

The 5th-Century BC Shipwreck at Tektaş Burnu, Turkey: evidence for the ship's hull from nail concretions

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The Tektaş Burnu ship (440–425 BC) sank along a rough and desolate stretch of the Turkish Aegean coast. Archaeological excavation of the shipwreck site by the Institute of Nautical Archaeology at Texas A&M University resulted in the retrieval of hundreds of small fragments from the ship's wooden hull and its metal fasteners. Recent study of this artefact assemblage suggests that the coastal trader was built with pine planks and made-frames, and assembled by a shell-based construction method. Fasteners include pegged mortise-and-tenon joints and double-clenched copper nails, and the ship may have had laced extremities consistent with other contemporaneous shipwrecks.

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Key words: Tektaş Burnu, shipbuilding, mortise-and-tenon joinery, copper fastenings, made-frames, 5th century BC.

In 1996, a Classical Greek shipwreck was discovered on the Turkish Aegean coast by the Institute of Nautical Archaeology (INA) at a depth of 38–40 m. The shipwreck at Tektaş Burnu (or Lone Rock Cape) was found off a rough and desolate stretch of coast situated south-east of the Greek island of Chios and south-west of Sığacık (ancient Teos, Fig. 1) (Carlson, 2003: 581). Excavation of the shipwreck between 1999 and 2001 revealed that the coastal

trader carried a cargo of wine, East Greek pottery and a smaller quantity of low-grade pine tar (Carlson, 2003: 581, 583–93).

Currently dated to 440–425 BC, the shipwreck is an important addition to the corpus of Mediterranean ships of the Archaic and Classical Greek periods. As the only Classical shipwreck to be fully excavated in Aegean waters, a well-preserved ship's hull would have added valuable information to the evidence for shipbuilding techniques of the period. Unfortunately, hardly any diagnostic hull timbers survived; only nail concretions and fragments of hull wood.

This article aims to show that even from such meagre evidence, much important information can be gleaned about the Tektaş Burnu ship: its size, the materials used to build it and the methods employed in its construction. It is worth noting here J. Richard Steffy's 1978 article in which he argues for the necessity of thoroughly studying even the most scanty ship remains: 'The value of excavated hull remains has nothing to do with the extent of survival; it is the amount of information gleaned from each fragment which is important' (Steffy, 1978: 53). The present study builds on this philosophy and presents the current status of its findings.

Finds distribution and ship size

It seems likely that the Tektaş Burnu ship came to rest on its port side propped between two large rocks, which kept the hull off the sea-bed and above sea-floor sediments, thereby creating favourable conditions for its near complete consumption by marine organisms.

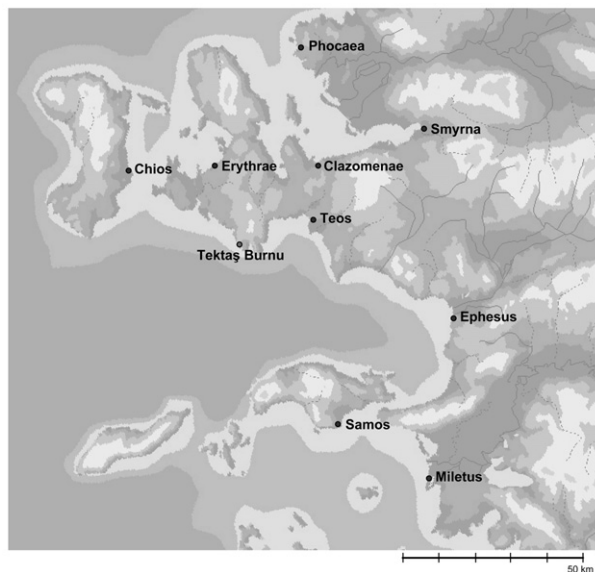


Figure 1. Map of the eastern Aegean and Asia Minor, with locations of Greek colonies, showing the location of the Tektaş Burnu shipwreck. (After Carlson, 2003, fig. 1)

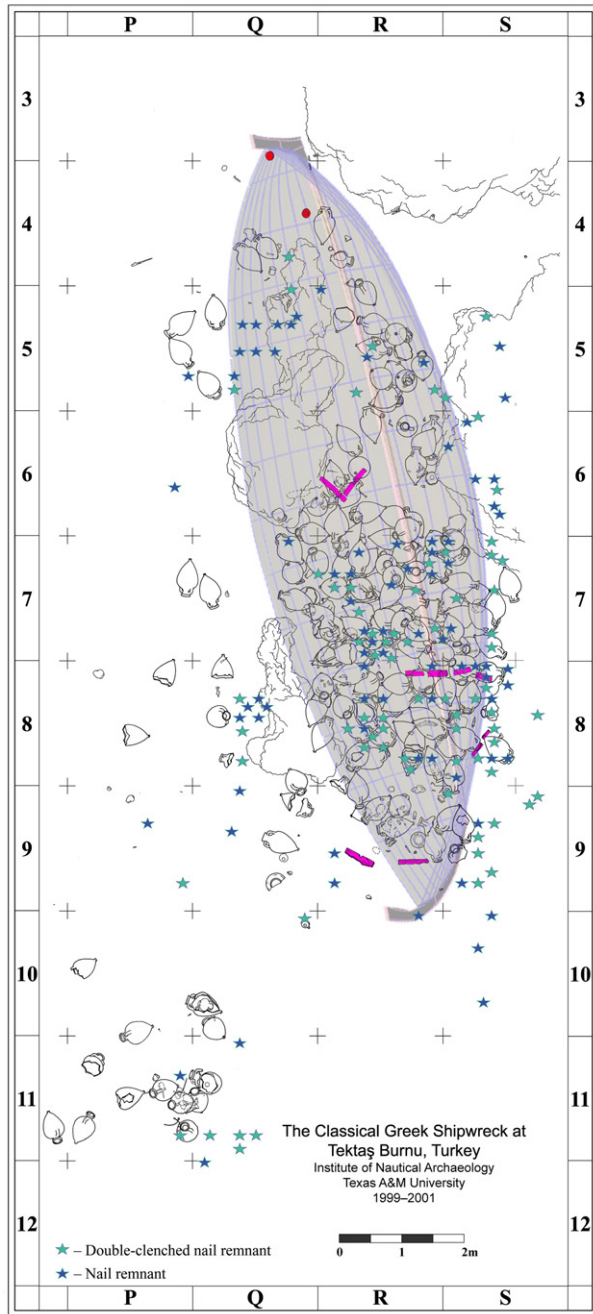


Figure 2. The Tektaş Burnu site plan. Anchor remains in magenta (additional anchor remains found in 2001 are located in grid squares K16/J16 and do not appear on this site plan), *ophthalmoi* in red. (Plan by Sheila Matthews and Mark Polzer, INA. Reconstruction of the ship by Wendy van Duivenvoorde)

When the wooden hull gave way to microbial decay and marine borer activity (Jurgens *et al.*, 2003: 396–404), most of the cargo and heavy objects fell directly below to the sea-bed, while part of the cargo and other objects slid down the slope on the ship's port side away from the main cargo mound (Fig. 2).



Figure 3. Marble *ophthalmoi*, or the ship's eyes, each measures c.140 mm in diameter. Tektaş Burnu, Turkey. (Photograph: Don Frey, INA)

Of the ship itself only small fragments of wood, metal fasteners and two marble discs, or *ophthalmoi*, were found. Archaeologists excavated the majority of the fasteners and wooden fragments from the main wreckage, especially between the stern and midships; most were found *in situ* underneath the cargo and other small finds and come from the ship's port side. Hull fragments from the vessel's exposed starboard side, which collapsed inward, would have fallen on top of the cargo mound and, especially, some of the nail remnants would, eventually, have worked their way in between and under the amphoras. Additionally, some nails remnants were found among and inside the amphoras that slid down the slope on the ship's port side, away from the main cargo mound (see Fig. 2).

The *ophthalmoi* are about 140 mm in diameter, retain remnants of the decorative concentric lines that were incised and painted on them, and were fastened to either side of the bow with a lead spike (Figs 2–3) (Nowak, 2001; Carlson, 2003: 594–6; 2009: 354–6). They symbolized the ship's 'eyes', and their location at the upper end of the site indicate the ship's orientation on the sea-bed. This orientation is corroborated by the location of the main assemblage of utilitarian and personal items belonging to the crew, which were found at the opposite end of the site; such items typically are stored in the stern area of the ship (Trego, 2004: 17–9, 21–2, 24–5, 33–8; see also Eiseman and Ridgway, 1987: 26–36; Artzy and Lyon, 2003; Kahanov, 2003: fig. 1; Udell, 2003; Sitry, 2004; and Katzev, 2005: 75–6).

The ship was carrying at least five wooden anchors when it sank—their remains include the lead stock cores, fragments of wood and ferrous concretions from the anchor teeth (Van Duivenvoorde, 2012: 406). Evidence of four of these anchors (three with two, and one with four lead stock cores) were discovered on the wreck-site between the stern and midships, which are uncommon locations as anchors would usually be stored at the bow (Fig. 2) (Trethewey, 2001: 112; Carlson, 2003: 595–6; Van Duivenvoorde, 2012: 406). After the hull gave way, these anchors probably settled directly into the sea-bed, near their original position on the ship, as they are too heavy to slide far down the slope. During the final excavation season in 2001, four additional anchor-stock cores were found further down slope where the sandy sea-bed dropped off

sharply to a depth of 54 m. They likely belonged to a fifth anchor associated with the ship that was deployed in the failed attempt to keep the vessel from being dashed against the rocks (Carlson, 2003: 595–6).

Based on the location of the ship's eyes and anchors, and distribution of the macro-botanical remains and copper fasteners of the hull, the maximum length of the Tektaş Burnu ship is estimated to have been c. 14 m—realistically, the ship could have been between 12 and 14 m long (Fig. 2).

The ship's hull and its construction

Although the hull remains of the Tektaş Burnu ship are scanty, an in-depth study of the 169 metal fasteners and numerous small wood fragments from the ship provides additional information on construction features and shipbuilding methods of the 5th century BC. Of the fasteners, 81 were positively identified as remnants of double-clenched copper nails that fastened frames to the ship's hull planking; 40 still have measurable planking remains around their shafts and 25 have diagnostic frame wood (Fig. 4; for a discussion on terminology, see McGrail, 2004). Others may have been used to fasten hull planks to the sternpost and stem, knees to endposts and keel and mast partners to futtocks (Steffy, 1985: 76–7, 81–4; Kahanov, 2003: 96–8). These types of copper nails are also found in the well-preserved hull of the Ma'agan Mikhael shipwreck in Israel (c. 400 BC) (Kahanov, 2003: 96–9; Yovel, 2004a). Furthermore, the author identified fragments of made-frames and hull planking, six tenon remnants and 13 pegs from among the hundreds of wooden hull fragments.

Thirteen complete double-clenched nails range between 120 and 220 mm in overall length (Fig. 5). The



Figure 4. Double-clenched copper nail (white dashed outline) with hull planking (a) and frame wood (b) preserved around its shaft, lot number 881. Tektaş Burnu, Turkey. (Photograph: Wendy van Duivenvoorde)

measurable nail shafts have an average thickness of 6 mm and were originally square in cross-section (Fig. 6). Generally, the first 20 to 30 mm directly beneath the nail-heads are circular in section and range in diameter from 7 to 12 mm (averaging 9 mm). The tips of the nails taper to a fine point. The nail-heads, mostly circular with rounded tops, have an average diameter of 22 mm.

Generally, copper nails fastening frames to planking in Archaic and Classical Greek period ship construction indicate a shell-based construction method, in which the planking of the ship was erected first and held together by closely spaced mortise-and-tenon joints. Each tenon was locked in place by a wooden peg on either side of the plank seam. Once the planking was assembled, frames were inserted. These were attached with copper nails that were driven from outside of the hull through the planking and the frames. The nails were then double-clenched over the inner face of the frames. The tip of the nail was clenched to make sure it would be out of the way and not snag on anything. The

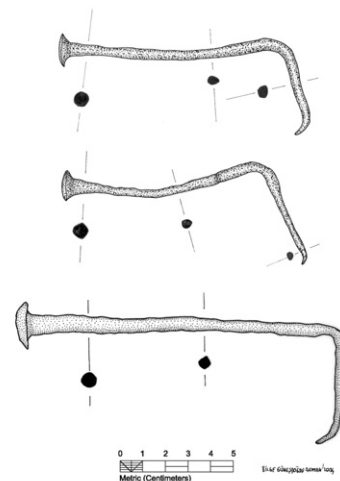


Figure 5. Three complete double-clenched copper nails from the Tektaş Burnu shipwreck. No original surface preserved. (Illustration: Bilge Güneşdoğdu Akman, INA)



Figure 6. Square cross-section of copper nail shaft with concretion layer around it, lot number 515 (shaft 5 × 5 mm). (Photograph: Wendy van Duivenvoorde)

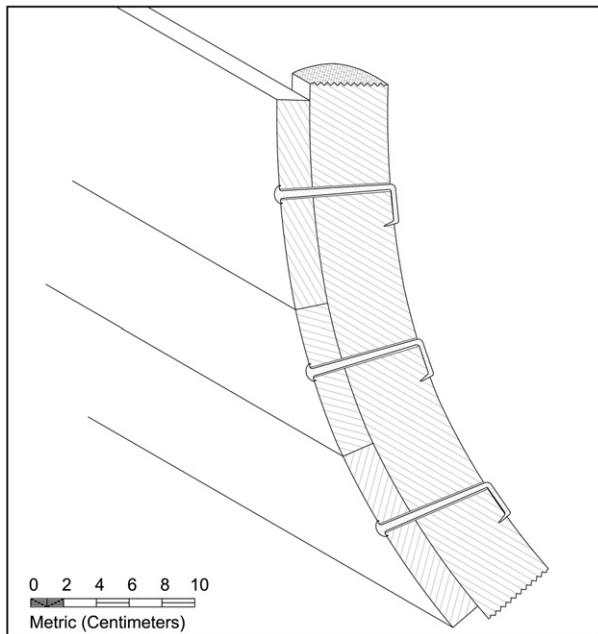


Figure 7. Schematic drawing of double-clenched copper nails fastening frames to hull planking (dimensions are to scale and based on the archaeological remains of the ship's fasteners, hull planking and frames), Tektaş Burnu ship. Planking joinery not shown. (Illustration: Wendy van Duivenvoorde)

remainder of the protruding nail was then hammered down to permanently lock the nail in place and prevent it from pulling out (Fig. 7) (Steffy, 1985: 91–3; 1998: 48). Metal fasteners were used to affix the frames to the planking in several western Mediterranean shipwrecks dating to the late 6th and early 5th centuries BC (Kahanov and Pomey, 2004: 16–25). The oldest known example to date is the Jules-Verne 7 shipwreck, which dates to 525–510 BC, and was found in the ancient harbour of the Greek colony of Massalia (Marseille) (Pomey, 1997: 195–8; 1998: 147; 2001: 425, 427–9; Kahanov and Pomey, 2004: 16–7). It predates the Tektaş Burnu ship by nearly a century.

In Mediterranean Archaic and Classical period ship construction, double-clenched nails are primarily associated with ships whose planks were edge-joined with mortise-and-tenon joinery rather than laced with ligatures. The widespread use of laced construction in the Mediterranean seems to occur through the 6th century BC, as is suggested by the exclusively laced Mediterranean ships at Giglio (c.580 BC), Bon Porté (c.540–510 BC), Cala Sant Vicenç (c.530–500 BC), Jules-Verne 9 (c.525–510 BC) and Pabuç Burnu (c.570–560 BC) (Bound, 1985; Pomey, 1985: 41–2; Bound, 1995: 63–5; Pomey, 1997; 1998; 2001; Nieto *et al.*, 2003; Kahanov and Pomey, 2004: 13–25; Polzer, 2004; 2010). In laced construction, the hull planks are aligned with coaks and edge-joined by ligatures laced through tetrahedral notches along the edge of the planks (Polzer, 2011:

366). Furthermore, frames are lashed and tree-nailed rather than nailed to the planks. No double-clenched copper nails have been found in any hull that was exclusively laced. This type of laced construction appears to be Greek in origin, as opposed to pegged mortise-and-tenon construction, which was used in Near Eastern shipbuilding since, at least, the late Bronze Age (Polzer, 2011: 360–70). Double-clenched nails have been found, however, on ships whose planks were joined with pegged mortise-and-tenons, but whose hull extremities were laced. These ships appear in a transitional period in Greek shipbuilding and represent a change from laced to mortise-and-tenon construction.

It is not known where the use of nails and double-clenching originated, as earlier shipwrecks have frames lashed to the planking with ligatures. Pomey asserts that it was adopted from the Phoenicians as was the mortise-and-tenon method of assemblage, but no copper fasteners have survived on Bronze Age Syro-Canaanite shipwrecks, such as Uluburun (1320 BCE $\pm$ 15 years) or Cape Gelidonya (1200 BC), that would support such a hypothesis (Pomey, 1997: 199–201; Pulak, 1999: 222; Manning *et al.*, 2009, date of Uluburun wreck). Furthermore, the remains of the so-called Phoenician ships at Mazarrón, dating to the 7th century BC, have diminutive frames lashed to the planking (Negueruela *et al.*, 1995: 195–6).

Wood preservation

More than half of the nail remnants of the Tektaş Burnu shipwreck have wood preserved around their shafts (Fig. 7). Analysis of three wood samples by Joel Jurgens of the Department of Plant Pathology at the University of Minnesota revealed that the wood remnants had become permeated with corrosion products of copper and other metals (Jurgens *et al.*, 2003: 402–5). These corrosion products helped inhibit microbial activity and preserved the wood. In addition to the copper nails excavated from the Tektaş Burnu shipwreck (and the wood attached to them), hundreds of small wood fragments were recovered. Most have been revealed to be associated with copper nails by nail holes or obvious copper corrosion products on their surfaces. Not all wood remains are from the ship's hull, however. Some are associated with the lead cores of the wooden anchor stocks.

Most of the wood degradation had occurred before impregnation by copper or lead, as wood decay was evident in the cellular structure of all analysed wood samples. After the microbial decay rendered the wood more porous, the metal corrosion products were able to penetrate the wood quite easily. This process occurred over many years after the ship sank; wood close to copper or lead corrosion sources stopped decaying as metal ion concentrations increased, protecting it from further bacterial attack. The remainder of the wood decayed completely (Jurgens *et al.*, 2003: 404).

Double-clenched copper nails

The use of double-clenched nails is seen on Classical period shipwrecks in the Mediterranean, such as at Ma'agan Mikhael in Israel (c.400 BC), Porticello in the Strait of Messina in Italy (c.400–385 BC) and near Kyrenia in Cyprus (construction c.315–305, sinking c.295–285 BC) (Tylecote, 1977: 274–5; Eiseman and Ridgway, 1987: 11–15; Fitzgerald, 1994: 196–7; Lawall, 1998 (date of the Porticello wreck); Kahanov *et al.*, 1999; Kahanov, 2003: 96–9; Yovel, 2004a: 83–104; Katzev, 2005: 72 (dates of Kyrenia ship)). This method of double-clenching nails remained standard practice in Mediterranean hull construction and continued to be employed until the beginning of the Roman Imperial period in the late first century BC (Fitzgerald, 1994: 196–7). In the 5th and 4th centuries BC these nails were made primarily of copper, whereas double-clenched nails of iron gradually became more common from the 2nd century BC onward (Fitzgerald, 1994: 197; Kahanov *et al.*, 1999: 286). The late 6th-century BC Jules-Verne 7 and Villeneuve-Bargemon 1 (César 1) ships, however, are reported to have been fitted with iron nails (Kahanov and Pomey, 2004: 16–17). These hulls then would be the only ones known from the Mediterranean dating to the Archaic and Classical periods with frames fastened to the planking with iron nails. However, archaeometallurgical analyses of these nails have yet to be published (Pomey, pers. comm., June 2004). Although iron becomes more common, copper nails continued to be used; see, for example, the Grand Congloué (2nd century BC), Kizilburun ship (1st century BC) and Nemi ships (AD 1st century) (Ucelli, 1950: 272; Benoit, 1961: 189–95; Littlefield, 2011).

Fasteners used in Archaic and Classical period ships were once generally assumed to be made of bronze, copper, or iron. It has been demonstrated that the metal composition of nails is easily misidentified. The nails of the Ma'agan Mikhael ship, for example, were initially published as of iron and have since been shown, through analytical study, to be of copper (Kahanov *et al.*, 1999: 277). This has led to inaccurate studies by other scholars. Olaf Höckmann, for example, discusses the 'iron nails' of the Ma'agan Mikhael and Gela shipwrecks in his article on the use of iron fastenings in shipbuilding from the 5th century BC onward (Höckmann, 2001: 18, 20–21).

Archaeometric studies of ship fasteners are rare and visual identifications by archaeologists have led to erroneous assumptions. Only recently have researchers focused more on the metallurgical study of ship fasteners, but still articles are published that provide new and unreliable data based on visual identifications. The most recent publication of the Antikythera ship, for example, lists the ship fasteners as bronze without providing any verifying analyses (Koutsouflakis, 2012). Having seen the fasteners in the 2012/2013 exhibition 'The Antikythera Shipwreck: The Ship, the Treasures

and the Mechanism' at the National Archaeology Museum in Athens, the red cupreous colour and striations on their surfaces—indicators that the metal was hammered into shape and their original surfaces have eroded away—may suggest they actually are made from copper. These exceptionally large ship nails warrant archaeometallurgical study. The author of the Gela 1 (500–480 BC) and 2 (c.450–425 BC) shipwreck publication refers variably to the ship nails as copper, bronze, or iron (Panvini, 2001: 20, 101). The same can be said about the later Capistello ship in Sicily (late 4th or early 3rd century BC), where one particular nail (CU-93) is referred to as being iron in one publication and copper in another (Frey, 1977: 9 and fig. 12; Frey *et al.*, 1978: 295). Re-examination of the primary documentation of the Capistello nails indicates, however, that none of the nails is made of iron. The photographic material shows that the appearance of the nails is atypical of ferrous corrosion products. This is evident also in the photographs of nails from the Gela shipwrecks, where the corrosion products look similar to those of copper and bronze, rather than of iron. Like the nails of the Capistello ship, the Gela nails probably are made of bronze or copper, and not iron. Lacking in-depth studies and chemical analyses of these nails, materials from these shipwrecks have been excluded from this study.

The use of both iron and copper in shipbuilding is, however, mentioned in at least two texts from the Classical period. One is a 5th-century BC papyrus document from Memphis, Egypt, in which 200 copper and iron nails are specified for the repair of a deck and deckhouse of a ship (Höckmann, 2001: 18–19). It should be noted that an additional 150 225-mm and 275 56-mm copper nails are mentioned in the same text regarding the replacement of the ship's sheer strake; the first group presumably to be used to fasten the frames to the new sheer strake and the latter to fasten the new deck planks to it. A second reference to the use of iron and copper in shipbuilding is found in the *Old Oligarch, Constitution of Athens* (2.1.11), dating to c.440 or 420 BC: '... it is from these very things that I have ships: Timber from one place, iron from another, copper from another ...'. It is not stated what the iron and copper were specifically used for in the ships of the oligarch. Although iron as a material is mentioned in these two texts, archaeological evidence for the use of iron nails in shipbuilding during the Archaic and Classical periods seems unique to the Jules-Verne 7 and César 1 ships.

Jørgen Kystøl of the GEUS Rock Geochemical Lab in Denmark performed a quantitative chemical analysis of four double-clenched nails from the Tektaş Burnu ship to determine their composition. The author used new titanium drill bits (1/16 inch) to obtain un-corroded copper samples from the head of each nail. Two bits were used for each sample: the first one to penetrate the first few millimetres and eliminate contamination from the exterior corrosion products; the

Table 1. Elemental composition: results of quantitative analysis of four double-clenched nails. Analysis by Jørgen Kystøl, GEUS Rock Geochemical Lab, Copenhagen, Denmark. Samples analyzed by AAS (Cu) and ICP-MS (remainder of elements). Approximate relative uncertainties: Cu, 2%; Zn, Ni, As, Pb, 10%; Sn, Sb, Ag, 25%

Lot #	Cu w/w %	Zn w/w %	Ni w/w %	As w/w %	Pb w/w %	Sn w/w %	Sb w/w %	Ag w/w %
766	99.7	0.07	0.82	0.11	0.21	0.08	0.01	0.01
805	94.9	0.13	0.04	0.11	0.06	0.00	0.01	0.02
881.02	99.7	0.09	0.67	0.42	0.05	0.10	0.03	0.07
1051	98.6	0.13	0.08	0.12	0.17	0.20	0.02	0.02

second drill bit to extract the actual sample shavings. The author purposely refrained from using surface or spot-testing analytical techniques, such as portable XRF, in order to analyse the actual metal content of the nails and avoid corrosion contaminants.

Prior to examination, the samples were dissolved in nitric acid, after which an initial semi-quantitative analysis of each was performed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The quantitative analysis of copper was made using atomic absorption, whereas the other elements were analysed in approximate concentrations by semi-quantitative analysis using ICP-MS (Table 1). The amount of copper in the samples varied between 94.9 and 99.7%. Concentrations of individual trace elements, such as zinc, lead, nickel and arsenic, were found to be less than 1%.

Copper seems to have been the preferred metal over bronze or iron for the production of nails in the Archaic and Classical periods, even though bronze (an alloy of copper and tin), or alloyed arsenic copper would have been harder and more durable than unalloyed copper. On the other hand, being a softer metal, copper is more malleable and easier to clench without risk of breaking (Lang *et al.*, 1990: 48). Furthermore, pure copper was more economical, easier to obtain and required less metallurgical skill and labour than bronze and iron.

Like the fasteners from the Tektaş Burnu shipwreck, double-clenched nails from contemporary ships such as those at Porticello, Ma'agan Mikhael and Kyrenia, as well as later wreck-sites, have shafts that are square in cross-section over most of their lengths (Fitzgerald, 1994: 197; Panvini, 2001: 101; Kahanov, 2003: 98). Metallographic studies of the nails from the Ma'agan Mikhael and Kyrenia shipwrecks have demonstrated that copper was initially cast in the shape of a rod and then shaped into a nail (or nails) on a swage block (Tylecote, 1977: 275; Kahanov *et al.*, 1999: 282; Shalev *et al.*, 1999: 17, 20). It was then cold hammered on an anvil to shape it further and to strengthen the copper (Tylecote, 1977: 275; Steffy, 1998: 48; Kahanov *et al.*, 1999: 282; Lucas and Harris, 1999: 211–15; Shalev *et al.*, 1999: 17 and 20). The head of the nail and square shaft are a direct result of the hammering, which explains also why the shaft near the nail's head remains

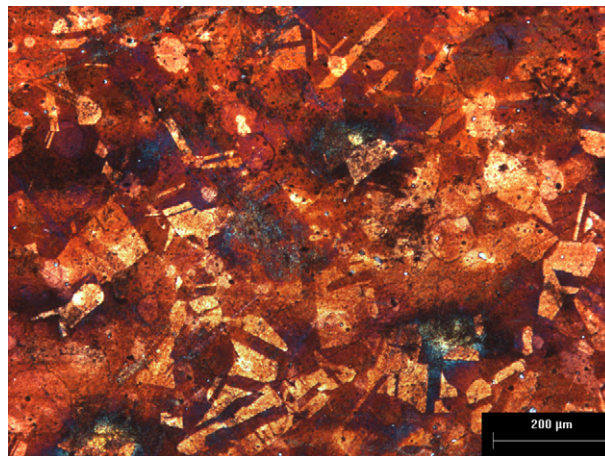


Figure 8. Equiaxed grain structure and twins of double-clenched copper nail, lot number 805. Tektaş Burnu, Turkey. Leica DLMA Polarized light microscope, magnification $\times 100$. (Micrograph: Jim Wiederhold, Anthropology Department, Texas A&M University)

circular in section. Hammering hardens the copper considerably and reduces its thickness by 70–80% of the original (Kahanov *et al.*, 1999: 282; Shalev *et al.*, 1999: 20). Lucas and Harris explain that if hammered excessively, copper becomes brittle, but that this can be adjusted easily by heating for a short time at about 500–700°C (Lucas and Harris, 1999: 213). The alternation of cold hammering with annealing creates an equiaxed grain structure that is evident in the copper nails of the Ma'agan Mikhael and Kyrenia shipwrecks (Tylecote, 1977: 275, fig. 3; Kahanov *et al.*, 1999: 282, figs. 13 and 14; Shalev *et al.*, 1999: 17, figs. 10 and 11). Metallographic analysis of the Tektaş Burnu copper nails indicates that they were made in a similar fashion (Fig. 8).

It is a common misconception that the Kyrenia ship fasteners have circular and square cross-sections (Steffy, 1998: 46–8; Steffy, pers. comm., May 2004). Since 2005, the author has studied the fasteners used in the construction of the Kyrenia ship and confirms that all nail shafts that retain their original shape and surfaces are square in cross-section over most of their lengths. Those where the metal has eroded beyond its original surfaces may indeed appear circular, but they

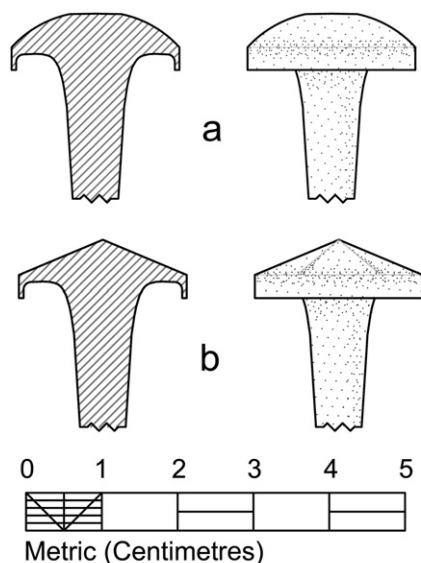


Figure 9. Typical rounded (a) and rose-type (b) nail-heads with thin rims around their lower perimeters. Tektaş Burnu, Turkey. (Illustration: Wendy van Duivenvoorde)

were most likely square when manufactured and used. The ancient craftsman who fashioned these nails did use rods with both square and circular sections. Once shaped, however, none remained circular in section over their entire length (Van Duivenvoorde, final report in preparation). When circular rods were used, they only remained so directly below the nail-heads for 10–20 mm, otherwise becoming square in section.

The nail-heads of the Tektaş Burnu copper fasteners demonstrate true craftsmanship in terms of their meticulous and, undoubtedly, time-consuming manufacture. The circular or roughly circular—occasionally even octagonal—nail-heads have slightly rounded or pyramidal tops (Fig. 9). Such rounded or rose-type nail-heads are stronger than flat heads, in addition to being decorative. It is difficult to distinguish whether all of the Tektaş Burnu nails originally had rose-type heads and are now simply worn, rounded by erosion, or whether some were purposely made with rose-type heads and others with simpler round heads. Rose-type nail-heads are used specifically for joining heavy timbers where considerable force is required to drive them through the ship timbers, as they provide ‘a surplus of metal when the head deformed under the blows of the hammer’ (Angus *et al.*, 1962: 957). Especially notable is the thin rim around the lower perimeter of the head as seen on the better-preserved nails. Only a few millimetres in height, this rim provided a secure ‘grip’ and an extra seal when it was driven into the wood (see also Galili *et al.*, 2010: 62–5).

Nails are more suitable for clenching if their shafts are square in cross-section. The central axis of such nail shafts is closer to their surfaces compared to nails with circular cross-sections, assuming their sectional areas

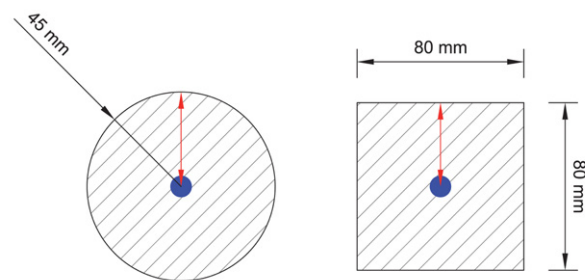


Figure 10. Schematic drawing of circular and square cross-sections of fasteners, with an equal cross-sectional area of 6400 mm², showing distance from centre axis (blue) to exterior surface of the nails (red). This distance for the nail shaft with a square section is 0.5 mm shorter than for the circular one. (Illustration: Wendy van Duivenvoorde)

are the same (that is the nail shafts have equivalent volumes of metal) (Fig. 10). Square nail shafts also distribute stress better, due to their greater surface area, making them easier to clench and less likely to deform the surrounding wood. Their greater surface area also gives them greater holding strength. It is for similar reasons that such nails are still used today, for example, by traditional shoemakers.

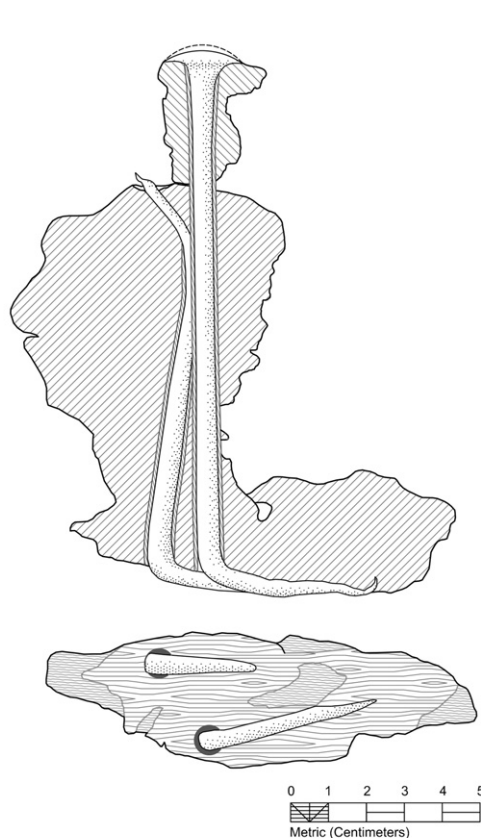
Copper samples taken from five double-clenched nails from the Tektaş Burnu ship were sent to the Danish Lithosphere Centre in Copenhagen for lead-isotope analysis. The samples were tested in three individual sessions, after which all data were normalized to the standard reference value for NBS981 (as specified in Baker *et al.*, 2004). Comparison of these data with the Oxford Analysis Lead Isotope Database (Oxalid) by Sophie Stos reveals that they are consistent with ores from four different mining areas, specifically Laurion (Attica), Solea and Larnaca (Cyprus) and the northern Aegean (Table 2). The copper from the northern Aegean (lot number 766) could come from the copper mines in the east Rhodope Mountains near the Black sea coast, or from mines on the south-eastern slopes of Essimi in Greece (Stos, pers. comm. May 2004; Stos-Gale *et al.*, 1997).

Repairs or reuse of timbers?

Two particular nail and wood concretions from Tektaş Burnu (lot numbers 810 and 881) each contain a pair of double-clenched copper nails and may indicate repair work or a reuse of timbers (Figs 11–12). The primary nail of each pair is seated less than 20 mm away from one that has been partially removed. The head and upper portion of the shank of this secondary nail have been cut off and the remaining shaft is bent near the surface of the plank (at the plank-frame seam). The clenched part of both primary nails is much longer than that of the secondary (partially removed) nails next to them. Note that the planking wood from lot 880 deteriorated or was ripped away (Fig. 12), most

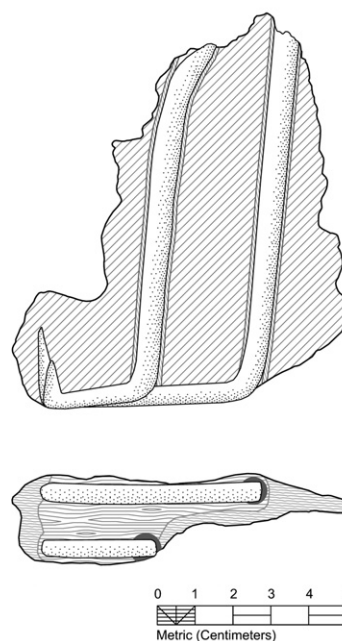
Table 2. Lead isotope data: results of lead isotope analyses of five double-clenched copper nails. Analyses by Thomas Kokfelt, Danish Lithosphere Centre, Copenhagen, Denmark

Lot #	208Pb/206Pb	207Pb/206Pb	206Pb/204Pb	Source
1051	2.06420	0.83320	18.82982	Laurion Attica
1051	2.06413	0.83324	18.82998	Laurion Attica
881.01	2.07683	0.84264	18.48580	Solea, Cyprus (Phoenix)
881.01	2.07669	0.84270	18.47879	Solea, Cyprus (Phoenix)
881.02	2.07947	0.84152	18.52779	Larnaca, Cyprus
881.02	2.07919	0.84154	18.52323	Larnaca, Cyprus
766	2.07003	0.83592	18.76105	Northern Aegean-East Rhodope
766	2.06958	0.83575	18.76145	Northern Aegean-East Rhodope
805	2.07294	0.83815	18.66035	Larnaca, Cyprus
805	2.07293	0.83840	18.64210	Larnaca, Cyprus

*Figure 11.* Double-clenched copper nail inserted next to secondary nail, lot number 881. Tektaş Burnu, Turkey. (Illustration: Wendy van Duivenvoorde)

likely after the ship's wrecking, taking the nail-head and upper shank with it. However, although the primary fastener of lot 810 is missing its head and the upper part of its shank, the remaining shank is straight and shows no sign of being cut or bent at the plank-frame seam, as clearly is the case with the secondary nail beside it.

It would appear that the original plank wood, through which the secondary nail was driven, was

*Figure 12.* Double-clenched copper nail inserted next to secondary nail, lot number 810. Tektaş Burnu, Turkey. (Illustration: Wendy van Duivenvoorde)

removed and the subsequently exposed upper portion of the nail broken or cut off. This may indicate that 1) the plank was removed and replaced during the ship's original construction; 2) reused frames were used in the ship's construction; or 3) a plank was removed and replaced during the ship's lifetime. When replacing a rotten or damaged plank with frame attached, the plank first had to be cut or broken away before the double-clenched nails could be removed, partially or in whole. Once the nails were out of the way, the replacement plank could be fitted and new nails driven through the planking and frame and clenched over twice.

Reused frames are not uncommon among Archaic and Classical period ship remains. For example, several frame timbers used in the construction of the Kyrenia

ship came from older vessels (for example F3, starboard side, and F19, F40 and F44, all from the port side) (final report in preparation). Where it can be positively determined, the double-clenched nails in these timbers were removed in their entirety, along with their associated treenail, and the resulting holes were carefully plugged with new treenails. Distinct impressions from the original double-clenched nail-ends are visible on the inner face of these timbers. None of these reused frames retain any of their old nails, and it is likely that the removed nails were melted down and their copper recycled. Recycling or reuse of scrap metal was common practice in the ancient Greek world (Murray, 1985). This suggests that the two partially removed double-clenched nails from the Tektaş Burnu ship were the result of a hasty repair since most of the old fasteners remain *in situ*.

The nails of lot 881 were sampled for lead-isotope analysis (Table 2). The copper of the primary nail comes from the Larnaca axis in northeast Cyprus (lot 881.02), whereas that of the secondary nail is identical to sulfide-copper ores from the Phoenix mine in the Solea axis in northwest Cyprus (lot 881.01).

Treenails

Ancient Mediterranean shipbuilding began with building up the planking. After the planks of the ship's lower hull were assembled, frames were installed and placed against them. Then, before the frames were fastened, holes were drilled from the inside of the ship, through the frames and hull planking in order to drive the nails through. In the case of the Kyrenia ship, a wooden treenail was inserted into each pre-drilled hole to ensure water tightness around the nail, and to prevent damage to, or splitting of, the planks by driving a nail directly into the wood. After the nail hole was plugged, a copper nail was driven into the treenail from the outside of the hull through the planking and frame and clenched over on the inside face of the frame as described above (Steffy, 1985: 84; 1998: 49). The pre-drilled nail holes and the treenails of the Kyrenia ship have a maximum diameter of 13 mm (final report in preparation; early publications list an average of 15 mm, see Steffy, 1998: 49). According to Kahanov, no treenails appear to have been used in the construction of the Ma'agan Mikhael ship (Kahanov *et al.*, 1999: 277, 284–6; Kahanov, 2001; 2003: 98). Initially, treenails were not observed around the nail shafts of the Tektaş Burnu ship either. It was assumed, therefore, that the method of nailing would have been similar to that of the Ma'agan Mikhael ship. Close examination of all Tektaş Burnu nail concretions by the author, however, has revealed that 14 nails, were driven through wooden treenails and only one definitely was not (lot number 805). The preservation of the other nails is not sufficient to provide conclusive evidence for either the presence or absence of treenails.



Figure 13. Double-clenched copper nail driven through treenail, lot number 881.02. Treenail (a) visible only on left side of nail shaft (b), as revealed by wood grain running parallel to nail shaft, whereas wood of frame (c) on the right side of nail runs perpendicular to shaft. Tektaş Burnu, Turkey. Dissecting microscope, magnification $\times 120$. (Micrograph: Wendy van Duivenvoorde)



Figure 14. Frame wood (a) containing treenail (b), through which double-clenched nail is driven, lot number 810.01. Nail shaft is located underneath the treenail and, thus, not visible in this micrograph. Tektaş Burnu, Turkey. Dissecting microscope, magnification $\times 60$. (Micrograph: Wendy van Duivenvoorde)

The treenails are only just visible as a thin layer of copper-impregnated wood around the nail, with wood grain running parallel to the nail shaft (Figs 13–14). Unlike the Kyrenia ship, where the treenails have a maximum diameter of 13 mm, the pre-drilled nail holes and treenails of the Tektaş Burnu ship range from 8 to

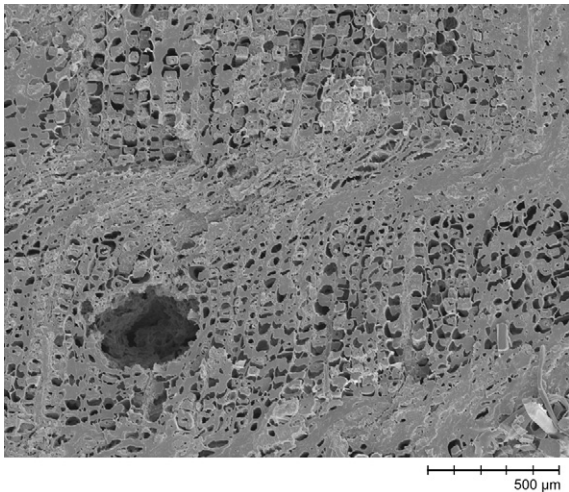


Figure 15. Severely collapsed and compressed wood structure of treenail, lot number 810.01, transverse section, *Pinus brutia*. Earlywood and latewood are clearly visible. Tektaş Burnu, Turkey. Jeol JSM-6400 scanning electron microscope, KeV 15, working distance 39 mm, magnification $\times 100$. (Micrograph: Wendy van Duivenvoorde)

11 mm. These treenails, therefore, are only a few millimetres larger in diameter than the nails, and are hardly visible to the untrained or un-aided eye. An additional complicating factor is that the nails are not always driven straight through the centre of the treenails. Several nails had treenail wood on only one side, indicating that the nail had diverged to the side of the treenail when it was hammered through (Fig. 13). In some cases, the treenail was split as a result of hammering the nail.

Five of the treenails were sampled for wood identification by Joel Jurgens (up to genus level) of the Department of Plant Pathology, University of Minnesota, and by Nili Liphshitz (up to species level) of the Botanical Laboratories of the Institute of Archaeology, Tel Aviv University. Since the treenails are of small diameter and only a few millimetres remain around the nail shafts, sample fragments were quite small. In addition, it was obvious that copper corrosion products from the nail had leached into the treenail wood. However, the small sample sizes and the corrosion penetration were not as problematic for wood identification as the severe compression suffered by the wood when the nails were driven through the treenails, and the degradation of the wood post deposition. Of the five samples examined, one could not be identified, while the other four are all *Pinus sp.*; three of these could be identified as *Pinus brutia* (Fig. 15). The unidentifiable sample came from the treenail seated around the secondary nail of lot 881.01 (Fig. 16).

Hull planking and framing

In addition to the treenails, the wood preserved around the double-clenched nails of the Tektaş Burnu ship can

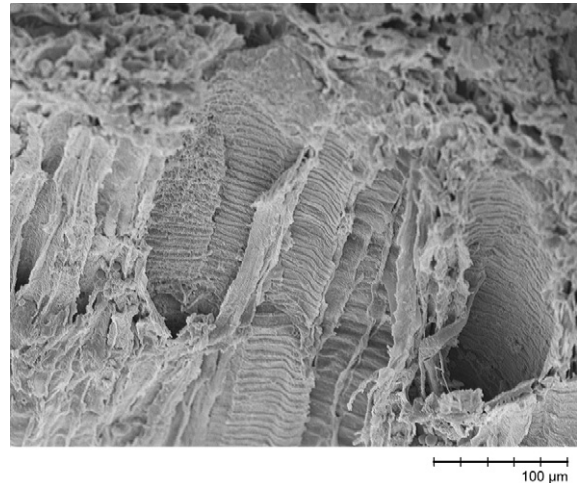


Figure 16. Wood structure of treenail with helical thickening in its vessels, lot number 881.01, longitudinal section, unidentified hardwood? Tektaş Burnu, Turkey. Jeol JSM-6400 scanning electron microscope, KeV 15, working distance 34 mm, magnification $\times 250$. (Micrograph: Wendy van Duivenvoorde)

be positively identified as hull planking and frame wood (Fig. 4). Although the wood remains represent only the vestiges of the actual planks and frames, they provide useful information about the ship's hull, such as planking thickness, moulded dimensions of the frames, and the types of wood from which these components were fashioned.

Hull planking

Planking wood is identified by its location directly against the nail-head. The planking thickness of the Tektaş Burnu ship has been accurately measured on 40 nails and ranges from 22 to 38 mm for those planking fragments that retain their original interior and exterior surfaces (Table 3).

Upon first glance, the planking thickness of exclusively laced ships, such as that of the Bon Porté and Jules-Verne 9 ships, appears to be slightly thinner than that of ships built with mortise-and-tenon joints. Their plank thickness varies between 20 and 30 mm, whereas that of the Ma'agan Mikhael and Kyrenia ships averages about 40 mm (Steffy, 1985: 77–84; Kahanov, 1998: 158–9; Pomey, 1998: 148; Kahanov and Pomey, 2004: 13). This would not seem unreasonable, considering that the planks of the latter had to accommodate tenons 6–7 mm in thickness. Additionally, it has been suggested that laced vessels had thinner planking to increase hull flexibility (Mark, 2005: 58, 62). Presumably then, from the opposite point of view, the planking thicknesses of mortise-and-tenon constructed vessels were greater in order to enhance the rigidity of these hulls (Pomey, 1998: 153; Mark, 2005: 62). The planking of the hybrid Jules-Verne 7 ship is 30 mm in thickness, making it thinner than that of the Ma'agan Mikhael and Kyrenia ships. Correspondingly, its

Table 3. *Thicknesses of hull planking, Tektaş Burnu ship*

Lot #	Location	Type	Planking th. (mm)
103*	Q5	Copper double-clenched nail with wood	31
259	Q5	Copper double-clenched nail with wood	33
264	R5	Copper double-clenched nail with wood	32
313.06*	R7	Copper double-clenched nail with wood	34
325	R5	Copper double-clenched nail with wood	30
435	Q4	Copper double-clenched nail with wood	38
446.04c	R7	Copper nail with wood	38
548	R5	Copper double-clenched nail with wood	30
555	R6	Copper double-clenched nail with wood	25
565	R6	Copper double-clenched nail with wood	33
676	S9	Copper double-clenched nail with wood	27
722	R9	Copper double-clenched nail with wood	29
780	P11	Copper double-clenched nail with wood	35
805	S8	Copper double-clenched nail with wood	34
808	R9	Copper double-clenched nail with wood	28
835	R8	Copper double-clenched nail with wood	35
836	R8	Copper double-clenched nail with wood	28
881	P11	Copper double-clenched nail with wood	34
883	R8	Copper double-clenched nail with wood	25
908	R7	Copper double-clenched nail with wood	35
918.03a	P8	Copper double-clenched nail with wood	32
946	R5	Planking wood with nail hole	27
994.01b	Q7	Copper double-clenched nail with wood	32
1000	R7	Copper double-clenched nail with wood	34
1003**	P8	Copper double-clenched nail with wood	38
1036a	Q7	Copper double-clenched nail with wood	28
1036a	Q7	Copper double-clenched nail with wood	25
1036a	Q7	Copper double-clenched nail with wood	30
1046	Q7	Copper double-clenched nail with wood	27
1051*	R8	Copper double-clenched nail with wood	26
1057	Q7	Copper double-clenched nail with wood	25
1061.01a	R8	Copper double-clenched nail with wood	28
1062.04(1)	R8	Wood with double-clenched nail hole	27
1072.01	R8	Copper double-clenched nail with wood	24
1082.01	Q8	Copper double-clenched nail with wood	28
1082.01	Q8	Copper double-clenched nail with wood	31
1089	Q8	Copper double-clenched nail with wood	22
1091	Q8	Copper double-clenched nail with wood	30
1091.01	Q8	Copper double-clenched nail with wood	37
1094	Q8	Copper double-clenched nail with wood	30
Average			30
Min.			22
Max.			38

* Planking from near one of the extremities of ship's hull (bow or stern).

** Planking from midships area.

tenons are thinner. The planking thickness of the Tektaş Burnu ship averages 30 mm and would seem, therefore, to be similar to that of the Jules-Verne 7 ship (Pomey, 1998: 150).

However, caution should be used when making such comparisons, since plank thicknesses of shell-based ships vary over the length of each strake. In general, strake thicknesses on the Ma'agan Mikhael ship, for example, decrease from about 45 mm amidships to 25 mm near the stem and sternpost (Kahanov, 2003:

73–8). Therefore, it is important to look at planking from similar locations on the hull when comparing thicknesses.

This location can be estimated by noting the angle between the moulded face of the frame oriented towards midships and the adjoining plank surface. Frame-wood fragments are preserved on the nail shanks between the plank wood and the clenched portion of the nail. Frame-wood grain always runs perpendicular to the nail shaft, in contrast to the grain

of the planking, which varies in relation to the shaft, depending upon hull location. Near midships, the angle between the midship-facing moulded frame face and the planking will be roughly 90 degrees, but, as the planking approaches either extremity, and its curvature becomes more extreme, this angle increases.

In the case of the Tektaş Burnu ship, only four of the double-clenched nails have frame and adjoining plank wood preserved well enough to provide conclusive evidence. The angle of interest (between the planking wood and moulded frame face) for three of these nails (lot numbers 103, 313.06 and 1051) is 134, 116 and 130 degrees, respectively. These all are significantly greater than 90 degrees, indicating that these frames were situated near the bow or stern of the ship. The corresponding plank remnants have thicknesses of 26, 31 and 34 mm, respectively (Table 3). The other double-clenched nail (lot number 1003) is encased in planking wood that meets the frame face at an angle of 90 degrees, indicating that it originated from near midships, rather than from one of the ship's extremities. The plank fragment around this nail is 38 mm thick.

The thickness of two-thirds of the planking fragments from the Tektaş Burnu ship varies between 22 and 32 mm. Based on the previous evidence, limited though it is, these fragments probably represent hull planking from near the ship's extremities.

In addition, the lead spike used to affix one of the marble eyes to the bow of the ship may provide corroborating evidence. The spike is encrusted with marine growth, except for the 24 mm directly below its head. This area, free of encrustation, may indicate the thickness of the hull planking through which the spike was driven (Nowak, 2001: 87).

Framing

Two types of frames were used during this period. The first were full or made-frames, comprised of futtocks scarfed to their floor and fastened to it with square wooden pegs, that were fully assembled before being installed. These frames had trapezoidal sections, a rounded top and a narrow base. All of these features were developed within a shipbuilding tradition that used ligatures to lace together hull planks and lash frames to planking (Polzer, 2011: 366–8). Such frames are found on the Bon Porté, Cala Sant Vicenç, Jules-Verne 7 and 9, César 1, Gela 1 and 2, Grand Ribaud F and Ma'agan Mikhael ships (Pomey, 1981: 225–6; Freschi, 1991: 207; Kahanov, 1998: 158; Pomey, 1998, 149–52; Panvini, 2001: 18–20, figs. 3, 5, 9, 100–106, 152–3, Tables XXXVI–XXXVII; Kahanov, 2003: 88–95). However, the made-frames of the hybrid Jules-Verne 7, César 1, Grand Ribaud F and Ma'agan Mikhael ships are no longer lashed to the planking, but are fastened to the hull with double-clenched nails (Kahanov, 2004: 15–22, 55–8, 62–3).

The second framing system consists of floors and futtocks alternating with half-frames, and is associated with mortise-and-tenon construction. This manner of framing, seen for the first time at Kyrenia, became characteristic of Mediterranean shipbuilding after the 4th century BC (Steffy, 1998: 48–51). Frame floors, futtocks and half-frames were consistently nailed to the planking with double-clenched nails until the late 1st century BC (Fitzgerald, 1994: 196–7).

Several frame fragments of the Tektaş Burnu ship indicate the use of made-frames. These small fragments of timber suggest rounded frame tops and floor-to-futtock scarfs with square treenails (Fig. 17). In using copper nails to join made-frames to planking, the Tektaş Burnu ship most closely resembles the Jules-Verne 7, César 1, Grand Ribaud F and Ma'agan Mikhael ships, and therefore, like these hulls, may also have had laced extremities (Kahanov and Pomey, 2004: 6–19, 21–2). Moulded dimensions of frame fragments from Tektaş Burnu were measured on 25 double-clenched nail/wood concretions; they vary from 57 mm to 140 mm, and average 91 mm (Fig. 4).

Noticeable are the small number of widely spaced frames on the Bon Porté, Jules-Verne 7 and 9, and Gela 1 shipwrecks (room-and-space varying from 0.90 m to 1 m) (Panvini, 2001: 19–21, figs. 3, 5 and 9, 101; Pomey, 1981: 225; 1998: 149–52; 2001: 426, 428). The number of frames increases over time, adding more lateral stiffening to the hull. The Ma'agan Mikhael ship has 14 frames, and the room-and-space is reduced to 750 mm (Kahanov, 1998: 158; 2003: 90–91). By the 4th century BC, the Kyrenia shipwreck has more than 56 frames with a room-and-space of approximately 250 mm (Steffy, 1985: 84; 1998: 51).

As frame spacing becomes narrower and more frame timber is employed in the hull construction, the number of double-clenched nails increases significantly. From the nails used to construct the Ma'agan Mikhael ship, about 182 copper nails remain (Kahanov, 2003: 98; Yovel, 2004a: 83, 97). Of these, probably 155 were used to fasten frames to the hull; one double-clenched nail per plank (Kahanov, 2003: 98; Yovel, 2004a, 83–7). The total number of nails (169) recovered from the Tektaş Burnu shipwreck is similar to that found on the Ma'agan Mikhael site. By contrast, excavation of the Kyrenia shipwreck yielded some 2750 nails. Two thousand of these were *in situ*, connecting preserved elements of the hull, while the other 750 were found loose on the site (Van Duivenvoorde, final report in preparation). The frames of the Kyrenia ship were fastened to the hull with two to three double-clenched nails per plank, and Steffy (1998: 49) estimated that about 3000 copper nails were used in the ship's construction, three-quarters of which were for fastening frames. The use of made-frames and the small number of preserved nails suggest that the Tektaş Burnu frames were probably widely spaced, like those on the Jules-Verne 7 and Ma'agan Mikhael ships, and fastened with a single nail per plank.

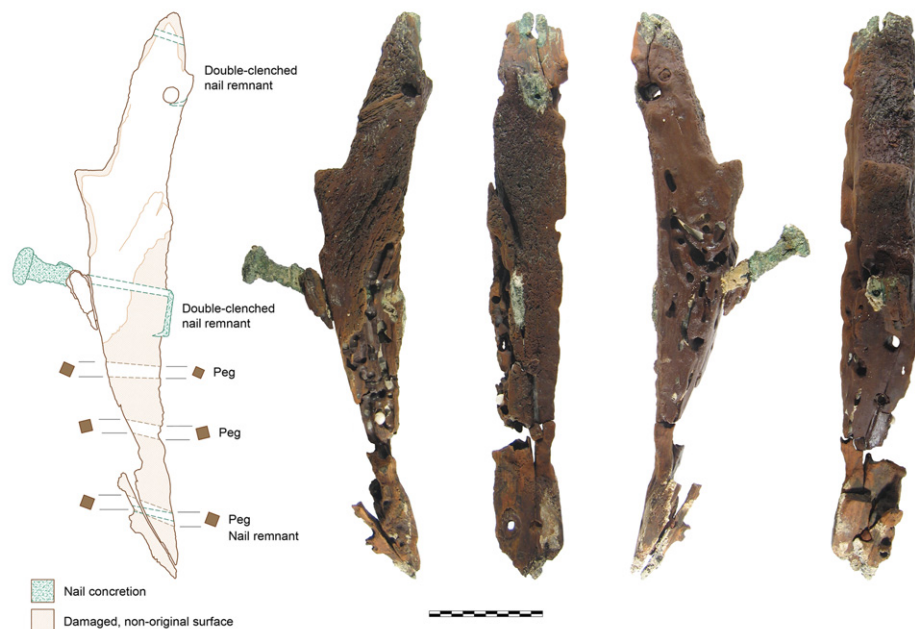


Figure 17. Made-frame remnant with floor/futtock scarf, lot numbers 912.01–8. *Pinus brutia*. Tektaş Burnu, Turkey. From left to right: Reconstruction drawing of obverse face and photographs of obverse, inner (rounded top), reverse and outer faces (narrow base; double-clenched nail-head not shown). Scale: 10 cm. (Photographs/illustration: Wendy van Duivenvoorde/Mark Polzer)

Wood species

Fourteen wood samples taken from the frames and planking of the Tektaş Burnu ship have been identified as pine and include three species: *P. brutia* (Calabrian pine), *Pinus nigra* (Austrian pine) and *Pinus sylvestris* (Scots pine) (Liphschitz, 2004a). Of the 14 samples, three could not be identified to species level. Nine samples are *P. brutia*, based on the even grain appearance, non-dentate ray tracheids and gradual transition from earlywood to latewood (Panshin and de Zeeuw, 1980: 411–12; Hoadley, 1990: 144–6; Rowena and Cutler, 2000: 391–4). One sample of frame wood is *P. sylvestris*, based on its inconsistent grain appearance, dentate ray tracheids and the abrupt transition between earlywood and latewood (Panshin and de Zeeuw, 1980: 411–12; Hoadley, 1990: 147–8; Rowena and Cutler, 2000: 391–4). Both pine species are native to the Mediterranean and were commonly used in ancient times (Blamey and Grey-Wilson, 1993: 27–8; Christensen, 1997: 6–7; Rowena and Cutler, 2000: 391–4; Liphschitz, 2004b). *P. sylvestris* is a cool-climate conifer found in northern Greece, northern Turkey and more western European regions (Atalay, 1983: 120, fig. 38; Christensen, 1997: 6–7; Rowena and Cutler, 2000: 391). It is the most common pine species in Europe. *P. brutia*, like *P. halepensis*, is a coastal pine native to the eastern Mediterranean region. The two species are almost identical and difficult to differentiate. Their distinction can be observed best in the radial

longitudinal section in the cross-field of the rays: the pits of *P. halepensis* are small and rounded, whereas the pits of *P. brutia* are much larger and somewhat elliptical. In addition, the resin ducts of *P. halepensis* are spread all over the width of the growth rings whereas, in *P. brutia*, they are concentrated in the latewood only (Liphschitz and Biger, 1990).

The wood of one plank is made of *P. nigra* (lot number 881). This particular conifer is a mountain pine that grows at altitudes up to 1200 m, and is native to mainland Greece, Thasos, Lesbos, Samos, Cyprus and Anatolia (Atalay, 1983: 120, fig. 38; Blamey and Grey-Wilson, 1993: 27; Christensen, 1997: 5–6; Rowena and Cutler, 2000, 391).

It is not surprising that the planking and framing of the Tektaş Burnu ship were fashioned primarily of pine, as these elements of all known contemporary Mediterranean ships, such as the Gela 1, Gela 2, Ma'agan Mikhael and Kyrenia ships, also were fashioned from pine (Steffy, 1985: 84, 87, 92; 1998: 41–3; Panvini, 2001: 111–13; Werker, 2003; Liphschitz, 2004b: 156–7). Most components of the Kyrenia ship, such as the keel, planks, frames, floor timbers and treenails, were made predominantly of a single species of pine, *P. brutia* (Liphschitz, 2009). The planking and frames of the Ma'agan Mikhael ship are also reported to be made of the same single species (Kahanov, 1997: 317; Hillman and Liphschitz 2004; Liphschitz, 2004b: 160–61).

In Classical Greece, timber for building war fleets was commonly sourced from Macedonia, Thrace and southern Italy (Meiggs, 1982: 124–5). Timber for the construction of merchantmen may have been obtained locally, in the vicinity of the shipyard, to avoid the cost of long-distance transportation. It seems that the shipwright of the Tektaş Burnu ship was not very particular about the types of pine he selected for the frames and planks, probably using whatever was readily available.

Mortise-and-tenon joints

Among the wood remains of the Tektaş Burnu shipwreck, six partial tenons have been identified. The best-preserved specimen comprises only one quarter of the original tenon (Fig. 18). It is broken down the centre of its width and at the plank edge, preserving half of one peg hole. Its preserved dimensions are length 80 mm, width 20 mm, thickness 8 mm, and peg-hole diameter 7.5 mm. The tenon's reconstructed dimensions correspond closely to the average dimensions of the tenons from the Ma'agan Mikhael and Kyrenia ships (Table 4). Although the author could not positively identify any planking remains with mortises among the tiny and fragmentary hull remains found on the Tektaş Burnu shipwreck site, the tenons with peg holes indicate the hull planks were fastened with pegged mortise-and-tenon joints.

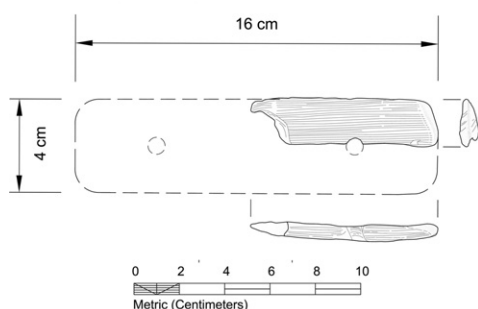


Figure 18. Reconstruction of quarter tenon, lot number 1156c. *Quercus coccifera*. Tektaş Burnu, Turkey. Obverse, side and reverse views. (Illustration: Wendy van Duivenvoorde)

Tenons and tenon pegs were predominantly made of oak in ancient times. For example, the Uluburun, Cape Gelidonya, Gela, Ma'agan Mikhael and Porticello shipwrecks all have oak tenons and pegs (Kahanov, 1997: 317; Steffy, 1998: 40–72; Pulak, 1999: 219, 237; 2003: 29; Panvini, 2001: 111–13; Werker, 2003). However, there are some rather odd anomalies; the tenons and pegs of the Jules-Verne 7 ship were cut from olive wood, an unusual choice in Mediterranean shipbuilding (Pomey, 1998: 150, note 3). Nevertheless, oak was the hardwood of choice for such ship fasteners during the Classical period. The tenons of the Ma'agan Mikhael and Kyrenia ships are oak, those from the former being *Quercus coccifera*, and the latter having tenons of both *Q. coccifera* and *Q. cerris* (Steffy, 1985: 87; Fitzgerald, 1995: 107–8; Liphshitz, 2004b: 157, 160–61; Liphshitz, 2009: 21). It is not surprising then that the tenons of the Tektaş Burnu ship are also oak; four (lot numbers 928.03, 995, 1156c and 1167) were identified as *Q. coccifera* (Liphshitz, 2004a).

Conclusions

The Tektaş Burnu ship was a modestly sized merchantman for its day, with a maximum length of about 14 m. It was built in a shell-based construction method with pine planks and frames. The hull planking was joined by oak tenons pegged in their mortises, and the frames were fixed to the planking with double-clenched copper nails. At least some of the frame nails were hammered into treenails mainly made from softwood. The copper of five nails is consistent with the ores from four different mining areas in Attica, Cyprus and the northern Aegean, indicating that the materials used in the Tektaş Burnu ship's construction were sourced from a variety of locales.

The few diagnostic frame fragments and the relative small number of nails indicate a construction closer to the Ma'agan Mikhael and Jules-Verne 7 ships than to the Kyrenia ship. Although the Tektaş Burnu hull remains preserve no evidence of ligatures or lacing holes, the small fragments of made-frames suggest that the ship was probably constructed using both pegged mortise-and-tenons joints to assemble the planking seams and ligatures to lace their hood ends to the ship's end posts.

Table 4. Average dimensions of tenons

Shipwreck	Tenon Length (mm)	Tenon Width (mm)	Tenon Thickness (mm)	Peg Diameter (mm)
Jules Verne 7 (Pomey, 1997: 198)	140–150	30–35	5	—
Tektaş Burnu	160	40	7	7.5
Ma'agan Michael (Kahanov, 2003: 84–88; Yovel, 2004b: 106)	154	39	6–7	7.4–9.5
Kyrenia (Steffy, 1985: 72, 81)	155	45	6	6–10

Acknowledgements

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Erratum

In the article given below the last line on page 16 should read ‘the planking from lot 810’ rather than ‘lot 880’. We apologize for this error.

Reference

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