and other gear.

Component	Est. weight in kg
Keel timbers, stem, sternpost	180
Planking (including wales)	976
Framing	738
Ceiling (stringers, common ceiling, sills)	303
Stemson and sternson	12
Stanchion blocks	22
Bulkhead	35
Through-beams	200
Mast	113
Yard	41
Mast step	20
Stanchions	15
Forward and aft decks	110
Iron bower anchors (3 at 60 kg each)	180
Iron best bower anchor (1)	75
Quarter rudders (2)	30
Crew members (3)	200
Miscellaneous (sail, rope, nails, spare supplies)	250
Total weight of empty hull and gear	3,500 kg

The ship's calculated capacity indicates, as expected, that this sturdy merchantman was relatively small in comparison to its contemporaries. The ship could safely carry just 1,200 *modii*.[234] As late as the early seventh century, very large ships of up to 20,000 *modii* (around 133 tons) were still operating out of Alexandria, as mentioned in the *Life of St. John the Almsgiver*.[235] Yet, in a Novella of Theodosius II (A.D. 439), ships as small as 2,000 *modii* (around 13 tons) could be requisitioned for

[234] Calculations for tonnage are based on the average ton of wheat equal to approximately 150 *modii* (Rickman 1980, xiii; Plin. *HN* 18.12.66). Thus a ship with a capacity of 7.86 tons could carry approximately 1,200 *modii*.
[235] *John Alms.* supplement of Leontius 10.

service in the *annona*.[236] The 1,200 *modii* capacity for YK 11 is a conservative estimate that assumes the ship's through-beams would not have been submerged. However, the presence of caulking between the through-beams and wales may indicate that the ship was regularly loaded in excess of the 1,200 *modii* estimate. Table 5.7 provides the hull's displacement and cargo capacity in both metric tons and *modii* at several different waterlines.

Table 5.7. Displacement and cargo capacity of YK 11 at various waterlines.

Location of waterline	Displacement in m^3	Displacement in metric tons*	Cargo capacity, metric tons**	Cargo capacity, *modii****	Note
WL 1	1.52	1.56			
10 cm above WL1	2.83	2.90			
15 cm above WL 1	3.58	3.67	0.17		Approx. waterline of the empty hull
20 cm above WL 1	4.39	4.50	1.00	150	
WL 2	5.23	5.36	1.86	279	
WL 3	10.02	10.27	6.77	1016	
5 cm above WL 3	11.08	11.36	7.86	1179	Est. load waterline
10 cm above WL 3	12.17	12.47	8.97	1346	
15 cm above WL 3	13.29	13.62	10.12	1518	
20 cm above WL 3	14.43	14.79	11.29	1694	
WL 4	15.60	15.99	12.49	1874	
5 cm above WL 4	16.79	17.21	13.71	2056	
10 cm above WL 4	18.00	18.45	14.95	2243	
15 cm above WL 4	19.24	19.72	16.22	2433	

* Based on a weight of 1,025 kg per cubic meter of saltwater.
** Total displacement less the weight of the empty hull (est. 3.5 tons).
*** Based on a ton of wheat equal to approx. 150 *modii* (Rickman 1980, xiii; Plin. *HN* 18.12.66).

[236] *Cod.Theod.* Theodosius II Nov. 8; Rougé 1966, 72.

Considering the contraction in trade that was occurring in the centuries leading up to and including the seventh century, and the return to small enterprise, the increasing use of smaller vessels is logical.[237] The use of smaller ships is reflected in the finds at Yenikapı, where most of the merchant vessels discovered are 15 m or less in length. Thus, while YK 11 was a smaller ship, it was perhaps not abnormally small.

YK 11 AND THE STUDY OF TRANSITIONAL SHIP CONSTRUCTION

The reconstruction of YK 11 is based on a thorough analysis of each individual timber and a comparison with roughly contemporaneous vessels. This study has identified several features that must be carefully considered in the analysis of Mediterranean ships of the first millennium A.D.

Repairs

The extent to which the YK 11 hull was repaired is perhaps its most important feature and that which holds the most significant implications for the study of transitional shipbuilding. A ship's repairs reveal a great deal about craftsmanship and how the shipwrights formulated solutions to problems.[238] Furthermore, identifying and properly interpreting repairs are essential to understanding a ship's construction and the shipwright's philosophy; failing to consider repairs could easily allow one to misinterpret even basic structural elements.[239] If a ship has been heavily repaired, as is the case in YK 11, its construction can only be fully understood after dismantling and

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[237] Lopez 1959, 71; Rougé 1966, 268.
[238] Steffy 1999, 395.
[239] Steffy 1999, 395.

thorough analysis, including a careful matching of fastening patterns, especially those between the planking and the framing.[240]

On YK 11, the mortise-and-tenon joints of the original planking below the waterline were not implemented in the repairs; the tenons were simply cut through and abandoned. "Patch" tenons have been identified in older ships as late at the second century A.D. but were not used on YK 11; perhaps this indicates that the shipwright considered the mortise-and-tenon joint as something that was useful during initial construction only, or perhaps he simply did not think the benefits provided by such joints were worth the labor required to create them.[241]

Subtle changes in the ship's framing also occurred over the course of these repairs. During the initial construction, the shipwright ensured that the flat, sawn face of each floor or half-frame was oriented toward amidships. In repaired frames, this was only the case on four of the nine replacement floors; only three of the replacement half-frames possessed a flat, sawn face, and none was oriented toward amidships. Although not certain, the evidence also seems to indicate that floor FR 4 was installed to replace a pair of half-frames at this location. The change in frame size during repairs is perhaps more significant: on average, replacement floors and half-frames are approximately 15-20% larger in sided dimension than their original counterparts. Perhaps these changes made to the original pattern and style of framing reflect alterations by a different

[240] Steffy 1985, 101.
[241] "Patch" tenons were observed on the fourth-century B.C. Kyrenia ship (Steffy 1985, 85 fig. 9, 97-8), the first-century A.D. Herculaneum ship (Steffy 1999, 397-98), and the second-century A.D. Grado ship (Beltrame and Gaddi 2007, 144).

shipwright, or perhaps they merely reflect the materials available during the repairs. These changes might also indicate compensation for a weaker hull.

Just as important as recognizing what changed in the ship over the course of its use and repair is identifying what did not change. Although the mortise-and-tenon joints were abandoned during later repairs, the use of char-bending was not. Char-bending could be implemented just as easily during repairs as it was during the initial construction, which was certainly not the case with edge joinery. Char-bending was used extensively in the planking toward the ship's extremities, facilitating the complex curves in these areas. How the shipwright conceived of this technique is to some extent unclear, but the use of char-bending may indicate an effort to achieve the desired form through shaping a plank independent of the ship's framing, even though the framing was already in place. If so, this may simply reflect the weakness of the short nails which fastened the planking and framing together, but it may also reflect a lingering conception of the hull planking as a shaped entity in and of itself.

Admittedly, YK 11 is an extreme case; the extent of repair to this ship is without parallel in the archaeological evidence of Mediterranean ships of the first millennium A.D., based on the published material. Yet is this ship abnormal? Repairs to ancient vessels are very common, and one of the primary obligations of the *navicularii* was to carry out annual repairs to their ships.[242] Many of the ships mentioned above have had some kind of repair, with timbers either replaced or reinforced; publications indicate repairs to the Kyrenia, Fiumicino 1, Port-Vendres 1, Tantura A, Tantura E, Port Berteau

[242] *Cod.Theod.* 13.5.14.

II, Saint-Gervais 2, Bozburun, Yenikapı YK 1 (late 10th century), YK 6 (10th-11th century), YK 23 (late 8th century), and YK 24 (late 10th century), and Serçe Limanı shipwrecks.[243] Of these, both the Tantura A (late fifth or early sixth century) and Saint-Gervais 2 (seventh century) ships have been identified as early examples of skeleton-based construction; however, based on similarities with YK 11, these conclusions should be reassessed in light of possible repairs.

Edge Fasteners

While it is by no means the only aspect to consider, the planking edge fasteners remain a significant feature that must be thoroughly studied in transitional ship construction.[244] YK 11 and other shipwrecks of seventh-century date, including the shipwrecks at Saint-Gervais, Pantano Longarini, and Yassıada, were some of the last ships built with mortise-and-tenon joints along plank edges, thus concluding a long tradition in shipbuilding which dates back to the Bronze Age.[245] The characteristics of such joints are identical despite the geographic range represented by these seventh-century ships: tenons are small and thin, much smaller than their respective mortises, relatively widely spaced (in comparison to edge fasteners of earlier ships), and not locked in place with transverse pegs. By the following century, these joints fall out of

[243] For Kyrenia, Steffy 1985, 95-9; for Fiumicino 1, Boetto 2000, 101; Boetto 2008, 47-8; for Port-Vendres 1, Liou 1974, 428; for Tantura A, Kahanov and Royal 1996, 22; Kahanov et al. 2004, 117-18; for Tantura E, Israeli and Kahanov 2012, 44; for Port Berteau II, Rieth et al. 2001, 74-5; for Saint-Gervais 2, Jézégou 1983, 33; for Bozburun, Harpster 2005a, 273, 296; for YK 1, Pulak 2007a, 209-11; for YK 6, Kocabaş 2008, 103; for Serçe Limanı, Bass et al. 2004, 165. A plank of the Dramont F ship is said to be lacking in mortises, which may also indicate a repair (Joncheray 1975a, 123).
[244] Pomey et al. 2012, 236; Steffy 1994, 83-5, fig. 4-8; van Doorninck 1976, 122-23, fig. 7.
[245] Jézégou 1983, 46-7; Jézégou 1989, 140; Throckmorton and Throckmorton 1973, 263; Bass and van Doorninck 1982, 55; Pulak 1999, 213-14.

use altogether, being replaced by coaks or dowels, as on the late eighth-century Yenikapı ship YK 23, or simply abandoned.

These weak, widely-spaced edge fasteners are the end-product of a gradual, centuries-long diminishing of the structural value of these joints. In the fourth-century B.C. Kyrenia ship, the tenons were larger, filling the mortises, were locked in place with wooden pegs, and were spaced an average of 12 cm apart.[246] By the fourth or fifth century A.D., tenons were generally smaller than their respective mortises and more widely spaced; this was noted on the Dramont F and Yassıada 2 shipwrecks.[247] Slightly later, shipwrights began to experiment with mortise-and-tenon joints that were not locked in place with transverse pegs. Several of the mortise-and-tenon joints on the fifth-century Dramont E shipwreck were locked with pegs on one side of a seam but were unpegged on the other side.[248] On the fourth- or fifth-century Fiumicino 1 ship, the shipwright used a combination of pegged mortise-and-tenon joints, unpegged mortise-and-tenon joints, and joints that were pegged on one side only.[249] Such a mix of pegged and unpegged mortise-and-tenon joints may indicate that these joints were, by the fifth century, viewed primarily as an aid in construction rather than a structurally significant element in the finished hull.

Through experimentation on ships such as Dramont E and Fiumicino 1, shipwrights discovered that planking could be assembled using unpegged mortise-and-

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[246] Steffy 1985, 81.
[247] Joncheray 1975a, 123; Joncheray 1977, 5-6; van Doorninck 1976, 122-23. The spacing between mortise-and-tenon joints was usually 25-32 cm on the Yassıada 2 ship. The fourth-century Pointe de la Luque B wreck, on the other hand, retained closely-spaced mortise-and-tenon joints, on average 10-12 cm apart (Clerc and Negrel 1973, 65).
[248] Santamaria 1995, 144.
[249] Boetto 2000, 100; Boetto 2008, 39-40.

tenon joints, which required less labor and material than their pegged counterparts. The fifth-century shipwreck at Parco di Teodorico may be the earliest known ship built entirely with unpegged mortise-and-tenon joints.[250] By the seventh century, planks were typically edge-fastened solely with unpegged mortise-and-tenon joints below the waterline, before this technique gave way to the use of coaks, which were both labor efficient and less likely to split and damage a plank.

In addition to the mortise-and-tenon joints, the attachment of the garboard to the keel on YK 11 is similar to that of other seventh-century ships and again reflects the gradual development of this particular joint through transitional shipbuilding. Like those of YK 11, the lower garboard edges of the Saint-Gervais 2 and Yassıada 1 ships were primarily attached to the keel not with mortise-and-tenon joints (although one such joint was observed on the Yassıada garboard), but with iron nails driven diagonally through the garboard edge into the ship's keel.[251] The use of diagonal nails as the sole direct attachment between the garboards and keel continued into the 8th to 10th centuries, recorded on the Bozburun, Tantura E, and Yenikapı YK 3, YK 15, and YK 23 ships.[252]

The use of iron nails in attaching the garboard to the ship's keel gradually developed out of a stronger attachment with mortise-and-tenon joints. On the Pointe de la Luque B, Port-Vendres 1, and Yassıada 2 ships, the garboards were attached to the keel with pegged mortise-and-tenon joints in the central part of the ship; these joints were not implemented toward the ship's extremities, though, and the joint was instead

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[250] Medas 2001, 112; Medas 2003, 46.
[251] Jézégou 1983, 46; Bass and van Doorninck 1982, 59; van Doorninck 1967, 88 note 5.
[252] For Bozburun, Harpster 2005a, 240, 335; for Tantura E, Israeli and Kahanov 2012, 44; for YK 3 and YK 15, Kocabaş 2008, 152, 164. Yenikapı YK 23 has not yet been published; personal observations were made during excavation in 2008.

achieved with diagonal iron or (in the case of Port-Vendres 1) copper nails.[253] By the time of the seventh-century Yassıada ship, these nails were used all along the garboard edge, reinforced with a few widely scattered mortise-and-tenon joints.[254] These labor-intensive joints were eventually abandoned altogether for the diagonal iron nails. Other ships at Yenikapı, of the late 9th to late 10th centuries, indicate a return to wooden edge fasteners between garboard and keel; the garboards of Yenikapı ships YK 1, YK 5, YK 14, and YK 24 were fastened to their keels with wooden coaks.

The plank-edge fasteners of YK 11, both the mortise-and-tenon joints along plank edges and the iron nails along the garboard edge, are very similar to those of other seventh-century ships and reflect just one stage in the development of these joints. The detail from this ship and from other merchantmen of preceding centuries both confirms and contributes to the timeline of the gradual development of edge fasteners first proposed by van Doorninck and Steffy.[255]

Surface Detail

Seemingly minute surface detail on individual timbers can greatly influence the interpretation of the overall hull. Although the conditions of excavation or preservation do not always allow for such detailed study of the timber surfaces, it should be undertaken whenever possible

On YK 11, the identification of score marks on the ship's planking has been most informative. In some areas, this detail could only be seen after pitch was removed from

[253] Negrel 1973, 60; Liou 1974, 422; Bass and van Doorninck 1971, 30; van Doorninck 1976, 120. Iron fasteners were also used toward the extremities in the Parco di Teodorico ship's garboard as well, and may have been used along its entire length (Medas 2001, 112).
[254] Bass and van Doorninck 1982, 59; van Doorninck 1967, 88 note 5.
[255] Steffy 1994, 83-5, fig. 4-8; van Doorninck 1976, 122-23, fig. 7.

plank surfaces. Even after pitch was removed, the score marks could be difficult to identify, being at times only visible in raking light. These marks, combined with the identification of repairs and the location of mortise-and-tenon joints, were the key to understanding the construction sequence of YK 11. Score marks have been used to aid in the interpretation of hull remains on several other shipwrecks, including the Ma‘agan Mikhael (fifth century B.C.), Port-Vendres 1 (A.D. 400), and Yassıada 1 (seventh century) shipwrecks.[256] Score marks were also noted on the second-century Saint-Gervais 3 and the mid-fifth- to mid-sixth-century Dor D shipwrecks, although their presence does not seem to have influenced the interpretation of the hulls.[257]

The removal of pitch is also important as disused fastener holes may be filled and sealed with a layer of pitch. Caulked or pitched fastener holes on planking at frame locations may indicate replacement of a frame, while such holes between frame locations may indicate the use of temporary supports or cleats during construction; examples of both seem to be present on YK 11. Pitched-over fastener holes were also identified on the inner face of original frames and prove that the stringers and common ceiling were removed and reattached during overhauls.

Finally, the identification of the use of char-bending on both original and repair planking of YK 11 has revealed the importance of this technique in ancient shipbuilding. Although it has been noted in the publications of several other shipwrecks, its importance has not been emphasized.[258] According to Basch, “To the historian of naval

[256] Mor 2004, 168; Liou 1974, 432; Bass and van Doorninck 1982, 71.
[257] Liou et al. 1990, 236-37, figs. 98 and 100; Kahanov and Royal 2001, 260-61, table 3.
[258] Barkai and Kahanov 2007, 24; Kahanov and Royal 1996, 22; Kahanov et al. 2004, 117; Kingsley 2002, 8 fig. 15, 19; Santamaria 1995, 143; Steffy 1985, 84, 94; Steffy 1999, 403.

architecture, what matters most is the evolution of structural method and the shapes of vessels."[259] As such, a technique such as char-bending, which aided in achieving the desired shape of the vessel, both with and without edge fasteners, has been unjustly overlooked. The use of char-bending on YK 11 could be identified through a blackened or charred surface, at times trimmed with an adze, and a notable hardening of the plank surface. Pitch removal may also be necessary to identify char-bent areas, but on YK 11 the pitch tended not to adhere to charred surfaces as frequently as to uncharred surfaces.

Caulking

The presence of caulking is often cited as evidence of a skeleton-based construction; recently, Pomey, Kahanov, and Rieth described seam-caulking as "…a significant archaeological fingerprint of a skeleton-based hull."[260] Caulking, however, is often poorly preserved and can be difficult to interpret. Even well-preserved caulking on YK 11, both driven and applied, was easily washed away during cleaning and was almost never preserved along plank edges that had been exposed. This being the case, the lack of preserved caulking noted on some shipwrecks may not necessarily be evidence that caulking was never present; this is especially true for ships that have not been fully excavated.

According to Steffy, "Mortise-and-tenon construction did not permit driven caulking…."[261] Basch concurs, interpreting several texts as evidence that the activity of caulking a ship's plank seams was foreign to Mediterranean shipbuilding in Antiquity;

[259] Basch 1972, 52.
[260] Pomey et al. 2012, 288-89, table 2; 297.
[261] Bass and van Doorninck 1982, 72.

he also notes that all “true” caulking is driven caulking.[262] However, Basch also notes that, for later transitional ships, in which mortise-and-tenon joints were more widely spaced, the hull was no longer the strong, watertight shell it had once been; in such cases, then, driven caulking was no longer technically inconceivable and was, instead, quite suitable.[263]

Basch’s argument is well supported by the archaeological evidence. Caulking was found on the early fifth-century shipwrecks Dramont E and Port-Vendres 1, both of which were edge-fastened.[264] On the Dramont E wreck, Santamaria notes that the caulking helped compensate for irregularities along plank seams. In addition to these earlier ships, caulking was noted on several other ships that were edge-fastened to some extent (either with coaks or mortise-and-tenon joints), including the Saint-Gervais 2 and Bozburun ships as well as all eight of the Yenikapı ships documented by INA, which range in date from the seventh to the late tenth century.[265] It is also noteworthy that, although caulking was not observed, a caulking iron was found on the Yassıada 1 ship.[266]

Analysis of the waterproofing material of YK 11 indicates that both applied caulking and driven caulking were used on this ship. The waterproofing fibers found on either side of mortise-and-tenon joints may best be described as applied caulking.

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[262] Basch 1986, 187-89.
[263] Basch 1986, 193.
[264] Liou 1974, 422, fig. 7; Santamaria 1995, 149-50.
[265] Jézégou 1983, 36; Harpster 2005a, 90, 222; Ingram and Jones 2011, 20; Pulak 2007a, 205-6. Caulking was also found on several other ships at Yenikapı, including YK 3, YK 6, YK 7, and YK 9, all of which were edge-fastened with coaks; these are being studied by a team from Istanbul University (Kocabaş 2008, 103, 125, 132, 157).
[266] Bass and van Doorninck 1982, 248-49.

However, in other areas on YK 11, even along unrepaired, edge-fastened seams, the orientation of the waterproofing fibers, perpendicular to the length of the plank, indicate a driven caulking. Some of the cut tenons on YK 11 suggest that the caulking process entailed the cutting of tenons with a knife before the caulking was driven in with a caulking iron. Because the waterproofing material appears to be similar, whether it was applied to a seam prior to assembly or driven into a seam after the planks were assembled, it can be difficult to determine whether it is applied or driven caulking, except where very well preserved.

In YK 11, as well as several other shipwrecks of fifth- to tenth-century date, caulking was present along edge-fastened plank seams, thus challenging the conventional wisdom that edge-fastened planking was not caulked. In the argument of whether or not caulking indicates a skeleton-based construction, the distinction between applied and driven caulking is to some extent irrelevant, as either form of waterproofing material indicates a plank seam that was not tightly sealed. Thus, the presence of waterproofing fibers along plank seams, whether applied or driven caulking, may reflect a gradually diminishing focus on the strength and watertightness of the external shell, but should nevertheless not be interpreted as the indication of a purely skeleton-based construction.

Attachment of Frames to the Keel

According to Basch, an "active" frame is necessarily attached to the ship's spine, while a "passive" frame may or may not be attached.[267] In the fourth-century B.C.

[267] Basch 1972, 16.

Kyrenia ship, none of the frames was attached to the ship's spine.[268] In contrast, all of the YK 11 frames that crossed or met the keel were fastened to it, either with a bolt or one or more iron nails. Analysis of score marks on the YK 11 planking indicates that many of these frames and at least one of the bolted floors was a "passive" frame, having been inserted after the planking had been assembled. Although the situation is obscured by numerous repairs, there is no evidence of an "active" frame in the extant hull of YK 11 below the waterline.

The bolting of frames to the ship's keel is a significant detail of its construction; in transitional shipbuilding of the first millennium A.D., this attachment reflects a shift toward strengthening the hull's internal framework. However, the evidence from YK 11 and several other ships provides further support for Pomey's argument that the bolting of a frame to the ship's spine is not necessarily proof that the frame was an "active" frame.[269] That every frame of YK 11, without exception, was attached to the ship's spine in a hull that was shell-built below the waterline is noteworthy. The evidence from YK 11, therefore, indicates that one should avoid over-interpreting the attachment of frames to the keel without also considering the context of other hull features such as score marks and the locations of edge fasteners.

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[268] Steffy 1985, 85.

[269] Pomey 2004, 31. "Passive" frames were bolted to the keel on the Madrague de Giens (Pomey 1988, 406), Dramont E (Santamaria 1995, 179), and Yassıada 1 (Bass and van Doorninck 1982, 60) shipwrecks.

Reconsidering a Skeleton-Based Construction

In light of the above observations, and through comparison with the hull of YK 11, the construction of two roughly-contemporaneous ships, Tantura A (late fifth or early sixth century) and Saint-Gervais 2 (seventh century), will be briefly reconsidered.

Tantura A is said to be the one of the earliest examples of skeleton-based hull construction in the Mediterranean, based on the use of iron nails, the presence of caulking along plank seams, butt joints at plank ends, and the lack of mortise-and-tenon joints along exposed plank edges.[270] However, plank seam caulking and the exclusive use of iron nails are also features of YK 11, which primarily followed a shell-based tradition. The lack of edge fastening along plank edges and butt joints at plank ends are also key features of several of YK 11's many replacement planks. Like YK 11, Tantura A had planks that were char-bent into form.[271] Could Tantura A also represent a similarly heavily-repaired vessel?

Several repairs to the Tantura A planking were noted, including graving pieces.[272] Two such graving pieces are described as small slats, 4-5 cm in width, along strake edges; these are very similar to the rectangular graving pieces of YK 11, which often filled areas along strake edges that were cut out between two or more damaged mortises. Although the use of char-bending, lack of edge fasteners on exposed planking, butt joints at frame locations, and planking repairs (especially the graving pieces) are not necessarily evidence that this hull is, like YK 11, a heavily repaired vessel that was

[270] Kahanov and Royal 1996, 23; Kahanov 2001, 268; Pomey et al. 2012, 260.
[271] Kahanov and Royal 1996, 22; Wachsmann and Kahanov 1997, 6; Kahanov 2001, 268; Kahanov et al. 2004, 117.
[272] Kahanov and Royal 1996, 22; Kahanov et al. 2004, 117-18.

originally built according to a shell-based tradition below the waterline, this cannot be ruled out without complete excavation, recovery, and detailed post-excavation study of the hull remains.

In comparing the Saint-Gervais 2 and YK 11 hulls, several of the former's features reflect a stronger internal framework and a weaker exterior shell. The sternson is larger than the ship's keel and is bolted through five frames; the YK 11 sternson, in contrast, is just slightly smaller than the keel and is only bolted through two frames.[273] The Saint-Gervais 2 sternson is furthermore locked in place both laterally as well as longitudinally through notching over frames.[274] The two central stringers are more substantial than those of YK 11 and are oriented in a way that lends significant longitudinal support to the ship's spine.[275] The Saint-Gervais 2 wales were attached to the exterior of the planking, thus reflecting a weaker girdling than that of YK 11.[276] Finally, two of the pairs of half-frames were held together with a transverse iron fastener.[277]

These features, combined with the paucity of mortise-and-tenon joints on plank edges and the fastening of the majority of frames to the ship's spine (either with bolts or iron nails), have led to the conclusion of a frame-first and skeleton-based construction for the Saint-Gervais 2 hull.[278] Jézégou admits that, although the attachment of frames to the keel does not necessarily indicate "active" frames, this feature, in combination with

[273] Jézégou 1983, 31-3, 75; Jézégou 1989, 139.
[274] Jézégou 1983, 46.
[275] Jézégou 1983, 38-9.
[276] Jézégou 1983, 48-9.
[277] Jézégou 1983, 156.
[278] Jézégou 1983, 119-21, 158-61; Jézégou 1989, 141-43.

other elements of the ship's construction, especially the paucity of edge fasteners, justifies a skeleton-based identification.[279]

Nevertheless, some characteristics of the Saint-Gervais 2 hull conversely reflect a stronger shell and a weaker skeleton than those of YK 11. First, the garboards are fastened to the keel in the same manner, but the Saint-Gervais 2 garboards are attached with iron nails spaced twice as close (average 15 cm) as those of YK 11 (average 29 cm).[280] Second, only two-thirds of the Saint-Gervais 2 frames are attached to the keel, with either bolts or iron nails, in contrast to all of the YK 11 frames.[281] There are also three floors that are composite, with a separate block of wood compensating for a gap between the floor and the keel; this introduces a weakness into the Saint-Gervais 2 hull's internal structure.[282] In addition to these, the use of diagonal scarfs within strakes of planking seems to betray a shell-based tradition; Steffy notes that, based on experiences in creating the model of the Yassıada 1 ship, a scarf of this type was much more difficult to create than a butt joint and would have provided no obvious benefit in a skeleton-based hull.[283]

The feature that is cited most often in support of Saint-Gervais 2 being a skeleton-based hull is the paucity of mortise-and-tenon joints along plank edges. The joints were sparse and irregularly spaced; "blind" mortises as well as mortises lacking a

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[279] Jézégou 1983, 164-65.
[280] Jézégou 1983, 46.
[281] Jézégou 1983, 82.
[282] Jézégou 1983, 33-5.
[283] Bass and van Doorninck 1982, 70-1. The use of three-planed scarfs in the Serçe Limanı hull (Bass et al. 2004, 107), however, suggests that the presence of a diagonal scarf does not necessarily indicate a shell-based hull.

tenon were observed.[284] Jézégou has also noted that, although the planking was not dismantled, the planks had become displaced in such a way as to expose many of the edges; this would not have been the case had the planks been edge-fastened with any regularity, and it furthermore allowed the excavators to confirm the rarity of the mortise-and-tenon joints.[285] She concludes that the mortise-and-tenon joints did not play a role in the ship's construction, and the presence of only a small number of the joints on the ship is a result of its having been built in a shipyard accustomed to shell-based shipbuilding.[286]

In light of the evidence from YK 11, however, it seems far more likely that the lack of regular edge fastening in the Saint-Gervais 2 hull is a result of extensive repair rather than an indication of skeleton-based shipbuilding. Many of the odd features of the mortise-and-tenon joints—irregular edge-fastener spacing, mortises lacking a tenon, "blind" mortises, and planks entirely lacking in mortises—are common to both ships. Furthermore, many of the tenons on intact seams of YK 11 had been cut through; this can and, in many areas, did lead to displacement of edge-fastened planks on YK 11 in a manner similar to what was described for the Saint-Gervais 2 ship.

That the Saint-Gervais 2 hull was aging and in need of repair is indicated by the presence of six reinforcement futtocks, inserted between frames and not extending to the ship's keel, that doubled-up the framing and reinforced the hull planking along the port

[284] Jézégou 1983, 46-7, 85; Pomey et al. 2012, 265-66. Jézégou suggests that "blind" mortises may result from the use of a plank cut with mortises in advance of its use; considering the variability in spacing of mortise-and-tenon joints on most ships, however, this seems unlikely.
[285] Jézégou, pers. comm.
[286] Jézégou 1983, 181.

side.[287] Unlike on YK 11, the Saint-Gervais 2 shipwright chose to add additional frames rather than replace existing frames. If the framing required reinforcement in this manner, would not the planking also have required some kind of repair? This would have almost certainly resulted in the introduction of planks lacking edge fasteners.

If the Saint-Gervais 2 ship was heavily repaired, which seems likely based on a comparison with YK 11, its identification as a skeleton-based hull must be reconsidered. This ship, typical of many ships during this period, exhibits features that reflect a complex combination of skeleton-first and shell-first techniques. If it is heavily repaired, none of the published features constitutes inconclusive proof of a strong skeleton-based tradition; rather, below the waterline, the ship is strikingly similar to YK 11, which was built primarily following a shell-based tradition. Other details, such as score marks on planking, combined with an identification of repair timbers, could have aided in interpreting the construction of this vessel; due to the nature of the salvage excavation, however, these could not be fully observed on the Saint-Gervais 2 ship.

[287] Jézégou 1983, 33, 61.

CHAPTER VI

THE RIG OF SHIP YK 11

RIGGING ELEMENTS FOUND NEAR YK 11

Large elements of the rig and equipment of YK 11—including the mast, yard, mast step, sail, and quarter rudders—were not found; none of these having been securely fastened to the ship, all were likely stripped from the vessel prior to its abandonment. However, 20 smaller wooden objects used to manage a ship's rig were found scattered on and around the ship. These artifacts were assigned UM ("unidentified member") numbers and, with a few exceptions, are not necessarily associated with YK 11. The small rigging artifacts may be divided into four groups: blocks (1), sheaves (7), toggles (7), and spool toggles (6). These numbers include the fragment of a large sheave and another spool-like object that were found by museum staff during the initial excavation; these could not be fully documented. In addition to these wooden rigging elements, several short lengths of rope or rope fragments were found scattered in and around the ship.

Block and Sheaves

The best preserved element of the ship's rig is a small pulley block found on top of the keel between FR 22 and FR 23, near the location of a through-beam (fig. 6.1). This piece is firmly associated by its find location with ship YK 11. The block is both complete and intact, and rope fibers within the block, identified by Liphschitz as *Graminae* (grass family), indicate use. The shell itself is of *Ulmus campestris* (common elm), while the sheave and the transverse pin or axle are both *Buxus sempervirens* (boxwood). The shell is surprisingly small, just 11.5 cm in length, 5.0 cm in width, and 3.0 cm in thickness. The sheave is 3.8 cm in diameter and 1.2 cm thick; it could only have accommodated a thin line approximately 1 cm in diameter.

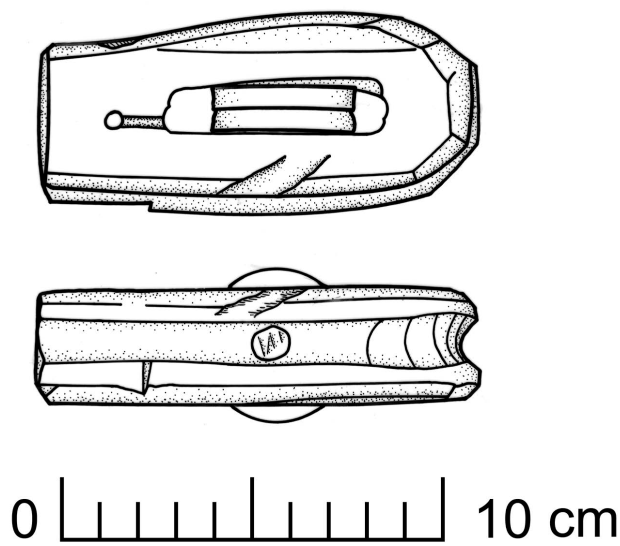

Figure 6.1. Two views of UM 151, a small pulley block found in YK 11.

The sheave was lathe-turned; a deep groove runs along the narrow center of the sheave's circumference. The shell itself was whittled, with tool marks especially well preserved in the curved groove that runs along the shell's perimeter, meant to accommodate the strap (fig. 6.2). Shell edges were chamfered to remove sharp edges. A small, 0.5 cm-diameter hole was cut through the shell near its flat end, in line with notches on the shell edges. A thin lanyard would have been run through this hole and wrapped around the strap to secure it. No trace of the strap or lanyard was preserved.

Fig. 6.2. Photograph of pulley block UM 151. Note tool marks within the groove along the shell perimeter and the pin fixing the sheave in place.

Table 6.1. Sheaves found near Yenikapı YK 11.

Number	Wood species	No. of pieces	Original maximum diam. (cm)	Orig. diam. along groove (cm)	Orig. diam. of central hole (cm)	Thickness (cm)
UM 177	*Buxus sempervirens*	1	5.5	5.0	1.5	1.8
UM 178	*Quercus coccifera*	1	est. 9	est. 8.7	est. 2.5	2.1
UM 183	*Quercus coccifera*	1	est. 5.5	est. 5.0	Not preserved	1.5
UM 186	*Quercus coccifera*	3	est. 7.5	est. 7.0	est. 2.3	1.6
UM 192	*Buxus sempervirens*	2	6.7	6.5	1.4	2.6
UM 197	*Buxus sempervirens*	1	6.8	6.3	1.6	2.5
No number	Unknown	1	16.0	15.5	3.0	2.5

In addition to the sheave of the small block, seven other sheaves were found in the wreck area (table 6.1, fig. 6.3). None of the sheaves is complete, and some of the dimensions in table 6.1 are estimates. Some part of the original outer edge and central hole are preserved on each piece, with the exception of UM 183, a small fragment with no trace of the central hole. One of these sheaves, the unnumbered piece at the bottom of table 6.1, was discovered by museum archaeologists during the excavation in the spring of 2008 and could not be fully documented.

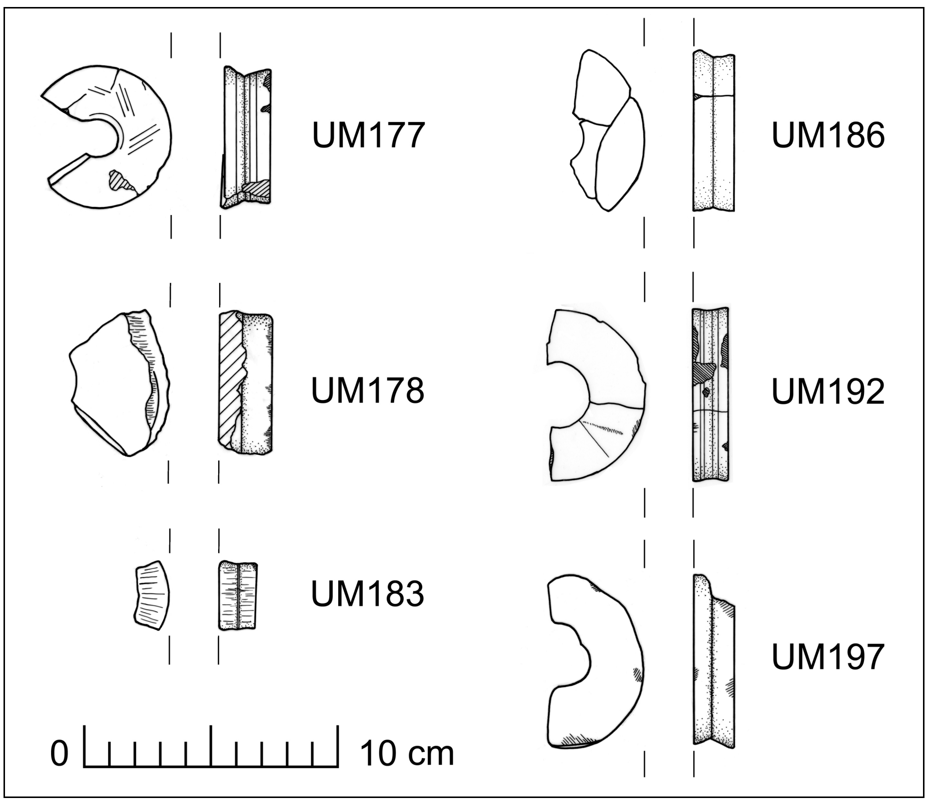

Figure 6.3. Fragments of sheaves found near YK 11.

The sheaves were turned on a lathe, as indicated by striations along the faces and within the shallow grooves along the outer edge. Half of the sheaves were made from boxwood (*Buxus sempervirens*) and are better preserved; the other sheaves, made from Kermes oak (*Quercus coccifera*), exhibit more surface damage. Most of the sheaves are relatively small, 5.5-9 cm in diameter; nevertheless, this is larger than the sheave of block UM 151 (3.8 cm diameter), confirming that the latter is unusually small. The unnumbered piece is the largest sheave found near YK 11, with an original diameter of 16 cm (fig. 6.4); as such, this piece was used as the basis of the masthead sheaves in the YK 11 rig reconstruction. The sheaves are relatively consistent in thickness, 1.5-2.6 cm.

Fig. 6.4. Unnumbered sheave fragment from YK 11. Diameter approximately 16 cm.

The original find location is unknown for UM 177 and the unnumbered sheave; the remaining sheaves were found underneath the ship's hull planking or outside of the ship. The find location, and the fact that every sheave had been broken, suggests that these sheaves more likely represent harbor trash that had littered the area rather than elements of the YK 11 rig. However, because their size and shape represent those of early Byzantine rigging elements, similar sheaves have been incorporated into the reconstructed rig of YK 11. Wear along the edges of the central hole on UM 177, UM 186, UM 192, and UM 197, and along the outer edge of UM 197, may have resulted from extended use.

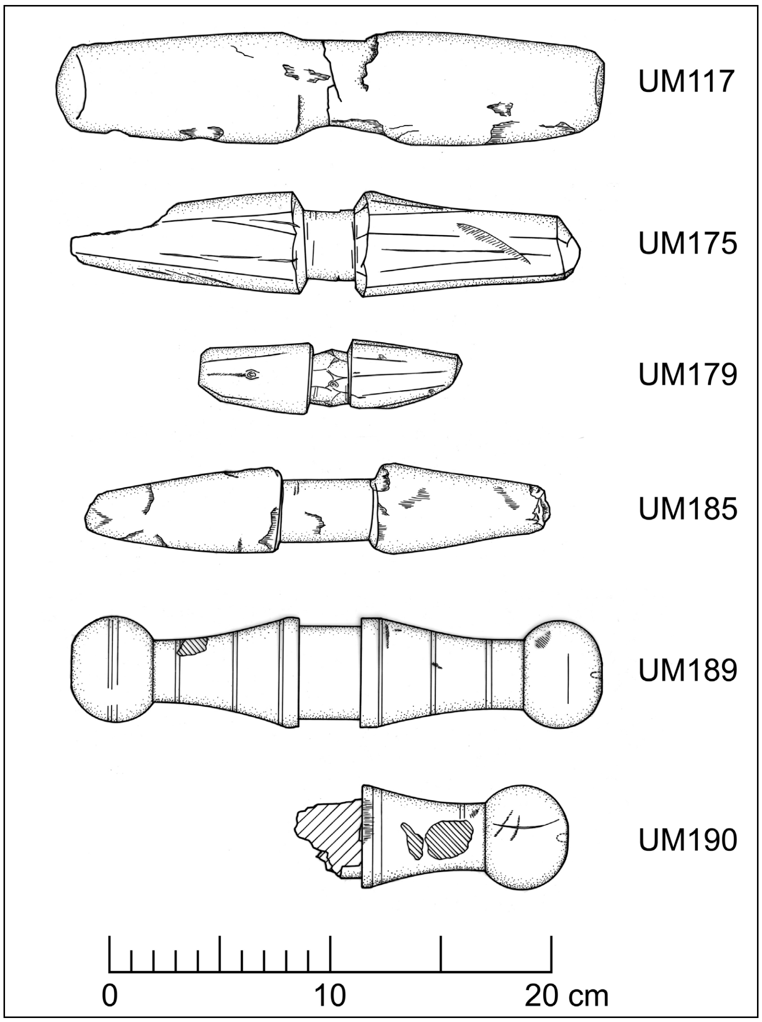

Figure 6.5. Toggles found near YK 11.

Toggles

Six toggles were found in the area around YK 11 in 2008 (fig. 6.5, table 6.2). Three of the toggles are complete and intact, and two others are complete but broken; only one, UM 190, is incomplete, having broken at its neck. The toggles are generally well preserved, especially the two boxwood toggles. Heavy wear around the neck of toggle UM 117 may indicate use, but there is no clear evidence of use on any of the other pieces. Nevertheless, the three broken toggles broke at the neck, which may have occurred during use. A seventh toggle was found and retrieved by Pulak when the wreck was first exposed in early 2006. This toggle, similar to UM 175 and UM 185, was found in a poor state of preservation, lying at the ship's stern, and still retained fragments of rope around its neck.[1]

Table 6.2. Toggles found near Yenikapı YK 11 in 2008.

Number	Wood species	No. of pieces	Length (cm)	Max. diam./width (cm)	Diam. or width at neck (cm)	Description
UM 117	*Acer pseudoplatanus*	2	24.7	5.1	4.0	Complete.
UM 175	*Quercus coccifera*	1	23.1	4.6	2.9	Nearly complete and intact.
UM 179	*Buxus sempervirens*	1	12.0	3.2	2.4	Nearly complete and intact.
UM 185	*Quercus cerris*	3	20.8	3.9	2.6	Complete.
UM 189	*Acer pseudoplatanus*	1	24.0	5.2	4.2	Complete and intact.
UM 190	*Buxus sempervirens*	1	12.4 (orig. est. 22 cm)	4.7	3.9	Toggle half.

[1] This toggle, which has no identification number, could not be cataloged and is not included in table 6.2.

UM 179, a small boxwood toggle, was found within the ship, just forward of FR 9, on the starboard garboard below the level of the ship's ceiling. Because the common ceiling in this location was not preserved, it is unclear whether the toggle had fallen into the bilge before the ship was abandoned or whether it came to rest there as unfastened boards of common ceiling floated away or became otherwise displaced. Nevertheless, its location indicates that this toggle was part of the rig of YK 11. Although generally well preserved, this toggle is damaged along one face, with a large fragment split away. Toggles UM 175, UM 185, and UM 189 were found directly under the ship's hull planking and may or may not be associated with YK 11. UM 190 was found in the wall of the excavation pit, about 3 m from the ship, and there is no find location recorded for UM 117.

Only two of the toggles, UM 189 (sycamore maple) and UM 190 (boxwood), are lathe-turned; both carefully-fashioned pieces terminate in spheroid knobs. On both pieces, the arms and end knobs are decorated with fine incised lines (fig. 6.6). The remaining toggles were whittled from sycamore maple, oak, or boxwood (fig. 6.7).

Five of the six toggles are 21-25 cm in length (or, in the case of UM 190, would have been if fully preserved). Only one toggle, UM 179, is significantly smaller, just 12 cm in length. It is perhaps noteworthy that this toggle and the small pulley block UM 151, both associated with YK 11, are smaller than any of the other toggles or sheaves, none of which are firmly associated with YK 11. Perhaps these rigging elements indicate that YK 11 was smaller than most contemporaneous merchantmen.

Fig. 6.6. Lathe-turned toggle UM 189. Note decorative incised lines on the arm and at knob.

Fig. 6.7. Cut marks at the neck of toggle UM 175.

Spool Toggles

Six other objects found in and around YK 11 are possible elements of rigging (table 6.3, fig. 6.8). These have been labeled spool toggles based on their resemblance to artifact MF 50 from the seventh-century Yassıada shipwreck.[2] These small objects, of unknown function, lack the central hole of a sheave and are characterized by a V-shaped groove, 0.5-0.9 cm in depth, along their circumference. Most of the spool toggles are relatively small, just 2.6-3.6 cm in diameter; one larger spool toggle was recovered by the museum staff and is significantly larger, approximately 7 cm in diameter.[3] Thicknesses are generally 0.8-0.95 cm, although both UM 180 and the larger, unnumbered spool toggle are 1.5-1.6 cm thick.

Table 6.3. Spool toggles found in and around Yenikapı YK 11.

Number	Wood species	No. of pieces	Max. diam. along edge (cm)	Diam. within groove (cm)	Thickness (cm)
UM 176	*Buxus sempervirens*	1	3.4	2.4	0.95
UM 180	*Buxus sempervirens*	1	3.6	1.7	1.6
UM 181	*Buxus sempervirens*	1	2.6	1.7	0.9
UM 182	*Buxus sempervirens*	1	2.6	1.7	0.8
UM 184	*Acer pseudoplatanus*	1	2.8	1.7	0.9
[No number]	Unknown	1	approx. 7	approx. 5.5	approx. 1.5

Three of these spool toggles, UM 180, UM 181, and UM 182, were found within the wreck in the same general location, around FR 10, near the ship's keel; two of these were found on top of the frame. These were relatively close to the small toggle (UM

[2] Bass and van Doorninck 1982, 288-89.
[3] This spool toggle, which has no identification number, could not be cataloged.

179) found near FR 9. No specific provenience was available for the unnumbered piece, and UM 176 and UM 184 were found under the ship's hull planking. Four of the five spool toggles, including the three found within the wreck, are of boxwood; UM 184 is of sycamore maple. All of the spool toggles are nearly complete and intact, with some small fragments broken along thin peripheral edges.

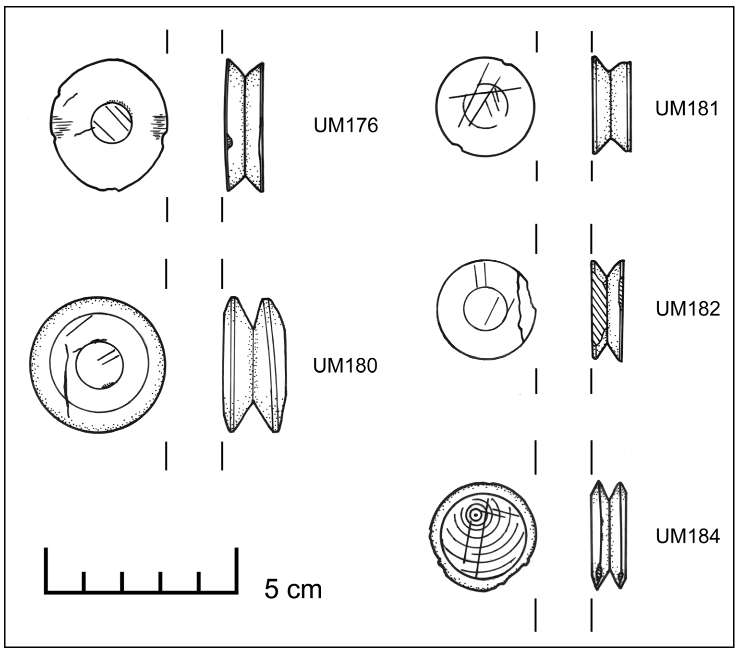

Figure 6.8. Spool toggles (wooden spool-like objects) found in and around YK 11.

All of the spool toggles were lathe-turned. UM 176, UM 181, and UM 182 are very similar in form; all three have flat faces and thin edges (fig. 6.9). UM 181 and UM 182 are nearly identical to each other and to Yassıada MF 50, with dimensions differing by no more than one millimeter. UM 180 and UM 184 differ slightly from the other numbered spools. These possess the V-shaped groove along their circumference but also possess an additional bevel to their flat faces. Both are of comparable diameter to the other numbered spools, but UM 180 is notably thicker.

Fig. 6.9. Spool toggle UM 181. Note lathe striations within groove and damage to thin edges.

Fig. 6.10. Spool toggle UM 182 and the twine wrapped around it.

The function of these objects is unclear. The wooden spool-like object at Yassıada was found near the probable mast location and was thus interpreted as a possible element of rigging.[4] A similar object found at the Roman port of Laurons in France is slightly thicker and of terracotta; this was interpreted as a spool for thread or

[4] Bass and van Doorninck 1982, 289.

fishing line.[5] A thin line of grass-like fibers was found within the groove of spool toggle UM 182 (fig. 6.10). The shallow depth of the groove on UM 182 (0.45 cm) and the size of the twine in the groove (0.3 cm) seem to indicate that these objects did not serve as spools, as twine of this size could only have been wrapped around the spool two or three times. These objects may more likely have served as a kind of small, button-like toggle. The concentration of these spool toggles near toggle UM 179 may indicate that a small store of ship's equipment was kept between FR 9 and FR 10; this is just forward of the bulkhead compartment, which itself may have been used to store goods or equipment of higher value.

Rope

Seven short lengths of rope were found scattered around and under shipwreck YK 11. Although poorly preserved and with sediment and shell inclusions, two general types of fibers and approximate diameters may be identified. Four of the samples consist of wide, soft fibers that are easily damaged; one of these samples has been identified by Liphschitz as *Graminae*. All four examples of this type are fragments of three-strand Z-twist rope (fig. 6.11).[6] Due to the nature of the fibers, all are distorted and compressed; the flattened pieces, up to 4.7 cm in width, indicate an original diameter of 3-4 cm. Two fragments of this type were found within the ship, one near where the base of the mast would have been located and the other just forward of where the mast step would have been located.

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[5] Ximénès and Moerman 1990, 22-3; Polzer 2008, 14.
[6] An explanation of these terms is provided in Charlton 1996, 10-4, fig. 2.

Figure 6.11. Detail from rope found forward of the location of the mast step.

The second type of rope consists of coarse, wiry fibers that are less easily damaged than the previous type; the fibers of this type have not yet been analyzed. Three examples of this type were found around the ship. Each example of this type was fashioned from yarns consisting of approximately 30 individual fibers twisted together in a Z-twist. One of the examples was poorly preserved, and another example is a three-strand Z-twist rope, 1.5-2.0 cm in diameter, found under the ship's hull planking (fig. 6.12). A third example of this type is a Z-twisted cable of three ropes, each consisting of three S-twisted strands; its diameter is approximately 3.0 cm.

Fig. 6.12. Detail from rope found under PS 2-PS 4 at FR 14-FR 15.

SOURCES FOR RECONSTRUCTING THE SHIP'S RIG

Reconstructing a rig for a vessel of this kind requires combining data from a variety of sources. There are no ship treatises or manuscripts of contemporaneous date which might clarify the details of such a rig. Byzantine iconography, furthermore, tends to be religious in nature, and there are relatively few detailed depictions of ships from the sixth-seventh centuries, despite the size of the Byzantine Empire and its reliance on maritime trade.[7] Furthermore, delicate rigging elements typically are not well preserved in the archaeological record; when they do survive, they are almost always disarticulated or piecemeal.[8] Nevertheless, by using a comprehensive approach and drawing information from a range of sources, a rig appropriate for a ship of this size and period may be hypothesized.

The most important source is the archaeological material associated with this shipwreck, which provides a suitable starting point for a reconstruction of its rig. Archaeological evidence for the rig of this ship includes the size and placement of some through-beams, the stanchion blocks, the location and approximate size of the mast step, and the various blocks, toggles, and rope fragments detailed above. As noted, the mast, yard, mast step, sail, and quarter rudders probably had been removed.

Next in importance is roughly contemporaneous Byzantine iconography depicting ships and comparable archaeological material from other sites, including other finds at Yenikapı as well as shipwrecks in the Mediterranean and Black Seas. Finally,

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[7] Basch 1991a, 14.

[8] One notable exception is the fifth-sixth century shipwreck D discovered in the Black Sea near Sinop (Ward and Ballard 2004, 6-11). However, due to its depth—320 m—it could not be recorded in detail.

details of the rig that could not be elucidated through these sources were better understood with the aid of later (late medieval or Renaissance period) manuscripts and modern ethnographic equivalents, primarily the *dhows* of the Persian Gulf and Indian Ocean. An overview of the sources used for the reconstruction of this ship's rig is presented in table 6.4.

Table 6.4. Overview of the sources used in reconstructing the rig of YK 11.

Source	**Element of Rig**
Archaeological evidence from YK 11 (Yenikapı excavation)	Location of through-beams Approximate location and size of mast step Stanchion blocks (lateral support for mast) Toggles, sheaves, intact block Rope diameter
Early Byzantine iconography	Hook-shaped masthead (*karchesion*) Mast support at base Halyard (doubling as backstay) Forestay/shroud Sail shape Rudder
Other archaeological sources	Mast step (Pointe de la Luque B, Dramont E, Saint-Gervais 2, Tantura F) Mast support at base (Black Sea D, Dramont E, Tantura F, Parco di Teodorico) Mast size and form at base (Dramont E) Mast-partner beam (Pisa wreck D) Attachment of masthead (Black Sea Wreck D) Pinrails/areas for tying off (Yenikapı wrecks, Black Sea Wreck D, Port Berteau II, Pisa wreck D) Blocks (other Yenikapı material, Serçe Limanı)
13-15th-century manuscripts	Length and proportion of yard Height of mast Placement and angling of yard
Later or modern ethnographic evidence	Handling of a lateen sail (*dhows*) Form, size, and attachment of sail (*dhows*) Mast support at base (*dhows*) Yard placement and composition (*dhows,* Italian lateen-rigged ships) Throat tackle (*dhows,* Italian lateen-rigged ships) Halyard attachment (*dhows,* Italian lateen-rigged ships) Shrouds (*dhows*)

Despite the substantial framework provided by the combination of sources noted here, there remained some amount of guesswork in reconstructing the rig of YK 11. When the available sources offered multiple solutions, decisions on detail were based on a presumed underlying philosophy of the shipbuilders and sailors who built and used this ship, a small, heavily-repaired, coastal sailing vessel operating around a large urban area. The presumed philosophy favors simple solutions over complex ones; cheaper or readily available materials over more costly, high-quality alternatives; and a rig that would be practical and easily managed over one that was of optimal sailing ability.

RECONSTRUCTED RIG OF YK 11

Choice of Rig

The first basic step in recreating a rig for a small, early Byzantine merchantman is the selection of a rig type; a small ship, with only one relatively central mast, could have been either square or lateen rigged.[9] The transition from square sail to lateen sail probably occurred in the last centuries of Late Antiquity. Although scholars once suggested an Arab origin for the lateen sail, it now appears likely that it developed earlier on from the square sail by modifying it into a triangular form through the use of brails.[10]

The last iconographic representation of a Late Roman ship bearing a square sail is in a sixth-century mosaic from Sant'Apollinare Nuovo in Ravenna, Italy, while a second-century A.D. tombstone from Athens is the earliest clear depiction of a lateen

[9] A sprit rig would require a mast placement closer to the bow.
[10] Hourani 1995, 103; Bowen 1956, 242; Casson 1971, 49-51.

sail.[11] Literary evidence also confirms that the lateen sail was in use prior to the seventh century. Synesius' account of his voyage from Alexandria to Cyrene in A.D. 404, and Procopius' account of Belisarius' expedition to Africa in A.D. 533, both indicate the use of lateen sails.[12] Based on this evidence, it is probable that a small Byzantine merchantman in the seventh century would have employed a lateen rather than a square sail. A lateen sail is more maneuverable and allows the ship to sail closer to the wind, both advantages being significant for a ship engaged in coastal trade.[13]

The basic elements of the rig may be inferred from roughly contemporaneous iconography. The two closest representations are the Kelenderis ship (fig. 6.13), from a fifth-sixth-century mosaic in southern Turkey,[14] and the Kellia ship (fig. 6.14), an early seventh-century painting from northern Egypt.[15] Another depiction, a graffito from Corinth, is roughly dated to the fifth-sixth centuries (fig. 6.15) and appears to represent a lateen-rigged ship with its yard lowered.[16] Based on these representations, Julian Whitewright has established a set of four rigging elements characteristic of lateen-rigged vessels of Late Antiquity; these may, in the absence of a clearly-depicted sail, aid in determining the rig of a ship. These four elements are (1) a vertical support system at the base of the mast, (2) a long yard, approximately the same length as the ship, (3) a hook-shaped masthead, and (4) a multi-block halyard that serves as a backstay.[17] These four

[11] van Doorninck 1972, 140, 154 fig. 18; Casson 1956, 5; Moll 1929, pl. B II.108, B Xb.112.
[12] Casson 1966, 49-51; Sottas 1939, 229-30; Procop. *Wars* 3.13.3.
[13] Hourani 1995, 101; Makris 2002, 96.
[14] Friedman and Zoroğlu 2006; Pomey 2006.
[15] Basch 1991b.
[16] Basch (1991a, 20-1) seems to question the nature of the rig, while Pulak (pers. comm.) and Whitewright (2009, 102) consider it a lateen rig.
[17] Whitewright 2009, 100.

elements have been combined with the archaeological evidence found in and around YK 11 to form the basis of the rig selected for this ship (figs. 6.16-6.17).

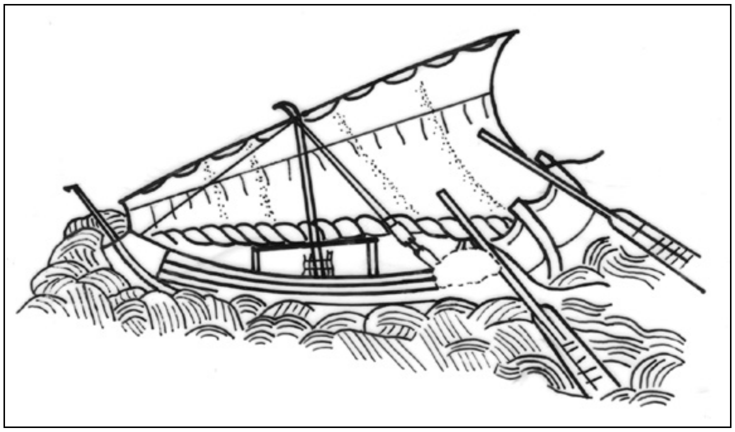

Figure 6.13. A merchant ship depicted in a fifth- or sixth-century mosaic at Kelenderis in southern Turkey (after Friedman and Zoroğlu 2006, 109 fig. 2).

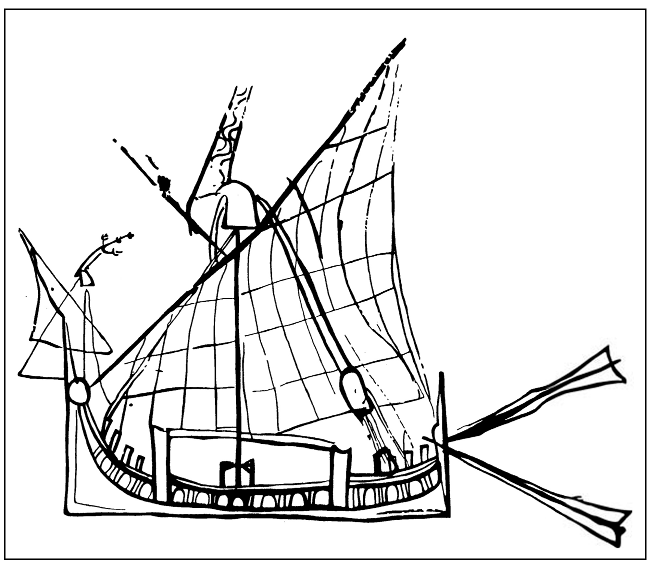

Figure 6.14. Seventh-century painting of a lateen-rigged ship found at Kellia near Alexandria, Egypt (from Basch 1991b, 2 fig. 1; used with permission).

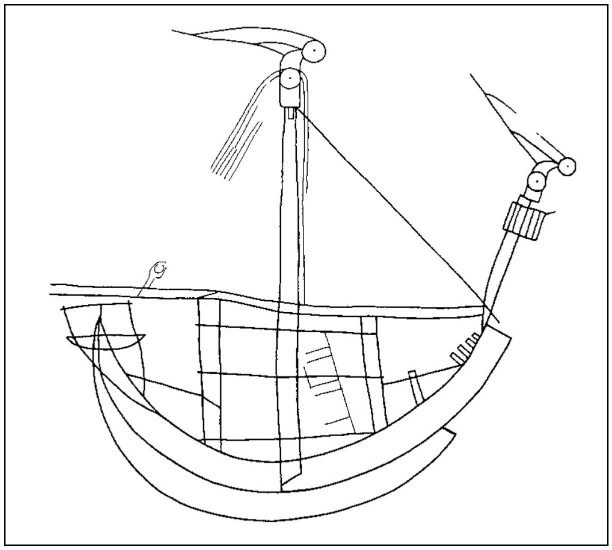

Figure 6.15. Fifth- or sixth-century graffito of a merchant ship from Corinth (from Basch 1991a, 17 fig. 8; used with permission).

Mast Support at Base

Although the mast step was gone, a recess along the inboard edge of central stringer CST 1, starting just aft of FR 19, provides the location of the mast step's forward end. There is no recess on CST 1 to indicate the location of the mast step's aft end; as a result, the precise location of the aft end is more difficult to determine. The inner face nail heads of FR 15 and FR 17 are countersunk into the frame surface, indicating that the mast step extended over these frames; this is not the case on FR 13. The keel ends of half-frames FR 14, FR 16, and FR 18 are either trimmed down or naturally tapered along the inner face, such that protruding nail heads would not have affected the positioning of the mast step. The aft end of the mast step must therefore have been located between FR 13 and FR 14. Its length has been reconstructed as 1.55 m, five times the average room and space of 31 cm.

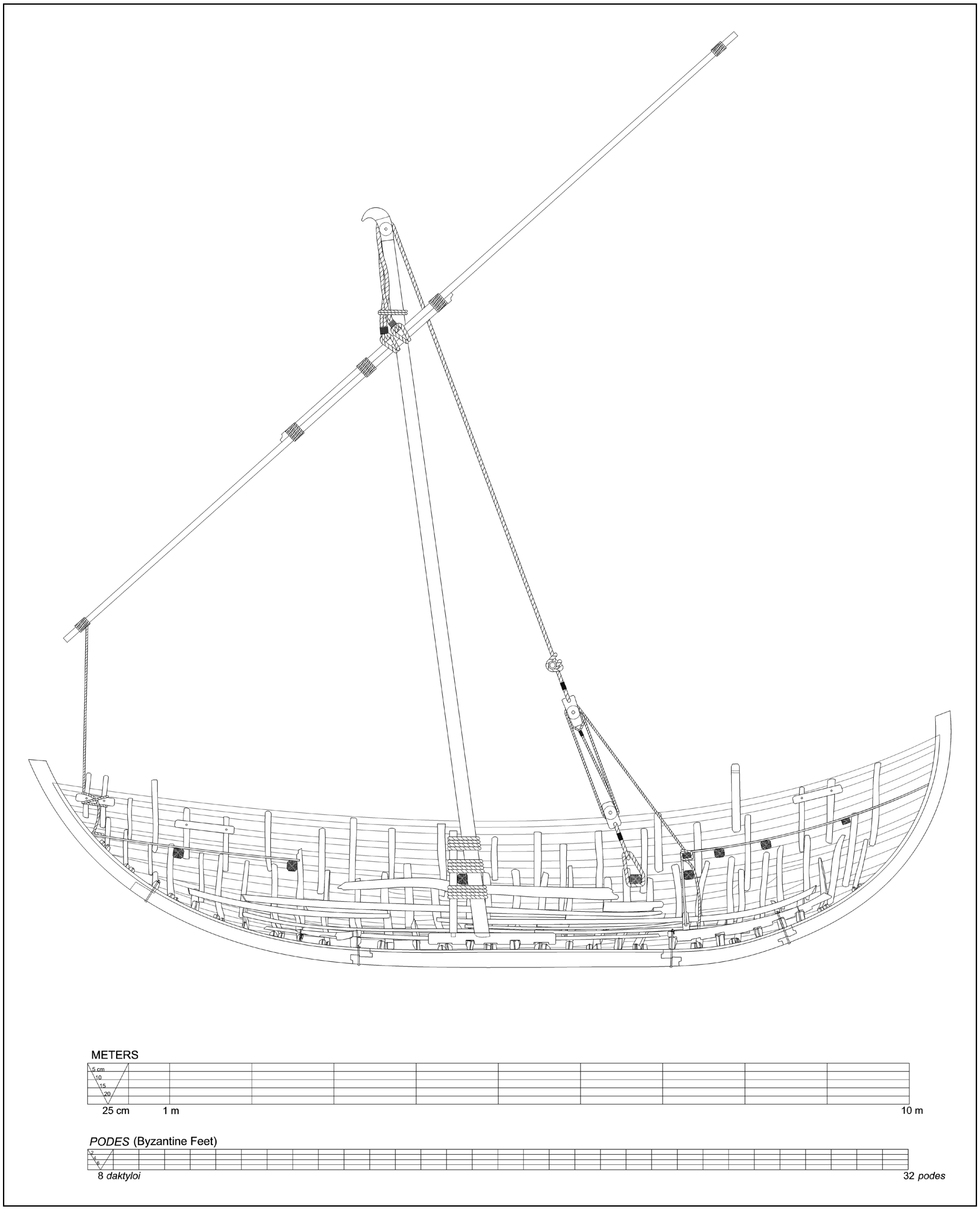

Figure 6.16. YK 11 construction plan, showing attachments of the mast and yard. Bow is to the left.

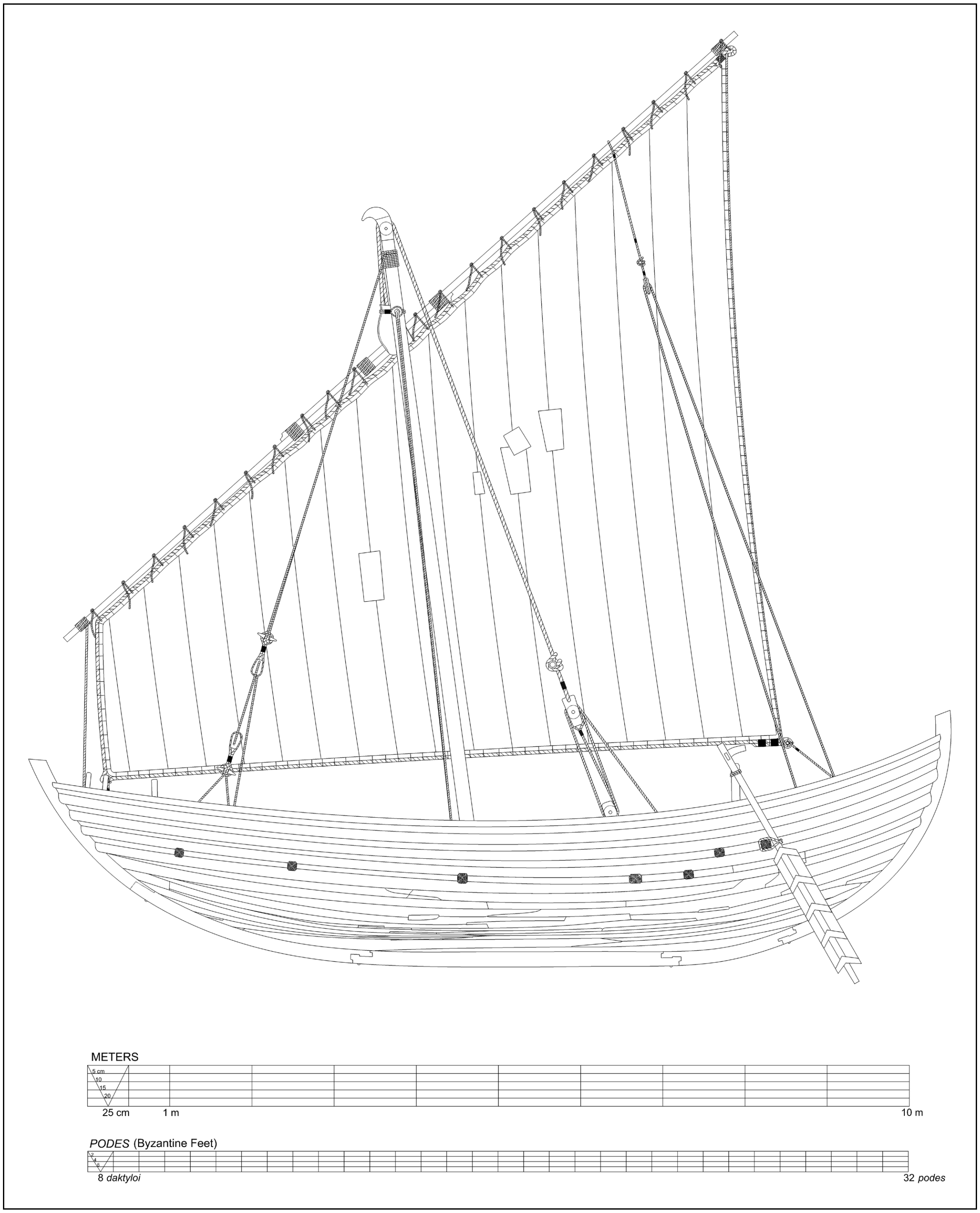

Figure 6.17. Reconstructed rig of YK 11. Bow is to the left.

The width of the mast step is based on the projected spacing between the two central stringers, only one of which was preserved. This spacing, 18 cm, is relatively large in sided dimension compared to other substantial timbers of YK 11 such as the keel or sternson. However, it is just slightly larger than, or equivalent to, the maximum sided dimension of the central stanchion blocks that flank the pair of central stringers at the mast step (15-18 cm in sided dimension). Some other contemporaneous mast steps, such as those of the Pointe de la Luque B, Dramont E, Saint-Gervais 2, and Tantura F shipwrecks, are wider than the gap between the central stringers and have a rebate cut into the outer face to accommodate the overlap.[18] The lack of pressure damage on the inner face of the preserved YK 11 central stringer, combined with the naturally rounded form of this stringer's inner surface, indicate that there probably was no such overlap on YK 11. Instead, the mast step would have been sufficiently stabilized laterally by being fitted snugly between the inboard edges of the two central stringers. In addition, the recessed area on the inner face of FR 15, 13.4 cm in width, may have accommodated a specially-cut projection on the mast step's outer face, further stabilizing the timber.

The molded dimension of the mast step is based primarily on comparable evidence from contemporaneous shipwrecks, which indicates a mast step slightly larger in sided dimension than molded dimension.[19] A molded dimension of 14 cm, just over three-quarters of the sided dimension, was selected for this reconstructed mast step. A molded dimension of 14 cm would allow sufficient space for 4-5 cm-deep notches on the mast step's outer face for the frames (as seen on the central pair of YK 11 stanchion

[18] Barkai 2009, 26-7; Clerc and Negrel 1973, 66; Jézégou 1983, 49-50, pl. 10; Santamaria 1995, 163.
[19] Barkai and Kahanov 2007, 24; Clerc and Negrel 1973, 66; Jézégou 1983, 39; Santamaria 1995, 161-63.

blocks) as well as mortises on the inner face for the mast heel and a forward stanchion. The outer face notches would lock the mast step in place longitudinally; the mast step was not normally fastened, but rather was held in place through its own weight. The aft end of the mortise for the mast heel was placed to align with the forward end of the mortises on the central stanchion blocks, similar to the alignment of mortises on the Tantura F ship.[20]

The stanchion blocks of YK 11 likely held stanchions that provided additional lateral support for the mast (the central pair) or support for through-beams (the forward and aft pairs). Evidence for such lateral support to the mast is also seen on the Tantura F, Dor 2001/1, and Parco di Teodorico ships.[21] Perhaps the stanchions that were fitted here supported longitudinal mast partners; such an enhanced support structure, the *xylokastron*, is one of the four key characteristics of Late Antique lateen rigs, clearly visible in the Kelenderis and Kellia depictions.[22] The location of the mortises at the central pair of stanchion blocks suggest stanchions at a slight diagonal toward the ship's centerline, which are proposed to have supported the longitudinal mast partners and helped these timbers to counter any lateral pressure from the mast.

SS 12 on YK 11 is a through-beam strake consisting of several relatively thin boards placed between the lower two wales (strakes 11 and 13). As noted in Chapter IV, gaps in strake 12, and corresponding wear and nail holes along the wale edges, mark the

[20] Barkai and Kahanov 2007, 22 fig. 2. On the Parco di Teodorico ship, the lateral mortises are aligned with the mortise for the mast heel (Medas 2003, 43-5, fig. 9.2). Placing the mast heel mortise in alignment with the stanchion block mortises on YK 11 caused the mast to rake forward excessively; the alignment of the Tantura F mortises, in contrast, produced a gentler forward rake closer to that seen in contemporaneous iconography.
[21] Barkai and Kahanov 2007, 24, 26; Mor and Kahanov 2006, 281; Medas 2003, 45.
[22] Pomey 2006, 327; Basch 1991b, 5.

location of several through-beams. The gap for a through-beam near FR 17 is just forward of the mortises in the central stanchion blocks; this through-beam, although not extant, almost certainly served as the ship's mast-partner beam. This beam, in combination with the proposed mast step, provides the location and forward rake of the mast (reconstructed as 8°). A shallow recess was cut out of the reconstructed mast-partner beam in order to accommodate the mast; a similar hollowing was noted on the mast-partner beam of wreck D at Pisa.[23]

The difficulty in reconstructing a simple lateen-rigged vessel lies in the complexity of the tacking procedure; although complicated, tacking was practiced out of necessity.[24] The tacking of an ancient Mediterranean lateen sail entails removing or slackening several lines, hauling the yard downward to a vertical position forward of the mast, rotating the yard and sail around the masthead, and allowing the yard and sail to fall back into place on the opposite side of the mast. Due to the complexity and potential for the tangling of lines, a simple model was constructed to test various line configurations for YK 11.

The nature of the tacking procedure precludes the use of permanent standing rigging; this being the case, the secure attachment of the mast at its base is a necessity.[25] Black Sea wreck D is the only archaeological example of a vessel of this period with an upright and intact mast. While dimensions for this are not available, it is clear that this mast was lashed to a stout, short vertical post stepped into the mast step just forward of

[23] Bruni 2000, 49, 68 fig. 38; Camilli and Setari 2005, 76.
[24] Howarth 1977, 101, 110.
[25] Bowen 1949, 114.

the mast; this short vertical post is notched in order to hold the lashing in place.[26] Evidence for a similar configuration is seen elsewhere in the archaeological record in the form of mast steps with a slot forward of that intended for the mast heel.[27] On the Dramont E ship, part of the stanchion itself was preserved but is surprisingly small, just 9 by 7 cm at its base.[28] A vertical support of this type, forward of the mast, may correspond to the *parastatai* noted in association with the masts of triremes.[29]

A similar system of supporting the mast at its base can be seen on Arab *dhows* of recent centuries; on these ships, a through-beam is sandwiched between the mast and the support post, the latter also notched for the lashings in the Byzantine fashion.[30] This support structure at the mast's base is said to be quite strong and, according to some eyewitness accounts, capable of keeping the mast upright without any additional lines.[31] Because the length of YK 11 is approximately 80% that of Dramont E, a forward stanchion of a similar size (9 cm diameter) was chosen to form a sturdy support for the mast of YK 11 (fig. 6.18). The proportional size of this stanchion in relation to the mast is closer to those seen on Black Sea wreck D and Arab *dhows*.[32]

On the Parco di Teodorico ship, the spacing between the lateral mortises and the mortise for the mast heel is approximately 25 cm (center to center), while the spacing between the mortise for the mast heel and the mortise for the forward support stanchion

[26] Ward and Ballard 2004, 11 and fig. 12A.
[27] This type of mast step was observed on the wrecks Anse des Laurons 2 (Gassend et al. 1984, 100), Pointe de la Luque B (Clerc and Negrel 1973, 63, 66-7), Dramont E (Santamaria 1995, 171), and Tantura F (Barkai and Kahanov 2007, 24, 26).
[28] Santamaria 1995, 171.
[29] Basch 1991b, 6; Casson 1995, 237 n. 59.
[30] Howarth 1977, 86-7; Jewell 1976, 21.
[31] Howarth 1977, 86.
[32] Hawkins 1977, 94; Howarth 1977, 87; Ward and Ballard 2004, 10 fig. 12a.

is 30 cm (center to center).[33] The spacing between the stanchion block mortises and the mortise for the mast heel is also 25 cm on YK 11, and a distance of 30 cm forward of the mast heel mortise places the support stanchion just forward of the mast-partner beam, as intended.

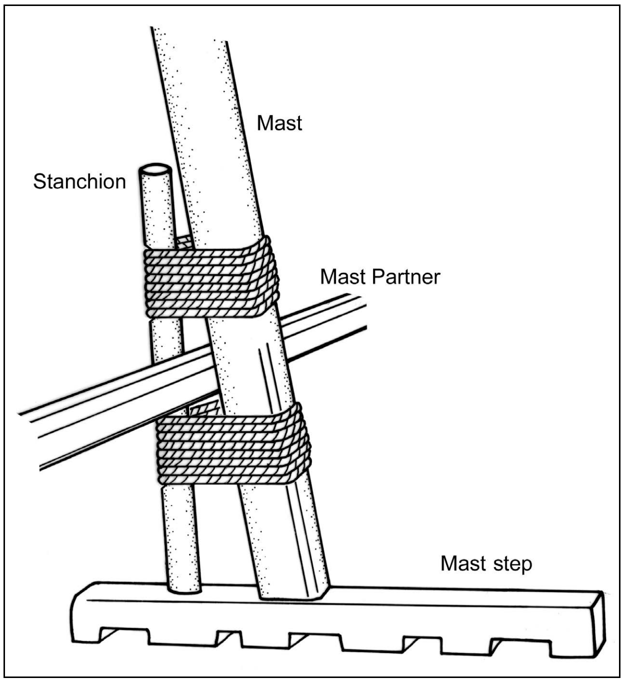

Figure 6.18. Proposed attachment of YK 11 mast at base.

Mast and Yard Size

The procedure for tacking a lateen-rigged ship requires angling the yard to a vertical position in order to shift it around the masthead. The height of the mast, therefore, must have been great enough to allow the lower extremity of the yard to be swung down without striking any portion of the ship's forward deck. The dimensions for

[33] Medas 2003, 43 fig. 9.2.

the YK 11 yard were therefore calculated first. One of the four basic characteristics of a Late Antique lateen rig is a yard approximately the same length as that of the ship, which is also the case in later Renaissance-period Italian lateen-rigged ships as well as Arab *dhows*.[34] Based on the reconstruction of the ship's lines presented in Chapter V, the hull of YK 11 had an overall length of just over 11 m. A yard length of 11 m was therefore selected.

Although a yard of 11 m could be a single piece on a lateen-rigged ship of this size, Arab *dhows* usually lash multiple pieces of timber together to create their yards; this latter method was chosen for YK 11 as it required shorter, and therefore more economical, lengths of timber.[35] A simple method of lashing the two yard timbers together was chosen, which utilized lashings around shallow notches toward the ends of each timber.[36] One notch on each timber is sufficient to keep the pieces from slipping apart; cutting a second notch on the other timber would weaken it at a key location and was thus avoided.

Lengths of the yard components were determined based on contracts for much larger Genoese ships of 13- to 14th-century date and 15th-century Venetian manuscripts.[37] The yard includes two different components: the *penna*, or upper portion, and the *carro*, or lower portion.[38] The *penna* is longer and thus heavier in order to

[34] Whitewright 2009, 100. References to yard length on more recent ships may be found in Bellabarba and Guerreri 2002, 245; Al-Hijji 2001, 80; and Jewell 1976, 21. A longer yard was feasible, but due to the size and function of ship YK 11, a more manageable yard length was selected.
[35] Bellabarba and Guerreri 2002, 243; Howarth 1977, 86; Jewell 1976, 21.
[36] Bellabarba and Guerreri 2002, 245 fig. 15; Hawkins 1977, 93 and 117.
[37] Pryor 1984; Anderson 1925.
[38] Bellabarba and Guerreri 2002, 243.

counterbalance the *carro*.[39] Calculations presented in Appendix C suggest a *penna* with a length of 7.43 m and *carro* with a length of 6.32 m. These two should have an overlap of 2.75 m. Because the calculations in Appendix C did not result in a reasonable yard diameter for a ship of this size, a slightly smaller maximum diameter of 9 cm was chosen for both the *penna* and *carro*. A yard might taper toward its ends, although this was not necessarily the case for smaller ships during the later medieval period.[40] The yard arms were tapered slightly (about 20%) for the YK 11 reconstruction in order to reduce some of the weight of the yard without compromising its strength. The ends of the *penna* and *carro* at the overlap were adzed down by a few centimeters in order to somewhat decrease the large diameter of the yard there.

The 15th-century *Fabrica di galere* manuscript suggests a ship-length-to-mast-height ratio of 1:0.81 or 1:0.9 for a lateen-rigged ship.[41] The former produces a mast of 9.1 m; decreasing this slightly to 8.5 m still provided a sufficient height for tacking maneuvers, which is the true test of its feasibility. Formulas for mast diameter are also present in *Fabrica di galere*, where a mast diameter is stated to be its height divided by 44.[42] For a mast of 8.5 m height, this results in a diameter of 19.3 cm.

The preserved lower portion of the mast of the fifth-century Dramont E shipwreck provides a confirmation of this size. The Dramont E ship, with a reconstructed length of 14.1 m, had a mast that, at its base, was rectangular in section,

[39] Pryor 1984, 288.
[40] Pryor 1984, 287.
[41] Pryor 1984, 286. Exactly what is meant by “length” of the ship is unclear and could refer to differing dimensions, such as total length or length at waterline. It is assumed to be total length for purposes of this project.
[42] Bellabarba 1988, 119.

with rounded corners, 23.5 cm sided and 27.5 cm along the ship's longitudinal axis.[43] Scaling this down by 20% (the length of YK 11 being approximately 20% shorter than that of Dramont E) produced a mast 18.8 cm sided and 22 cm along the ship's longitudinal axis at its base; this was decreased to a maximum diameter of 18 cm to better fit the proposed YK 11 mast step. The diameter of the mast at the level of the rigging should be 2/3 its maximum diameter according to the *Fabrica di galere* formulas, which for an 18 cm-diameter base is 12 cm.[44] Considering the small size of YK 11, this upper mast diameter was adjusted to 15 cm in order to counter the weight of the yard.

A mast, 8.5 m in length, with a base of 15.5 x 18 cm, approximately rectangular in section, and a top 15 cm in diameter, rounded in section, has a volume of approximately 0.19 m^3. A cubic meter of seasoned red pine has a variable density of between 457-597 kg.[45] For a volume of 0.19 m^3, then, the weight of the mast would be 87-113 kg. This weight would not be unmanageable for two sailors, and the shallow angling to the slot in the mast step would facilitate unstepping the mast when necessary.

Yard Attachment

The two remaining characteristic elements of Late Antique lateen rigs relate to the attachment of the yard: the hook-shaped masthead and the heavy halyard system.[46] The curving, hook-shaped masthead (*karchesion*) seems to be associated specifically with lateen-rigged ships and is present on the representations from Kellia, Kelenderis,

[43] Poveda 2012, 332; Santamaria 1995, 164. The mast was of fir (Santamaria 1995, 187).
[44] Bellabarba 1988, 119.
[45] Guller and Yasar 2010, 1766. The majority of the ship was built of *Pinus brutia,* which would not be unexpected as a mast material.
[46] Whitewright 2009, 100.

and Corinth.[47] A ninth-century manuscript illustration, showing a fleet of ships with the hook-shaped masthead, indicates that this form was typical at that time.[48] This type of masthead lingers well into the Byzantine period, appearing up to the 12th century.[49]

A Byzantine hook-shaped masthead has not yet been found in the archaeological record, although there have been some attempts to reconstruct it.[50] For YK 11, the hook-shaped masthead was reconstructed as a double block with a shell that curves over into a hook-like projection. The block is closed above the sheaves to maintain the halyards in their proper location, preventing them from becoming displaced during tacking in rough weather. The function of the hook-like projection remains unclear, but iconography suggests that the halyard ran under the hook rather than over it.[51] That mastheads of this type had two sheaves rather than one is suggested by the graffito at Corinth, where Lucien Basch interprets the two circles on the masthead as the artist's attempt to show detail in perspective.[52] The Corinth graffito also clearly shows that the masthead had a tenon at its base that fit into a mortise at the top of the mast.[53] The mortise at the top of the mast of Black Sea wreck D suggests a similar arrangement.[54] The size of the masthead is based on the diameter of the mast at its top (15 cm) and the fragment of a large sheave found near YK 11 (fig. 6.4), 16 cm in diameter.

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[47] Basch 1991b, 5; Pomey 2006, 328; Basch 1991a, 20. Basch refers to this piece as the *calcet*.
[48] Grabar 1943, pl. LXXIII no. 1. This illustration is from the Bibliotheque Ambrosienne de Milan M. 35, 677.
[49] Hellenic Ministry of Culture 1998, 82-4, figs. 1, 2, and 5.
[50] Basch 1991a, 20, fig. 14.
[51] Hellenic Ministry of Culture 1998, 82, fig. 1. Pulak (pers. comm.) has suggested that the hook-like form facilitated the yard's clearing of the masthead during tacking.
[52] Basch 1991a, 20.
[53] Basch 1991a, 20.
[54] Ward and Ballard 2004, 10, fig. 7.

The heavy halyard system, which serves as a kind of backstay, is the fourth element characteristic of Late Antique lateen rigs.[55] The depictions from Corinth and Kellia both suggest that two individual lines are attached to the yard (figs. 6.14-6.15).[56] For the reconstruction, these are the ends of one line which run from the upper block aft of the mast, through the masthead block and down to the yard.[57] Here the ends are spliced together, forming an eye, which is doubled back on itself, slipped over the ends of the yard, and shifted to the pivot point, about 2/5 from the yard's lower end (fig. 6.19).[58] The halyard ties around the yard were probably covered with a stitched leather pad, resembling a bag, which served to prevent the yard from chafing against the lines or the mast (fig. 6.20), as is the case with those of Arab *dhows*.[59] In order to remove the halyards from the yard, they would have to be slipped off of the yardarm; the halyard was therefore made long enough for this to occur. The halyards could then be slipped out through the masthead block if the mast were also to be unstepped.

The halyard ran aft of the mast to a double purchase block-and-tackle system through which the yard could be hoisted into place.[60] The upper and lower blocks clearly appear on the depictions at Kelenderis and Kellia.[61] Double blocks were found at Yenikapı, and the two halyard blocks used in this reconstruction are based on both unpublished finds from Yenikapı as well as a treble block recovered from the 11th-

[55] Whitewright 2009, 100.
[56] Basch 1991a, 17 fig. 7; Basch 1991b, 5.
[57] Hawkins 1977, 92; Howarth 1977, 86.
[58] Bellabarba and Guerreri 2002, 244.
[59] Al-Hijji 2001, 79; Hawkins 1977, 94; Howarth 1977, 76.
[60] Howarth 1977, 86; Jewell 1976, 21; Whitewright 2009, 100.
[61] Basch 1991b, 5; Pomey 2006, 328.

century shipwreck at Serçe Limanı.[62] For the YK 11 reconstruction, the upper block was fastened to the halyard with a large toggle, the form of which is based on UM 189 from YK 11 (fig. 6.5). The lower block was attached to the through-beam aft of the mast by means of a spliced loop; this is also the case on some *dhows*.[63] The lanyard between these two double blocks, 2.5 cm in diameter, leads aft from the top block and is tied off at the deck beam above the bulkhead; at the ship's centerline, the deck and bulkhead planks were cut short to permit this.[64] The decision to lead the lanyard down from the upper block is based on the relatively small size of the yard and the number of men required to hoist it.[65]

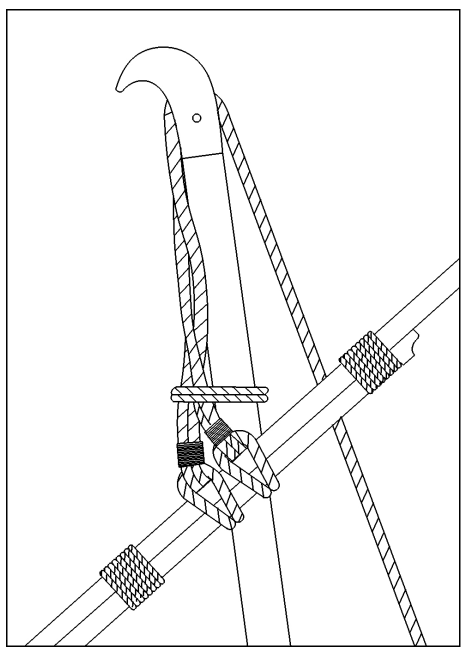

Figure 6.19. Attachment of the YK 11 yard to the halyard.

[62] Bass et al. 2004, 171-73; Çölmekçi 2007, 238 fig. 4.
[63] Hawkins 1977, 93; Jewell 1976, 21.
[64] Hawkins 1977, 92.
[65] Leading the lanyard from the lower block would be more logical on a larger ship where many men would be required to hoist the yard into place, as this would facilitate more men pulling at once.

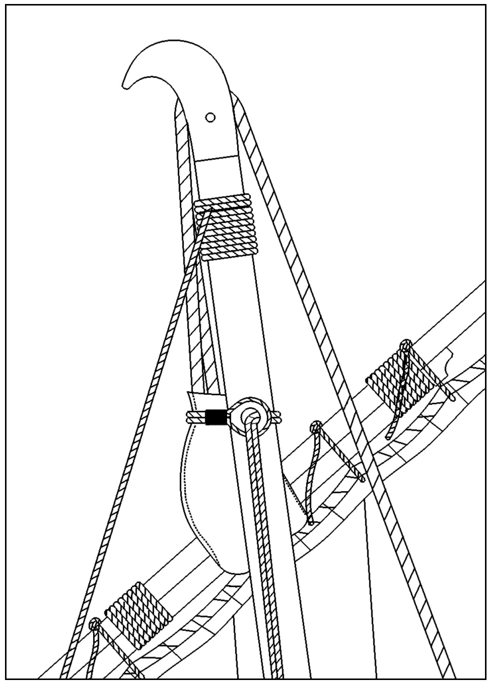

Figure 6.20. Throat tackle and yard attachment on YK 11.

One final aspect of the attachment of the yard is the throat tackle (or parral), which holds the yard to the mast.[66] Although this level of detail may not be observed in the relevant iconography, the method employed on Renaissance-period Italian lateen-rigged ships as well as Arab *dhows* of the past century provides a simple and tenable solution, a double line of rope which runs around the mast and the halyard ties just above the yard (fig. 6.20).[67] Because this would need to be loosened in order to tack, a heart thimble is included in the YK 11 reconstruction, based on one of the rigging elements recovered from the Serçe Limanı ship.[68] The line from the throat tackle is led down and

[66] According to Casson (1995, 260-63), this likely corresponds to the *chalinos* mentioned in Athenian Navy Yard records.
[67] Bellabarba and Guerreri 2002, 245; Hawkins 1977, 25, 94; Howarth 1977, 86; Jewell 1976, 21.
[68] Bass et al. 2004, 176-77.

tied off on the through-beam which supports the mast; in tacking, this line is loosened and shifted to the opposite side of the mast.[69]

Forestay or Shroud

There is no true standing rigging on this simple lateen rig, as nearly all lines must be detached or loosened in order to tack. However, the three Late Antique depictions of lateen vessels mentioned above all show a line leading forward from near the base of the masthead; this has been described as either a forestay or a runner-stay.[70] As placed in the YK 11 reconstruction, this line is more like a shroud. There are two such lines, one to starboard and one to port. Only the windward line is used, while the leeward line would be slack, tied up near the base of the mast, or could alternatively be attached to the foot of the sail.[71] Arab *dhows* usually have two such shrouds on either side, and they are said to look relatively weak, although this is compensated for by the secure fastening at the base of the mast.[72] Although, as indicated by Late Antique iconography, there is only one shroud on either side in this reconstruction, additional shrouds could easily be added.

The shrouds are fastened just below the base of the masthead. They consist of a line with a spliced eye in one end which fits over the top of the mast; this is held up by a rope stopper, which might also be the case on Black Sea wreck D.[73] This line leads to a single block, fastened with a small toggle to a gun purchase tackle. The toggles and

[69] Howarth 1977, 110.
[70] Basch 1991b, 6; Pomey 2006, 328. Basch (1991a, 20-1) notes that a true forestay would not allow for the tacking of the vessel.
[71] Al-Hijji 2001, 22-3, 122; Bowen 1949, 122; Hawkins 1977, 13, 17; Oman Ministry of Information and Culture 1979, 119, 128, 133.
[72] Howarth 1977, 86.
[73] Ward and Ballard 2004, fig. 7.

blocks used here are based on artifacts recovered from around YK 11. The lanyard from this block is tied off on a simple cleat nailed over futtocks.[74]

Running Rigging and Sail

Two lines are attached which allow manipulation of the yard; the uppermost is the vang, which is located near, but not at, the top end of the *penna*.[75] A vang is just barely discernable on the painting at Kellia, showing as a slightly thicker line aft of the halyards.[76] Later Byzantine depictions show two vangs, although this does not seem necessary.[77] On this reconstruction, the vang is tied off on a simple cleat on the windward side of the ship. During tacking, the vang is slackened with the aid of a single whip tackle placed somewhat near the yard; after tacking is complete, the ends of the vang are shifted to the opposite side of the ship.[78] As with the shroud, the vang's block is fastened with a small toggle so that it can be easily removed and replaced if necessary. Vangs are usually left somewhat slack on Arab *dhows*.[79]

The second line which is used to manipulate the yard was the bowline, termed a *marganali* on medieval lateen rigs; this was fastened to the lower end of the *carro*.[80] This line, although not always present, prevents excessive movement of the yard and may be seen on Arab *dhows* as well as Italian lateen-rigged ships.[81] In the

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[74] On Arab *dhows*, lines from these shrouds would be attached to "…any convenient part of the bulwarks…" (Howarth 1977, 86).
[75] Lever 1998, 42; Ray 1992, 210.
[76] Basch 1991b, 5-6.
[77] Brindley 1926, 13. Because the sail rotates about the yard when tacking, the vang, slackened but not detached during tacking, will remain in its proper position.
[78] Howarth 1977, 110; Landström 1961, 83.
[79] Bowen 1949, 114; Hawkins 1977, 64; Howarth 1977, 25; Jewell 1976, 82.
[80] Lever 1998, 42; Ray 1992, 211.
[81] Bellabarba and Guerreri 2002, 249; Hawkins 1977, 13; Howarth 1977, 26, 99. Al-Hijji (2001, 82) refers to it simply as the forward yard tackle.

reconstruction, this line is tied off on a simple cleat fastened over futtocks; it will also be shifted to the opposite side of the ship upon tacking.

Determining an appropriate sail size and shape was somewhat subjective. A quadrilateral lateen sail with a short luff was selected as opposed to a triangular or "true" lateen.[82] The mosaic at Kelenderis, of fifth-sixth-century date, depicts a quadrilateral lateen, while later ninth-century depictions show a triangular lateen.[83] The quadrilateral lateen has therefore been interpreted as a precursor to the triangular lateen, albeit one which remained in use in certain regions even after the adoption of the triangular lateen.[84] A quadrilateral lateen sail is slightly easier to handle than a triangular lateen, and also more efficient, allowing for more canvas to be placed on the same yard length; it is therefore considered an appropriate sail for a merchantman such as YK 11.[85]

Without any clear indication of the angles and size of a Byzantine quadrilateral lateen sail, the sail form of a Kuwaiti *dhow* was utilized for this reconstruction. Kuwaiti *dhow* sails have a head that is one and one quarter the length of the foot.[86] A head length of 10.3 m was selected for the 11 m yard, which resulted in a foot of 8.2 m. When using this ratio, the angle between the head and the luff is 129º, and the angles along the foot of the sail are approximately 90º.[87]

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[82] Several different terms have been used for this type of sail, including Arab lateen (now more or less rejected, as it suggests an Arab origin), Eastern lateen, settee, or quadrilateral lateen; all refer to a lateen sail possessing a short luff.
[83] Brindley 1926, 13; Pomey 2006, 328-29.
[84] Pomey 2006, 329. Bowen (1956, 242) makes the same claim, but instead calls this sail a "dipping lug" rather than a lateen sail.
[85] Al-Hijji 2001, 86; Howarth 1977, 86.
[86] Al-Hijji 2001, 90. This is for a somewhat lower-aspect sail; higher-aspect sails have a head to foot ratio of 1.5:1 and utilize a different angle between the head and the luff.
[87] Al-Hijji 2001, 90.

The sail is made of strips of linen, two Byzantine feet in width (62.5 cm).[88] The strips were sewn together with a conservative overlap of half of a Byzantine foot (approximately 16 cm) to create a strong canvas.[89] In keeping with the economical nature of YK 11, as evidenced by heavy repairs and recycled timbers, some patches were applied to the sail, especially near its center of effort; similar patched sail fragments were found at the Roman port of Berenike in Egypt.[90] The outer 5 cm of the sailcloth was folded over onto itself, around a 2.5 cm-diameter rope, and stitched down; a thick boltrope was then lashed onto the head, luff, and foot of the sail, with a thinner boltrope on the leech.[91] The sail is lashed to the yard with a series of robands (thin rope 1.5 cm in diameter) tied between the sail and the boltrope and fastened onto the yard with a simple reef knot, as is done on modern *dhows*.[92] This provides a simple yet effective fastening, which is nevertheless flexible enough to allow for tacking, in which the sail must be rotated around the yard.

The tack and clew of the sail are controlled through the tack and sheet, respectively.[93] Due to the small size of the ship, these were reconstructed as simple lines, attached to the cringles at the sail's corners with toggles, and tied off on cleats nailed to the upper portions of the top timbers or, as on the Port Berteau II ship, to top timbers that

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[88] Bass et al. 2004, 154; Black and Samuel 1991, 220; Casson 1995, 234; Schilbach 1970, 13-6. The early 10th-century *Book of the Eparch* confirms the presence of linen weavers and merchants within the city of Constantinople (*Book of the Eparch* 9.1, 9.7, Freshfield 1938, 27-9). Wool may alternately have been used for the sailcloth (Black and Samuel 1991, 222-24). Linen and wool were the primary textiles produced in the sixth century, and either would have made suitable sails (Morrisson and Sodini 2002, 205).
[89] Jewell 1976, 21.
[90] Hawkins 1977, 118; Wild and Wild 2001, 214, figs. 2-3.
[91] Al-Hijji 2001, 90; Bellabarba and Guerreri 2002, 255; Howarth 1977, 86.
[92] Al-Hijji 2001, 90-1; Howarth 1977, 92.
[93] Hawkins 1977, 60; Landström 1961, 83; Ray 1992, 210-11.

extended above the sheer strake.[94] These are led over to the opposite side of the ship upon tacking.[95]

Other Elements of the Ship's Rig and Equipment

Two further elements of the YK 11 reconstruction are line weight and quarter rudders. Line weight for this ship was determined based on archaeological evidence from around YK 11. Fragments of rope recovered were of two general sizes, approx. 2.0 cm diameter and 3-4 cm diameter. The larger diameter rope was used as the halyard and as the boltrope along the sail's head, luff, and foot. The smaller diameter rope was used in all other lines (block lanyards, throat tackle, vangs, shrouds, and the stopper for the shrouds near the masthead). A slightly smaller line, 1.5 cm in diameter, was used for the robands that attached the sail to the yard. An even smaller twine was used as serving.

The quarter rudder for this ship is based partly on the scant archaeological material available and partly on iconography. Rudder fragments from the fourth-century B.C. Kyrenia ship indicate thin blades attached to a central stock.[96] Depictions of Byzantine rudders suggest a similar structure was used from the 4th to 11th centuries A.D., although the stock extends beyond the lower end, perhaps intended to prevent damage to the delicate blades.[97] In this reconstruction, thin blades fore and aft are

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[94] Hawkins 1977, 94; Rieth et al. 2001, 49-51.

[95] Although only one bowline was used in this reconstruction, it could perhaps have had two bowlines along with additional blocks for easier adjustment. This could simplify the tacking procedure, as the bowlines would not need to be moved, but merely slackened (Howarth 1977, 110; Landström 1961, 83).

[96] Steffy 1989, 254-55, 261.

[97] Compare, for example, the rudders depicted in the 4th-century Murano diptych (Weitzmann 1979, 403), a 6th-century ivory pyxis (Weitzmann 1979, 427), and 9th-11th-century manuscripts illustrating the sermons of Gregory of Nazianzus (*Ms. grec 510*, Omont 1929, pl. LII; *Ms. grec 533*, Omont 1929, pl. CIV). Part of a rudder recovered from the Anse des Laurons 2 shipwreck, in contrast, consists of a stock and part of the blade cut from a single piece of wood; one or more other pieces of the blade were attached with treenails (Gassend 1998, 200-1).

attached to a central stock with tenons; the rudder is further reinforced by wooden bands nailed over the blade and stock.[98] A tiller is fastened near the top end of the rudder stock, approximately 1 m above deck level.

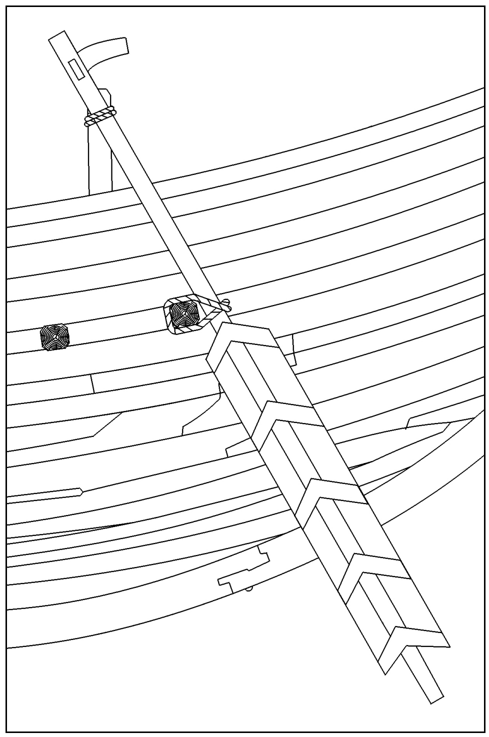

Figure 6.21. Braced mount for the YK 11 quarter rudder.

The ship would have possessed two quarter rudders, one to port and one to starboard; one of these may have been hoisted out of the water at times.[99] Very little is known of rudder attachments between the 6th and 11th centuries A.D.[100] Roman iconography suggests that rudders were mounted at an angle of 30-45º, and the former

[98] A similar rudder may be seen in the ninth-century Chludov Psalter (Moll 1929, pl. G 2.d1; Basch 1991a, fig. 3a-b; Hellenic Ministry of Culture 1998, 38, fig. 9).
[99] Casson 1971, 228; Hellenic Ministry of Culture 1998, 38, fig. 9; Mott 1996, 50.
[100] Mott 1996, 54.

was selected for the YK 11 reconstruction.[101] A simple braced mount was selected, with the top attachment to a stanchion fastened to the inside of the ship rather than an upper through-beam (fig. 6.21). The braced mount is common on small coastal vessels and facilitates the raising and lowering of the rudder.[102]

OVERVIEW OF THE YK 11 RIG

The rig proposed here for YK 11 (fig. 6.17) is hypothetical, based largely upon contemporaneous iconography and ethnographic equivalents where the archaeological material is lacking. This being the case, the actual sailing qualities of such a rig are difficult to assess. Nevertheless, the basic components—forward raking mast, quadrilateral lateen sail, halyard, vang, bowline, and shrouds fastened forward of the mast—are also visible in very similar, simple rigs of recent wooden ships of the Persian Gulf and Arabian Sea.[103] The simplicity of the reconstructed YK 11 rig, then, does not preclude its functionality.

The presumed philosophy of those who used this ship was considered in all aspects of the reconstruction. The desired rig was to be simple and economical, yet functional, allowing two or three sailors to engage in coastal trade. All blocks are fastened with toggles and are therefore easily removable. The yard could be hoisted or lowered by just two sailors, and two or three could unstep the mast if needed. The simplicity of the entire rig allows it to be dismantled completely in very little time.

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[101] Mott 1996, 17.
[102] Mott 1996, 20. This mount was chosen for its simplicity. However, this does not allow much alteration to the angle of the rudder or to its height.
[103] Hawkins' (1977, 13) photograph of a *zarook*, a traditional trader or fishing craft of Yemen, presents a rig very similar to that produced in the YK 11 reconstruction.

CHAPTER VII

CONCLUSION

The seventh century was a significant period of transition for the Byzantine Empire. Demographic change due to immigration and recurrent episodes of plague, hostile incursions in the Balkans and along the Empire's eastern border, and the widespread loss of territory created serious challenges. These resulted in a contracted economy and a more militarized society as the Empire successfully transitioned from Late Antiquity to the Middle Ages. It was in this context that a small, sturdy merchantman, YK 11, operated.

While it is unknown where YK 11 might have sailed, long-distance or interregional trade would have been inefficient for a ship of this size.[1] Instead, it is likely that YK 11 engaged in regional trade, which encompassed trade between Constantinople and coastal Thrace and Bithynia.[2] Although the ship could have potentially engaged in trade along the southwestern coast of the Black Sea, the presence of the customs house at Hieron, on the Bosphorus Strait, may have served as a deterrent.[3] Its most likely area of operation was therefore within the Sea of Marmara.

With a full-load draft of approximately one meter, YK 11 could have docked in even the smallest ports or natural coves. Unlike the Saint-Gervais 2 ship and several other ships at Yenikapı, YK 11 did not possess a transverse hole through the ship's keel

[1] Pomey and Tchernia 1978, 251. Laiou (2002, 705) specifies that trade of this kind generally deals with distances greater than 300 km, which, from Constantinople, would reach into the Aegean.
[2] Laiou (2002, 705) defines regional trade as that within distances of 50-300 km.
[3] Procop. *Anek.* 25.2-6.

to facilitate hauling the ship onto shore.[4] The ship's wineglass-shaped hull would also be slightly less convenient for beaching but does not preclude this activity.[5] The wineglass form was also less efficient for achieving optimal cargo capacity; however, it resulted in a sleeker vessel, one that could potentially outrun the Slav pirates that infested the coasts during this period. Thus, although it was a small ship capable of carrying a limited amount of cargo, it may have been of significant value in supplying the capital and other cities of the Marmara coast, particularly in times of need. After many long years of service, the ship was finally abandoned as a derelict in the shallow, forgotten, western corner of the Theodosian Harbor, an area quickly rendered unusable by siltation.

The YK 11 hull remains were fully excavated in 2008 in association with Istanbul's Marmaray Project. The ship was preserved up to the turn of the bilge on the starboard side and to the level of the second wale on the port side. Original planks, of Turkish pine, were edge-fastened with unpegged mortise-and-tenon joints up to the level of the ship's waterline; above this, the planks lacked edge fasteners. Over the life of the vessel, as planks succumbed to dry rot, damage from *Teredo navalis*, and general wear, they were pried off and replaced with new planks, also of Turkish pine, but lacking mortise-and-tenon joints. Repairs were concentrated along the bottom of the hull and at the stern. Both the original planking and the replacement planks were converted into their final form with the aid of char-bending, which resulted in blackened or charred interior surfaces near the ship's extremities.

[4] Jézégou 1983, 32; Kocabaş 2012b, 111.
[5] Cleaning and re-pitching the ship's exterior would have required hauling the ship onto shore.

The hull planking was payed with pitch on multiple occasions, both outside and within. Yet, the hull planking continued to deteriorate, and planks that had already been replaced eventually needed additional repair. Small areas of rotten wood, especially at edge fasteners, were chiseled out along plank edges, of both original and replacement planking, and replaced with small graving pieces, usually of Turkish pine or, less commonly, Mediterranean cypress. Significant gaps in some areas of the planking were simply stuffed with wads of grassy caulking and sealed with pitch. The ship's framing, following a pattern of alternating floors and paired half-frames, suffered as well, and many framing timbers—especially floors—were also replaced over the life of the vessel. Such repairs were not insignificant and necessitated the temporary removal of the ship's stringers and ceiling.

At first glance, one might mistakenly interpret YK 11, having very few edge fasteners, caulked plank seams, and framing attached to the spine of the ship with iron nails and bolts, as a skeleton-based vessel. Yet, with the detailed documentation of each component timber, a careful analysis of fastening patterns on planking, frames, and keel, and a thorough study of the preserved surface detail, in particular the score marks on the extant planking, the ship's construction processes and, to some extent, underlying philosophy have been identified as primarily shell-based.

YK 11 is an excellent example of a mixed construction, which was evident in various forms throughout this transitional period. The ship was initially designed and built shell-first below the waterline; hull form was determined primarily through the edge-fastened planking, without any clear use of "active" or control frames. Above the waterline, however, the ship was built primarily according to skeleton-first techniques, with planking fastened to pre-erected framing. The longitudinal strength of the hull was derived from an exterior shell of edge-fastened planking below the waterline and substantial wales above; a series of through-beams integrated the two sides of the hull and provided transverse support. Several stringers, a stemson, and a sternson provided additional longitudinal support. Individual elements of framing, although fastened to the keel and of substantial size relative to other timbers on YK 11, were not interconnected and thus do not represent a fully-integrated skeleton.

To determine whether a hull is primarily shell-based or skeleton-based, Hocker has suggested that the design, assembly sequence, and structural philosophy of the shipwright be considered.[6] A careful analysis of the score marks and placement of mortise-and-tenon joints on original planking indicate that, in both design and assembly, YK 11 was primarily shell-based. The structural philosophy is more difficult to identify and appears to be a combination of shell- and skeleton-based concepts; nevertheless, the lack of interconnected framing, the small number of bolts, and the edge-fastened planking with curving S-scarfs hint at the shipwright's underlying shell-based philosophy. Thus, according to Hocker's three criteria, YK 11 is primarily a shell-based hull.

Over time, however, edge-fastened planking and other timbers rotted and were replaced to such a great extent that, by the end of its life, the ship's strength was derived from a true mix of longitudinal and transverse timbers. The extent of repairs and

[6] Hocker 2004a, 6.

replacements of worn timbers, both planking and framing, significantly complicate the study of the ship's construction. Of the 37 planks preserved below the ship's waterline, just 11 were original, edge-fastened planks, and even these, with cut tenons and small graving pieces, no longer reflect a strong, interconnected shell. At the end of the vessel's working life, the hull comprised a complex assortment of shell- and skeleton-first techniques, with the latter prevailing in areas that had been repaired. Although this repaired vessel may at first glance appear to be skeleton-based, this is far from the case, as the ship was conceived and built as a shell-based hull.

The presence of such extensive repairs is perhaps YK 11's most valuable contribution toward the study of transitional ship construction. The nature and abundance of these repairs prove that, where possible, in order to obtain the most accurate interpretation, a hull must be fully excavated, dismantled, and studied in detail. It is essential for all of the repairs to be identified as such. Yet, even on a heavily repaired vessel such as YK 11, construction processes and concepts may still be determined to some extent. Surface detail, especially score marks, abandoned fastener holes, and the distribution of mortise-and-tenon joints are instrumental in understanding the construction of such a ship.

The presence or absence of edge fasteners along plank edges, caulking within plank seams, and the attachment of frames to the ship's keel have often been cited as indications of a predominantly shell-based or skeleton-based construction for ships of this period. While valuable contributions toward the understanding of the vessel, oversimplification of, and an excessive focus on, these features can produce misleading results. Edge fasteners along plank edges remain an important aspect of the shell- to skeleton-based shipbuilding transition. The need to fully dismantle a ship's planking is especially important for hulls dating from the 5th to 11th centuries A.D., a period during which planks were often edge-fastened with unpegged mortise-and-tenon joints or coaks, neither of which leaves a trace on visible surfaces once planks have been assembled. The lack of edge fasteners along exposed edges on a shipwreck of this period could result from widely-spaced joints or the presence of repairs rather than from an absence thereof throughout the hull during the initial construction. Caulking or waterproofing material along plank seams does not necessarily indicate planks lacking edge fasteners or a skeleton-based construction. Caulking fibers, if present, should be studied in detail to determine whether it was driven caulking or applied caulking and considered in light of other aspects of the ship's construction. Finally, the attachment of frames to the ship's keel should be carefully considered alongside other details such as score marks; do the attached frames represent "active" frames, or do these frames merely reinforce the ship's shell-based structure?

Optimally, all of these features would be considered in the study of a well-preserved shipwreck. This is, of course, not always possible, as full excavation, dismantling, and study generally entails conservation and long-term storage of the hull remains. Neither requirement is to be taken lightly, considering the financial burden thereof and the waning interest of donors once the excitement of an excavation has passed.[7] Due to the nature of the Yenikapı excavation, however, the ships were

[7] Throckmorton and Throckmorton 1973, 266.

necessarily dismantled and removed from the construction zone. As a result, these ships provide an excellent opportunity to study transitional shipbuilding and reinforce the benefits of full excavation. The study of YK 11 is especially valuable in this regard and indicates that the detailed analysis of individual elements of construction must be interpreted in light of the overall ship in order to determine the design, assembly sequence, and structural philosophy behind the ship's construction. Despite the complex nature of transitional ship construction and the extensive repairs the ship underwent, YK 11 provides a significant insight into the development of Mediterranean shipbuilding.

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APPENDIX A

TOOLS USED ON YK 11

An analysis of tool marks and other features preserved on the YK 11 timbers indicates several different tools used in the construction and repair of the ship. These tools are presented here in alphabetical order.

ADZE

The versatile adze was one of the primary tools used in shipbuilding and the characteristic tool of the shipwright.[1] Adze blades were not designed to cut deeply into wood and were therefore usually thinner and lighter than the blades of axes.[2] They could be used for rough shaping and removing large quantities of wood as well as finer detail work.[3] A second- or third-century relief from the National Museum in Ravenna depicts a shipwright using an adze to shape a frame for insertion into a planked vessel,[4] and a second-century image of a shipwright adzing the stem of a vessel is preserved in the catacombs of St. Callistus in Rome, carved into the wall.[5]

Evidence of adzing was preserved on all of the major categories of timber on YK 11. It was used to trim plank edges, shape frames, and dub chamfers into timbers where a sharp edge was not desired. Based on tool marks, a blade of 3.5-5 cm width was most

[1] Moll 1930, 160; Bass and van Doorninck 1982, 242.
[2] Ulrich 2007, 18.
[3] Ulrich 2007, 18. Goodman (1964, 21-2) notes two passages in Homer's *Odyssey* (21.42-50, 23.195-98) that refer to the careful use of an adze for precise work.
[4] Casson 1995, 206 n. 24, pl. 163; Ulrich 2007, 18-20, fig. 3.9. Ulrich provides a first-century date for the relief.
[5] Moll 1930, 161.

commonly used in the construction and repair of YK 11.[6] However, in many cases, subsequent blows from an adze obliterated parts of other tool marks, such that an exact size is not always available.

Five adze blades, nearly identical in form, were found on the contemporaneous seventh-century shipwreck at Yassıada. These unsocketed blades are of the "slot adze" or wedged adze variety, considered the simplest form of adze; two of the blades were found with an iron collar.[7] The striations observed within many of the adze marks on YK 11 timbers were probably caused by a chipped blade, not unlike the damage seen on the Yassıada ship's Fe 15 adze blade. The adze blades from Yassıada were approximately 7-8 cm in width, somewhat larger than any tool mark on the YK 11 timbers.[8] A more complex form, Roman socketed adzes were commonly combined with another tool such as a hammer or axe.[9] One such adze-hammer from Yassıada, with a blade width of only 5.8 cm, was closer in size to the tools used for building YK 11.[10]

BOW DRILL

Many of the nails in the planking of YK 11 were driven into pilot holes that had been bored through part or all of the thickness of the plank, at times even into the frame. These holes, variable in diameter but usually between 0.8-1.0 cm, may have been created with either a bow drill or an auger, although Goodman notes that only bow drills appear

[6] Adze blades of similar width have been found at Roman sites throughout Europe. A list of finds is provided in Gaitzsch 1980, 43 Abb. 3.
[7] Bass and van Doorninck 1982, 240-42; Goodman 1964, 25-7; Ulrich 2007, 16.
[8] Bass and van Doorninck 1982, 240-42.
[9] Ulrich 2007, 16-8.
[10] Bass and van Doorninck 1982, 242-43.

in Roman depictions of drilling.[11] A bow drill operated by a shipwright is depicted in a fourth-century Vatican gilt glass vessel.[12] A bow drill consisting of a wooden stock and nave, but lacking the iron bit, is among the many artifacts of Byzantine date recovered from Yenikapı; the stock was lathe-turned with a series of grooves to increase friction on the thong, by which the drill was turned in a reciprocating motion.[13]

In his study of Roman iron tools, Gaitzsch notes that drill bits tend to follow the Roman standard of the *digitus*, with ½, 1, and 1½ *digitus* well represented, although intermediate sizes are also known.[14] The 0.8-1.0 cm diameters of the pilot holes on the planking of YK 11 correspond well with the ½ *digitus* of 0.93 cm, and the Byzantine *lepton* (½ *daktylos*) of 0.975 cm.[15] The larger drilled holes, which accommodated the bolts on the keel, may likewise correspond to a Roman *digitus* (1.85 cm) or Byzantine *daktylos* (1.95 cm).[16] The holes drilled for the nails that attached the frames to the keel and wales were usually 1.1-1.6 cm (average 1.3 cm) and may reflect use of a drill bit of intermediate size. Drill bits for use with a bow drill were found on the seventh-century shipwreck at Yassıada; these would have created holes between 0.6 and 1.4 cm diameter.[17]

The drilling of holes along the edges of a mortise prior to chiseling the mortise would help prevent splitting; this technique is reflected in a first-century depiction from

[11] Goodman 1964, 161. Breast augers, a specialized tool developed by shipwrights, were not developed prior to the late 10th or early 11th century (Goodman 1964, 172-73).
[12] Ulrich 2007, 32, fig. 3.23.
[13] Ulrich (2007, 31) notes similar features on a Roman bow drill found in Egypt. The drill from Yenikapı, YKM 05.171, was made of boxwood; it is 21.6 cm in length and 6.7 cm in maximum diameter (Pekin and Kangal 2007, 303, no. Y74).
[14] Gaitzsch 1980, 30-2.
[15] Gaitzsch 1980, 23; Hultsch 1882, 88-98; Schilbach 1970, 275, under the entry δάκτυλος.
[16] Schilbach 1970, 16.
[17] Bass and van Doorninck 1982, 251.

Pompeii, in which a bow drill lies beneath the workbench of a man cutting mortises with a chisel and mallet.[18] Although one might expect the mortises along YK 11's plank edges to have been started with small drilled holes, this was not the case, hence the frequent splitting and cracking to mortise edges. Even on the late fourth-century B.C. Kyrenia shipwreck, the walls of mortises were chisel-cut without the aid of a drill; only some of the ship's ceiling planking, which had been recycled from another ship, had mortises that were cut between pre-drilled holes.[19]

CAULKING IRON

The orientation of the fibers in some of the ship's preserved caulking suggests that it was driven between plank seams with a caulking iron. Although no clear tool marks or damage have been preserved, a tool not unlike that found on the seventh-century Yassıada shipwreck, with a thin, flaring blade, would be expected.[20]

CHISEL

Mortises on the planks and other timbers of YK 11 would have been cut with a chisel struck with a hammer or mallet; a shipwright engaged in a similar activity is depicted on the fourth-century Vatican gilt glass vessel noted above.[21] Roman and Byzantine mortising chisels were tapered along one face and were usually less than 2 cm in width; these also may have followed a standard of measurement, such as ½ *digitus*

[18] Ulrich 2007, 29 fig. 3.17, 31.
[19] Steffy 1985, 90.
[20] Bass and van Doorninck 1982, 248-49, fig. 11-15, Fe 31.
[21] Ulrich 2007, 35 fig. 3.23.

and 1 *digitus* (0.93 and 1.85 cm, respectively), or 1 *lepton* and 1 *daktylos* (0.975 and 1.95 cm, respectively).[22] Tool marks in broken mortises on YK 11 planking suggest a mortising chisel of quadrangular section, 0.45 cm thick, with a distinct bevel along one face at the tip (fig. A.1). The width of the chisel is more difficult to ascertain; tool marks in other mortises seem to indicate a blade 1-2 cm in width, but mortising chisels were generally not beveled along their long edge,[23] suggesting a width closer to its thickness. Perhaps more than one chisel was used in creating the YK 11 mortises. Although of a greater thickness (up to 1.0 cm), chisel Fe 24 from the Yassıada ship, 1.5 cm in width, seems to have had a similar profile and is noted as being well-suited to cutting mortises.[24]

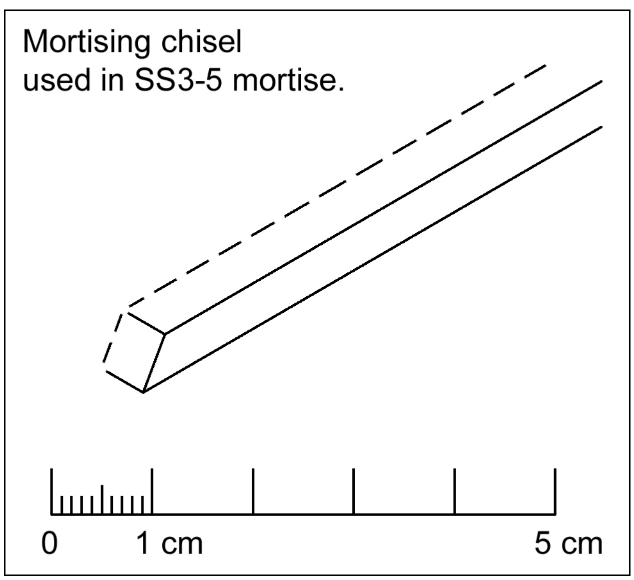

Figure A.1. Reconstructed mortising chisel, based on tool marks in a broken mortise on SS 3-5.

[22] Gaitzsch (1980, 168) notes that widths of approximately ½ *digitus* and 1 *digitus* are well represented in Roman mortising chisels in the archaeological record.
[23] Gaitzsch 1980, 163 fig. 24.
[24] Bass and van Doorninck 1982, 246-48, fig. 11-14.

Chisels were also used for cutting mortises in the inner (top) face of stringers and stanchion blocks and for countersinking certain nail heads. Tool marks on these timbers indicate the use of relatively narrow blades, one approximately 1.5 cm in width and another 2.0-2.3 cm in width. A 3.0 cm-wide chisel was used to cut the keel notch on the outer face of some frames. Wider chisels may also have been used for cutting limber holes in frames and cutting plank edges for repair, although these tool marks, 2-5 cm in width, may represent an adze rather than a chisel.

CLAW

Due to the widespread use of iron nails and the extent of repairs to the ship, a claw or nail extractor would have been an essential tool for those building and repairing YK 11. Curved iron tools with a tapered, forked end for this purpose are known from Roman sites.[25] Claws found in association with one of the ships at Nemi and on the second century B.C. Chretienne C shipwreck on the southeast coast of France may have been used by the associated shipwrights.[26] Two combination hammer-claws were also found on the 11th-century Serçe Limanı shipwreck; both were found in a basket with used nails, suggesting regular use for the maintenance and repair of the ship.[27] Sharp depressions to either side of disused nail holes are likely evidence of the use of a similar tool on YK 11 (fig. A.2).

[25] Gaitzsch 1980, 175-79.
[26] Ucelli 1950, 134-35, fig. 142; Gaitzsch 1980, 176-77; Joncheray 1975b, 99-100, fig. 47.J.
[27] Bass et al. 2004, 308-9, fig. 18-7 T21-T22.

Figure A.2. Evidence for the use of a claw for the extraction of nails. Note sharp tool marks to either side of three disused nail holes, near edge; SS 7-6 (UM 31), outer face.

SAW

Although not as prevalent as adzing, evidence of sawing is preserved on nearly every frame, plank, and stringer of YK 11. The planks were plainsawn rather than quartersawn, which made these planks more susceptible to shrinkage upon drying.[28] The planking, wales and stringers of YK 11, due to their great size, comprise the most difficult to cut. The shipwrights must have used a large frame saw for ripping a log (that is, cutting it lengthwise) into usable planks or half-logs.[29] Such frame saws employed a thin blade mounted in a wooden frame, the teeth of the blade perpendicular to the frame;

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[28] Ulrich 2007, 236.
[29] Ulrich 2007, 47-8.

the blade could be tightened by a screw at one end.[30] This form has remained in continual use until the present day.[31]

A large frame saw operated by two men may have been used in conjunction with a saw-pit; more likely, though, the timber to be sawn was set on one or more trestles above ground.[32] If trestles were used, the timber could be either horizontal, on two trestles, or diagonal, with one end on a trestle and the other resting on the ground.[33] In each configuration, the top man stands on the timber while the pitman sits or stands on the ground beneath. Gaitzsch has suggested that the triangular teeth of the saw would angle downward in order to facilitate the work of the top man.[34] The use of a crutch at the forward end rather than a trestle, as seen in several depictions of the 15-17th century, would facilitate the job; a second crutch could easily be inserted in order to shift the support during sawing, which would keep the sawyers from having to remove and reinsert the saw.[35]

Most of the YK 11 frames possess one face that was sawn. These timbers, being much smaller in size but still of considerable length (up to 2.4 m), might have been sawn with a hand saw or a larger frame saw. The latter seems more likely simply out of ease of cutting, although either would be feasible. There is evidence on at least two frames

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[30] Gaitzsch 1980, 193; Goodman 1964, 118-19; Ulrich 2007, 48. The tension of the frame prevented the saw blade from buckling. Both a large frame saw, suitable for ripping a log, and a smaller frame saw may be seen together in a first-century marble relief from Rome (Ulrich 2007, 11 fig. 2.3) and a 12th-century mosaic in Monreale, Sicily (Moll 1929, pl. B Xe.124). In the latter depiction, the large frame saw is being used in shipbuilding.
[31] Goodman 1964, 131. Goodman (1964, 136-37) observed the use of a large frame saw, similar to the Roman type, in use in Cairo in 1961.
[32] Meiggs 1982, 348-49, fig. 14d. Goodman (1964, 131-32) notes that a small proportion of the known depictions of such saws involve a pit.
[33] Goodman 1964, 132.
[34] Gaitzsch 1980, 201.
[35] Goodman 1964, 136.

(FR 6 and FR 8) of sawing from different directions at opposite ends. This is not an unexpected practice with a hand saw; however, ripping a timber from opposite ends with a frame saw was also observed in use by Swiss sawyers around 1900.[36]

SCRIBER OR KNIFE

A scriber or knife would have been used to mark planks and other timbers as an aid in the ship's construction.[37] Theophrastus mentions carpentry marks on wood, noting that softer woods, being more easily marked, are preferable.[38] The use of score marks on both original and repair planking and other timbers, such as frames, aids significantly in determining the construction sequence of YK 11. Score marks on timbers have been identified on several other shipwrecks of shell-based construction, including the Ma‘agan Mikhael (fifth century B.C.), Port-Vendres 1 (A.D. 400), and Yassıada 1 (seventh century) ships.[39] A knife may have been used to cut through tenons during repairs and prior to the recaulking of YK 11.

[36] Goodman 1964, 137-38.
[37] Ulrich 2007, 34.
[38] Theophr. *Hist. pl.* 5.5.1.
[39] Bass and van Doorninck 1982, 59, 71; Mor 2004, 167-68, Liou 1974, 432.

APPENDIX B

SPECIES OF WOOD USED IN YK 11

Analysis carried out by Dr. Nili Liphschitz of the Institute of Archaeology, the Botanical Laboratories, at Tel Aviv University, has identified eleven different wood species used in building YK 11. These include ash, beech, cypress, elm, three species of oak, two species of pine, sycamore maple, and tamarisk (fig. 5.2). Boxwood was also identified in several of the rigging elements scattered around the wreck; these may or may not have belonged to YK 11.

The vast majority of timbers have been identified as *Pinus brutia* (Turkish pine); *Cupressus sempervirens* (Mediterranean cypress) was frequently used for some of the ship's internal structures, and *Quercus cerris* (Turkey oak) formed the ship's keel. The other wood species were used infrequently. Fir is notably absent from the wood types found in and around YK 11. Theophrastus notes that silver fir is unlikely to split and bears weight well;[1] for this reason, and due to its long, straight trunk, fir is optimal for masts and yards.[2] It may, therefore, have been used in the rigging of YK 11 but was not preserved.

Forests and woods are plentiful around Constantinople, and these must have been exploited for timber for shipbuilding or other purposes. Due to the sharp decline in Rome's population after the fifth and sixth centuries, timber was readily available closer

[1] Theophr. *Hist. pl.* 5.6.1.
[2] Theophr. *Hist. pl.* 5.1.7.

to that city in later periods.[3] Perhaps a more plentiful supply of local timber was available by the late sixth century in Constantinople as well. Based on the wood types used in the vessel's construction, it is possible that YK 11 was built in a shipyard near Constantinople.[4] According to Theophrastus, although the best quality timber was Macedonian, good timber could also be obtained from the Black Sea, as well as Rhyndakos on the Asian shore of the Sea of Marmara, near Bursa.[5] Forests on the south coast of the Black Sea provided fir, beech, pine, oak, and maple, and this could then have been easily transported by water to Constantinople.[6] Meiggs notes that the plentiful forests along the south shore of the Black Sea and around the Sea of Marmara do not seem to have suffered from deforestation in the Roman period as did other areas of the Mediterranean.[7]

ASH

Fraxinus excelsior, European ash, was relatively rare on YK 11; it was used for two of the ship's frames near the stern: FR 2 and FR 3. One of the bulkhead planks was ash, as was the bulkhead frame of unknown provenience (UM 157). It was used in two other UM timbers, one of which was a frame fragment. European ash is found

[3] Meiggs 1982, 383.
[4] Davis 1965, 1:76-8. Makris (2002, 97) notes that Constantinople was the Empire's foremost center for shipbuilding.
[5] Theophr. *Hist. pl.* 5.2.1.
[6] Meiggs 1982, 334-39, 358.
[7] Meiggs 1982, 393-94.

throughout Europe and may grow up to 25 m in height.[8] Vitruvius considered aged ash to be both strong and sturdy.[9]

BEECH

Fagus orientalis, Oriental beech, was identified only in one in-situ timber, common ceiling SC 1B. The delicate grooves along the edges of this ceiling plank indicate a recycled timber, perhaps part of the finely-cut interior woodwork of a structure in the city. Beech was also identified in eight of the UM timbers found around the ship, four of which were parts of oars.

Vitruvius notes that, like Turkey oak, beech has a loose texture which tends to decay when exposed to moisture.[10] However, according to Theophrastus, beech does not decay in water and was considered useful for shipbuilding.[11] It was also used for making wagons and carts.[12] Although fir was considered a good wood for crafting oars,[13] it is noteworthy that all of the oars or oar-like timbers found near YK 11 were of beech.

BOXWOOD

Buxus sempervirens, common boxwood, was used in ten of the eighteen elements of ship's rigging found in and around YK 11. This includes two of the six toggles, three of the six loose sheaves, and four of the five spool toggles. Boxwood was also used for

[8] Ulrich 2007, 251.
[9] Vitr. *De arch.* 2.9.11.
[10] Vitr. *De arch.* 2.9.9.
[11] Theophr. *Hist. pl.* 5.4.4, 3.10.1.
[12] Theophr. *Hist. pl.* 5.7.6.
[13] Meiggs 1982, 119.

the pin and the sheave of intact pulley block UM 151. Most of these objects were lathe-turned. Boxwood does not appear to have been used in the construction of YK 11.

Theophrastus considered this wood to be both hard and heavy.[14] With its close grain and bitter taste, it was impervious to attack by shipworm.[15] Pliny notes that it does not float due to its density, which may explain why the boxwood rigging elements found around the ship, although in excellent condition, were not reused elsewhere.[16] Boxwood was frequently used for combs, and many such objects were recovered at Yenikapı.[17]

CYPRESS

Cupressus sempervirens, Mediterranean cypress, was the second most common wood species used in YK 11 and was especially favored for the ship's ceiling. This wood was used for four of the ten stringers (SST 2, SST 3-1, SST 3-2, and SST 4) and five of the ten pieces of common ceiling (SC 1C, SC 2, SC 5, SC 6, and SC 7). Three of the six stanchion blocks are also of Mediterranean cypress (S-Blocks 1, 2, and 3). Cypress was used for some small pieces of repair planking (SS 3-6 and SS 7-6/UM 31) as well. It was identified in several UM timbers, usually fragments of planking or ceiling; at least three of the cypress UM timbers are fragments of edge-fastened planking and indicate the use thereof in the initial construction of the hull. An unidentified wale fragment (UM 40) and the only known fragment of a through-beam (UM 81) are also of

[14] Theophr. *Hist. pl.* 5.4.1.
[15] Theophr. *Hist. pl.* 5.4.5.
[16] Plin. *HN* 16.76.204.
[17] Ulrich 2007, 245-46; Pekin and Kangal 2007, 286 no. Y44.

cypress. Only two of the unidentified cypress timbers are frame-like fragments, and cypress is notably absent in the extant framing of YK 11.

According to Vitruvius, cypress is a sturdy wood that is not prone to breakage or rot; furthermore, as with pine, its natural resins create a bitter taste that deters wood-borers.[18] Theophrastus also considered this wood to be long-lasting and resistant to decay.[19] As such, it is interesting that it was preferred for internal rather than external timbers on YK 11.

Cypress, which can attain a height up to 30 m, was considered a suitable timber for building warships; along with pine, it was the primary timber used by Theodoric to build his fleet of *dromons* in the early sixth century.[20] Both Nikephoros and Theophanes note that, in 715, an Arab fleet had come to Phoenix (most likely on Rhodes rather than the Lycian Phoenix) to collect cypress wood that was "suitable for shipbuilding;" the Byzantines attempted to block this activity, preferring to burn the timber rather than allow it to be procured by the Arabs.[21]

In Antiquity, cypress was found in the southern parts of Greece and Asia Minor, especially on Crete, Lycia, and Rhodes.[22] It is unclear whether or not cypress grew locally in Constantinople in the late sixth century A.D., although Rival notes that it could be found in Thrace.[23] If it did not grow locally at the time, cypress, valued for several of

[18] Vitr. *De arch.* 2.9.12.
[19] Theophr. *Hist. pl.* 5.4.2.
[20] Meiggs 1982, 46, 120, 152; Cassiod. *Var.* 5.16; Veg. *Mil.* 4.34.
[21] Nikeph. 50.1-6; Theoph. 385; Mango 1990, 116-17.
[22] Davis 1965, 1:76-8, map 11; Meiggs 1982, 46; Rival 1991, 17-8, map 1; Theophr. *Hist. pl.* 4.5.2.
[23] Rival 1991, 17.

its qualities, would almost certainly have been imported into the city.[24] Although it is unlikely for YK 11 to have been built using costlier imported materials, the shipwright may have been using lengths of cypress that were leftover from the construction of another ship.

ELM

Ulmus campestris, common elm, was used for the aftermost frames, half-frame FR 1 and futtock F 2. It was also used for the short stemson (UM 47) and the shell of the intact pulley (UM 151) found resting on the ship's planking between the forward pair of stanchion blocks. Six of the UM timbers were cut from this wood species. Elm timbers are noteworthy for their excellent preservation on YK 11 and elsewhere at Yenikapı.[25] Elm appears to have been used for both original and replacement timbers on YK 11.

Vitruvius considered elm, if aged, to be both strong and sturdy.[26] According to Theophrastus, it is strong but moist, and unlikely to warp; it is suitable for shipbuilding.[27] Elm could, however, be difficult to work.[28]

OAK

Quercus cerris, Turkey oak, was commonly used in many of the merchant vessels found at Yenikapı but was relatively rare on YK 11. On this ship, it was used for

[24] Vitr. *De arch.* 2.9.12; Theophr. *Hist. pl.* 5.4.2.
[25] The elm frames of galley YK 2, for example, exhibited excellent preservation in contrast to frames made of Oriental plane (*Platanus orientalis*).
[26] Vitr. *De arch.* 2.9.11.
[27] Theophr. *Hist. pl.* 5.3.4-5, 5.7.3.
[28] Meiggs 1982, 242.

all three parts of the ship's keel and one of the keel's scarf keys, three frames (FR 15, FR 16P and FR 25), and one of the common ceiling timbers (SC 4). It is noteworthy that these are all original elements of the ship's initial construction rather than later repairs, with the exception of SC 4, which may or may not be original. Turkey oak was also identified in several of the UM timbers, one of which was an element of rigging, toggle UM 185.

Turkey oak is a fast-growing species that can reach heights of 35 m.[29] It was to be found throughout Turkey as well as in Italy, Greece, and the eastern Mediterranean, but this species did not have a reputation as a high-quality timber.[30] Theophrastus noted that this species grows tall and straight and produces strong wood.[31] According to Vitruvius, however, Turkey oak has a loose texture which tends to decay when exposed to moisture.[32] Floors of buildings fashioned from Turkey oak were short-lived.[33]

All of the 49 tenons sampled from YK 11 are oak, the vast majority (43) being *Quercus coccifera* (Kermes oak), although a small number of *Q. cerris* (4) and *Q. petraea/Q. pubescens* (1) were also identified.[34] Kermes oak was also used for some of the rigging pieces scattered across the wreck, including an intact toggle (UM 175) and three sheaves (UM 178, UM 183, and UM 186.) The wood from this small, shrub-like species of oak[35] was identified in three other UM timbers of unknown function but, with the exception of the tenons, was not used in the construction of the ship. Kermes oak is

[29] Ulrich 2007, 258. According to Davis (1965, 7:674), it attains heights of 25 m.
[30] Davis 1965, 7:674-76, 7:890 map 86; Meiggs 1982, 45.
[31] Theophr. *Hist. pl.* 3.8.4.
[32] Vitr. *De arch.* 2.9.9.
[33] Vitr. *De arch.* 7.1.2.
[34] One tenon could only be identified as *Quercus* sp.
[35] Davis 1965, 7:681.

found throughout the Mediterranean, including southern and western Anatolia as well as the area around the Sea of Marmara.[36] Theophrastus considered it a strong wood, useful for making axles.[37]

Theophrastus considered oak in general to be both hard and heavy, and it was furthermore difficult to work.[38] He notes that it was commonly used for riverboats but not seagoing ships, as it tends to rot in seawater but not freshwater.[39] Nevertheless, Theophrastus also states that oak was used for the keels of warships, which facilitated hauling onto shore, while fir was used for the keels of merchant ships.[40] Perhaps the use of oak in the YK 11 keel reflects frequent hauling onto shore, as would be expected of a ship engaging in coastal trade.

PINE

Most of the YK 11 timbers are *Pinus brutia* (Turkish pine). This includes nearly all of the ship's planking (with the exception of small timbers SS 3-6 and SS 7-6/UM 31), both of the in-situ wales, 70% of the ship's extant frames, six of the ten stringers, and two of the six stanchion blocks. The in-situ bulkhead frame and three of its four planks are Turkish pine, as is the recycled keel timber that formed the sternson (KS 1).[41] This wood species also comprised approximately half of the UM timbers found around

[36] Davis 1965, 7:681-82, 7:892 map 90.
[37] Theophr. *Hist. pl.* 5.4.8, 5.7.6.
[38] Theophr. *Hist. pl.* 5.4.1, 5.5.1.
[39] Theophr. *Hist. pl.* 5.4.3.
[40] Theophr. *Hist. pl.* 5.7.2.
[41] This is somewhat surprising, as all original keel timbers of YK 11 are of oak rather than pine.

the wreck. However, it was surprisingly rare in the common ceiling, with only one timber—SC 1A—of Turkish pine.

Pinus nigra (European black pine) was far less common but was used for one stanchion block (S-Block 4), one in-situ futtock (F 4), and the key that locked the Keel 1-Keel 2 scarf together. Another fragment of black pine found within the exposed aft end of Keel 1 may be what remains of the key at the Keel 1-Sternpost scarf. This wood species was identified in several of the UM timbers, notably two pole-like fragments (possibly parts of an oar or handle), UM 156 and UM 171.

Pine, along with fir, was one of the most commonly used woods in ancient Rome.[42] According to Vitruvius, pine is a sturdy wood that is not prone to breakage or rot; furthermore, the natural resins in pine create a bitter taste that deters wood-borers.[43] Literary references of the fourth through sixth centuries A.D. identify both pine and cypress as the primary woods used in the construction of warships.[44] Mountain pines such as *Pinus nigra* were more resinous, but coastal pines, such as *Pinus halepensis* (Aleppo pine) or *Pinus brutia,* were more plentiful.[45] However, literary references to pine are not always clear as to which species is being discussed.[46]

Pinus nigra is a mountain pine found in the Eastern Mediterranean at altitudes up to 1,200 m; it was prized by shipbuilders for its strong, large timbers.[47] *Pinus halepensis* was the most widespread Mediterranean pine and is usually found in coastal areas of

[42] Meiggs 1982, 241.
[43] Vitr. *De arch.* 2.9.12.
[44] Cassiod. *Var.* 5.16; Meiggs 1982, 120, 152; Veg. *Mil.* 4.34.
[45] Theophr. *Hist. pl.* 3.9.2; Meiggs 1982, 469.
[46] Meiggs 1982, 44.
[47] Meiggs 1982, 44, 119; Theophr. *Hist. pl.* 3.9.1-2.

mainland Greece and areas westward of Greece.[48] Theophrastus identified pitch from *Pinus halepensis* as being of high quality and describes the extraction and preparation thereof in detail.[49]

Pinus brutia is very similar to *Pinus halepensis*; the two have been considered one species in the past but are now generally accepted as representing two distinct taxa.[50] *Pinus brutia*, also known as Turkish or Calabrian pine, occurs in the eastern Mediterranean, especially in the Greek islands, Cyprus, and coastal Turkey (including Thrace) and Syria.[51] There is no evidence of its growth along the southern Syro-Palestinian coast in antiquity.[52] It is generally found in warm or temperate zones, 0-500 m in northern Turkey and 200-1,200 m in southern Turkey, but has been found at altitudes up to 2,000 m.[53] Having occasional false growth rings and a relatively short life span of not more than 200-250 years, *Pinus brutia* is generally not a good candidate for dendrochronological dating.[54] Several adaptations, to its cones, seeds, and seedlings, allow this species to regenerate after forest fires.[55] *Pinus brutia* usually reaches heights of 20-30 m (not exceeding 35 m) and may have a diameter as great as 1.2 m (not exceeding 2.1 m).[56] In Antiquity, this wood was used for shipbuilding on Cyprus.[57]

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[48] Meiggs 1982, 43-4. Aside from areas in Cilicia, it is not found wild in Anatolia (Davis 1965, 1:75).
[49] Theophr. *Hist. pl.* 9.2-3.
[50] Frankis 1999, 173-74; Quézal 2000, 1-2.
[51] Davis 1965, 1:73-5, map 9; Meiggs 1982, 44; Rival 1991, 25, 27 map 5.
[52] Weinstein-Evron and Lev-Yadun 2000, 121.
[53] Frankis 1999, 181; Quézal 2000, 6.
[54] English Heritage 2004, 15; Lev-Yadun 2000, 74-5.
[55] Thanos and Doussi 2000, 291-93. Theophrastus (*Hist. pl.* 3.9.5) also mentions the ability of certain pines to regenerate after a fire.
[56] Frankis 1999, 180.
[57] Meiggs 1982, 44; Theophr. *Hist. pl.* 5.7.1.

SYCAMORE MAPLE

Acer pseudoplatanus, or sycamore maple, was used for some of the ship's ceiling (PC 1 and SC 3) and one futtock (F 19). This wood was identified in several UM timbers, including two small floors (UM 33 and UM 34) and one pole or oar handle (UM 37). It was also used in three of the rigging elements: two toggles (UM 117 and UM 189) and a spool toggle (UM 184). Sycamore maples are the tallest of the European maples and may reach up to 40 m in height.[58] According to Pliny, maples were commonly used in the production of furniture.[59]

TAMARISK

Although very rare on YK 11, *Tamarix* (x5), tamarisk, was identified in two frames, futtock F 13 and floor FR 23, both of which are original to the initial construction of the ship. It was also identified in a UM timber found near the wreck. Theophrastus identifies this as a weak wood.[60] Although tamarisk is often found in drier climates of the Mediterranean, *Tamarix smyrnensis*, in the x5 group, grows around Constantinople.[61]

[58] Ulrich 2007, 244.
[59] Plin. *HN* 16.26.66.
[60] Theophr. *Hist. pl.* 5.4.8.
[61] Baum 1978, 46-7; Meiggs 1982, 71.

APPENDIX C

CALCULATIONS FOR DETERMINING THE SIZE OF THE YARD

USED IN THE RECONSTRUCTED RIG OF YK 11

Variables used:

P = *Penna* (longer, upper portion of yard)
C = *Carro* (shorter, lower portion of yard)
L = Length of yard (with *penna* and *carro* overlapped) = 11 m
TL = Total length of the combined pieces of the yard = P + C
LO = Length of overlap between the *penna* and *carro*
D = Diameter

According to the 15th-century *Fabrica di galere* manuscript, the length of the overlap between the *penna* and the *carro* (LO) should be one-fifth the total length of the combined components.[1] This results in the following formulas:

LO = 0.2 x TL
L = 11 m = TL - LO
L = 11 m = TL - (0.2 x TL)
11 m = 0.8 x TL
TL = 13.75 m

TL = 13.75 m = P + C
C=0.85 x P [Extrapolated from 13-14th-century Genoese contracts][2]
13.75 m = P + 0.85P
13.75 m = 1.85P
P = 7.43 m
C = 6.32 m
LO = 2.75 m

[1] Pryor 1984, 289.
[2] Pryor 1984, 288.

The 15th-century Venetian Timbotta manuscript prescribes a yard diameter of its length divided by 88.[3] If length refers to the length of the composite yard, the following formula results:

$D = L / 88$
$D = 11\ m / 88 = 12.5\ cm$

Alternately, length-to-diameter ratios of the component pieces of the yards (*penna* and *carro*) were calculated based on dimensions of the yard components of an archetypal 13th-14th-century ship.[4] These resulted in length-to-diameter ratios of about 1:54 for the *penna* and about 1:47 for the *carro*, which produce the following:

For $P = 7.43\ m$
$D = P / 54$
$D_{(penna)} = 13.8\ cm$

For $C = 6.32\ m$
$D = C / 47$
$D_{(carro)} = 13.4\ cm$

These alternate diameters for the component pieces of the yard are slightly larger than that suggested by the Timbotta manuscript. Yet, both formulas result in a yard that is as large as, or larger than, the maximum sided dimension of the ship's keel. Therefore, the maximum diameter of any component of the yard was set at 9 cm, which is the minimum sided dimension of the preserved portion of the ship's keel. The total sectional size of the yard will be slightly larger along the overlap of the *penna* and *carro*.

[3] Anderson 1925, 156.
[4] Pryor 1984, 287-88.

APPENDIX D

CALCULATIONS FOR DETERMINING THE WATERPLANE, MIDSHIP, BLOCK, AND PRISMATIC COEFFICIENTS OF YK 11

WATERPLANE COEFFICIENT[1]

The waterplane area (A_w) is the area of the hull at the plane of full-load immersion, corresponding to 5 cm above the third waterline in the YK 11 ship's lines. This area extends to the inside of the planking, stem, and sternpost. Using Rhinoceros modeling software, this area could be accurately calculated as 20.82 m^2. To determine the waterplane coefficient, the waterplane area is enclosed in a rectangle representing the maximum hull dimensions at the load waterline: molded breadth (B_m, breadth to inside of the planking) and the length of the waterline at full load (L_{wl}, length to inside of the stem and sternpost). The waterplane coefficient corresponds to the ratio between the waterplane area (A_w) and the area of this rectangle (A_{rw}).

A_w = 20.82 m^2
B_m = 3.22 m
L_{wl} = 8.79 m
$A_{rw} = B_m \times L_{wl}$
A_{rw} = 3.22 m x 8.79 m = 28.30 m^2
Waterplane coefficient = A_w / A_{rw}
Waterplane coefficient = 20.82 m^2 / 28.30 m^2 = 0.74

[1] This dissertation follows the definitions of dimensions, proportions, and coefficients provided by Steffy (1994, 253-55).

MIDSHIP COEFFICIENT

Using Rhinoceros modeling software, the molded area of the immersed midship section (A_{mm}) could be accurately calculated as 1.83 m^2. The midship coefficient is the ratio of the molded area of the immersed midship section at full load (A_{mm}) to the area of a rectangle (A_{rm}) whose sides represent molded draft and breadth (B_m).

A_{mm} = 1.83 m^2
Draft, molded = 0.84 m
B_m = 3.22 m
A_{rm} = *Draft, molded* x B_m
A_{rm} = 0.84 m x 3.22 m = 2.70 m^2
Midship coefficient = A_{mm} / A_{rm}
Midship coefficient = 1.83 m^2 / 2.70 m^2 = 0.68

BLOCK COEFFICIENT

The block coefficient describes the relationship between the displacement volume of a hull (*Displ., molded*) and that of a block whose volume (V_b) is the product of the molded draft (*Draft, molded*), molded breadth (B_m), and molded length at the load waterline (L_{wl}). The displacement volume of the hull used here (*Displ., molded*) comprises the volume of the ship inside of both planking and keel; this was accurately calculated as 10.45 m^3 using the Analyze Volume command within Rhinoceros modeling software.

Displ., molded = 10.45 m^3
Draft, molded = 0.84 m
B_m = 3.22 m
L_{wl} = 8.79 m
V_b = *Draft, molded* x B_m x L_{wl}
V_b = 0.84 m x 3.22 m x 8.79 m = 23.78 m^3
Block coefficient = *Displ., molded* / V_b
Block coefficient = 10.45 m^3 / 23.78 m^3 = 0.44

PRISMATIC COEFFICIENT

The prismatic coefficient describes the relationship between the displacement volume of the hull (*Displ., molded*) and that of a prism (V_p) whose sides are equal to the full-load waterline length (L_{wl}), using molded dimensions throughout. The section of the prism is the molded area of the immersed midship section at full load (A_{mm}), calculated using Rhinoceros modeling software. The displacement volume of the hull used here (*Displ., molded*) comprises the volume of the ship inside of both planking and keel; this was accurately calculated as 10.45 m^3 using the Analyze Volume command within Rhinoceros modeling software.

Displ., molded = 10.45 m^3
A_{mm} = 1.83 m^2
L_{wl} = 8.79 m
$V_p = A_{mm} \times L_{wl}$
V_p =1.83 m^2 x 8.79 m = 16.09 m^3
Prismatic coefficient = *Displ., molded* / V_p
Prismatic coefficient = 10.45 m^3 / 16.09 m^3 = 0.65

APPENDIX E

GLOSSARY

The following glossary defines terms used in this text to describe the remains, reconstruction, and rig of YK 11. Unless noted otherwise, definitions follow those provided in Steffy's illustrated glossary.[1] Further detail is provided if the use of a specific term for YK 11 differs from its standard interpretation.

Bulkhead. A vertical partition within the ship. On YK 11, the bulkhead ran athwartships near the stern and consisted of narrow planks fitted into a slotted frame. The frame was mounted on the vessel's sternson and ceiling.

Buttock Lines. Projections on a lines drawing that reveal vertically oriented longitudinal hull shapes.

Carro. The shorter, lower portion of the ship's yard.[2]

Ceiling. The internal planking of the vessel. On YK 11, this includes stringers, common ceiling, and sills.

Central stringer. One of a pair of stringers fastened to the inner face of framing to either side of the ship's keel, between the stemson and sternson. These provided longitudinal support for the hull and maintained the position of the mast step laterally. Only the starboard central stringer was preserved on YK 11.

Common ceiling. Short planks of ordinary ceiling used to prevent cargo and ballast from falling between the frames. These filled the gaps between stringers.

***Daktylos* (pl. *daktyloi*).** Byzantine finger (unit of length measurement), 1/16 of a *pous* (Byzantine foot); equal to 1.95 cm.[3]

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[1] Steffy 1994, 266-98.
[2] Bellabarba and Guerreri 2002, 243.
[3] Schilbach 1970, 16.

Floor. A frame timber that crosses the keel and spans the bottom of the ship, with arms terminating near the turn of the bilge. These generally alternated with half-frames on YK 11.

Futtock. A frame timber other than a floor timber, half-frame, or top timber. On YK 11, futtocks were placed adjacent to their associated floor or half-frame.

Gun tackle purchase. A purchase made by reeving a rope through two single blocks and fastening the end to the strap of the first block.[4]

Half-frame. A frame that spans the entire width of the inner face of the keel and extends up one side of the ship, either to or above the first wale. These generally alternated with floors on YK 11.

Heart thimble. A block of wood with a large hole in the center and a groove cut around the perimeter.[5] In the reconstructed rig of YK 11, a heart thimble facilitates the loosening of the throat tackle or parral.

Hood end. The end of a plank that fits into the stem or sternpost rabbet. On YK 11, hood ends were fastened to the stem and sternpost with iron nails.

Keel. The main longitudinal timber of the ship upon which the frames were mounted; the backbone of the hull. On YK 11, the keel consisted of a flat portion (Keel 2) and a curved, transitional portion at both bow (Keel 3) and stern (Keel 1).

Limber hole. Aperture cut in the bottom (outer) surface of a frame to allow the free passage of bilge water. Half-frames of YK 11 have one limber hole; floors have two. On YK 11, the limber holes are triangular and located to one side (for half-frames) or both sides (for floors) of the frame surface in contact with the keel.

Mast step. A large rectangular timber mortised to receive the tenoned heel of the mast and, forward of this, a support stanchion or post. This timber was not preserved on YK 11 but has been reconstructed as a substantial timber notched to fit over framing. The notches maintained the position of the mast step longitudinally while the central stringers maintained its position laterally; it was not fastened in place.

Mast-partner through-beam. Through-beam just forward of amidships against which the raking mast was steadied.

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[4] Lever 1998, 16 fig. 139.
[5] Bass et al. 2004, 177 no. RG 21; Lever 1998, 14.

Midship frame. The broadest frame in the hull; the frame representing the midship shape on the body plan. On YK 11, this is FR 16.

Penna**.** The upper portion of the ship's yard; the *penna* is longer and thus heavier in order to counterbalance the *carro* or lower portion.[6]

Planking. The outer shell of the hull.

Pous **(pl.** ***podes*****).** Byzantine foot (unit of length measurement); equal to 31.23 cm.[7]

Pulley block. An element of rigging that increases applied force. A pulley block consists of a shell, sheave (or wheel), and pin (or axle); the shell is grooved along its perimeter to accommodate a strap.[8] Well preserved pulley block UM 151 was found within the YK 11 hull.

S-twist. Term used to describe rope that has been twisted to the right; also called left-laid.[9]

Sill. A crenelated plank custom-cut to fit over and between the framing, preventing foreign matter from falling into the bilges; located around the level of the first wale on YK 11. These timbers serve a similar function as the *albaola* (sill) and *escoperadas* (filling planks) in Basque shipbuilding,[10] but the YK 11 sills are less substantial and of one component rather than two.

Stanchion block. An approximately rectangular timber, mounted atop frames, with a deep mortise in the inner (top) face; the mortise presumably accommodated a stanchion to support through-beams and the *xylokastron*. Six stanchion blocks were preserved on YK 11, arranged in pairs flanking the central stringers, stemson and sternson. Similar timbers have been described as mast step sisters or lateral sisters in other publications.[11]

Station lines. The projections on a lines drawing that represent the various body shapes of a hull.

Stem. An upward curving timber scarfed to the keel at its lower end, into which the two sides of the bow were joined.

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[6] Bellabarba and Guerreri 2002, 243; Pryor 1984, 288.
[7] Schilbach 1970, 13-6.
[8] Lever 1998, 13.
[9] Charlton 1996, 151.
[10] Loewen 2007, 161-64.
[11] Mor and Kahanov 2006, 275; Barkai and Kahanov 2007, 24.

Stemson. A curved timber mounted on the inner face of frames, providing longitudinal support for the scarf between the flat portion of the keel (Keel 2) and the forward transitional portion of the keel (Keel 3). On YK 11, this timber was labeled UM 47. Some publications use the term central longitudinal timber for similar timbers.[12]

Sternpost. An upward curving timber scarfed to the keel at its lower end, into which the two sides of the stern were joined.

Sternson. A curved timber mounted on the inner face of frames, providing longitudinal support for the transitional keel timber (Keel 1) between the flat portion of the keel (Keel 2) and the sternpost. On YK 11, this timber was labeled KS 1. Some publications use the term central longitudinal timber for similar timbers.[13]

Strake. A continuous line of planks, running from bow to stern. This may include both exterior planking and ceiling.

Stringer. Longitudinal timber fixed to the inner (top) surfaces of the frames; part of the ship's ceiling.

Throat tackle. Parral, *chalinos*; a collar of cords holding the yard against the mast.[14] On YK 11, this was reconstructed as a double line running around the mast and the halyard ties just above the yard.

Through-beam. An athwartships timber that extended through and beyond the outer hull planking. These supported the quarter rudder and provided athwartships stiffness to the upper part of the hull. On YK 11, these through-beams were sandwiched between wales. There is evidence for two levels of through-beams on YK 11.

Top timber. The uppermost member of a frame, terminating at the planksheer or caprail. No in-situ top timbers were found on YK 11.

Turn of the bilge. The outboard part of the lower hull where the bottom curves toward the side.

Vang. A line attached near, but not at, the top end of the *penna*, allowing manipulation of the yard.[15]

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[12] Pomey et al. 2012, 261.
[13] Pomey et al. 2012, 261.
[14] Casson 1995, 230.
[15] Lever 1998, 42; Ray 1992, 210.

Wale. A thick strake of planking located along the side of a vessel for the purpose of girding and stiffening the outer hull. On YK 11, these consisted of rough half-logs.

Waterlines. Lines on a hull drawing representing the horizontal sections of the hull. In the text, the term waterline generally refers to the location of the plank above which edge fastening was abandoned on YK 11: SS 8 in the stern and SS 9 in the bow. This corresponds roughly to the area between the calculated waterline of the empty hull (15 cm above WL 1 in the ship's lines) and the estimated load waterline (5 cm above WL 3 in the ship's lines).

Whip tackle. A simple purchase achieved by reeving a rope through a single block.[16]

Xylokastron**.** A longitudinal timber or structure at or near deck level that provided additional support to the ship's mast; also called a tabernacle.[17]

Z-twist. Term used to describe rope that has been twisted to the left; also called right-laid.[18]

[16] Lever 1998, 16.
[17] Basch 1991b, 4-5.
[18] Charlton 1996, 152.