The International Journal of
NAUTICAL ARCHAEOLOGY

The International Journal of Nautical Archaeology (2015) **44**.1: 39–73
doi: 10.1111/1095-9270.12083

Eight Byzantine Shipwrecks from the Theodosian Harbour Excavations at Yenikapı in Istanbul, Turkey: an introduction

Cemal Pulak, Rebecca Ingram and Michael Jones

Institute of Nautical Archaeology at Texas A&M University, P.O. Drawer HG, College Station, TX 77841, USA

Excavations at Yenikapı in Istanbul, Turkey, related to the Marmaray Project, have unearthed remains of Constantinople's Theodosian Harbour, including 37 Byzantine shipwrecks of 5th- to 11th-century date. Eight of these shipwrecks, six round ships and two of the first long ships, or galleys, to be excavated from the Byzantine period, were studied by archaeologists from the Institute of Nautical Archaeology. These well-preserved shipwrecks are an important new source of information on the maritime commerce of Constantinople and the gradual shift from shell-based to skeleton-based shipbuilding in the Mediterranean during the second half of the first millennium AD.

Key words: Constantinople, Theodosian Harbour, Marmaray Project, medieval, transition in ship construction, galley.

In November 2004, the Istanbul Archaeological Museums began conducting salvage archaeological excavations in association with Istanbul's Marmaray Project (Kızıltan, 2010: 1–2). This project, a major extension of the Turkish State Railways, joins the Istanbul suburbs of Gebze, on the city's Asian side, and Halkalı, on its European side, via an immersed-tube tunnel underneath the Bosporus Strait (Özmen, 2007: 24–6). The associated Metro Project integrates this new segment of the railway with the Greater Istanbul Municipality transportation system. Established as the site of one of the project's primary interchange stations, the neighbourhood of Yenikapı in Istanbul's old city became the scene of the largest excavation, over 58,000 m^2 in area (Gökçay, 2007: 166). These excavations soon began to unearth the remains of the Theodosian Harbour, the largest harbour of the Byzantine capital of Constantinople. Archaeological excavations associated with the Marmaray Project have also yielded significant finds from smaller harbours at Sirkeci and Üsküdar (ancient Chrysopolis) (Kızıltan, 2007: 32–123; 2010: 15–6). In addition to tens of thousands of artefacts, the remains of harbour installations, and loose ship timbers and ship's equipment, archaeologists at the Yenikapı site discovered 37 well-preserved shipwrecks dating from the 5th to 11th centuries AD (Kızıltan, 2013: 3). The rich array of finds from this site provides an unparalleled glimpse into maritime trade, ship construction and technology, and life in the Byzantine capital during a pivotal period in Mediterranean history.

History of the Theodosian Harbour

The Theodosian Harbour, situated on the city's Sea of Marmara (*Propontis*) shore, was the largest of Constantinople's four main commercial harbours between the 4th and early 7th centuries AD, and the recent excavations confirm that it continued to be used for small- and medium-sized ships until at least the late 10th or early 11th century AD (Mango, 1986: 121; Müller-Wiener, 1994: 9–10). While its precise date of construction is unknown, the Theodosian Harbour complex was probably begun around AD 390, during the reign of Theodosius I (r. 379–395), at the site of a natural bay in the city's 12th district (Mango, 1986: 121; Mango, 2001: 20) (Fig. 1). The harbour, called *Portus Theodosiacus*, is first mentioned in the *Notitia urbis Constantinopolitanae*, a list of the city's monuments and other significant structures dating to *c.*AD 425 (Müller-Wiener, 1994: 9). The Lykos River (Bayrampaşa Deresi), one of the city's few natural water sources, flowed into the city from the north-west and drained into the harbour (Mango, 1995: 9–10). The recent excavations at Yenikapı have indicated that, prior to the construction of the harbour, the natural bay provided shelter for ships from the 6th to 4th centuries BC; Classical-period finds from the site, including amphoras from Chios, Samos and Thasos, may have originally been destined for Greek colonies along the Black Sea (Öncü, 2013: 19–20). Half of an Archaic-period two-armed wooden hook anchor was also found in the excavation area (Gökçay, 2010: 149).

Published by John Wiley & Sons Ltd. 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA.

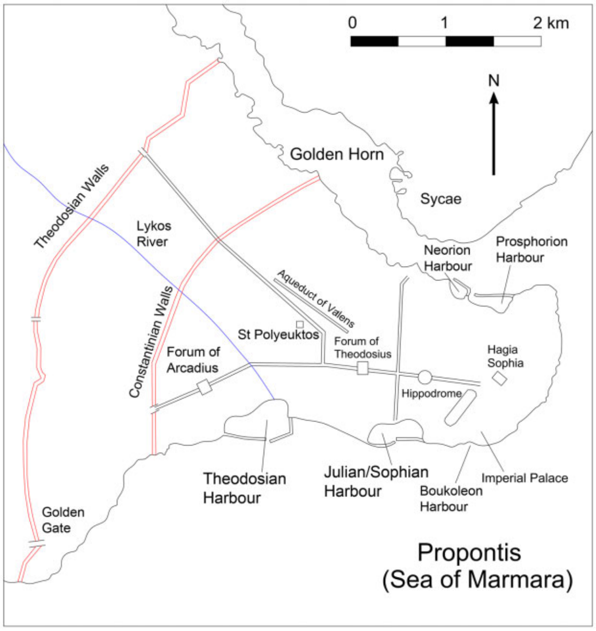

Figure 1. Map of Constantinople during the Byzantine period. (Map M. Jones, after Müller-Wiener, 1977: 18, Abb. 38; Treadgold, 1997: 674; Mango, 2002: 64)

Figure 2. Wooden dock piles were found throughout the site, often piercing the hulls of wrecked ships, as seen in this excavation photo of 9th-century shipwreck YK 14; April 2007. (Photo M. Jones/INA)

In the 4th century AD, the Theodosian Harbour, as well as the Julian Harbour farther to the east, were constructed as part of the programme begun by Constantine I and continued by his successors to expand the city into an imperial capital (Magdalino, 2000: 211). Several descriptions of the city by authors in the Late Roman period mention the use of pilings and in-filling to increase the city's area along the shores. Mango speculates that the major construction projects of the 4th century AD would have required the levelling of many areas of the peninsula, while displaced earth would have been dumped in bays, similar to the procedure used during the construction of the Laleli Mosque near Yenikapı in 1760 (Mango, 2001: 18–20, 28). At some point in its history, possibly as early as the 4th century AD, an underground channel was constructed for the final stretch of the Lykos River as it approached the harbour as well (Mango, 2001: 20, n. 14).

Constantinople reached its maximum port capacity upon the construction of the Theodosian Harbour in the late 4th century; available wharfage contracted in later centuries (Mango, 1986: 121). Prior to the recent excavations at the site, the harbour, also described as the Harbour of Kaisarios by some sources between the 6th and 9th centuries, was known almost exclusively from sections of the surviving harbour walls, some of which are still visible above ground today, and a few incidental references in textual sources (Guilland, 1953: 222–25; Berger, 1993: 468–69; Magdalino, 2013: 14). Based on the work of Niketas Choniates (2.4.130), the area around the harbour was also known as *Vlanga* as early as the 12th century (Berger, 1993: 469), a name which persists in nearby street names (Küçük Langa Caddesi, Langa Bostanları Sokağı) to the present.

Petrus Gyllius, a French scholar visiting the site of the harbour in the mid 16th century, equated the Theodosian Harbour with the older Eleutherian Harbour on the city's southern shore, although some scholars believe this to be an error (Ball, 1988: 201–2; Berger, 1988: 581–82; Müller-Wiener, 1994: 9). The latter harbour, known only from the late 10th-century *Patria Konstantinupoleos*, was said to have been built during the reign of Constantine the Great and later filled in by Theodosius I (*Patria* II.63; Müller-Wiener, 1994: 9).

One of the main features of the harbour was a large, protective mole erected on the southern side of the natural bay, running from west to east; the harbour's entrance was guarded by a large tower at the end of the mole. Mango (1986: 121) estimates that the harbour was 700 m in diameter, making it the city's largest, while van Millingen (1899: 298) provides a similar estimate of 786 x 218 yards (approximately 719 x 199 m). Gyllius described the ruins of both features, still visible in the 16th century, noting that the mole was 600 paces in length, which Berger estimates to be approximately 400 m (Ball, 1988: 201; Berger, 1993: 476). The harbour walls may have been built as early as AD 439, although their exact date of construction is unknown; remnants of probable Middle Byzantine (11th–12th century) walls visible today along Kuleboyu Sokak may represent a later renovation (*Chron. Pasch*. 583; Mango, 2001: 24–5; Dark, 2013: 30–1). While the recent excavations at Yenikapı have not uncovered the ancient harbour's full extent, they have revealed architectural remains consisting of the harbour's western and northern extremities, including large stone and concrete piers, previously buried foundations of defensive walls, and part of the harbour's protective mole (Gökçay, 2007: 177). Additionally, thousands of wooden piles used in piers and other harbour structures were found throughout the excavated areas (Fig. 2). Timbers from these structures are currently being studied by the Aegean Dendrochronology Project and the Forestry Department at Istanbul University in order to identify the wood types used, determine the period of use for wooden harbour constructions, and integrate them into pre-existing dendrochronological sequences (Doğu *et al.*, 2011; Pearson *et al.*, 2012).

Along with the Harbour of Julian (r. 361–363), located farther east on the Marmara shore and built in approximately the same period, the Theodosian Harbour was intended for importing commercial goods and supplies necessary for the expanding city (Müller-Wiener, 1994: 8–10; Magdalino, 2000: 210–11). As part of the *annona*, the state-administrated system of food allotments, massive quantities of grain and other provisions were shipped to Constantinople to sustain the growing population of the capital (Mango, 2000: 190). According to the *Notitia*, two large, government-run granaries, the *Horrea Alexandrina* and the *Horreum Theodosianum*, were located between the Theodosian Harbour and the Harbour of Julian, confirming that these harbours accommodated the large vessels bringing grain from ports as far as Alexandria in Egypt (Mango, 1986: 121; Magdalino, 2000: 211). One of these granaries, later known as the *Lamia*, was the only such structure still known to have been in use in Constantinople by the 10th century (Mango, 1985: 54–5; Haldon, 1986: 204–9; Magdalino, 2000: 213; Mango, 2000: 200–1; Magdalino, 2007: 23–6). As a result of the difficulties faced by the large grain-carrying ships in navigating against the strong current of the Hellespont, Justinian I built granaries on the island of Tenedos (Bozcaada) in the 6th century, allowing the grain to be transferred from Tenedos to the capital using smaller vessels (Procop. *Aed.* 5.1.7–16; Müller-Wiener, 1994: 9; Magdalino, 2000: 215). A decrease in the use of the largest vessels, and resultant decline in demand for mooring space, may explain why there is no literary reference to the dredging or renewal of the Theodosian Harbour, even though it was already silting up by the 7th century (Müller-Wiener, 1994: 9; Magdalino, 2000: 215). Building materials were also imported through the Theodosian Harbour, including timber, brick, and Proconnesian marble from Marmara Island (*Prokonnesos*), all of which were needed for the extensive building programmes and rapid expansion of the city in its first century as an imperial capital (Magdalino, 2000: 212). In addition to its commercial uses, the Theodosian Harbour may also have served a military function. Theophanes (353) notes the assembly of the Byzantine fleet in this harbour during the first Arab siege of Constantinople from 674 to 678, referring to the harbour itself as the Proclianesian harbour of Caesarius (Kaisarios) (Guilland, 1953: 225; Mango and Scott, 1997: 493–94). The presence of naval vessels in the harbour in the Middle Byzantine period has been corroborated by the discovery of six oared galleys amongst the site's shipwrecks.

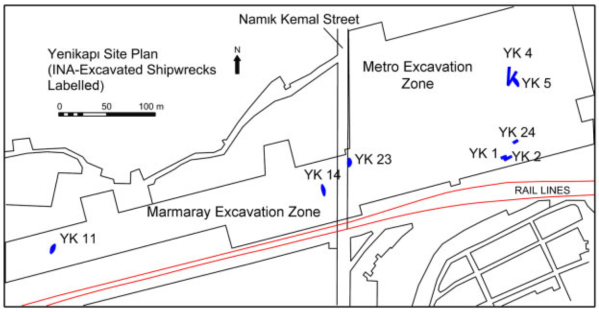

Figure 3. Map of the Yenikapı site, showing the locations of shipwrecks recovered by the Institute of Nautical Archaeology. (Map M. Jones, after Kocabaş, 2008: 184–85; Gökçay, 2010: 135, Fig. 1)

Although the Theodosian Harbour was Constantinople's largest port upon its completion, its usable area gradually decreased over time. This occurred as silt, carried into the harbour by the Lykos River, began accumulating at the harbour's western end and gradually progressed eastward (Janin, 1950: 219). The distribution and date of shipwrecks at Yenikapı, with a high concentration of shipwrecks dating to a later period toward the harbour's eastern end, confirms this (Liphschitz and Pulak, 2009: 165) (Fig. 3). Layers of marine sand, probably deposited in the harbour basin during storms, also appear to have played a role in decreasing the available anchorage area within the mole (Pulak, 2007: 203–4; Perinçek, 2010: 207–8, 210–11). Historians have postulated a major decrease in the city's population in the 7th century, which corresponds with the loss of large portions of the Byzantine Empire to the Arabs; one possible consequence of the decreased population may have been a less-pressing need for large harbour facilities (Mango, 1985: 54; 1986: 128–30; Magdalino, 2007: 18–9). Nevertheless, the area around the Theodosian port continued to play a prominent role in the economic life of the city. Documentary references from the 10th century indicate the importance of the *Forum Tauri* or 'Forum of the Bull' (also known as the Forum of Theodosius) near the Theodosian Harbour as a market for pigs, Easter lambs and possibly fish, which by law were to be sold at the waterfront. The Byzantine author Leo of Synada also mentions the importation of livestock to Constantinople by sea during this period (Leo of Synada, ep. 54.30–4, ep. 54.60–4; Freshfield, 1938: 39–41; Magdalino, 2007: 26–7).

Dendrochronological analyses of some of the wooden piles from the site indicate that, by the 15th century, only a small part of the harbour remained in use (Kuniholm *et al.*, 2007: 383). The small sizes and wide spacing of these later piles suggest they formed small wharves servicing mostly fishing boats, lighters, and other small vessels. The earliest surviving map of Constantinople, drawn in Cristoforo Buondelmonti's *Liber Insularum Archipelagi*, was completed after 1418 and widely recopied and modified over the course of the next century; in this map, the harbour is shown as filled in aside from a small outlet for the Lykos River (Manners, 1997: 73, 76, 78–84). Gyllius also mentions that by the 16th century the harbour area had been filled in completely (Ball, 1988: 201). Thereafter, the harbour lay all but forgotten beneath the reclaimed land, with the area used primarily as gardens or orchards well into the 20th century (Janin, 1950: 220; Berger, 1993: 470–73).

Fortunately for archaeologists, the waterlogged silt and sand deposits in the harbour resulted in excellent conditions for the preservation of organic materials such as wood, leather, and rope. A large proportion of these artefacts are scattered ship timbers, ship's equipment such as stone and iron anchors, and elements of ship's rigging such as ropes, toggles and blocks. Most importantly, archaeologists at the site recovered the well-preserved remains of at least 37 vessels that had been lost or abandoned in the harbour between the 5th and early 11th centuries AD. Many of these, including a large group which sank together or within a short period of time around AD 1000, appear to have been lost as the result of violent storms, which quickly covered the shipwrecks with sand and preserved them (Perinçek, 2010: 206–8, 210–11, 215). No shipwrecks have been found dating after the late 10th or early 11th century, after which the harbour basin was probably accessible only to local fishing boats and the smallest coasters. Altogether, the Yenikapı shipwrecks comprise the largest and best-preserved group of Byzantine-period ships ever discovered and excavated at an archaeological site.

Excavation and documentation methodology

In the summer of 2005, the Istanbul Archaeological Museums invited one of the authors, Cemal Pulak, to form a research team to supervise the recording, dismantling, study, and publication of YK 1 and YK 2, the first shipwrecks found at Yenikapı. As additional shipwrecks were discovered at the site by museum archaeologists, the number of shipwrecks allocated for study by the INA team increased; between 2005 and 2008, Pulak directed the recovery and documentation of a total of eight of the Yenikapı shipwrecks (Pulak, 2007: 206–8; Ingram and Jones, 2011: 8–11) (Fig. 3; Table 1). The ships recorded and raised by the INA team include six round ships (YK 1, YK 5, YK 11, YK 14, YK 23, YK 24) dating from between the early 7th and late 10th centuries AD, and two of the six Byzantine galleys found at the site (YK 2, YK 4), the first early medieval galleys ever discovered in the Mediterranean region. After completing a detailed study of all eight shipwrecks and the conservation of four of them (YK 11, YK 14, YK 23, YK 24), INA will return the hull remains to the Istanbul Archaeological Museums for display in a planned museum devoted to the Yenikapı excavation finds. The additional shipwrecks discovered at the site are being documented, studied, and conserved by a team from Istanbul University's Department of Conservation of Marine Archaeological Objects under the direction of Ufuk Kocabaş (Başaran *et al.*, 2007; Kocabaş and Özsait Kocabaş, 2007; Kocabaş, 2008; Kocabaş, 2010; Kocabaş, 2012a; Kocabaş, 2012b; Özsait Kocabaş, 2012; Türkmenoğlu, 2012; Akkemik and Kocabaş, 2013; Akkemik and Kocabaş, 2014; Kocabaş, this volume).

Over the course of more than three full years working at the site, the INA team developed a standard set of techniques appropriate for the work environment at Yenikapı. Early in the project it was decided to map and dismantle the shipwrecks rather than attempt to remove the hulls from the site in one piece, which would require heavy equipment, more elaborate storage facilities, and would not allow the exhaustive documentation that is possible with full dismantling. After early experiments with other methods during the documentation of YK 1, the INA team settled on the use of multi-stage total-station mapping for the documentation of each shipwreck, a recording method used on shipwreck excavations on land since the 1990s (Bruseth and Turner, 2005: 55–6; Lemée, 2006: 82–4). However, each vessel, in its unique archaeological context, presented the INA team with a fresh set of logistical challenges. Therefore, the same overall approach was employed throughout, but was adapted to the specific problems presented by each shipwreck.

The shipwrecks at Yenikapı were unusually well preserved because, in most cases, they were rapidly buried after sinking. Since waterlogged timbers will shrink and become distorted upon drying, the first concern in recording and dismantling these vessels was to maintain a sufficient level of moisture within the hull timbers. To achieve this, a protective tent was built over the wreck-site prior to the final removal of overburden and, once the hull was fully exposed, an overhead water-sprinkler system was installed over each shipwreck.

Once each ship had been exposed and cleaned, a photomosaic was created, facilitating the development of an initial sketch plan and the labelling of component pieces. Although some of the ships' timbers were distorted due to pressure from the weight of the sediments deposited over them, large sections of the hulls retained their original form. To precisely capture this form prior to dismantling, each ship was mapped with a total station operated by a team from İmge Harita in Istanbul. This laser-based surveying device was used to record three-dimensional coordinates for thousands of points associated with significant features of the shipwrecks. Importing this data into Rhinoceros® NURBS modelling software, INA archaeologist Sheila Matthews created a three-dimensional map of each ship *in situ* (Fig. 4). The creation of a photomosaic and mapping with a total station was conducted multiple

Table 1. *Overview of Yenikapı shipwrecks studied by the Institute of Nautical Archaeology*

							Primary wood type		Keel		Framing			Planks		
Number	Location	Probable date of construction	Type	Date of excavation	Estimated length	Estimated breadth	planking	framing	sided	moulded	average sided	average moulded	average room and space	average thickness	edge fasteners	Average edge-fastener spacing
YK 1 (MRY 1)	O-P 32–34, O 35	10th cent.	Round ship	July 2005-January 2006	10 m	3.5 m	*Quercus cerris*	*Quercus cerris*	10 cm	14 cm	8 cm	11 cm	28 cm	1.7-2.5 cm	Coaks	27 cm
YK 2 (MRY 2)	P 31–35	9th or 10th cent. (?)	Galley	April-August 2006	30 m	4 m	*Pinus nigra*	*Platanus orientalis, Ulmus campestris*	N/A	N/A	6 cm	6 cm	20 cm	2.5-2.8 cm	Coaks	74 cm
YK 4 (Metro 1)	2Bb1/4-2Bc1/4, 2Ba4	Early 10th cent.	Galley	September 2006-April 2007	30 m	4 m	*Pinus nigra*	*Platanus orientalis*	14 cm	17 cm	7 cm	7 cm	23 cm	2.5-3.0 cm	Coaks	154 cm
YK 5 (Metro 2)	2Ba2-2Ba4	10th cent.	Round ship	March-September 2006	14.5 m	5 m	*Quercus cerris*	*Quercus cerris*	12 cm	9 cm	8 cm	11 cm	28 cm	2.0-2.5 cm	Coaks	31 cm
YK 11 (MRY 5)	J-K 88–89	Early 7th cent.	Round ship	May-November 2008	11.2 m	3.8 m	*Pinus brutia*	*Pinus brutia*	11 cm	19 cm	9 cm	10 cm	31 cm	2.0-2.5 cm	Mortise and Tenon	45 cm
YK 14 (MRY 7)	K-L-M 146	Early 9th cent.	Round ship	April-September 2007	14.7 m	3.4 m	*Quercus cerris*	*Quercus cerris*	11 cm	14 cm	6 cm	10 cm	23 cm	2.0-2.5 cm	Coaks	39 cm
YK 23 (MRY 8)	H-I 1	Late 8th–early 9th cent.	Round ship	January-May 2008	15 m	5 m	*Quercus cerris*	*Quercus cerris*	18 cm	33 cm	11 cm	15 cm	38 cm	2.5-4.0 cm	Coaks	50 cm
YK 24 (MRY 9)	M 36	10th cent.	Round ship	July-August 2007	8 m	2.5 m	*Quercus cerris*	*Quercus cerris*	8 cm	11 cm	6 cm	10 cm	27 cm	2.0-2.3 cm (est.)	Coaks	28 cm

Note: Excluding plank thickness ranges, measurements provided in centimetres have been rounded to the closest centimetre; measurements provided in metres have been rounded to the closest decimetre.

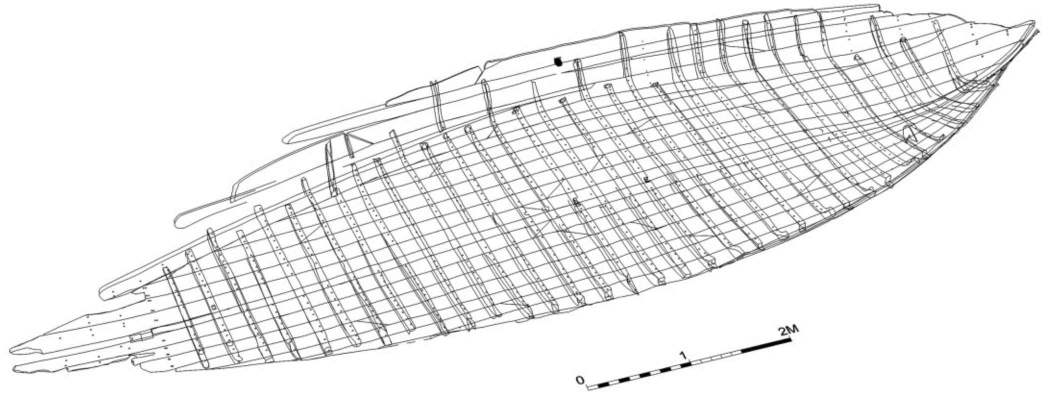

Figure 4. Three-dimensional digital map of round ship YK 5. (S. Matthews)

times for each shipwreck, as layers of timbers,including disarticulated timbers above the shipwreck, layers of stringers and ceiling planking, and framing were dismantled and removed, exposing lower hull timbers such as the keel and planking. Between two and four stages of mapping were carried out, depending on the surviving hull elements.

Once each layer of ship timbers had been mapped, the INA team collected a variety of data both prior to and during the dismantling of that layer, although *in situ* documentation was necessarily limited due to the narrow time constraints imposed on this salvage project. Field data collected includes *in situ* photographs, preliminary notes on the ship's construction, basic timber and hull-fastener dimensions, and a summary assessment of the condition of each piece. The *in situ* documentation of each ship also entailed the creation of 1:1-scale drawings of the ship's fully exposed planking after the removal of frames and other timbers. This step results in a detailed record of the relative positions of the hull planking on the wreck-site to supplement the total-station data, and it also serves to record the condition of the hull planks and surface features, such as pitch and caulking repairs, which may be damaged or sampled during the dismantling process.

After each layer of ship timbers had been mapped and *in situ* recording completed, the layer was dismantled and the timbers placed in individual, foam-lined wooden crates, which were then transferred to large freshwater storage tanks located on the Yenikapı site. Custom-built wooden moulds were manufactured to support intact but fragile hull planks—many of which were 6–7 m in length—that retained their original shape and curvature. Timbers from four of the ships (YK 1, YK 2, YK 4, and YK 5) remained at the excavation site for eventual conservation treatment in the conservation laboratory at Istanbul University. The timbers from the other four shipwrecks excavated by the INA team (YK 11, YK 14, YK 23, and YK 24) were transported by truck from Istanbul to INA's Bodrum Research Center for detailed documentation and conservation.

The post-excavation documentation of each shipwreck is an intensive process and includes a written catalogue, detailed photographs, sketches, and full-scale drawings of one or more faces of each component piece of the surviving hull. The INA team's methodology in timber recording is based largely on that developed by Fred van Doorninck and J. Richard Steffy in their excavations and studies of Byzantine shipwrecks, especially those at Yassıada and Serçe Limanı, Turkey (Bass and van Doorninck, 1982: 32–64; Bass *et al.*, 2004: 73–169). The primary records for individual hull timbers are 1:1 scale drawings made on clear plastic film. These drawings provide an accurate, economical, and efficient means of recording significant hull detail. In addition, they frequently helped to correct errors in the total-station and field data from the excavation by recording details such as fasteners and fastener holes, score marks and other tool marks, edge-fastener locations and dimensions, and obscured plank seams that were often missed during the total-station mapping and dismantling of the ships. In this role, the 1:1 drawings are crucial for producing an accurate reconstruction of the ship. The ships' planks, for which *in situ* drawings were created prior to dismantling, were often redrawn individually during the post-excavation documentation to record details that were not apparent before the thorough cleaning of the timbers. Completed drawings were later scanned to produce high-resolution digital files. A written catalogue of each timber was also compiled, which includes various measurements as well as notes and sketches on the timber's significant features, context, and function in the hull of the ship. Finally, sampling of each piece for wood species identification and other organic materials in direct association with the ship timbers, such as plank-seam caulking, is also completed during the recording process for later analysis. Wood species identification for all eight shipwrecks was carried out by Nili Liphschitz of the Institute of Archaeology, The Botanical Laboratories, Tel Aviv University (Fig. 5).

The post-excavation timber documentation for wrecks YK 1, YK 2, and YK 5 was completed at

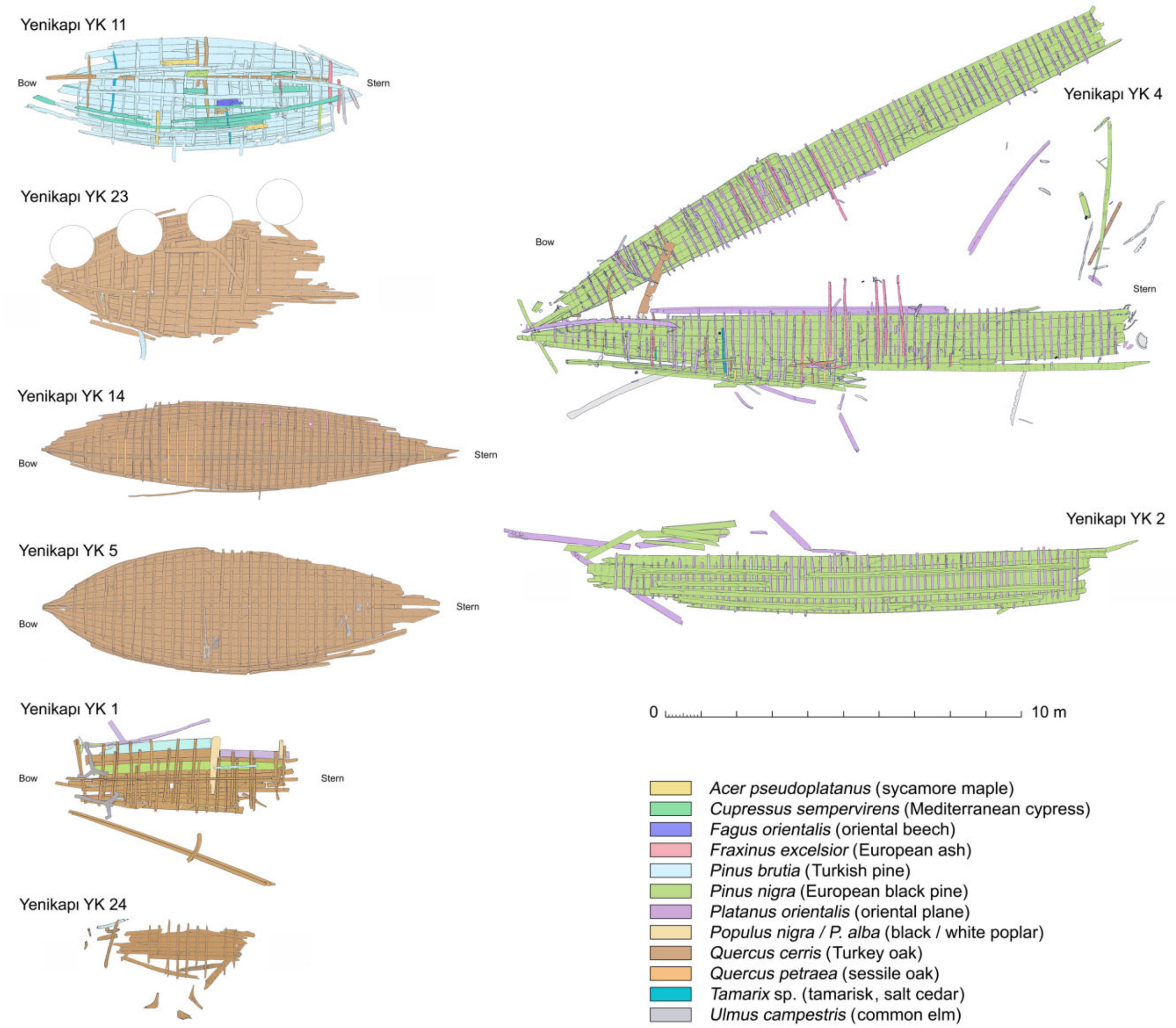

Figure 5. Wood species used in Yenikapı ships studied by Pulak and INA; wood species were identified by Nili Liphschitz of Tel Aviv University. Bow and stern labels are omitted on vessels for which this designation remains unclear.

Yenikapı by the INA team between 2005 and 2008. The detailed timber documentation for the large galley YK 4 was also completed at Yenikapı between 2007 and 2012. The four shipwrecks transported to Bodrum in 2008, YK 11, YK 14, YK 23, and YK 24, were placed into freshwater storage immediately upon arrival. Post-excavation documentation of YK 11 and YK 14 was completed in Bodrum between 2009 and 2012, and post-excavation documentation of the small vessel YK 24 was completed in Bodrum during 2011. The post-excavation documentation of YK 23 is still in progress. After documentation, these four shipwrecks will be conserved using Polyethylene Glycol (PEG) in the Hethea Nye Wood Conservation Laboratory at INA's Bodrum Research Center.

Round ships

Of the 37 shipwrecks excavated at Yenikapı, 31 are vessels propelled primarily or entirely by sail; following Lane's (1934: 2–3) definition, these vessels are referred to as round ships in this report. Most of these round ships are merchantmen designed and built to maximize cargo capacity and sailing qualities such as manoeuvrability, although some of the smaller wrecks could possibly represent other specialized vessel types such as lighters or fishing boats. All six of the round ships documented by the INA team, with the possible exception of YK 24, were sailed with a single mast fitted with a lateen or settee (quadrilateral lateen) sail, and they would have been steered with a pair of quarter rudders similar to those seen in contemporaneous Byzantine ship depictions (Zafiropoulou, 1998: 37–8, 70, 82, 84; see also Pulak, 2007: 211; Pryor, 2008: 485). Although inconclusive at this stage of our studies, YK 24, the smallest vessel in the group, may have been sailed with a spritsail rather than a lateen sail, as was the case on Yenikapı shipwreck YK 6 (Kocabaş, 2008: 111).

These ships were likely only partially decked. Only three of the vessels excavated at Yenikapı were found with much of their cargo still present: YK 1, studied by INA (Pulak, 2007: 208; Denker *et al.*, 2013a: 210–18), YK 12 (Kocabaş, 2010: 30; Denker *et al.*, 2013b: 197–209; Özsait Kocabaş, 2013: 49), and YK 35 (Polat, 2013: 154–90) documented by Istanbul University. The shipwrecks are thought to have been deposited in the harbour in one of two ways. Some vessels appear to have been considered too old and unprofitable to sail and were abandoned as derelicts in shallow water or along the shoreline of the harbour. Others in better condition, including the vessels found with cargo, must have sunk in storms and were quickly buried; these shipwrecks occur primarily in the central and eastern sections of the site and tended to be deposited in thick, sandy stratigraphic layers.

The remains of the vessels discovered at Yenikapı span the period from the 5th to the 11th centuries AD, a time of major developments in ship construction and maritime technology that are still only partly understood. Until the first millennium AD, the earliest shipwrights adhered to what has been termed a shell-based philosophy, under which the design, assembly, and structural strength of a vessel focused on the ship's exterior planking (Basch, 1972: 15–23; Hasslöf, 1972: 42–72; Pomey, 1988: 400–5; Hocker, 2004a: 6; Pomey, 2004: 25–9). Hocker (2004a: 6) includes structural philosophy as a significant aspect of the shipbuilding concept, defining it as:

> [T]he 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. For example, he may choose thick, edge-joined planking with light internal reinforcement, thus relying on the shell for the majority of the hull's strength. Or, he may build a heavily-framed hull with light, non-edge-joined planking and so depend more on the skeleton. Few plank-built hulls rely entirely on shell or skeleton; instead, the two complement each other in an integrated system.

One aspect of a shell-based philosophy of shipbuilding is a shell-first construction sequence, in which the ship's planking is assembled prior to the insertion of framing; as a result, the form of the vessel is primarily dependent upon the shaping of the planking over the course of construction. Such design and assembly methods were usually executed by skilled shipwrights who learned their trade from their peers and through many years of practice, with little or no reliance on written plans or formulas. By the end of the first millennium, however, most Mediterranean shipwrights had presumably transitioned to a skeleton-based philosophy, in which the design, assembly, and structural strength focused mostly on a ship's internal framework. Under this philosophy, ships are often built skeleton- or frame-first, in which 'active' or control frames, often shaped using moulds, proportions or geometric progressions, are erected before the planking is added and thus serve to dictate the form of the vessel (Basch, 1972: 16; Pomey *et al.*, 2012: 235–36). While the discontinuation of edge fastening of a ship's planking is not the only indication of the transition from shell-based to skeleton-based shipbuilding, it remains a key aspect of this fundamental change in how ships were conceived and built (van Doorninck, 1976: 122–23; Steffy, 1994: 83–5). However, Pomey *et al.* (2012: 297–301) note that other factors, such as the attachment of frames to the keel, the shape of plank scarfs, and the overall structure of the vessel, must also be considered when assessing a ship's philosophy of construction. It is also important to note that in practice, most vessels—including the Yenikapı ships described below—incorporate elements of both methods, but not necessarily of both philosophies in their construction.

Following a shell-based construction method, ancient Mediterranean shipwrights connected hull planks together with closely spaced mortise-and-tenon joints, with the tenons locked in place with transverse pegs driven through the hull. This style of construction is very labour-intensive and requires large amounts of timber but produces a rigid and seaworthy hull (Steffy, 1985: 101). The earliest archaeological evidence for this technique derives from the fragmentary hull remains of the late 14th-century BC Uluburun shipwreck, discovered near Kaş on the southern coast of Turkey (Pulak, 1999: 211–15; Pulak, 2002: 618–29). A variant of this Bronze Age construction method was common in Mediterranean ship construction by the 5th century BC and became a standard technique used in the design and construction of Hellenistic and Roman ships (Steffy, 1994: 43, 46, 77–8, 83–4). However, by the 4th century AD, Mediterranean shipwrights began to experiment with simplifying this method, first by cutting fewer and smaller mortise-and-tenon joints; by the 6th and 7th centuries, the tenons were no longer locked in place with pegs, and they served mostly as aids in aligning and joining the hull planking rather than as a significant source of hull strength in their own right (Bass and van Doorninck, 1982: 55–6).

One of the major contributions of the Yenikapı excavations has been the discovery that mortise-and-tenon joints had been replaced with wooden edge-fastening pins or dowels called 'coaks' in nearly all of the shipwrecks from the site dated to the 8th century and later. This report follows Steffy's definition of a coak as '[a] rectangular or cylindrical pin let into the ends or seams of timbers about to be joined in order to align or strengthen the union' (Steffy, 1994: 269, 289, fig. G-9 (m-n)). These edge fasteners are also referred to as ‘dowels’ in other reports (Harpster, 2005a; Harpster, 2005b; Kocabaş, 2008: 101–2; Pomey *et al*., 2012: 274, 282–84, 290). Prior to the excavations at Yenikapı, the use of coaks had been documented on a single Byzantine shipwreck, the 9th-century shipwreck found at Bozburun, Turkey (Harpster, 2005b). However, at least 23 of the shipwrecks at Yenikapı, including both round ships and galleys, were built with coaks as edge fasteners, including seven of the eight under study by INA and at least 16 of the vessels studied by Istanbul University based on published preliminary reports (Kocabaş, 2008; 2012b: 111–12), a clear indication that coak construction was a major feature of Middle Byzantine shipbuilding technology on at least a regional level. In addition to ships with mortise-and-tenon or coak edge fasteners, five of the Yenikapı ships being studied by Istanbul University are reported as lacking edge fasteners: YK 10, YK 17, YK 27/28, YK 29 and YK 31 (Türkmenoğlu, 2012: 124–25; Kocabaş and Özsait Kocabaş, 2013: 44–5, Kocabaş this volume).

By the end of the first millennium AD at the latest, shipwrights were abandoning shell-first construction methods in favour of systems of skeleton-first construction. This method of design allowed shipwrights to build a wider range of hull shapes in a way that required less labour and materials than shell-first construction (Steffy, 1994: 85, 91; Kahanov *et al*., 2004: 126); the skeleton-first shipbuilding method became the preferred method for the construction of most wooden ships in the Western world from the medieval period to modern times. However, the discoveries at Yenikapı are showing that changes to maritime technology in this period were not as straightforward as previously thought, particularly when they are compared to other recently discovered Byzantine-period shipwrecks. Several researchers contend that skeleton-first construction may have emerged as early as the 6th century, based on several shipwrecks excavated at Tantura Lagoon apparently built without the use of planking edge fasteners (Kahanov *et al*., 2004: 113–26; Kahanov and Mor, 2009: 21–4; Mor, 2010: 89–91; Pomey *et al*., 2012: 237, 291–308). While years of additional research will be required to fully realize the significance of the Yenikapı shipwrecks in the development of Mediterranean shipbuilding, some of the implications of their discovery are already clear. The transition to skeleton-first shipbuilding probably involved much experimentation that likely included regional variations in ship construction methods, as well as the gradual modification of more traditional techniques, some of which are described in the following preliminary reports on the Yenikapı shipwrecks documented and studied by INA. As research progresses, a more detailed analysis of the construction of these ships and their relation to the development of Mediterranean shipbuilding will be possible, and these will be presented in future publications concerning the individual shipwrecks.

YK 11

YK 11 (MRY 5) was discovered in January 2006 near the harbour’s western extremity in grid squares J-K 88–89 (Figs 3, 6 and 7). The post-excavation documentation of this shipwreck was conducted by Rebecca Ingram between 2009 and 2012 as part of her doctoral dissertation at Texas A&M University (Ingram and Jones, 2011: 11–3).

Because the wreck lay outside the primary construction zone, it was first fully uncovered in January 2008. Due to a pressing need to excavate and remove wreck YK 23 from an immediate construction zone elsewhere on the site, the INA team delayed work on YK 11 until May 2008. The *in situ* documentation and dismantling of YK 11 was completed on November 19, 2008. The viscous, muddy sediments in which the wreck was found complicated *in situ* recording; it was located in one of the lowest areas of the site, and rapid flooding by groundwater caused frequent delays.

Artefacts found in association with shipwreck YK 11 and preliminary radiocarbon analysis indicate a construction date for the ship in the first half of the 7th century AD (Table 2). The preserved portion of the hull, 9 m in length and 3 m in breadth, extended to the turn of the bilge on the starboard side and to the second wale on the port side (Fig. 7). Based on the shifting of some hull timbers, the scattering of disarticulated ship timbers throughout the wreck area, and

Table 2. *Radiocarbon analysis results for shipwrecks YK 11 and YK 14. All samples analysed by The University of Georgia, Center for Applied Isotope Studies. Dates calculated using OxCal 4.2*

Shipwreck	Sample ID	δ13C.‰	^{14}C age years BP	±	From	To	%	From	To	%
YK 11	FR 22A	–23.9	1400	20	633	659	68.2	611	662	95.4
YK 11	FR 7	–27.2	1270	20	689	771	68.2	678	776	95.4
YK 11	FR 16P	–27	1420	20	616	649	68.2	601	656	95.4
YK 11	KEEL3	–27.2	1380	20	645	662	68.2	619	672	95.4
YK 14	YK-14-1	–27.4	1200	20	780	870	68.2	774	888	95.4
YK 14	YK-14-2	–26.7	1220	20	772	869	68.2	713	884	95.4
YK 14	YK-14-3	–25.4	1220	20	772	869	68.2	713	884	95.4
YK 14	YK-14-4	–27.9	1180	20	782	888	68.2	776	934	95.4

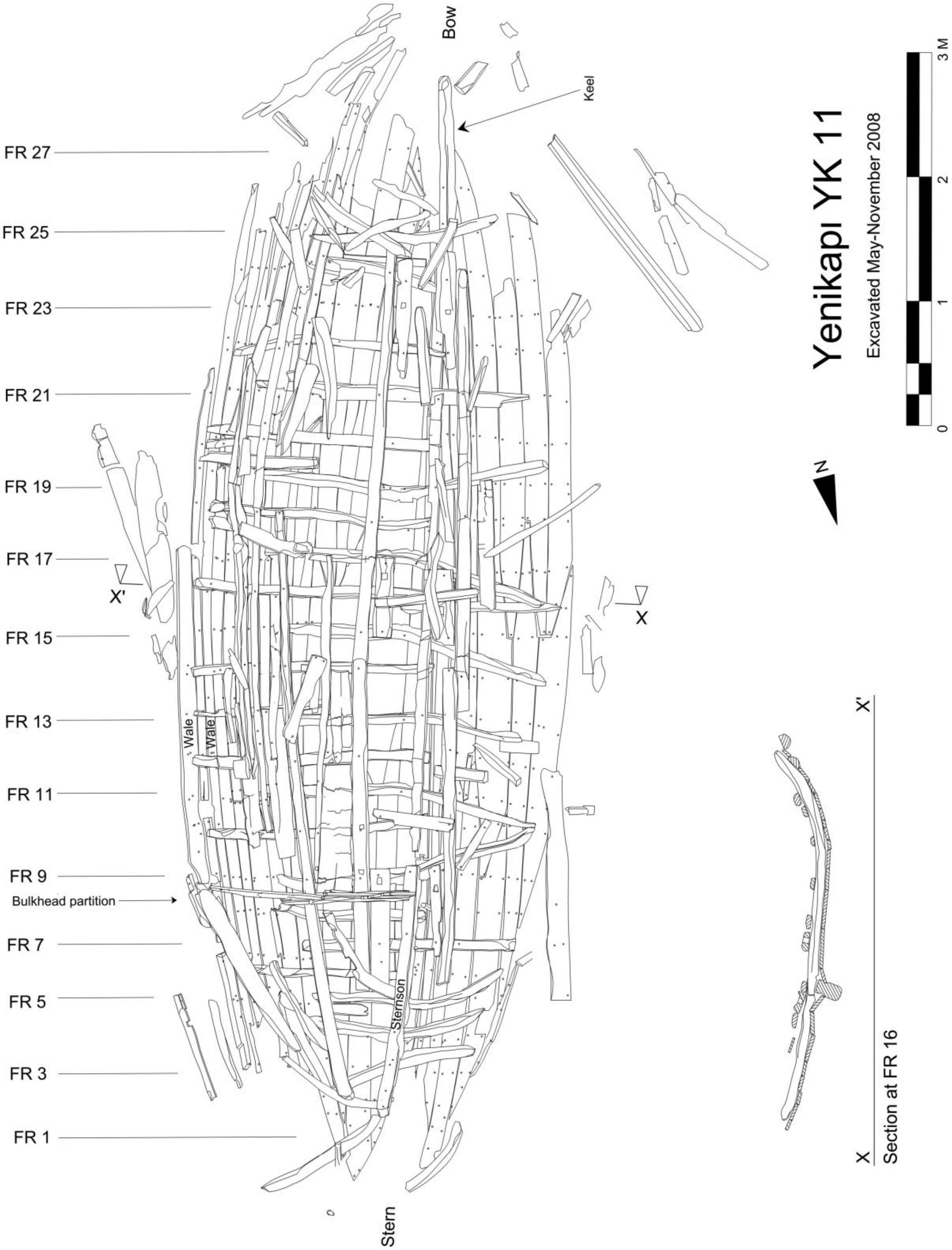

Figure 6. YK 11 site plan. (Plan S. Matthews)

the presence of shipworm damage (including *Teredo navalis* and *Limnoria* spp.), the YK 11 hull was exposed for some time after it sank. These circumstances suggest that this heavily repaired vessel had been abandoned as a derelict in the shallow western corner of the Theodosian Harbour. Nevertheless, most of the ship's timbers are exceptionally solid due to their eventual burial in anaerobic sediments.

Figure 7. Shipwreck YK 11 *in situ*, with upper level of disarticulated timbers removed; July 2008. (Photo O. Köyağasıoğlu/INA)

Although the ship is relatively small, the *in situ* documentation of YK 11 was somewhat more complex than that of other vessels at Yenikapı. The ship possessed four distinct layers of timbers—from the top, these are disarticulated ship timbers, ceiling, framing, and exterior planking—necessitating four separate phases of excavation, photomosaic creation, and mapping with a total station; the other round ships studied by INA at Yenikapı, lacking an extensive layer of ceiling or disarticulated timbers, were mapped and excavated in two phases. In contrast to the other Yenikapı round ships studied by the INA group, YK 11 was built predominantly of Turkish pine (*Pinus brutia*) with a keel of Turkey oak (*Quercus cerris*). The YK 11 shipwright's choice of timber for these hull components is consistent with Theophrastus's recommendations for using fir or pine for hull planking and more durable oak for the keel timbers of merchant ships (*Hist. Pl.* 5.7.1–3). A variety of other wood species are represented throughout the ship, with significant variation in the ceiling. After careful analysis of the hull remains, it is clear that YK 11 was built with a combination of shell-first and skeleton-first techniques. There are many similarities between the YK 11 hull and other ships of similar date, notably Saint-Gervais wreck 2 (Jézégou, 1983: 31–51; Jézégou, 1989: 139–43), dated perhaps as late as the second half of the 7th century (Pomey *et al.*, 2012: 264) and Yassıada wreck 1 (Bass and van Doorninck, 1982: 32–64), of early 7th-century date.

Figure 8. Intact tenon recovered from port-side planking of ship YK 11. (Photo R. Ingram/INA)

The three elements of YK11's tripartite oak keel, on average 190 mm in moulded dimension and 106 mm sided, were fastened together with keyed hook scarfs and reinforced with iron bolts. These bolts also served to fasten a stemson and sternson—the latter a repurposed pine keel—notched to fit over framing, to the spine of the vessel. Between the stemson and sternson, a pair of close-set stringers centred on either side of the keel and nailed to the ship's framing provided additional longitudinal support to the vessel; these timbers flanked the ship's removable mast-step, which was not preserved.

Thin pine planking, usually 20–25 mm thick, was edge-fastened with small, unpegged mortise-and-tenon joints up to the second strake below the first wale (Fig. 8). No mortise-and-tenon joints were present between the garboards and the keel; instead, the ship's garboards were fitted into a shallow rabbet on the keel and fastened with short iron nails driven from the hull exterior. From the strake below the first wale, planks lacked edge fasteners; this feature, as well as other evidence, indicates that these planks were fastened to pre-erected frames at this stage in the hull's construction. Along the ship's sides, pine half-log wales alternated with strakes of planking; a narrow strake of planking between the two preserved wales on the port side retained apertures which accommodated the ship's through-beams. One such aperture, that for the ship's mast-partner through-beam, enabled the proper identification of the bow and stern of the vessel. Based on a loose fragment found near the ship, the through-beams were notched on all sides and attached to the wales with long iron nails. All of the vessel's plank seams were caulked with a mixture of grass fibres and a resinous waterproofing material. The latter was also used on the interior and exterior surfaces of the hull planking; samples of this material were identified as pine pitch by Edith Stout and Sarjit Kaur of Vassar College's Amber Research Laboratory.

The ship's frames, providing transverse support to the hull, followed a traditional Mediterranean pattern of alternating floor timbers and paired half-frames. This framing pattern is seen on merchantmen as early as the Kyrenia ship, which sank around 300 BC (Steffy, 1985: 84), and as late as the 8th or early 9th century AD on Yenikapı shipwreck YK 23. Elements of framing were preserved at 26 frame stations, and an additional four frame stations are indicated on the vessel's preserved planking. Floor timbers span the bottom of the ship, with their extremities extending just to the turn of the bilge; in contrast, half-frames span the width of the keel and extend up one side of the ship, through the turn of the bilge to, or just beyond, the first wale. The average room and space (including floor timbers and half-frames) is 307 mm. Every floor timber and half-frame of YK 11 was fastened to the ship's keel or posts with long iron nails, and the frames were attached to the ship's planking with shorter iron nails driven from outside of the hull. At each frame station, floor timbers and half-frames are paired with futtocks placed adjacent to, but not fastened to, the floor timber or half-frame, with ends overlapping by the width of one or more planks. With an average sided dimension of approximately 90 mm and an average moulded dimension of about 100 mm, YK 11's frames are larger than those on many of the other Yenikapı round ships.

In addition to the central stringers, the ship originally possessed at least five additional pine and Mediterranean Cypress (*Cupressus sempervirens*) stringers on either side. Small pieces of common ceiling, or short planks used to prevent cargo and ballast from falling between a vessel's frames (Steffy, 1994: 269), filled the gaps between stringers, while sills, or crenelated planks fastened around frames near the first wale, prevented foreign matter from falling into the bilges. Altogether, the stringers, common ceiling, and sills indicate a fully internally planked central hold area. Remains of a transverse bulkhead, consisting of a slotted frame with thin, vertical planks, were found near the ship's stern.

Figure 9. Port face of YK 11 KS 1, a repurposed keel serving as a sternson. (Photo R. Ingram/INA)

The frugality of the owner is reflected throughout the YK 11 hull, in both the choice of materials during initial construction as well as the frequency of repairs to the vessel. The presence of recycled pieces, such as an old keel timber reused as a sternson (Fig. 9) or the finely cut, slotted panel reused as a piece of common ceiling, and the use of short iron nails in the attachment of frames reflect the importance placed on using inexpensive and readily available materials. In addition, the extent of repairs to this small merchantman is truly impressive: in addition to the replacement of many planks, some of the ship's framing had also been replaced, which entailed the temporary removal of the ship's ceiling.

The reconstruction of YK 11, achieved with the aid of Rhinoceros® NURBS modelling software, indicates a slack bilge with hollow garboards, or wineglass-shaped hull, 11.23 m in length and 3.76 m in breadth, with a length-to-beam ratio of 2.9:1. The ship's estimated cargo capacity is approximately eight metric tonnes.

YK23

Shipwreck YK 23 (MRY 8) was discovered in spring 2007 in the course of night-shift construction work at the Yenikapı site (Fig. 10). A hole-boring machine used for the construction of concrete retaining walls around the periphery of the construction area unearthed many fragments of ship timbers from excavation grid squares H-I 1, in the central section of the site near the eastern edge of Namık Kemal Street. After this discovery, the area was isolated from nearby construction activities by the installation of a steel coffer dam. The area was then excavated by staff archaeologists from the Istanbul Archaeological Museums in November and December of 2007. Excavations revealed a 9 x 3.7 m portion of a heavily built round ship with one end relatively well preserved; the ship was preserved up to the turn of the bilge on one side and up to the third wale on the opposite side. There were no clear indications as to which end of the vessel was the bow and which the stern, and this designation remains unclear at the current stage of research.

While the ship was very well preserved, the boring machine inflicted significant damage to the better-preserved side of the vessel. As part of the construction site's retaining wall, the 1.5 m-diameter holes were filled with concrete, resulting in four concrete pillars

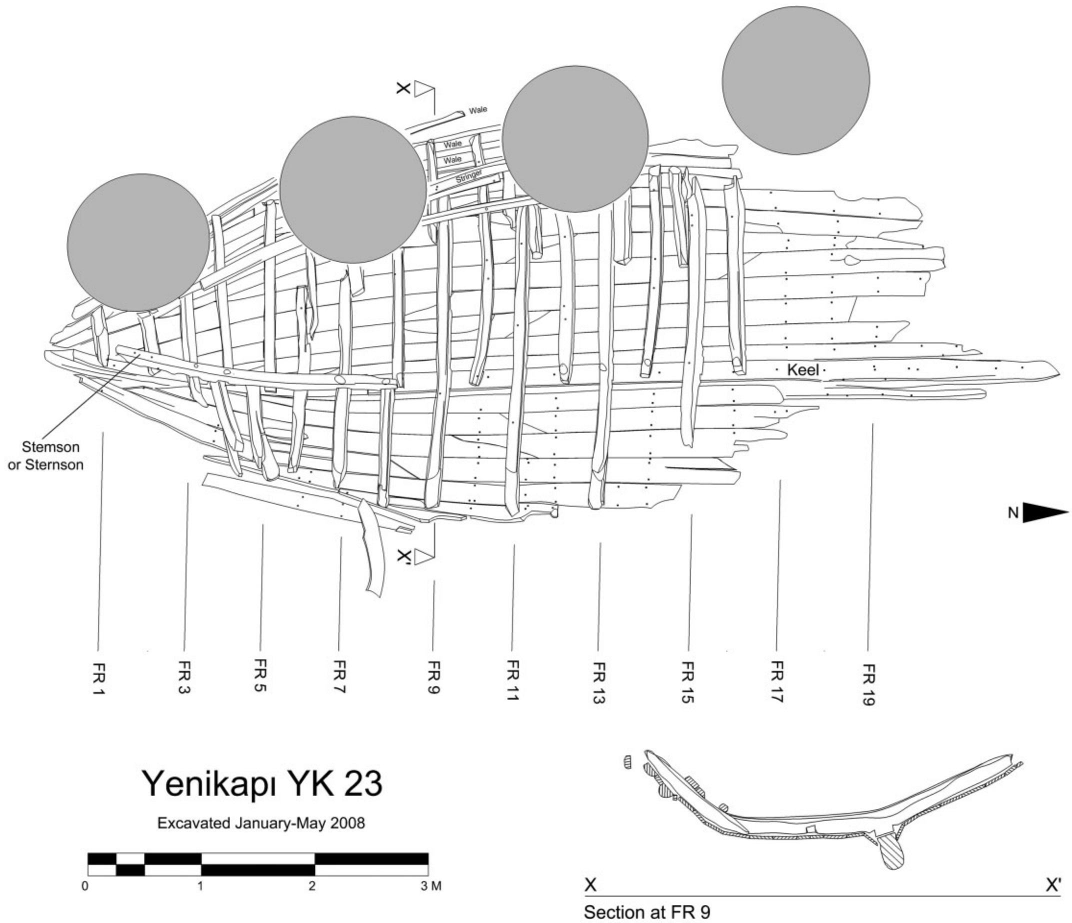

Figure 10. YK 23 site plan. (Plan S. Matthews)

that pierced the shipwreck (Fig. 11). Ship timbers along the periphery of these columns were broken and splintered. At some point after the ship sank, but while the harbour was still in use, at least 14 wooden piles were driven into the harbour floor in the area around the ship, with two of the piles driven through the hull itself. The hull was found in a layer of fine gray sand with shell and artefact inclusions; the ship may have sunk in a storm, with its cargo dispersed in the harbour or salvaged soon afterwards.

In situ documentation and dismantling of YK 23, begun in early January 2008, was completed by early May. Preliminary study during the excavation has revealed YK 23 to be a medium-sized round ship of robust construction with a shallow, wineglass-shaped hull profile. Analyses of wood samples from hull timbers indicate that the ship was built entirely of Turkey oak. Based on artefacts found in the same stratigraphic layer, including a collection of copper coins found inside the shipwreck, the latest of which was issued by Nicephorus I (r. 802–811), the ship's construction is tentatively dated to the late 8th or early 9th century AD. The coins provide a *terminus post quem* for the loss of the vessel, and it is hoped that future radiocarbon and dendrochronological analyses will provide a more accurate date for the ship's construction.

Preserved elements of the ship's spine include a heavy keel, a short, curving transitional piece, and what appears to be part of an endpost. The three timbers were interconnected by means of keyed hook scarfs reinforced with iron bolts. Like the keel scarf bolts of YK 11, the YK 23 bolts also run through the frames placed over the keel scarfs and through a substantial, fully preserved longitudinal timber at one end of the hull, either a stemson or sternson. This timber, notched to fit over framing, was attached with several nails in addition to the bolts, thus providing significant support to the ship's spine (Fig. 12). The ship's oak keel, approximately 175 mm sided and up to 330 mm moulded, is preserved to a length of 6.6 m (broken at one end). In order to facilitate the removal of the keel, the coffer dam was intentionally flooded, allowing archaeologists to gingerly manoeuvre the heavy timber into a foam-lined, reinforced storage crate; more than 30 workers were needed to carry this crate out of the excavation pit and into an on-site freshwater storage tank. The garboards were fastened to the keel with iron

Figure 11. Shipwreck YK 23 *in situ*, showing coffer dam, at left, and concrete pillars through the better-preserved side of the ship, at right; December 2007. (Photo İ. İvgin/INA)

Figure 12. *In situ* central longitudinal timber on YK 23, either a stemson or sternson; January 2008. (Photo R. Ingram/INA)

nails. A transverse hole, approximately 80 x 70 mm in diameter, was found near the keel's broken end; it was presumably used for hauling the ship ashore. Similar transverse holes were found in the keel timbers of three other shipwrecks documented by the INA team (YK 1, YK 14 and YK 24), in a disarticulated keel timber from a small vessel found under YK 5, and in at least six other shipwrecks at Yenikapı documented by Istanbul University (YK 6, YK 7, YK 8, YK 9, YK 12, and YK 15) (Kocabaş, 2008: 104, 117, 119, fig. 15a-b, 126, 135, 136, fig. 37b, 148, 164, 166, fig. 80); on the Saint-Gervais 2 ship a similar hole still retained remnants of rope (Jézégou, 1983: 32).

The ship's robust oak planking, 25–40 mm thick, was edge-joined with coaks in the lower portion of the hull. Most of these coaks, approximately 11 mm in diameter, have a roughly rectangular section and an average spacing of 500 mm. Score marks used to align coak joints during construction survive on the inner faces of hull planks at a number of locations. Caulking of grass and pitch was found in all of the vessel's plank seams. Eight strakes of planking were preserved along one side and 11 along the better-preserved side, although these upper strakes were significantly damaged by the action of the hole-boring machine. Preliminary study of the planking during the dismantling of the ship revealed that the ship had undergone fairly extensive repairs, including the caulking of *teredo* worm damage and the insertion of a number of repair planks, suggesting that it had been in service for a significant period by the time it sank. On the better-preserved side, parts of three oak half-log wales were preserved; an aperture between the first two wales likely represents the location of a through-beam toward the ship's preserved end.

YK 23's framing followed the pattern of alternating floor timbers and paired half-frames seen on YK 11, with futtocks adjacent, but not attached, to floor timbers and half-frames. Score marks on the planking at the edges of frame locations confirm that a number of the frames were installed in the hull after the assembly of the lower planking. Parts of 27 distinct framing elements were preserved at 16 frame stations, and fastener holes on the extant planking delineate an additional seven frame stations. The average room and space on this ship was approximately 380 mm. The frames were fastened to the ship's planking solely with short iron nails driven from the exterior, again similar to the attachment of the frames on YK 11; almost all of the floor timbers and half-frames were nailed to the keel. The YK 23 frames, however, were heavier than those of YK 11, with average dimensions of 110 mm sided and 150 mm moulded.

Remains of at least two stringers were found on the better-preserved side of the ship, although a number of additional timber fragments brought up by the hole-boring machine remain to be examined. The *in situ* stringers were attached to the ship's framing with iron nails.

The YK 23 hull, noteworthy for its robust structure, would originally have been approximately 15 m in length and 5 m in breadth. The massive frames, thick planks, and substantial keel are characteristics of a strong, sturdy vessel capable of transporting cargoes on open-sea voyages. Although the YK 23 shipwright made use of coaks for edge-fastening planking instead of mortise-and-tenon joints, he continued using the traditional framing pattern of alternating floor timbers and paired half-frames common in earlier

Mediterranean ships. The construction of the ship entirely from oak—perhaps due to its local availability—is another common feature of the later Yenikapı round ships. This choice of material is in contrast to Theophrastus' recommendations for the construction of merchant ships (*Hist. Pl.* 5.7.1–3) and to the wood species used in the construction of many ancient and early medieval Mediterranean ships (Steffy, 1994: 41, 54, 71, 80, 85, 258–59). Overall, while this ship's descent from classical Mediterranean shell-built hulls is apparent, it also displays some innovations in construction methods, as well as the use of different construction materials.

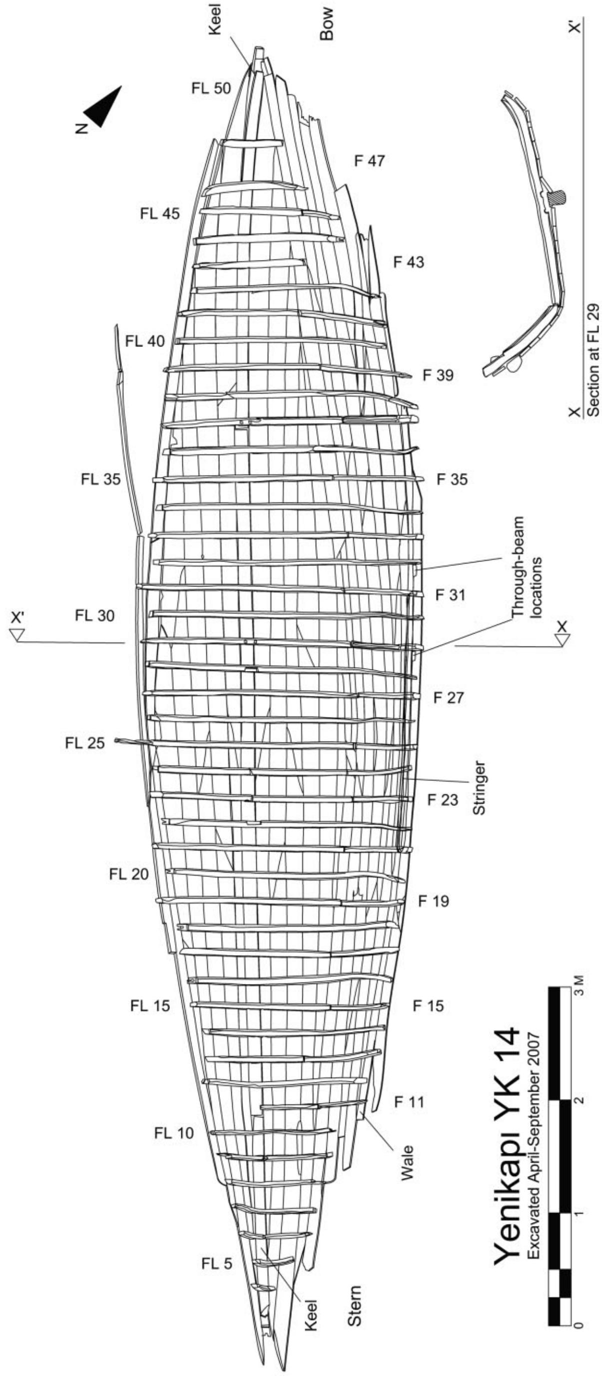

Figure 13. YK 14 site plan. (Plan S. Matthews)

YK14

YK 14 (MRY 7) was discovered in the central section of the Marmaray excavation area in grid squares K, L, and M 146, approximately 20 m west of Namık Kemal Street and south-west of the YK 23 shipwreck (Fig. 13). The shipwreck was found in January 2007 and was fully excavated and dismantled between April and September of that year. Post-excavation documentation of YK 14 was conducted by Michael Jones between 2009 and 2012 as part of his doctoral dissertation at Texas A&M University (Ingram and Jones, 2011: 13–4; Jones, forthcoming). The surviving portion of the ship, which measured approximately 12 x 2.5 m, represents perhaps one-third of the total original hull, preserved to the turn of the bilge on the port side and to one strake above the first wale on the starboard side.

The shipwreck was discovered in a thick layer of gray, silty sand with inclusions of shells and ceramic fragments. Based on the near absence of shipworm damage and the excellent preservation of the ship's timbers, the surviving hull was buried quickly after sinking, probably in a storm. Eight medieval wooden piles were driven into the sediments over the shipwreck, three of which penetrated the ship's hull (Fig. 2). No evidence of the ship's cargo or ballast was found during the excavation, suggesting that the hull's contents were either lost during the sinking of the ship or were salvaged soon afterwards. Pottery fragments discovered in the stratigraphic layer which contained the shipwreck were tentatively dated to the late 9th or early 10th century AD during the ship's excavation; more recently, however, AMS radiocarbon dates of samples from hull timbers and a dendrochronological date of a timber likely associated with the ship suggest a construction date in the first half of the 9th century (Table 2).[1]

YK 14's hull was built primarily of Turkey oak, with some additional elements of sessile oak (*Quercus petraea*) and sycamore maple (*Acer pseudoplatanus*) (Liphschitz and Pulak, 2009: 168). YK 14's three complete, rabbeted keel timbers are relatively small in section compared to most other round ships of similar size known from this period, with average dimensions of 112 mm sided and 144 mm moulded. Transverse holes, approximately 50 mm in diameter and probably intended to facilitate hauling the ship ashore, were cut through the port and starboard faces of the keel timbers in two locations: one in the curved keel timber toward the bow, and the second amidships. The keel and endposts were joined with keyed hook scarfs, only one of which, near the ship's bow, was reinforced with an iron bolt. The bow and stern of the vessel were identified based on the shape of the hull, on the

Figure 14. Edge fasteners along exposed plank edge of YK 14; September 2007. (Photo M. Jones/INA)

Figure 15. Intact coak from YK 14's port side. (Photo M. Jones/INA)

assumption that the stern section is narrower than the bow, and the locations of probable mast-partner beams.

The planks, typically 20–25 mm thick, with slightly thicker garboards, were edge-joined with coaks from the garboard to the first and only surviving wale, at the presumed location of the ship's waterline. Based on several features, including the absence of edge fasteners on their upper and lower edges, the wale and the single strake surviving above it were apparently fastened to pre-erected frames rather than to adjacent strakes. Plank seams were caulked with a combination of grass and pine pitch; samples of resinous waterproofing material from the caulking and surfaces of YK 14's hull were identified as pine pitch at Vassar College's Amber Research Laboratory. The garboards were fastened to the keel with wooden treenails supplemented by iron nails; both types of fasteners were driven diagonally from the exterior of the hull. Most hull planks in the same strake were joined with S-scarfs, 500 mm long on average and typically secured with 2–3 coaks. Coaks used as planking edge fasteners were typically 11–13 mm in diameter and spaced 390 mm apart on average, although this varied significantly based on location in the hull, the placement of plank scarf ends, and the shapes of adjacent strakes (Figs 14, 15). In many areas, score marks, used to align coak joints during construction and to mark the locations of frame edges, survived on the inner surfaces of the hull planking. Two through-beams were fastened slightly forward of midships and the location of the mast-step, as shown by a pair of apertures cut into the strake

Figure 16. L-shaped floor timbers in YK 14's hull amidships, photographed during the dismantling of the hull; May 2007. (Photo M. Jones/INA)

above the wale amidships and fastener holes in the wale itself; one or both of these timbers probably served as mast-partner beams.

Evidence for approximately 50 frame stations was preserved on YK 14, including 45 surviving floor timbers and, where frames were not extant, fastening holes for frames in the planking. Floor timbers were closely and regularly spaced, with an average room and space of 230 mm. In contrast to some of the other round ships found on the site, YK 14's frames were comparatively light, with average maximum cross-sectional dimensions of 58 mm sided and 95 mm moulded; beyond the turn of the bilge, the cross-sectional dimensions of the floor timbers decreased, often significantly. While earlier ships were constructed with a framing pattern of floor timbers alternating with paired half-frames, YK 14 was built with flat, L-shaped floor timbers whose long arms alternated in orientation and extended past the turn of the bilge to the strake above the first wale. The short arms of the floor timbers were scarfed into, although not fastened to, futtocks at the turn of the bilge area (Fig. 16). Frames were typically fastened to the ship's planking with 1–2 treenails per strake, supplemented with iron nails in some locations, most often at the turn of the bilge. Rounded limber-holes were cut into the outer faces of the floor timbers at either side of the keel. Only 20 of the ship's approximately 50 floor timbers—based on both surviving floor timbers and the locations of frame fasteners in the keel and hull planking—were nailed to the keel, at every second or third frame.

The framing configuration used in YK 14's hull offers several advantages. It allows the positioning of floor timber-to-futtock joints, which occur at the turn of the bilge, to alternate from side to side, thereby avoiding potential points of weakness in the hull. This framing pattern also allows for more standardized and easily fabricated floor timbers. The large number of later round ships with this style of framing found at Yenikapı, as well as the very similar framing patterns used in the late 9th-century Bozburun ship and early 11th-century Serçe Limanı ship, attest to the popularity of this design in Middle Byzantine shipbuilding (Bass *et al.*, 2004: 93; Harpster, 2009: 301–10).

Similar frame shapes are also found in flat-floored Roman-period vessels, including river vessels such as 'Zwammerdam-type' barges (de Weerd, 1988: 45, fig. 5; Hocker, 2004b: 68).

There is no surviving evidence of a keelson or any other significant longitudinal element inside the hull aside from one partially preserved stringer. Mortises cut into two floor timbers amidships indicate the original location of the vessel's mast-step, based on the seating of the *in situ* mast-step preserved on the contemporaneous YK 12 documented by Istanbul University (Kocabaş, 2008: 123, 124, fig. 22; Özsait Kocabaş, 2012: 115). Grooves cut into the inner faces of two futtocks delineate the location of a pair of bulkheads forward of midships.

Multiple repairs were identified in YK 14's hull, including repair pieces recycled from the hull planks of other coak-built vessels, reinforcement fasteners added during the ship's sailing career, evidence of the re-caulking of plank seams, and areas of damage plugged with pine pitch and caulking. These features indicate that the ship had been in use for a number of years before it sank. Both treenails and iron nails were employed for repairs. Besides their use in fastening repair planks, some of the iron nails, as well as some examples of treenails, used in the hull appear to be replacements for treenails damaged or destroyed by wood rot; these fasteners are sometimes associated with caulking and pitch repairs around treenail holes, plank seams, or in the spaces between the frames and hull planking. This damage may be due in part to Turkey oak's propensity to rot as a species of the more porous red oak group rather than the white oak group more often favoured for ship construction (Doğu *et al.*, 2011, 1011); several ancient writers comment on Turkey oak's inferiority as construction timber for this reason (Vitr., *De Arch.* 2.9.9; Pliny, *HN* 16.8.22). The choice of Turkey oak as the primary construction timber for YK 14 and many other cargo vessels from the Yenikapı site may therefore have been dictated by cost and availability rather than durability.

YK 14's hull has been reconstructed as 14.65 m in length and 3.4 m in breadth, resulting in a length-to-beam ratio of 4.2:1.[2] This is a rather long and narrow hull for a cargo carrier—a length-to-beam ratio of approximately 3:1 is typical for most ancient cargo vessels, including most of the round ships excavated at Yenikapı—and suggests a possible specialized function for the ship. The vessel's shallow draft and relatively flat bottom are well-suited for beaching and for sailing in shallow coastal waters and rivers; its long, narrow hull may have also been designed for speed.

YK5

YK 5 (Metro 2), a well-preserved, medium-sized round ship, was discovered in grid squares 2Ba2–2Ba4 near the eastern end of the Yenikapı excavation site in late 2005 and was excavated and dismantled between March and September of 2006 (Fig. 17). YK 5's hull was discovered partly overlying the port side of the galley YK 4. The ship's position, in a sandy stratigraphic layer dated by artefact finds to the late 10th century AD, as well as the lack of shipworm damage to the timbers of both shipwrecks, suggests that YK 5 may have collided with YK 4 during a storm before sinking. This storm or series of storms may have buried

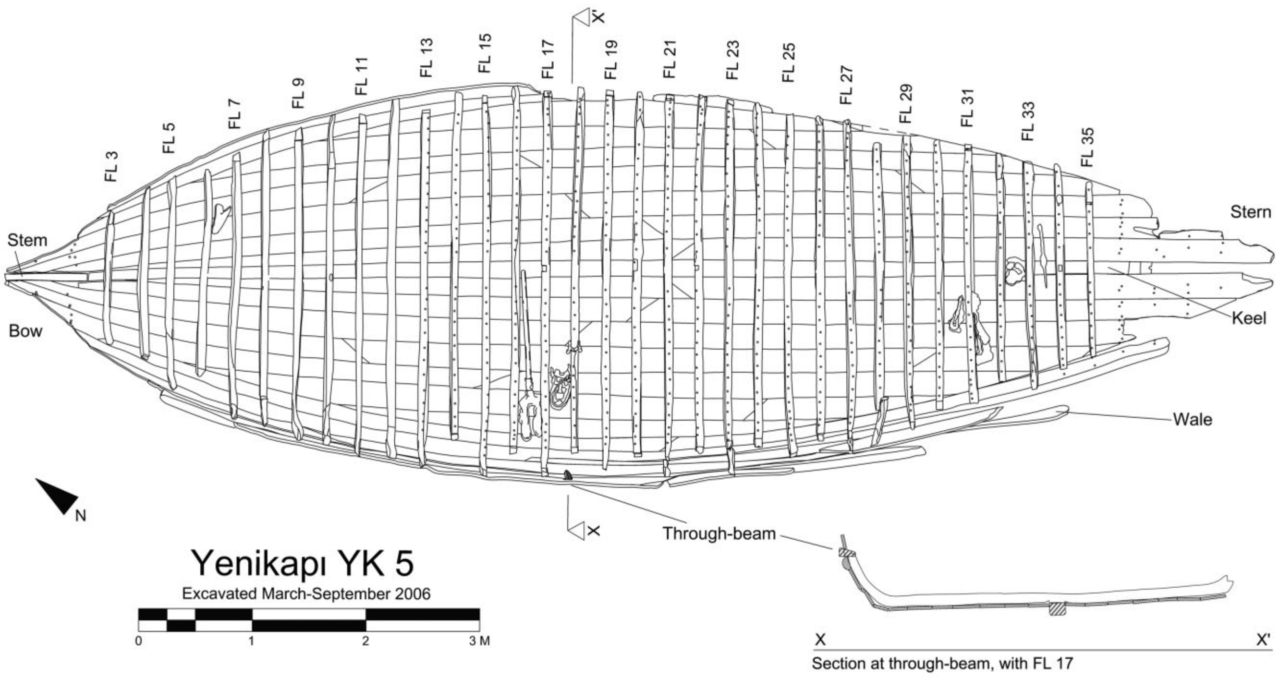

Figure 17. YK 5 site plan. (Plan S. Matthews)

up to 25 ships in the eastern half of the site, possibly including YK 1, YK 2, and YK 24 (Pulak, 2007: 203, 211; Liphschitz and Pulak, 2009: 167; Perinçek, 2010: 206). The excellent condition of the ship's timbers and scant evidence of repairs in the hull—there is a single repair to the vessel's preserved stem—indicate that YK 5 was relatively new when it sank. The ship's cargo and equipment were probably lost or salvaged soon after its sinking, although several iron objects, including an axe, an iron spit, and an iron spade-fork with a wooden handle, were found inside the hull.

About one-third of YK 5's hull was preserved, over an area of approximately 12 x 3.5 m. The starboard side of the ship was extant to the turn of the bilge, while the better-preserved port side was preserved to one strake above the first wale. A complete, slightly hogged main keel timber, over 8.2 m in length, a smaller, complete curved keel timber, and a fragment of the stem survived. The bow of the vessel was identified based on the shape of the preserved stem and the presumably fuller bow as well as the location of the ship's mast-step (based on mortises in the floor timbers) and mast-partner through-beam. The hull of the ship, with the exception of a few wooden fasteners, was built entirely of Turkey oak (Liphschitz and Pulak, 2009: 167).

The methods used to build YK 5 appear to be nearly identical to those used in the construction of YK 14 about a century and a half earlier. YK 5 is a mixed-construction hull; the lower hull was built shell-first with regularly spaced coaks as planking edge fasteners from the garboards to the first wale. Planking edge fasteners are one of the most common characteristics of shell-first construction, although the use of a small number of pre-erected frames or temporary cleats cannot be ruled out at this stage of research. From the height of the first wale, the vessel was presumably constructed and shaped around the ship's framing based on the lack of edge fasteners in the upper and lower edges of the wale and the surviving strake above it. One significant difference in YK 5's design that differentiates it from YK 14 is its hull shape. Originally, the YK 5 hull would have been approximately 14.5 m in length and 5 m in breadth, and it was built with much wider, flatter floor timbers and a sharper turn of the bilge than YK 14, presumably to maximize cargo capacity.

YK 5's keel is roughly rectangular in section. The moulded dimensions of the keel timbers are on average 89 mm, while the sided dimensions are on average 121 mm. The keel and stem tapered along the length of the vessel, with smaller cross-sectional dimensions at the better-preserved forward end of the shipwreck; unusually, for most of the ship's length the sided dimensions of the main keel timber are larger than the moulded dimensions, a feature absent from the other Yenikapı shipwrecks under study by INA. The lack of a rabbet in the keel also allowed for a flatter-bottomed hull, giving the ship a cross section similar to the nearly contemporaneous Serçe Limanı ship (Bass *et al.*, 2004: 157) (Fig. 18). The keel and endpost timbers were connected with keyed hook scarfs; only the scarf between the curved transitional timber and the surviving stem fragment was fastened with a pair of treenails.

Figure 18. *In situ* framing of ship YK 5; April 2006. (Photo S. Matthews/INA)

YK 5's starboard side was preserved up to the beginning of the turn of the bilge, while the planking, including one wale, survived on the port side up to one strake above the first wale. The ship's planks are on average 20–25 mm thick and were edge-fastened with regularly spaced wooden coaks up to the first wale, which is estimated to be the location of the vessel's waterline. The coaks are typically 11–13 mm in diameter, with round or polygonal cross sections; on average, coaks were spaced approximately 310 mm apart. Of 22 coaks sampled, 16 were sycamore maple while the rest were Turkey oak (Liphschitz and Pulak, 2009: 167). Plank seams were filled with a thick caulking of grass and pitch. The locations of coaks, as well as some frame locations, were marked by scoring similar to that seen on YK 14 and YK 23. Coaks were also used to fasten planking scarfs to each other and to adjacent strakes; on most planks these are short diagonal scarfs, 270 mm long on average, and approximately half the length of those seen on YK 14. The edge-fastening techniques used in YK 5's hull were almost identical to those used to construct YK 14. However, there were very few small or irregular hull planks used in YK 5's construction; its builders fashioned a nearly symmetrical configuration of hull planking on the port and starboard sides from the garboards to the turn of the bilge, in contrast to YK 14, whose builder may have had fewer large timbers available.

YK 5 originally possessed approximately 40–45 frames, based on 33 surviving floor timbers and evidence for fastener holes from seven floor timbers surviving on the ship's planking. The framing pattern, nearly identical to that on YK 14, consists of L-shaped floor timbers alternating in orientation and scarfed to in-line futtocks on the ends of the shorter arms; the futtocks were not fastened to the floor timbers. YK 5's floor timbers are slightly larger and more regular in

Figure 19. *In situ* through-beam of YK 5, as viewed from ship exterior; note the slight displacement of the plank abutting the through-beam; September 2006. (Photo S. Matthews/INA)

form than those on YK 14, with an average moulded dimension of 110 mm and average sided dimension of 75 mm. The ship's frames and planking were fastened primarily with treenails of Turkey oak supplemented in some areas with iron nails, most often at the turn of the bilge and garboard areas of the hull (Liphschitz and Pulak, 2009: 167). Fifteen of the 33 floor timbers preserved on the shipwreck were fastened to the keel with long iron nails driven through pre-drilled pilot holes; typically every second or third floor timber was fastened to the keel. Triangular limber-holes were cut in the outboard face of each floor timber along either side of the keel.

The position of YK 5's mast-step is indicated by mortises over the keel in three floor timbers amidships (FL 17, 20, and 22) similar to those found on YK 12 and YK 14; the locations of these mortises indicate that the mast-step was at least 1.35 m long. The end of a single through-beam was discovered slightly forward of amidships, resting in a cut aperture in the highest surviving plank above the wale (Fig. 19). The through-beam was cut with an I-shaped notch to fit the timber's end into the aperture in the hull planking; no other fasteners were used to hold the through-beam in place. Because the through-beam is located at the forward end of the mast-step, it likely served as a mast-partner beam.

While similar to YK 14 in many respects, YK 5's construction is notable for its broader, more flat-floored and capacious hull, as well as evidence of standardization and simplification of various aspects of the ship's construction in comparison to the earlier mixed-construction vessels from the Yenikapı site studied by INA.

YK 24

YK 24 (MRY 9) is the smallest and most poorly preserved of the INA-documented shipwrecks from Yenikapı (Fig. 20). It was discovered early in the summer of 2007 in the Marmaray excavation area in grid square M 36, to the north-east of YK 1 and YK 2, in a sandy stratigraphic layer dated to the 10th century AD. The shipwreck was excavated, documented and dismantled in three weeks in July and August of 2007. YK 24 may have been a small cargo or fishing vessel, perhaps designed for local use on the Bosporus or Sea of Marmara. Only a small portion of the original hull was preserved in an area of about 5 x 3 m, with many of its timbers dislodged from their original positions, including an endpost and a mast-step; very little of the hull survived past the turn of the bilge (Fig. 21). The hull was originally about 8 m in length and 2.5 m in breadth. Based on extensive repairs to the vessel, YK 24 had been heavily used by the time of its deposition. It is unclear how the vessel sank, although surrounding stratigraphy and damage to the hull suggest it may have been lost in a violent storm.

The ship was built entirely of Turkey oak. The surviving keel timbers, all of which were complete, consisted of a main central timber (Keel 2) and three other timbers, two of which were found in their original positions on the shipwreck. Altogether, these keel timbers exhibited an average sided dimension of 82 mm and average moulded dimension of 106 mm. The main keel timber, Keel 2, is 3.19 m in length and roughly rectangular in cross section; both ends of this timber terminate in short, three-plane scarfs fastened with a combination of nails and treenails. A transverse hole, 40–45 mm in diameter, was cut through the port and starboard faces of Keel 3, a curved keel timber from one end of the vessel.

Seven complete and partial strakes of planking survived on the shipwreck, including both garboards and five additional strakes from one side of the vessel extending to the turn of the bilge. YK 24's planking was 20–23 mm thick in areas where the original thickness was preserved, although most of the surviving planks are significantly thinner due to compression. Few scarf ends are preserved in the surviving planking, but at least one plank terminated in a short diagonal scarf similar to those used in the construction of YK 5. Grass caulking mixed with pitch was found between the plank seams of the hull, and traces of pitch were evident on the inner and outer faces of the hull planks. As on YK 5, the inboard edges of the garboard strakes were fastened to the port and starboard faces of the central keel timber with regularly spaced coaks. YK 24's planking was edge-fastened with coaks similar to those seen on YK 5 and YK 14; these were spaced 280 mm apart on average. As on other coak-built

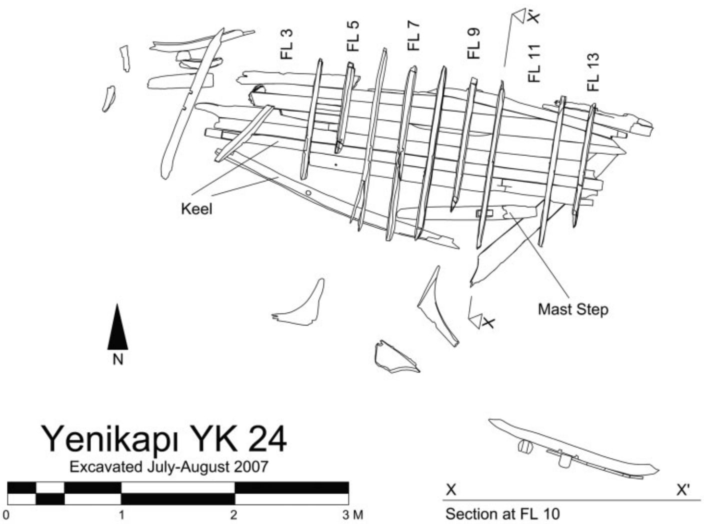

Figure 20. YK 24 site plan. (Plan S. Matthews)

Figure 21. Shipwreck YK 24 during excavation; July 2007. (Photo M. Jones/INA)

vessels, some coak locations were clearly marked by scoring on the inner faces of the hull planking. Caulked treenail holes were found between frame locations in the lower planking of the hull. Most of these appear to have been fasteners for bilge keels or runners along the hull's bottom. At least two contemporary vessels of similar size from Yenikapı (YK 6 and YK 7) have bilge keels or runners in the same general area of the hull (Kocabaş, 2008: 103, 111–13, 138–39).

YK 24's hull was flat-floored, with evidence of 14 frame stations in the main section of the shipwreck. Eleven floor timbers survived in the articulated section of the hull, in addition to several disarticulated frame fragments found in the immediate area of the shipwreck. Nine of the floor timbers in the central section of the ship were fastened to the keel, six with treenails (FL 2, FL 4, FL 6, FL 8, FL 10, and FL 12) and three with iron nails (FL 5, FL 9, and FL 13); three others (FL 3, FL 7, and FL 11) were not fastened to the keel. The floor timbers resemble those of YK 5 but are much shorter and smaller in cross-sectional dimension. The vessel's floor timbers are fairly light, with average maximum moulded dimensions of 97 mm and average maximum sided dimensions of 61 mm; frames were spaced on average 270 mm apart. Frames were fastened to hull planks with both treenails and iron nails.

Evidence for extensive repairs, including at least one major overhaul, is apparent in the surviving section of YK 24's hull. These repairs included the addition of several graving pieces, apparently inserted into rotten or leaky sections of the hull along plank seams. A large number of iron nails used in the hull, many of which were driven in or near treenails, was likely added to reinforce treenails that had loosened after years of service. Two unusually shaped keel blocks (Keel 1 and Keel 4) were installed at either end of the keel, between the keel (Keel 2 and Keel 3) and endposts; unlike the central keel timber (Keel 2), these blocks, as well as a curved keel timber from one end of the hull (Keel 3) (Fig. 22), were not edge-fastened to the garboards with coaks. It is likely that all three of these keel timbers

Figure 22. *In situ* repair timber on the keel of YK 24 (YK 24 Keel 1); July 2007. (Photo M. Jones/INA)

Figure 23. Mast-step of ship YK 24 *in situ*; July 2007. (Photo M. Jones/INA)

were added during the same repair episode; the short keel blocks likely replaced more complex keyed hook scarfs used to join the original keel and endpost timbers.

Another of YK 24's significant hull elements is the vessel's disarticulated mast-step, found next to the shipwreck; this is the only example found on the eight vessels studied by INA at Yenikapı. This timber is preserved to a length of 1.27 m, with a maximum cross section of 120 x 95 mm; its original length was probably only slightly longer (Fig. 23). One end of the mast-step is damaged, but the preserved end shows that it was originally nailed at either end to floor timbers; the mast-step's under face is also notched to fit over the vessel's floor timbers. The mast-step has a single mortise for the mast's heel, approximately 150 x 65 mm in size and cut through the timber from its inner face. Due to the poor preservation of the mast-step and the ends of the hull, the mast-step's original location on the ship has not been confirmed at this stage of research.

YK 24 appears to be one of a fairly common class of small vessel from Yenikapı dating to the 10th or early 11th centuries. Other contemporaneous vessels from Yenikapı with similar characteristics, such as YK 6, YK 7, and YK 9, have been described in publications by the Istanbul University team at Yenikapı (Kocabaş, 2008: 103–11, 125–39). These vessels are 8–10 m long, possess flat floor timbers, were built with coaks and relatively light, in-line frames, and in some cases possess bilge keels and transverse holes in their keels for hauling. These vessels' smaller numbers of timbers, and their more diminutive size, are the main features distinguishing their hull construction from larger contemporary round ships such as YK 5. Additionally, some of these vessels may have had a different rig and served a wider range of functions than the larger round ships. Byzantine sources include names of a number of small craft types that could perhaps be applied to YK 24 and the other small vessels discovered at Yenikapı; such vessels as the *sandalion* were crewed by up to four men, were rowed as well as sailed, and were often used as fishing boats or as auxiliary boats for larger vessels, including *dromons* (Jal, 1848: 1315; Haldon, 2000: 212, n. 41; Makris, 2002: 93).

YK 1

YK 1 (MRY 1) was the first shipwreck discovered at the Yenikapı site in the late spring of 2005 in the eastern section of the Marmaray excavation area (grid squares O-P 32–34 and O 35) (Fig. 24). The ship was likely built sometime in the later 10th century and was sailed for a number of years based on repairs to the hull (Liphschitz and Pulak, 2009: 166). Its sinking is dated to the late 10th or early 11th century based on its cargo of several dozen amphoras of a piriform shape commonly found on the Yenikapı site, perhaps linked to wine production in the area around Ganos (Gaziköy) on the Sea of Marmara (Pulak, 2007: 208; Günsenin, 2009: 147, 149–50; Denker *et al*., 2013a: 211–15) (Fig. 25). A coil of rope and a pair of iron anchors, presumably spares in position for casting as needed when the ship sank, were found at one end of the ship, identifying the bow of the vessel (Denker *et al*., 2013a: 218). The thick layer of sand found around the wreck seemed to indicate that the ship had been at anchor when it was broken to pieces in a storm, which may have also sunk YK 2, YK 4, YK 5, and YK 24. It appears that the ship was never relocated after its sinking, since both the valuable anchors and amphoras would have been salvaged if discovered (Pulak, 2007: 203, 208).

The surviving section of YK 1's hull covered an area of about 6.5 x 3 m, while the ship itself was probably about 10 m long and approximately 3.5 m in breadth (Pulak, 2007: 211). Unusually, the starboard side of the ship from the turn of the bilge to the caprail was preserved; the amphora cargo appears to have shifted as the ship sank and formed a protective layer over the surviving hull timbers. The bottom of the hull was

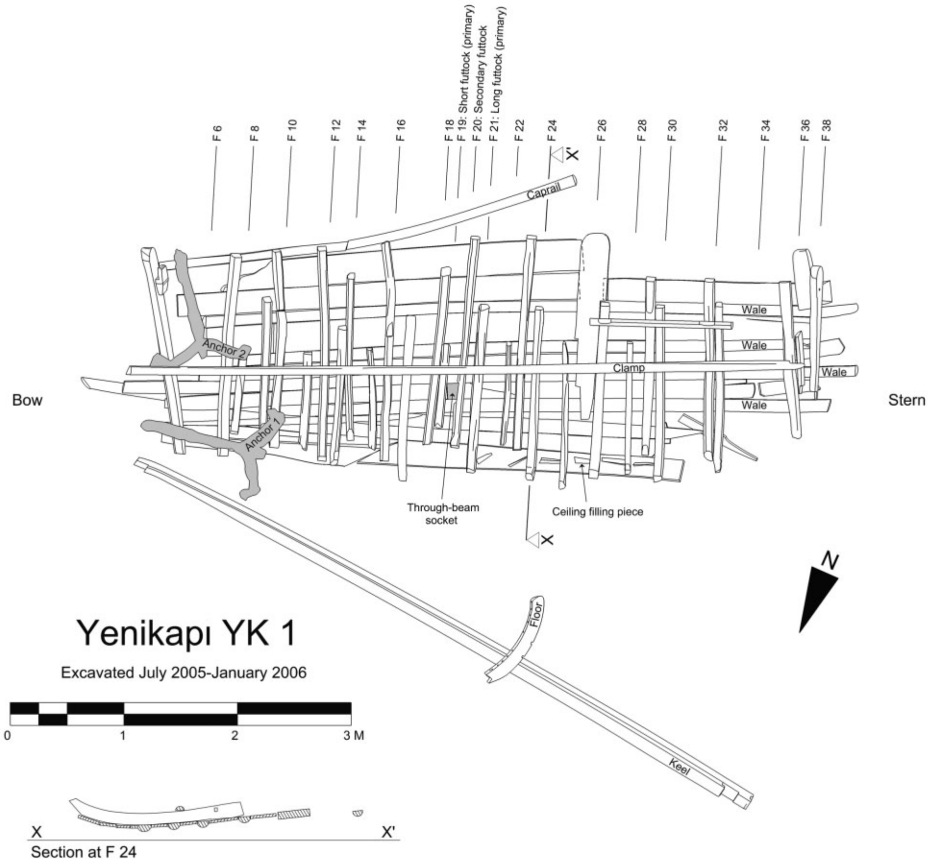

Figure 24. YK 1 site plan. (Plan S. Matthews)

Figure 25. Shipwreck YK 1 *in situ*, with a Ganos-style amphora visible next to a concreted iron anchor at the ship's bow; August 2005. (Photo M. Jones/INA)

completely lost, aside from the main keel timber and one curved floor timber from one end of the ship.[3] In addition to the anchors and rope, oak toggles for the ship's rigging as well as a number of small objects that may have been cargo or personal possessions of the crew were found (Denker *et al*., 2013a: 216–17).

YK 1's surviving hull planking consists of 15 strakes, including four wales and a caprail. The lowest 11 strakes are original, while the four strakes above these were added during an overhaul of the ship, probably a number of years after its initial construction. The surviving hull planks are usually 17–25 mm thick, and they are edge-fastened with coaks from the turn of the bilge—the lowest preserved area—to below the first wale; coaks on the port and starboard faces of the keel show that the ship was also edge-fastened across the bottom of the hull. The plank seams were caulked with grass and pine pitch. The coaks used as planking edge fasteners are round or polygonal in section, typically 10 mm in diameter, and were spaced on average 270 mm apart. Individual planks in each strake were most often joined with diagonal or S-scarfs, on average 420 mm long, although shorter vertical flat scarfs were also used in some areas. Score marks were found on some of the hull planking delineating the locations of frames.

YK 1's 6.2 m-long keel, lacking rabbets, was rectangular in section with a rounded outer face; its average sided dimension is 103 mm and average moulded dimension 136 mm. However, the keel's moulded and sided dimensions taper from a maximum of 128 mm sided and 180 mm moulded at the aft end, to 60 mm sided and 75 mm moulded at the forward end. A pair of transverse holes, each approximately 50 mm in diameter, was cut through the port and starboard faces of the timber amidships and toward the vessel's stern. Unlike YK 5 and YK 14, YK 1's keel is rockered rather than straight, indicating a more rounded hull.

Similar to YK 5, YK 14, and YK 24, YK 1 was built with a framing pattern of alternating L-shaped floor timbers paired with short futtocks. Seven complete original futtocks, along with fragments of the alternating floor timbers, were preserved; these are of similar form to those from YK 5 and YK 14. On average, the cross sections of preserved futtocks were 113 mm moulded and 82 mm sided. The average cross-sectional dimensions of preserved floor timber fragments, measured at the ends of the long arms that had broken off just above the turn of the bilge, were 95 mm moulded and 66 mm sided. Based on the locations of floor timber fasteners and impressions in pitch on the inner face of the keel, the room and space of 280 mm between the floor timbers was similar to that above the turn of the bilge. Twelve of the estimated 20 floor timbers crossing the main keel timber were nailed to it, with the majority of the floor timbers fastened to the keel concentrated in the central section of the ship. Between the futtocks were six small pieces of planking

Figure 26. Slotted timber on YK 1 that accommodated removable strakes of planking; August 2005. (Photo M. Jones/INA)

embedded in pitch; they served as extensions of the ceiling planking, filling gaps between the frames just above the turn of the bilge. A single light stringer, 6.24 m long, was fastened to futtocks with treenails and nails at the estimated location of the ship's waterline. An aperture in the hull, approximately 150 x 130 mm with finished plank ends on either side, was found in the planking amidships just above the first wale. This was likely the location of a mast-partner through-beam, which damaged the hull planking on one side of the aperture when it was torn from the hull during the sinking of the ship.

At some time during the ship's career, YK 1 was subjected to a major overhaul, in which the sides of the ship were raised by about 0.60 m to increase the vessel's freeboard. As the ship was originally designed, the upper parts of the hull were supported by at least 24 futtocks, 16 of which survived. To increase the height of the ship's bulwarks, 12 additional, roughly shaped top timbers or 'secondary futtocks' (to distinguish them from the 'primary futtocks' installed during the initial construction of the ship) were added in between the original, primary futtocks and fastened only with iron nails in order to support the new strakes (Pulak, 2007: 208–11; Liphschitz and Pulak, 2009: 166–67). Two newly added futtocks had grooves cut into their edges for a removable plank, a feature probably used to accommodate a loading ramp (Fig. 26). As with YK 5, YK 14, and YK 24, all of the original hull timbers used in the ship's construction as well as the ship's secondary futtocks were made from Turkey oak. All of the sampled treenails and coaks from the ship were also made from this oak species (Liphschitz and Pulak, 2009: 166–67). However, during the overhaul, the additional planking and new caprail used to extend the ship's bulwarks were made from a variety of less rigid, non-oak species such as oriental plane (*Platanus orientalis*), Turkish pine, and poplar (*Populus nigra* or *P. alba*). This may reflect a shift toward lightweight woods in the upper portions of the hull, or perhaps merely reflect the shipwright's use of whatever timbers were readily available in the immediate area where the repairs were taking place. A large number of iron nails were likely added to the hull at this time as well: many of the nails fastening the frames to the hull planking were driven into or near original treenails to reinforce the treenails fastening the planking to the frames, which may have loosened over time (Liphschitz and Pulak, 2009: 167). Together, these features suggest that YK 1 had provided many years of service prior to its loss in the Theodosian Harbour.

Galleys

Six of the 37 shipwrecks excavated at Yenikapı were oared long ships or galleys, notably the first shipwrecks of this type discovered from the Byzantine period. Hull remains of galleys from any period are extremely rare, since most shipwrecks are preserved by a protective layer of cargo or ballast stones, and by design galleys carried little of either in order to maximize speed and manoeuvrability. Because Byzantine galleys were previously known only from textual and iconographic sources that are often difficult to interpret, the exceptionally well-preserved remains of such ships at Yenikapı make a pivotal contribution to the study of Byzantine naval technology.

Two of the Yenikapı site's six galleys, YK 2 and YK 4, were studied by the INA team. Both ships had long, narrow hulls suitable for speedy warships. Pryor and Jeffreys (2006: 1–6, 188–92) note that Byzantine sources use a number of terms for warships, which are often used generically or interchangeably; moreover, the meaning of these terms often changed over time. However, the Yenikapı galleys most closely resemble what several 9th- and 10th-century Byzantine authors referred to as *galeai*. Smaller than *dromons* and other Byzantine warship types designed primarily for close combat with enemy fleets, the *galea* was a light naval vessel with a single bank of oars (Pryor and Jeffreys, 2006: 190). According to the early 10th-century *Taktika* of Leo VI, such ships were used in Byzantine naval fleets primarily for scouting and speedy communication, but they were also equipped for naval warfare (*Taktika* 19.10, 19.81). Other names for light galleys that are sometimes used interchangeably with *galeai* indicate specific structural features of the vessels. These include *monēreis* (or rowed vessels with a single bank of oars) and the classical Greek term *pentēkontoroi* ('fifty-oared ships'), which indicate the number of oarsmen used for these vessels as well as their arrangement in the ship on a single level (Pryor and Jeffreys, 2006: 190).

The slender hulls of YK 2 and YK4 would have originally been approximately 30 m in length, with a maximum breadth of around 4 m. The ships were propelled by a single bank of rowers, likely with 25 rowers per side based on the spacing of the rowers' benches and oar-ports. Twenty-five benches, seating one rower each on the port and starboard sides, were also used on each of the two levels on 10th-century bireme *dromons* described by Leo VI (*Taktika* 19.8, 19.9; Pryor and Jeffreys, 2006: 254–55); 16 sockets for benches were cut in a partially preserved wale timber from the Yenikapı galley YK 16 studied by Istanbul University (Kocabaş, 2008: 180–81, fig. 90–91).

Because textual sources from the Byzantine period indicate that galleys were sailed as well as rowed, YK 2 and YK 4 would have been equipped with a single mast fitted with a large lateen sail. Documentary sources indicate that the larger bireme *dromons* described in Leo's *Taktika* were sailed with two masts that would have been lowered during battle (Pryor and Jeffreys, 2006: 231, 234–45). Smaller galleys had single masts; one entry in a naval inventory in the 10th-century *Book of Ceremonies* records the allocation of 11 sails to nine *karabia* (a term for a warship) and two *monēria*; the latter term is used interchangeably with *galeai* in Leo's *Taktika* (Pryor and Jeffreys, 2006: 188–89, 246, 489, 564). Both YK 2 and YK 4, incorporating strong yet flexible materials, would have been light, sleek, and swift, well-suited to military uses.

YK 2

Shipwreck YK 2 (MRY 6) was the first oared galley discovered at the Yenikapı site in the early summer of 2005 (Fig. 27). Located in grid squares P 31–35 in the eastern part of the Marmaray excavation area, this ship lay in close proximity to vessel YK 1, which seems to indicate that both ships were sunk in the same storm in the late 10th or early 11th century. Preliminary AMS radiocarbon analysis of two treenails securing frames to planking indicates a construction date for the ship in the 9th or 10th century (Table 3). Although the shipwreck had been found in 2005, it could not be excavated until the work with YK 1 had been completed and a new, 5 m-deep steel coffer dam constructed around the wreck area. As a result, the ship was not fully uncovered until March 2006. The INA team began work with the shipwreck the following month, conducting the *in situ* documentation and dismantling of the hull from April to August.

The hull remains of YK 2 consisted of one side of the bottom of the ship, possibly that of the port side, preserved for a length of approximately 14.5 m. Neither the ship's keel nor any substantial part of the opposite side of the hull was preserved. Unlike many of the other Yenikapı shipwrecks, there is no evidence of repairs to YK 2's hull, indicating that it was a relatively new ship at the time it was lost.

The preserved hull planking consisted of five broad strakes preserved along one side of the hull, from the garboard strake to just above the turn of the bilge. Two or three individual planks, dubbed to form from European black pine (*Pinus nigra*), comprised each strake; these planks were joined by gently curving S-scarfs, fastened with coaks and usually spanning four frames

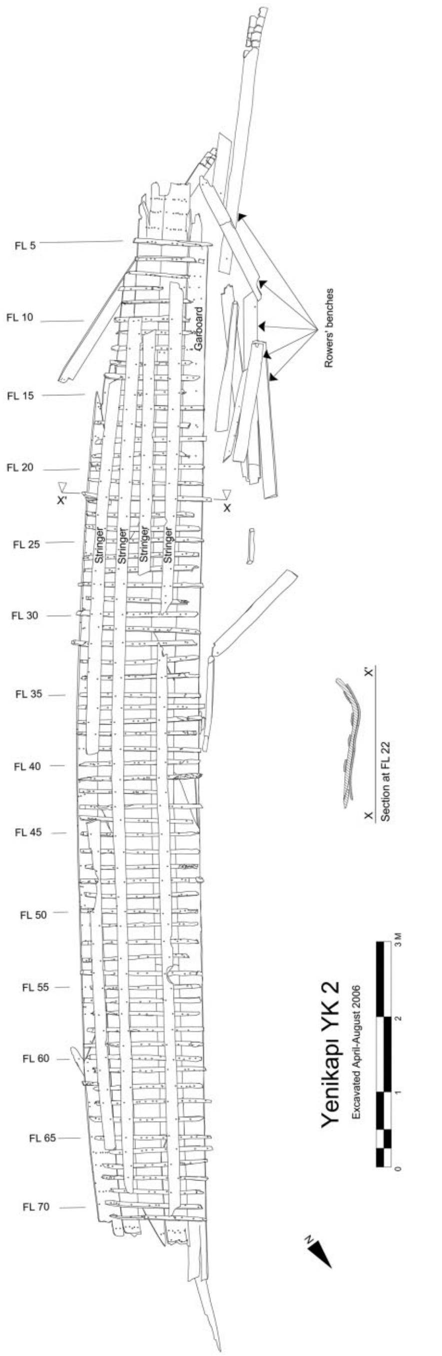

Figure 27. YK 2 site plan. (Plan S. Matthews)

each (Liphschitz and Pulak, 2009: 168–69). The large size and high quality of the logs used to fashion these planks contrasts with the timber used to construct most of the Yenikapı round ships. On average, planks were 25–28 mm in thickness and 300–350 mm in width; original lengths, known for just three of the planks, ranged from 6.97 to 10 m. Caulked plank seams and scarf edges were edge-joined with faceted coaks, approximately 10 mm in diameter, cut from young branches of Turkey oak. Coak spacing along the plank seams was highly variable, ranging from 0.17 to 1.42 m and averaging 0.73 m. The lower edge of the garboard is the only plank edge lacking coaks; instead, this edge was attached to the ship's keel exclusively with closely spaced iron nails—average spacing: 180 mm—driven from the hull exterior, as was also the case on YK 11 and YK 23, the 7th- and 9th-century round ships documented by the INA team.

Parts of 70 distinct frames were preserved *in situ* at 67 frame stations, while fastener holes on the ship's planking indicate the locations of an additional eight frame stations. Liphschitz identified the majority of frames as oriental plane (57 frames), while the remaining frames are common elm (*Ulmus campestris*, 13 frames). As with the earlier round ships from the site, the framing of YK 2 followed the traditional Mediterranean framing pattern of alternating floor timbers and paired half-frames, with parts of 33 floor timbers and 34 half-frames identified on the shipwreck. The inboard ends of three futtocks were also identified, paired with, but not attached to, the ship's floor timbers. The frames were relatively light, on average just 60 mm moulded and sided, and were closely spaced, with an average room and space of just 200 mm; omitting half-frames, the average room and space of floor timbers is 400 mm and exhibits less variation than that of half-frames. Triangular limber-holes, cut into the outer face of floor timbers and half-frames, allowed for the free passage of bilge water within the hull. All elements of the YK 2 framing were attached to planking with a combination of treenails and iron nails, typically two to three treenails and three to four iron nails per strake. The treenails were cut primarily from Turkey oak, but other woods, including common elm, tamarisk (*Tamarix* [X4]), and Atlantic pistachio (*Pistacia atlantica*), were also identified. Thirty-two frames from the wreck, including 17 floor timbers and 15 half-frames, are preserved to the limber-hole or just beyond; there is evidence that at least 11 of these timbers, including both floor timbers and half-frames, were fastened to the keel.

The ship's longitudinal structure was reinforced using four strakes of stringers, also of European black pine (Fig. 28). These wide, relatively flat pieces are on average 165 mm wide and 20–30 mm thick. Just one of the stringers is complete and is nearly 12 m in length. Stringers were fastened to the inner face of frames with short iron nails, generally with one nail per frame location.

In addition to the *in situ* planks, frames, and stringers, a number of displaced timbers were identified as elements of YK 2's hull, most significantly parts of up to nine separate beams which likely functioned as rowers' benches or thwarts. Most of these timbers were found in a jumbled heap near one end of the vessel (Fig. 29). The beams were of European black pine or, less commonly, oriental plane. Only one of the beams is complete, with another two nearly so; although its precise location in the hull remains unclear, the

Table 3. *Radiocarbon analysis results for shipwrecks YK 2 and YK 4. All samples analysed by Swiss Federal Institute of Technology (ETH) Zurich. Dates were calculated using OxCal 3.10*

Shipwreck	Sample ID	δ13C.‰	^{14}C age years BP	±	From	To	%	From	To	%
YK 2	TR5/240	–27.2	1185	50	770	940	68.2	690	980	95.4
YK 2	TR5/249	–27	1200	45	770	890	68.2	680	970	95.4
YK 4	TR7/745	–24.3	1160	50	780	970	68.2	710	990	95.4
YK 4	TR9/757	–20.9	1115	50	880	990	68.2	780	1020	95.4

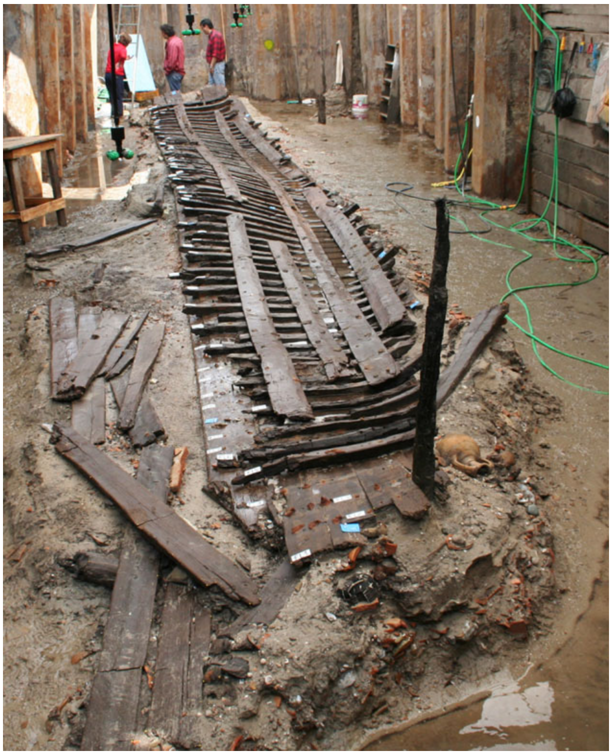

Figure 28. A series of wide, flat stringers reinforced the longitudinal structure of galley YK 2; April 2006. (Photo S. Matthews/INA)

complete beam's original length—3.69 m—suggests it was originally located near midships. The beams range in width from 150 to 190 mm and are approximately 20–40 mm thick. Eight of the nine beams retain part of one or two original ends, which are cut with notches 85 to 195 mm deep; based on other galley shipwrecks from the site, these notched ends would have been fitted into sockets cut into the upper surfaces of the ship's lowest wale, although none of these timbers was preserved on YK 2.

YK 4

The second galley found at Yenikapı, YK 4 (Metro 1), is one of the most extensively preserved galleys found at the site, as well as the largest shipwreck documented by the INA team at Yenikapı (Fig. 30). Located toward the eastern end of the Theodosian Harbour in Metro area squares 2Bb–Bc1/4 and 2Ba4, this galley

Figure 29. At least nine disarticulated deck beams, which would have also functioned as rowers' benches, were found near one end of galley YK 2; April 2006. (Photo S. Matthews/INA)

had split along its keel so that the port and starboard sides extended from the ship's bow at an angle (Fig. 31). Because the port side of YK 4 lay directly under the well-preserved end of vessel YK 5, it is likely that both ships sank during the same violent storm in the late 10th or early 11th century. Surprisingly, preliminary radiocarbon analysis of two treenails from the YK 4 frames indicates an initial construction date between the 8th and 10th century (Table 3). Although there were extensive repairs to this vessel, a lifespan of more than a century seems unlikely; additional radiocarbon and dendrochronological analyses should

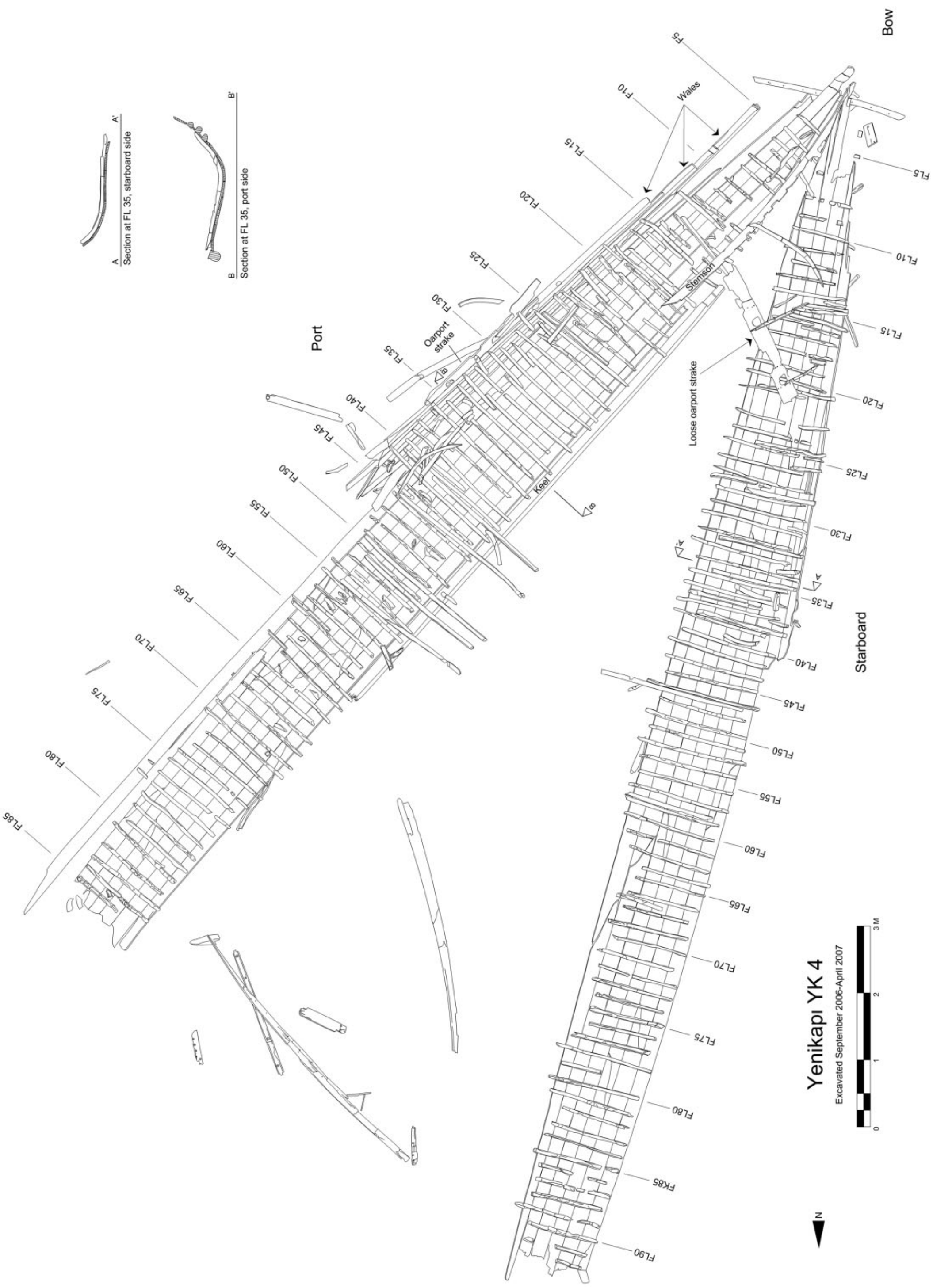

Figure 30. YK 4 site plan. (Plan S. Matthews)

further refine this date. The ship, approximately 18 m of which had been preserved, was first uncovered in June 2006; the INA team began work with the wreck in September 2006 and conducted the *in situ* documentation and dismantling of the ship over the next seven months, completing the task in April 2007.

YK 4 was preserved to the turn of the bilge on the starboard side, and up to and including a section of the oar-port strake, above the third wale, on the port side, making this the only ancient seagoing naval galley found in the Mediterranean region with some of its oar-ports still in place. Part of the ship's bow was also

Figure 31. Longitudinally split galley YK 4 shortly after excavation, with the ship's bow in the foreground; October 2006. (Photo M. Jones/INA)

preserved. The ship's rabbeted keel, on average 165 mm in moulded dimension and 140 mm sided, was of oriental plane, as was a substantial stemson, notched to fit over framing and securely attached to the ship's keel and stem with forelock bolts (Liphschitz and Pulak, 2009: 169).

The ship's preserved planking, eight strakes on the starboard side and 15 strakes on the port side, was of European black pine, as was the case with galley YK 2 (Liphschitz and Pulak, 2009: 169). The planks are, on average, 25–30 mm thick, with some over 11 m in length. Up to the ship's waterline, the planks were edge-fastened with widely spaced coaks. Edge-fastener spacing was highly variable, ranging from 0.45 to 5.92 m and averaging 1.50 m. Similar to YK 2 and the earlier round ships at the site, the garboards of YK 4 were fastened to the keel with closely spaced iron nails (average spacing: 192 mm), driven from the hull exterior, rather than coaks.

The port-side planking of YK 4 includes three wales, also of European black pine. On the lowest wale, shallow sockets, cut into the timber's upper face, would have accommodated the ends of wide, flat through-beams that doubled as rowers' benches or thwarts. While only small fragments of such benches were preserved in association with the YK 4 hull (including fragments of three bench ends found *in situ* in the lowest wale's sockets), those found in association with galley YK 2 are probably close parallels (Fig. 32). Nine such bench sockets were preserved on the lowest YK 4 wale. The centre-to-centre spacing between these bench sockets shows a significant variation that ranges between 0.874 and 1.048 m, but averaging 0.96 m. It appears that the builders could make minor adjustments to the locations of the benches along the length of the ship where necessary by placing the bench

Figure 32. View from the exterior of galley YK 4, with bench notches visible above the lowest wale; inset photo shows an *in situ* fragment of a rower's bench; February 2007. (Photo K. Bircan/INA)

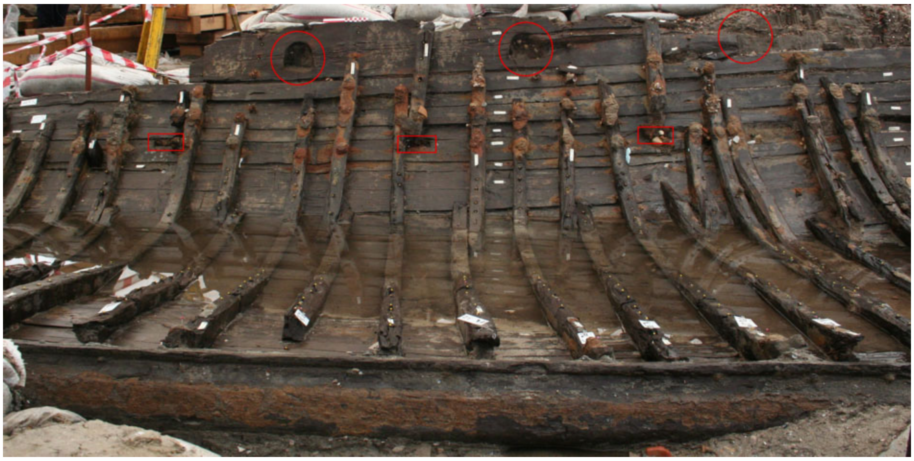

Figure 33. Port side of galley YK 4, view from interior; oar-ports are circled, and bench notches are highlighted with rectangles; November 2006. (Photo M. Jones/INA)

sockets on the wale as needed. This spacing is consistent with that of the bench sockets on galley YK 16, whose centre-to-centre spacing ranged from 0.90–0.97 m (Kocabaş, 2008: 180, fig. 90).

These features indicate the approximate locations of the seated rowers in relation to other hull features. In addition to the position and attachment of the rowers' benches, the partially preserved oar-port strake of YK 4, the uppermost preserved strake on the vessel, provides several key details which allow for a more complete understanding of the ergonomics of rowing these ships (Fig. 33). Although only two complete oar-ports and part of a third were preserved, the oar-port plank reveals the spacing between oar-ports, and thus between the rowers themselves, to be an average of 0.945 m. This distance corresponds closely to three Byzantine feet (based on the Byzantine *pous*, or foot, equal to 312.3 mm) as well as the *interscalmium* distance (the distance between *skalmoi*, or tholepins) for rowers on classical warships, the minimum practical distance required for effective rowing (Schilbach, 1970: 13–6; Morrison *et al*., 2000: 245–46, 268–69; Pryor and Jeffreys, 2006: 287, 291). Furthermore, placement of the oar-ports and the wale sockets that accommodated the rowers' benches reveals the approximate vertical height from the upper face of the benches to the centre of the oar-ports as 410 and 440 mm, and the approximate offset distances between the oars and the rowers' benches as 450 and 480 mm, measured from the approximate centre of the oar-port to the edge of the bench forward of the oar-port. Wear patterns in the lower corners of the two fully preserved oar-ports indicate the direction the rowers faced, and, therefore, the orientation of the bow and stern of the vessel. Finally, the presence of staining and small, tack-like fastener holes on the outer face of the oar-port strake provided archaeological evidence of leather sleeves, fastened outboard of the oar-ports, that prevented water from entering the hull (Fig. 34); these features, known as *askōmata* on ancient warships and *manikellia* on Byzantine ones, were previously known only from documentary references and a small Roman-period oared vessel from the San Rossore excavations at Pisa (Bruni, 2000: 47; Pryor and Jeffreys, 2006: 279–80).

Figure 34. Exterior of YK 4 oar-port strake, with small tack holes and staining denoting the location of a leather sleeve. Note the wear from rowing at the lower left-hand side of the oar-port. (Photo R. Ingram/INA)

YK 4 was originally built with a framing pattern of alternating floor timbers and paired half-frames. Frame timbers were preserved on the shipwreck at nearly 100 frame stations. As on YK 2, the YK 4 framing was also predominantly of oriental plane (85%), although there is significantly more variation in wood species used for the remaining frames: common ash (*Fraxinus excelsior*), sycamore maple, Turkey oak, tamarisk (*Tamarix* [X5]), and European black pine are all represented in the YK 4 framing (Liphschitz and Pulak, 2009: 169). The extant frames, approximately 60–70 mm moulded and sided, exhibited an average spacing of 230 mm across the length of the ship. All floor timbers were nailed to the keel with a single iron nail, as were all the half-frames; the half-frames were not fastened to each other. Frames were attached to planking with a combination of treenails and iron nails, usually with two to three treenails and one or two iron nails per strake.

Unlike on galley YK 2, however, there was deviation in the framing pattern of YK 4, as weak points in this ageing hull had been reinforced with additional floor timbers; the shipwright made these repairs near midships, where the mast would have been located, as well as at the bow, which would have been subject to significant stresses due to the action of the sea. It is perhaps noteworthy that these reinforcement frames, rarely of oriental plane, account for much of the variety reflected in the wood species of the ship's framing. Moreover, while the treenails used to attach the original frames were invariably of Turkey oak, those used to attach the reinforcement frames, added later in the ship's life, were of a variety of wood species, including oriental plane, common ash, sycamore maple, and European black pine, perhaps reflecting the use of locally available woods and possibly a decreased focus on using optimal materials in this older vessel. In addition to the reinforcement of the ship's framing, repairs to the planking confirm that YK 4 was a worn, ageing hull that had been in service for many years by the time it sunk.

The construction features of YK 2 and YK 4 show a high degree of sophistication in design as well as the use of high-quality materials. The long, narrow hull shape required for a war galley is subject to significant longitudinal stresses, such as hogging and sagging, and some hull flexibility is inevitable on such lightly built ships. The use of strong longitudinal reinforcement timbers, including the keel, a stemson and sternson, a keelson or a keelson-like timber—which was lost during sinking, but the presence of which is indicated by a bolt concretion protruding from the keel's inner face—wales, and stringers, were part of the solution. However, a light scantling is also desirable; relying exclusively on heavy timbers for longitudinal strength would unduly increase the hull's weight and thus make it less suitable for propulsion by oars. The builders of YK 2 and YK 4 therefore chose to build their ships with very long and wide planks of black pine (*P. nigra*), thereby minimizing the number of plank seams and scarf joints, both of which are weak points subject to significant stresses in a flexible hull. Moreover, the treenails used in affixing the framing to hull planking were made of young oak branches or withies. Such fasteners are both strong and flexible; unlike treenails of more rigid heartwood, these treenails would flex in unison with the ship and would be less prone to loosening over time.

Conclusion

Although the study of the Yenikapı shipwrecks will take many years to complete, their importance for our understanding of Mediterranean seafaring and cultural interaction is already clear, particularly in the area of shipbuilding technology. The Yenikapı excavations provided a unique opportunity to fully record and dismantle an entire assemblage of shipwrecks in a terrestrial excavation, in conditions that allow a more exhaustive documentation of the vessels' features than is possible on most underwater sites. Most previous hull-construction studies of Byzantine-period vessels—with the significant exception of the ongoing research on shipwrecks at Tantura Lagoon on the coast of Israel—have focused on single shipwrecks that are often either poorly preserved in comparison to those at Yenikapı, or, due to funding, logistical, or environmental constraints, could not be documented to the same level of detail as shipwrecks excavated from waterlogged sediments on land. As a result, until fairly recently, there were very few well-preserved examples of Byzantine vessels available to researchers, particularly dating after the 7th century AD; the finds at Yenikapı have more than doubled the number of known Byzantine vessels that can be studied in a detailed manner (Pomey *et al.*, 2012: 286–89, tables 1–2). It is also significant that the shipwreck finds from Yenikapı span the period from late antiquity to the end of the first millennium AD, allowing researchers to study the transition from shell- to skeleton-first ship construction with an unprecedented volume of material from a single region.

The Yenikapı ships are also exceptional in their variety. This broad assemblage of ships includes a wide range of vessel types, from small coasters and fishing boats to the largest class of late antique cargo carriers and the only known well-preserved hulls of early medieval seagoing galleys. Such diversity in material is not normally available to archaeological researchers at a single site, much less one of such importance as the Byzantine capital, Constantinople. The thorough examination of these ships within their historical context thus holds meaningful implications for the study of late antique and medieval Mediterranean history well beyond the field of the history of shipbuilding technology. Prior to the excavations at Yenikapı, all that was known of the ships that supplied Constantinople was derived from documentary evidence and excavations of shipwrecks elsewhere in the Mediterranean. With a sizable collection of shipwrecks from one of the main harbours of Constantinople, the empire's political, cultural, and economic capital, archaeologists and historians will gain a clearer understanding of the role of maritime activity in the success of the Byzantine Empire and its capital.

As more shipwrecks from the late antique and medieval periods have been discovered and studied, long-term changes as well as regional variations in shipbuilding are becoming more apparent, differences that will prove vital in understanding the shell-to-skeleton construction transition in the Mediterranean. Ongoing research on the Yenikapı ships is providing new insights on the evolution of ship construction during this crucial era, in particular the overwhelming evidence for the continued importance of shell-first construction techniques in the early medieval Mediterranean. The shipwrecks studied by the INA team at Yenikapı, dating from the early 7th to late 10th century AD, span a period when skeleton-first construction methods evolved and spread in the Mediterranean; these ships furthermore represent a fairly comprehensive selection of the vessel types discovered at the site. Each of these eight ships is an example of a mixed mode of construction incorporating both shell-first and skeleton-first building methods. These hull remains confirm that the builders of the Yenikapı ships, like the shipwrights who constructed other previously studied Byzantine vessels, slowly simplified shell-first building methods over time, part of a gradual transition toward a skeleton-based building philosophy that eventually dominated ship construction throughout the Mediterranean and north-western Europe (Basch, 1972: 29; Hasslöf, 1972: 57–60; Hocker, 2004a: 6; Pomey, 2004: 25–9). That the shift from a shell-based to a skeleton-based building philosophy was already well underway by the early 7th century is reflected in the construction of YK 11, a small, sturdy merchantman with planks edge-joined with unpegged mortise-and-tenon joints, but lacking edge fasteners in the upper portions of the hull. YK 11 is representative of the earliest shipwrecks excavated at Yenikapı; its descent from classical and Roman parallels is evident based on its mortise-and-tenon joints, wineglass-shaped cross section of the hull, and framing pattern of alternating floor timbers and paired half-frames. Other Yenikapı shipwrecks built with mortise-and-tenon joints include YK 22, YK 26, YK 34, and YK 35 (Kocabaş and Özsait Kocabaş, 2013: 40–3, Kocabaş, this volume). Disarticulated hull planks from mortise-and-tenon-built hulls were also found at the Yenikapı site; one early plank fragment was found with pegged mortise-and-tenon joints (Pulak, 2007: 205). Although the methods used to construct YK 11 are often called 'mixed' construction, the fundamental design of the hull is still essentially dictated by a shell-based building philosophy.

Shell-first construction using coaks as edge fasteners is a documented feature of a number of shipbuilding traditions throughout the world (Basch, 1972: 31–4; Horridge, 1979: 14–6); however, there was relatively little evidence for its use in the Mediterranean before the discovery of the Yenikapı ships. Their use on a Byzantine ship had only been documented once previously, on the 9th-century Bozburun shipwreck (Harpster, 2005b: 89–94). The Yenikapı shipwrecks have revealed that by around AD 900 at the latest, coaks had replaced mortise-and-tenon joints as wooden edge fasteners in mixed-construction hulls: the vast majority of the shipwrecks from the Yenikapı site dating to the 8th century AD or later were built using coaks. The construction of YK 23 is similar to that of YK 11 in many respects, the most significant difference being that mortise-and-tenon joints had been replaced by coaks. By the 9th century, the framing pattern of alternating, wineglass-shaped floor timbers and paired half-frames, known since the Classical period, had been replaced in the round ships at Yenikapı by flat-floored, in-line framing that produced a boxier hull and likely facilitated the construction and design of the vessel by producing more standard frame shapes. YK 14 is one of the earliest ships from the site built with this combination of coaks and in-line frames. These design features were used in many other Yenikapı ships built over the next two hundred years, including YK 1, YK 5, and YK 24, each probably of 10th-century date. The builders of these ships seem to have been guided by a continued interest in developing cheaper and more efficient construction methods, while still adhering to essentially shell-first principles of shipbuilding. Intriguingly, these later ships, particularly YK 5, share a number of characteristics with the frame-first Serçe Limanı ship, including similarities in hull shape and framing pattern (Bass *et al*., 2004: 155–60). While these frames are used in essentially shell-built hulls in YK 5, YK 14, and YK 24, such standardized framing may well have influenced the development of skeleton-based hull-design methods during this period.

The role of coaks in the construction of the Yenikapı ships also appears to vary between vessel types. In the galley hulls, their spacing and placement seem to indicate that their primary role was aiding in the alignment of hull planks during construction and securing scarf ends. In the round ships built using coaks, on the other hand, the large number of coaks used along plank edges may have contributed to the longitudinal strength of the hull as well. In both categories of vessels, the use of coaks as edge fasteners in the lower hulls does not preclude the use of temporary frames, cleats, or pre-erected frames in the construction process, although research at this time has, as yet, uncovered no conclusive evidence of the use of such devices in the construction of the round ships detailed here. At the very least, the use of coaks for plank-edge joinery was a feature of an important regional shipbuilding industry, one that was perhaps centred on the shores of the Sea of Marmara and provided many of the vessels used for supplying and defending the imperial capital. Why this method of shell-first construction survived in so many of the vessels used in a harbour of Constantinople is still unclear, but the cost of construction, the availability of timber and other resources, and the preferences and traditions of local shipbuilders must have all played a role. The picture is further complicated by the presence at Yenikapı of at least six vessels built without plank-edge fasteners, similar to several 5th–9th-century shipwrecks discovered at Tantura Lagoon (Türkmenoğlu, 2012: 124–25; Kocabaş and Özsait Kocabaş, 2013: 44–5, Kocabaş, this volume). The relationship between these vessels, and the shipwrights who created them, to contemporaneous ships built with edge-fastened planking is currently one of the major questions in the study of late antique and early medieval shipbuilding (Pomey *et al.*, 2012: 291–97).

Finally, important new finds at the Yenikapı site include the discovery of six well-preserved medieval warships. The hull remains of YK 2 and YK 4, studied by the INA team, attest to the sophistication of the design of Byzantine naval vessels, in particular that of the *galea*. The materials and construction of these high-performance vessels contrast those of many of the Yenikapı round ships, differences which can probably be ascribed to the use of imperial state resources. While Byzantine shipwrights often appear to have built their merchantmen as cheaply as possible, the galleys were constructed with timber of the finest quality, from a variety of wood species carefully selected for their unique properties. As long, narrow vessels intended to be rowed as well as sailed, galley hulls were subject to different stresses than merchant ships; these ships were thus designed and built accordingly, optimized for both speed, lightness, and manoeuvrability. In addition, details of the construction of YK 4 support hypotheses on the ergonomics of rowing ancient and medieval galleys; these hypotheses are based primarily on indirect evidence for the rowing of classical warships and experimental reconstructions (Pryor and Jeffreys, 2006: 287, 291). That such hypotheses seem to be confirmed by the evidence from Yenikapı suggests that many fundamental design features of ancient galleys were carried on into late antique and medieval rowed vessels. This being the case, it is also noteworthy that traditional features of ancient Mediterranean vessels, such as the use of the framing pattern of alternating floor timbers and half-frames, persisted even longer in the site's galleys than in the site's round ships of contemporaneous date.

Overall, the eight ships studied by the INA team at Yenikapı confirm that the development of Mediterranean shipbuilding in late antiquity and the early medieval period was a more complex process than previously thought. Byzantine shipwrights seem to have been adapting to the often harsh economic and political conditions of their times by retaining some aspects of older technology and traditions while experimenting with or modifying others. Further research on these and other shipwrecks found at Yenikapı promises to provide some compelling answers as to how and why these changes took place.

Acknowledgements

The excavation was financed by the Institute of Nautical Archaeology (INA); the past and present members of the INA Board of Directors Lucy Darden, John De Lapa, Gregory Cook, Faith Hentschel, John Baird, and Charles Consalvo, without whose generous financial support the excavation could not have been completed; Yüksel Proje International Inc.; the Gama-Nurol Partnership; as well as other private donors. Post-excavation documentation was financed by INA, the Center for Maritime Archaeology and Conservation (CMAC), the Nautical Archaeology Program, the College of Liberal Arts, the Department of Anthropology, and the Melbern G. Glasscock Center for Humanities Research at Texas A&M University; the American Research Institute in Turkey (ARIT) and US Department of State, Bureau of Educational and Cultural Affairs; and the American Philosophical Society's Lewis and Clark Fund for Exploration and Research. The INA team included Cemal Pulak (director), Sheila Matthews (assistant director), and the following archaeologists and staff: Yasemin Aydoğdu, Korhan Bircan, Murat Bircan, Can Ciner, Emrah Çankaya, Mehmet Çiftlikli, Tuba Ekmekçi, Funda Genç, Rebecca Ingram, İlkay İvgin, Michael Jones, Sarah Kampbell, Gülser Kazancıoğlu, Orkan Köyağasıoğlu, Matthew Labbe, Ryan Lee, Asaf Oron, Robin Piercy, Jessica Stika, Evren Türkmenoğlu, and Seda Ülger. Many thanks to the director of the Istanbul Archaeological Museums Zeynep Kızıltan, former director İsmail Karamut, assistant directors Rahmi Asal and Gülbahar Baran Çelik, and archaeologists Yaşar Anılır, Sırrı Çölmekçi, Metin Gökçay, Bekir Köşker, Özlem Kömürcü, Emre Öncü, Mehmet Ali Polat, and Arzu Toksoy for their assistance in the field. Comments by the two anonymous reviewers greatly improved this article and are much appreciated.

Notes

1. The tentative dendrochronology date is based on an analysis of sample YK 14001 by the University of Arizona's Tree Ring Research Laboratory. The sample was radially split from a fast-growing tree and included raw ring-width data of 189 years plus one unmeasured outer ring; the sequence was dated from AD 602-790. Sapwood is absent, and the felling date is estimated as occurring after AD 801.
2. Previously published estimates of YK 14's dimensions indicate a length of 14 m and a breadth of 3.5–4 m (Pulak *et al.*, 2013: 30; Jones, forthcoming). The length-to-beam ratio of 4.2:1 was calculated using YK 14's length between perpendiculars of 14.2 m (Steffy, 1994: 253–54).
3. This ship is incorrectly reported as having a preserved bilge keel in Pomey *et al.*, 2012: 290, table 3.

References

Akkemik, Ü. and Kocabaş, U., 2013, Woods of the Old Galleys of Yenikapı, İstanbul. *Mediterranean Archaeology and Archaeometry* **13**.2, 31–41.

Akkemik, Ü. and Kocabaş, U., 2014, Woods of Byzantine Trade Ships of Yenikapı (Istanbul) and Changes in Wood Use from 6th to 11th Century. *Mediterranean Archaeology and Archaeometry* **14**.2.

Ball, J., 1988 (1st ed. 1729), *Pierre Gilles: The Antiquities of Constantinople*. New York.

Başaran, S., Kocabaş, U., Kocabaş, I. and Yılmaz, R., 2007, Istanbul University Yenikapı Byzantium Shipwrecks Project: Documentation, Lifting, Conservation and Reconstruction, in Z. Kızıltan (ed.), *Istanbul: 8000 Years brought to Daylight*, 190–5. Istanbul.

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

Bass, G. F. and van Doorninck, F. H., 1982, *Yassı Ada*. Vol. **I**, *A Seventh-Century Byzantine Shipwreck*. College Station, TX.

Bass, G. F., Matthews, S. D., Steffy, J. R. and van Doorninck, F. H., 2004, *Serçe Limanı. An Eleventh-Century Shipwreck. Vol. I, The Ship and Its Anchorage, Crew, and Passengers*. College Station, TX.

Berger, A., 1988, *Untersuchungen zu den Patria Konstantinupoleos*. Bonn.

Berger, A., 1993, Der Langa Bostanı in Istanbul. *Istanbuler Mitteilungen* **43**, 467–77.

Bruni, S., 2000, The Urban Harbour of Pisae and the Wrecks Discovered at the Pisa-San Rossore Railway Station, in S. Bruni (ed.), *Le navi antiche di Pisa*, 21–79. Pisa.

Bruseth, J. E. and Turner, T. S., 2005, *From a Watery Grave: The Discovery and Excavation of La Salle's shipwreck* La Belle. College Station, TX.

Chron. Pasch., Whitby, M. and Whitby, M. (trans.), 1989, *Chronicon Paschale, 284–628 AD*. Liverpool.

Dark, K., 2013, *Constantinople: Archaeology of a Byzantine Megalopolis*. Oxford.

de Weerd, M. D., 1988, A Landlubber's View of Shipbuilding Procedure in the Celtic Barges of Zwammerdam, The Netherlands, in O. L. Filgueiras (ed.), *Local Boats: Fourth International Symposium on Boat and Ship Archaeology, Porto 1985*, 35–51. Oxford.

Denker, A., Demirkök, F., Kiraz, M. and Akbaytogan, T., 2013a, YK 1, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 210–18. Istanbul.

Denker, A., Demirkök, F., Kongaz, G., Kiraz, M., Korkmaz Kömürcü, Ö. and Akbaytogan, T., 2013b, YK 12, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 197–209. Istanbul.

Dogu, D., Kose, C., Kartal, S. N. and Erdin, N., 2011, Wood Identification of Wooden Marine Piles from the Ancient Byzantine Port of Eleutherius/Theodosius. *BioResources* **6**.2, 987–1018.

Freshfield, E. H., 1938, *Roman Law in the Later Roman Empire. Byzantine Guilds, Professional and Commercial*. Cambridge.

Gökçay, M., 2007, Architectural Finds from the Yenikapı Excavations, in Z. Kızıltan (ed.), *Istanbul: 8,000 Years Brought to Daylight: Marmaray, Metro, Sultanahmet Excavations*, 166–79. Istanbul.

Gökçay, M., 2010, Selected Wooden Finds from Yenikapı, in U. Kocabaş (ed.), *Istanbul Archaeological Museums Proceedings of the 1st Symposium on Marmaray-Metro Salvage Excavations, 5th–6th May 2008*, 135–52. Istanbul.

Guilland, R., 1953, Les Ports de Byzance sur la Propontide, *Byzantion* **23**, 181–238.

Günsenin, N., 2009, Ganos Wine and its Circulation in the 11th Century, in M. M. Mango (ed.), *Byzantine Trade, 4th–12th Centuries*, 145–53. Burlington.

Haldon, J., 1986, Comes Horreorum—Komēs tēs Lamias. *Byzantine and Modern Greek Studies* **10**, 203–10.

Haldon, J., 2000, Theory and Practice in Tenth-Century Military Administration: Chapters II, 44 and 45 of the *Book of Ceremonies*, *Travaux et Memoires* **13**, 201–352.

Hasslöf, O., 1972, Main Principles in the Technology of Shipbuilding, in O. Hasslöf, H. Henningsen and A. E. Christiansen (eds), *Ships, Shipyards, Sailors, and Fishermen. Introduction to Maritime Ethnology*, 27–72. Copenhagen.

Harpster, M., 2005a, *A Re-assembly and Reconstruction of the 9th-Century AD Vessel Wrecked off the Coast of Bozburun, Turkey*, PhD dissertation, Texas A&M University, Department of Anthropology. College Station.

Harpster, M., 2005b, Dowels as a Means of Edge-to-Edge Joinery in the 9th-century AD Vessel from Bozburun, Turkey, *IJNA* **34**.1, 88–94.

Harpster, M., 2009, Designing the 9th-century AD Vessel from Bozburun, Turkey. *IJNA* **38**.2, 297–313.

Hocker, F. M., 2004a, Shipbuilding: Philosophy, Practice, and Research, in F. M. Hocker and C. A. Ward (eds), *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*, 1–11. College Station, TX.

Hocker, F. M., 2004b, Bottom-Based Shipbuilding in Northwestern Europe, in F. M. Hocker and C. A. Ward (eds), *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*, 65–93. College Station, TX.

Horridge, G. A., 1979, *The Konjo Boatbuilders and the Bugis Prahus of South Sulawesi*. Basildon.

Ingram, R. and Jones, M. R., 2011, Yenikapı: Documenting Two Byzantine Merchant Ships from the Yenikapı Excavations in Istanbul, Turkey. *The INA Annual* **2010**, 8–17.

Jal, A., 1848, *Glossaire Nautique*. Paris.

Janin, R., 1950, *Constantinople byzantine: Développement urbain et répertoire topographique*. Paris.

Jézégou, M.-P., 1983, *L'épave II de l'anse Saint-Gervais a Fos-sur-Mer*, doctoral thesis, Université de Provence. Aix-Marseille l. Aix-en-Provence.

Jézégou, M.-P., 1989, L'épave II de l'anse Saint-Gervais a Fos-sur-Mer (Bouches-du-Rhone): un navire du haut Moyen-Age construit sur squelette, in H. Tzalas (ed.), *Tropis I: 1st International Symposium on Ship Construction in Antiquity, Piraeus 1985*, 139–46. Athens.

Jones, M. R., forthcoming, A Middle Byzantine Period Cargo Vessel from the Yenikapı Excavations in Istanbul: A Preliminary Analysis, in Proceedings of the Research Center for Anatolian Civilizations' Fifth Annual Symposium, 'Istanbul and Water', at Koç University, Istanbul, Turkey, 4–5 December 2010. Leuven.

Kahanov, Y. and Mor, H., 2009, Dor 2001/1: Updated Information and the Retrieval of a Section of the Shipwreck, in R. Bockius (ed.), *Between the Seas: Transfer and Exchange in Nautical Technology, Proceedings of the Eleventh International Symposium on Boat and Ship Archaeology, Mainz 2006*, 17–24. Mainz.

Kahanov, Y., Royal, J. and Hall, J., 2004, The Tantura Wrecks and Ancient Mediterranean Shipbuilding, in F. M. Hocker and C. A. Ward (eds), *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*, 113–27. College Station.
Kızıltan, Z. (ed.), 2007, *Istanbul: 8,000 Years Brought to Daylight: Marmaray, Metro, Sultanahmet Excavations*. Istanbul.
Kızıltan, Z., 2010, Excavations at Yenikapı, Sirkecı, and Üsküdar within Marmaray and Metro Projects, in U. Kocabaş (ed.), *Istanbul Archaeological Museums Proceedings of the 1st Symposium on Marmaray-Metro Salvage Excavations, 5th–6th May 2008*, 1–16. Istanbul.
Kızıltan, Z. (ed.), 2013, *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*. Istanbul.
Kocabaş, U. (ed.), 2008, *Yenikapı Shipwrecks. The 'Old Ships' of the 'New Gate' (Yenikapı Batıkları. Yenikapı'nın Eski Gemileri)*. Vol. **I**. Istanbul.
Kocabaş, U., 2010, Istanbul University Yenikapı Shipwrecks Project: The Ships, in U. Kocabaş (ed.), *Istanbul Archaeological Museums Proceedings of the 1st Symposium on Marmaray-Metro Salvage Excavations 5th–6th May 2008*, 23–33. Istanbul.
Kocabaş, U., 2012a, The Latest Link in the Long Tradition of Maritime Archaeology in Turkey: The Yenikapı Shipwrecks. *European Journal of Archaeology* **15**, 309–23.
Kocabaş, U., 2012b, Byzantine Shipwrecks at Yenikapı, in N. Günsenin (ed.), *Between Continents: Proceedings of the Twelfth Symposium on Boat and Ship Archaeology, Istanbul 2009*, 107–13. Istanbul.
Kocabaş, U. and Özsait Kocabaş, I., 2007, Istanbul University Construction Techniques and Features of Shipwrecks in the Yenikapı Byzantine Shipwrecks Project, in Z. Kızıltan (ed.), *Istanbul: 8000 Years brought to Daylight*, 196–201. Istanbul.
Kocabaş, U. and Özsait Kocabaş, I., 2013, A New Milestone in Ship Archaeology: The Yenikapı Shipwrecks Project, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 35–46. Istanbul.
Kuniholm, P. I., Griggs, C. B. and Newton, M. W., 2007, Evidence for Early Timber Trade in the Mediterranean, in K. Belke, E. Kislinger, A. Külzer and M. A. Stassinopoulou (eds), *Byzantina Mediterranea: Festschrift für Johannes Koder zum 65 Geburtstag*, 365–85. Vienna.
Lane, F. C., 1934, *Venetian Ships and Shipbuilders of the Renaissance*. Baltimore.
Leo of Synada, Vinson, M. P. (trans.), 1985, *The Correspondence of Leo, Metropolitan of Synada and Syncellus*. *Corpus Fontium Historiae Byzantinae* XXIII. Washington, D.C.
Lemée, C. P. P., 2006, *The Renaissance Shipwrecks from Christianshaven*. Ships and Boats of the North Volume 6. Roskilde.
Liphschitz, N. and Pulak, C., 2009, Shipwrecks of Portus Theodosiacus. Types of Wood Used in Some Byzantine Roundships and Longships found at Yenikapı, Istanbul. *Skyllis: Zeitschrift für Unterwasserarchäologie* **9**.2, 164–71.
Magdalino, P., 2000, The Maritime Neighborhoods of Constantinople: Commercial and Residential Functions, Sixth to Twelfth Centuries. *Dumbarton Oaks Papers* **54**, 209–26.
Magdalino, P., 2007, *Studies on the History and Topography of Byzantine Constantinople*. Aldershot.
Magdalino, P., 2013, The Harbours of Byzantine Constantinople, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 11–5. Istanbul.
Makris, G., 2002, Ships, in A. E. Laiou (ed.), *The Economic History of Byzantium: From the Seventh through the Fifteenth Century*, 91–100. Washington, DC.
Mango, C., 1985, *Le développement urbain de Constantinople (IVe–VIIe siècles)*. Paris.
Mango, C., 1986, The Development of Constantinople as an Urban Centre, in *The 17th International Byzantine Congress, Major Papers*, 117–36. New Rochelle.
Mango, C., 1995, The Water Supply of Constantinople, in C. Mango and G. Dagron (eds), *Constantinople and its Hinterland*, 9–18. Aldershot.
Mango, C., 2001, The Shoreline of Constantinople in the Fourth Century, in N. Necipoğlu (ed.), *Byzantine Constantinople: Monuments, Topography, and Everyday Life*, 17–28. Leiden.
Mango, C. (ed.), 2002, *The Oxford History of Byzantium*. Oxford.
Mango, C. and Scott, R. (trans.), 1997, *The Chronicle of Theophanes Confessor: Byzantine and Near Eastern History, AD 284–813*. Oxford.
Mango, M. M., 2000, The Commercial Map of Constantinople. *Dumbarton Oaks Papers* **54**, 189–207.
Manners, I. R., 1997, Constructing the Image of a City: The Representation of Constantinople in Christopher Buondelmonti's *Liber Insularum Archipelagi*. *Annals of the Association of American Geographers* **87**, 72–102.
Mor, H., 2010, The Dor 2001/1 Shipwreck: Hull Construction Report, in P. Pomey (ed.), *Transferts technologiques en architecture navale méditerranéenne de l'Antiquité aux temps moderns: identité technique et identité culturelle. Actes de la Table Ronde Internationale d'Istanbul, 19–22 Mai 2007, Varia Anatolica* XX, 87–95. Istanbul.
Morrison, J. S., Coates, J. F. and Rankov, N. B., 2000, *The Athenian Trireme: The History and Reconstruction of an Ancient Greek Warship*. Cambridge.
Müller-Wiener, W., 1977, *Bildlexikon zur Topographie Istanbuls*. Tübingen.
Müller-Wiener, W., 1994, *Die Häfen von Byzantion—Konstantinupolis—Istanbul*. Tübingen.
Nik.Chon., Magoulias, H. J. (trans.), 1984, *O City of Byzantium, Annals of Niketas Choniatēs*. Detroit.
Öncü, Ö. E., 2013, The Harbour of Yenikapı in the Archaic, Classical, and Hellenistic Periods, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 16–21. Istanbul.
Özmen, H. I., 2007, A Tribute to History and Culture: 'Marmaray,' in Z. Kızıltan (ed.), *Istanbul: 8000 Years brought to Daylight*, 22–7. Istanbul.
Özsait Kocabaş, I., 2012, Hull Characteristics of the Yenikapı 12 Shipwreck, in N. Günsenin (ed.), *Between Continents: Proceedings of the Twelfth Symposium on Boat and Ship Archaeology, Istanbul 2009*, 115–20. Istanbul.

Özsait Kocabaş, I., 2013, The Centuries-long Voyage of Ship Yenikapı 12, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 47–55. Istanbul.
Patria, Preger, T. (ed.), 1907, *Scriptores originum Constantinopolitanarum*. Leipzig.
Pearson, C. L., Griggs, C. B., Kuniholm, P. I., Brewer, P. W., Ważny, T. and Canady, L., 2012, Dendroarchaeology of the Mid-First Millennium AD in Constantinople. *Journal of Archaeological Science* **39**, 3402–414.
Perinçek, D., 2010, Geoarchaeology of the Excavation Site for the Last 8,000 Years and Traces of Natural Catastrophes in the Geologic Profile, in U. Kocabaş (ed.), *Istanbul Archaeological Museums Proceedings of the 1st Symposium on Marmaray-Metro Salvage Excavations, 5th–6th May 2008*, 191–218. Istanbul.
Plin. *HN*, Bostock, J. and Riley, H. T. (trans.), 1892, *The Natural History of Pliny*. London.
Polat, M. A., 2013, YK 35, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 154–90. Istanbul.
Pomey, P., 1988, Principes et méthodes de construction en architecture navale antique, in *Navires et commerces de la Méditerranée antique*, *Hommage à Jean Rougé, Cahiers d'Histoire* **33**, 397–412. Lyon.
Pomey, P., 2004, Principles and Methods of Construction in Ancient Naval Architecture, in F. M. Hocker and C. A. Ward (eds), *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*, 25–36. College Station, TX.
Pomey, P., Kahanov, Y. and Rieth, E., 2012, Transition from Shell to Skeleton in Ancient Mediterranean Ship-Construction: Analysis, Problems, and Future Research. *IJNA* **41**.2, 235–314.
Procop. *Aed.*, Dewing, H. B. (trans.), 1971, *Buildings, General Index to Procopius*. London.
Pryor, J. H., 2008, Shipping and Seafaring, in E. Jeffreys with J. Haldon and R. Cormack (eds), *The Oxford Handbook of Byzantine Studies*, 482–91. Oxford.
Pryor, J. H. and Jeffreys, E. M., 2006, *Age of the ΔΡΟΜΩΝ: The Byzantine Navy ca 500–1204*. Leiden.
Pulak, C., 1999, The Late Bronze Age Shipwreck at Uluburun: Aspects of Hull Construction, in W. Phelps, Y. Lolos and Y. Vichos (eds), *The Point Iria Wreck: Interconnections in the Mediterranean, ca. 1200 BC; Proceedings of the International Conference, Island of Spetses, 19 September 1998*, 209–38. Athens.
Pulak, C., 2002, The Uluburun Hull Remains, in H. Tzalas (ed.), *Tropis VII*: *7th International Symposium on Ship Construction in Antiquity*, Pylos 1999, 615–36. Athens.
Pulak, C., 2007, Yenikapı Byzantine Shipwrecks, in Z. Kızıltan (ed.), *Istanbul: 8000 Years brought to Daylight*, 202–15. Istanbul.
Pulak, C., Ingram, R., Jones, M. and Matthews, S., 2013, The Shipwrecks of Yenikapı and Their Contribution to the Study of Ship Construction, in Z. Kızıltan and G. Baran Çelik (eds), *Stories from the Hidden Harbour: Shipwrecks of Yenikapı*, 22–34. Istanbul.
Schilbach, E., 1970, *Byzantinische Metrologie*. Munich.
Steffy, J. R., 1985, The Kyrenia Ship: An Interim Report on Its Hull Construction. *American Journal of Archaeology* **89**, 71–101.
Steffy, J. R., 1994, *Wooden Ship Building and the Interpretation of Shipwrecks*. College Station, TX.
Taktika, Dennis, G. T. (ed. and trans.), 2010, *The* Taktika *of Leo VI. Text, Translation, and Commentary*. Washington, DC.
Theophr. *Hist. pl.*, Hort, A. (trans.), 1916, *Enquiry into Plants*. Cambridge.
Treadgold, W., 1997, *A History of the Byzantine State and Society*. Stanford.
Türkmenoğlu, E., 2012, Preliminary Report on the Yenikapı 17 Shipwreck, in N. Günsenin (ed.), *Between Continents: Proceedings of the Twelfth Symposium on Boat and Ship Archaeology, Istanbul 2009*, 121–25. Istanbul.
van Doorninck, F. H., 1976, The 4th Century Wreck at Yassi Ada: An Interim Report on the Hull. *IJNA* **5**.2, 115–31.
van Millingen, A., 1899, *Byzantine Constantinople: The Walls of the City and Adjoining Historical Sites*. London.
Vitr. *De arch.*, Morgan, M. H. (trans.), 1960, *The Ten Books on Architecture*. New York.
Zafiropoulou, D. (ed.), 1998. *Sailing on the Seas of Byzantium*, D. Turner (trans.). Athens.