Varia Anatolica

The VIth-Century B.C. Shipwreck at Pabuç Burnu, Turkey. Evidence for Transition from Lacing to Mortise-and-Tenon Joinery in Late Archaic Greek Shipbuilding

Mark E. Polzer

Abstract

In 2002 and 2003, the Institute of Nautical Archaeology excavated the remains of a Greek ship that sank off the coast of Pabuç Burnu, Turkey, sometime in the second quarter of the VIth century B.C. Scant remnants from the vessel's hull have provided the first archaeological evidence for laced shipbuilding in the Aegean.

The diagnostic features preserved in the hull fragments are consistent with those of Greek laced construction, as evidenced in other shipwrecks from the same period found in the western Mediterranean. The planking joinery included edge inserts, or coaks, between the strakes and ligatures laced through oblique holes drilled through tetrahedral notches. The ship's framing consisted of widely spaced made-frames, with top-timbers inserted along the upper sides of the hull. The frames had trapezoidal sections, were notched over the planking seams on their underside, and were lashed to the hull. The top-timbers had rectangular sections and were both lashed and treenailed to the planking.

Notable in this vessel's construction is the use of tenons as coaks, the earliest example of tenon usage in Greek shipbuilding. Additionally, two repair planks were attached to the hull with lacing and dowels, coaks, inserted along one side through diagonal holes drilled from the edge to the surface of the planks. These features testify to a critical moment in Greek boat building when tenons replaced dowels as coaks in laced construction, paving the way for the eventual supplanting of lacing by pegged mortise-and-tenon joinery. Furthermore, they suggest that mortise-and-tenon technology could have evolved naturally within the Greek tradition of laced construction, rather than being incorporated from Phoenician or other shipbuilding practices.

Résumé

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En 2002 et 2003, l'Institute of Nautical Archaeology a fouillé les vestiges d'un bateau grec naufragé au large de Pabuç Burnu, sur les côtes de Turquie, au cours du second quart du VIe siècle av. J.-C. Les maigres restes de la coque du navire ont livré les premières données archéologiques sur la construction par ligatures en mer Égée.

Les caractéristiques observées sur les fragments de coque correspondent à celles de la construction grecque par ligatures telles qu'elles ont été mises en évidence sur d'autres épaves de la même période découvertes en Méditerranée occidentale. L'assemblage des bordages comporte l'insertion de languettes, ou goujons, entre les virures et des ligatures passant à travers des trous obliques percés à partir d'évidements tétraédriques. La membrure du navire est constituée de membrures assemblées, largement espacées, et de membrures de revers insérées le long des bords supérieurs de la coque. Les membrures ont une section trapézoïdale, leur face inférieure est entaillée au-dessus des joints de virure, et elles sont ligaturées à la coque. Les membrures de revers ont une section rectangulaire et sont à la fois ligaturées et chevillées au bordé.

L'usage de tenons en tant que goujon dans la construction de ce navire est particulièrement remarquable et constitue le premier exemple de l'emploi de tenons dans la construction navale grecque. De plus, deux bordages réparés étaient assemblées à la coque par des ligatures et par des chevilles cylindriques, des goujons, insérées le long d'un bord à travers des trous percés en diagonale depuis le bord jusqu'à la surface de la planche. Ces particularités témoignent du moment critique dans la construction navale grecque du remplacement des chevilles cylindriques, employées comme goujon, par des tenons, dans la construction par ligatures, ouvrant la voie à un éventuel remplacement des ligatures par des assemblages par tenons et mortaises. En outre, ils suggèrent que la technique par tenons et mortaises aurait pu évoluer naturellement au sein de la tradition grecque de construction par ligatures plutôt que d'avoir été emprunté aux Phéniciens ou à d'autres pratiques de construction.

THE VITH-CENTURY B.C. SHIPWRECK AT PABUÇ BURNU, TURKEY EVIDENCE FOR TRANSITION FROM LACING TO MORTISE-AND-TENON JOINERY IN LATE ARCHAIC GREEK SHIPBUILDING

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En 2002 et 2003, l'Institute of Nautical Archaeology a fouillé les vestiges d'un bateau grec naufragé au large de Pabuç Burnu, sur les côtes de Turquie, au cours du second quart du VI^{e} siècle av. J.-C. Les maigres restes de la coque du navire ont livré les premières données archéologiques sur la construction par ligatures en mer Egée.

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The Institute of Nautical Archaeology's (INA) shipwreck excavation in 2002 and 2003 at Pabuç Burnu, a small promontory on the southwestern coast of Turkey near Bodrum, has provided the first physical evidence for Archaic Greek ship construction in the Aegean. This is important because, prior to it, all Greek shipwrecks from the period with preserved hull remains had been found in western Mediterranean waters, though the laced construction exhibited in their remnants is believed to be Greek, and possibly East Greek, in origin (Pomey 1997: 199). The ceramic finds from the wreck so far have provided the best evidence for dating the ship's sinking, which likely occurred in the second quarter of the VIth century, around 570-560 B.C. (Greene et al. 2008: 700).

Most of the wreck material was found buried in deep sand on the sloping seabed off the western side of the cape at a depth of between 40 and 50 meters. Some ceramics, however, were scattered down a rock ledge that demarcated the upper, shallowest extent of the site (Fig. 1). The debris field measured almost 26 m north to south and 14 m east to west. The distribution of the ceramics and other objects on the site showed that the shipwreck was oriented approximately north to south, with the stern galley area of the ship situated at the northern and uppermost extremity at the base of the rock ledge.

The main concentration of artifacts lay strewn between sectors J6 and P11 and suggests that the ship may have been about 17-18 m long. Though tentative at best, this estimate is not inconsistent with the size of a stone anchor stock recovered from the middle of the wreck that measured 1.65 m long and weighed 115 kg (Greene et al. 2008: 687). A more conservative estimate, taking into account the incline of the seabed and possible dispersion of the ship's contents as they spilled out, would put the ship's length closer to 13-15 m. Judging from the size and number of recovered amphoras (approximately 260) and evidence for additional agricultural produce, the ship was carrying at least six tons of cargo when it sank, a light load for a ship of this size. The Grand Ribaud F ship (510-490 B.C.), the largest known wreck from this period at 20-25 m length, was carrying 800-1000 amphoras and had an estimated capacity upwards of 38 tons (Pomey and Rival 2002: 119). The Vth-century B.C. ship from Tektaş Burnu, Turkey, is estimated to have been about 14 m long and sank with some 200 amphoras on board (van Duivenvoorde in press), while the Ma'agan Mikhael ship that wrecked a few decades later is estimated to have been 13.8 m long with a displacement of 23 tons (Winters and Kahanov 2003: 131). The 14-m long Kyrenia ship that sank off the northern coast of Cyprus early in the IIIrd century B.C. could hold approximately 400 amphoras and had an estimated capacity of over 30 tons (Katzev 2005: 76). No evidence for ballast was found at Pabuç Burnu and one cannot ignore the possibility that the ship was not fully laden for its final voyage, a condition that may well have contributed to its unfortunate fate.

Excavation at the southwestern and deepest extent of the site revealed the fragmentary remains of six planks from the ship's hull, most likely from near the bow (Fig. 2) (Greene 2003: 9; Polzer 2004: 3-5; Polzer in press). In general, the hull fragments are in poor condition with much of their waterlogged wood damaged by marine borers (*Teredo navalis*). The three largest preserved planks are each approximately 2 m long, 20-30 cm wide, and 3-4.5 cm thick (Table 1).

Four of the fragments (UM1-UM4) were grouped together mostly in the upper corner of sector N15. Fragment UM1 retains most of both original edges, as well as a curved (S) scarf with a hook, while fragment UM3 has only one preserved original edge. The remains of planks UM2 and UM4 consist of only one small fragment each and some disarticulated scraps, though UM4 preserves traces of both edges and a curved hood end. The two largest pieces of planking (UM1 and UM3) were oriented approximately north to south, parallel to the main artifact spread. The scant remnants of UM2 and UM4 were found between these two but somewhat askew, with fragment UM2 slightly overlapping UM3. Plank fragments UM5 and UM6 were found within 2.5 m of opposite ends of this assemblage and oriented roughly perpendicular to it. Plank UM5 was preserved in two parts still aligned on the seabed but missing a 50-cm section between them (the length given in Table 1 is the combined dimension of the preserved portions). Together, the two fragments retain parts of both original edges and a diagonal scarf at one end. Fragment UM6 includes parts of one original edge and a butt scarf. None of the preserved fastening holes on any two planking fragments align.

Preserved tool marks and identification of wood samples taken from all six fragments reveal that the planks were first sawn from Austrian pine (*Pinus nigra*) and then carved to shape with an adze.[1] Pine was the wood of choice for hull planking in Greek boatbuilding: the VIth-century B.C. ships at Giglio (Bound 1991a: 43), Place Jules-Verne (Pomey 1999: 150-151), and Gela (Terranova and Campo 2001: 111); the Vth-century B.C. ships at Gela (Terranova and Campo 2001: 113), Tektaş Burnu (van Duivenvoorde in press), and Ma'agan Mikhael (Hillman and Liphschitz 2004: 145); and the IVth-century B.C. Kyrenia vessel (Steffy 1994: 43, 258) were all constructed with pine planks.

Since almost the moment of exposing the first plank fragment at the end of the 2002 excavation campaign, we have known that the ship's planking was assembled with ligatures —i.e., that it was laced— in a manner similar to a number of Archaic Greek ships from the Western Mediterranean. The hulls of these ships were built according to a "shell-based" method in which the planks were edge-joined with ligatures laced through oblique holes and tetrahedral notches and then locked in place with small wooden pegs driven into the lacing holes. When the Greeks first began lacing together the hulls of their ships is not known, but it is clear that by the VIth century B.C., they had developed their method to perfection, integrating a consistent and coherent host of features, techniques, and their applications

1) The wood was identified by Brian Jordan of the Department of Wood & Paper Science at the University of Minnesota, and subsequently confirmed by Nili Liphshitz at the Botanical Laboratory of the Institute of Archaeology at Tel-Aviv University.

into an elegant boatbuilding tradition (Prins 1986: 23-24). Ligatures had long been used in Egyptian vessels, as attested in the Cheops's funerary boat at Giza from ca. 2650 B.C. (Lipke 1984: 64; Lipke 1985; Steffy 1994: 23-28). Representations of boats from the Cycladic island of Syros, dating from 2800-2200 B.C., have been interpreted as depicting lashed or laced vessels (Basch 1987: 86), while bronze figures from Sardinia from as early as the IXth century B.C. testify to the use of ligatures in boatbuilding there (Bonino 1985). Laced boats are known as well from other regions, especially the northern Adriatic (Brusic and Domjan 1985; Berti 1990). However, Egyptian shipwrights lashed, rather than laced, their planks together with ligatures running athwartship. And while Adriatic boats were laced longitudinally along the seams, the application of the ligature holes and other details differ, and never include the use of tetrahedral notches; this feature has so far been found exclusively in Greek construction (Pomey 1999: 150).

The date, provenience, and hull construction features of the Pabuç Burnu ship place it firmly within an Archaic Greek laced boatbuilding tradition. That tradition is defined by a combination of construction features best preserved in the Giglio (580 B.C.), Bon Porté (540-510 B.C.), and especially Place Jules-Verne 9 (525-510 B.C.) wrecks, all of which have Greek origins (Bats 1996; Cristofani 1996; Kahanov and Pomey 2004: 24; Pomey and Long 1992: 191-192). Two other shipwrecks from this century, at Cala Sant Vicenç (Nieto et al. 2005a) and wreck 1 at Gela (Panvini 2001), have mostly similar features but with some variations similar to the Pabuç Burnu hull —more will be said on this below. The defining characteristics of Greek laced construction that these wrecks share include the use of wooden edge inserts, or coaks, to align the edges of the strakes and provide longitudinal stiffening, and plant ligatures to bind together the planks of the hull and to attach the frames to the strakes. The hulls were assembled without the use of metal fasteners. None of the original ligatures from the Pabuç Burnu ship survived, but fragments recovered from other wrecks have been identified as monocotyledons and flax (Bound 1991a: 49; Pomey 1999: 149, 150 n. 3; Shimony and Werker 2003).

The ligatures were laced through oblique holes pre-drilled along the edges of the planks from the inboard side through tetrahedral notches chiseled into the surface of the planks. The notches facilitated drilling of the ligature holes, reduced strain and wear on the ligatures and hole edges by providing a less acute corner around which the lacing were bent, and orientated the diagonal lacings between oppositely adjacent holes in the adjoining strakes (Pomey 1999: 150). The ligatures were laced over a cloth batten, or wadding, that was laid along the inboard seam. The wadding protected the lacing and plank edges from wear by providing a softer and more rounded surface, and allowed the lacing to be cinched down more tightly. While the Pabuç Burnu hull remains retained none of the actual wadding material, its original presence is confirmed by the absence of any pitch along the edges of the planks beyond the base of the lacing notches (i.e., along the seams). Wadding material was recovered from the Jules-Verne 9 wreck and tentatively identified as flax (*Linum usitatissimum*) (Pomey 1999: 149, 150 n. 3). Vestiges of cloth wadding were also preserved in the Cala Sant Vicenç wreck (Nieto et al. 2005b: 203). Once the planks were bound together securely, the ligatures were locked in place with small wooden pegs that sealed the holes and strengthened the bonds. The pegs were an essential element of laced joinery, without which the ligatures alone could not have held the planks together (Coates 1985: 17). The preserved pegs in the Pabuç Burnu hull were made of alder (*Alnus* sp.) and measure 6 mm in diameter.

After the planking shell was completed, it was reinforced with the insertion of substantial, preassembled made-frames consisting of floor timbers and futtocks scarfed end-to-end and fixed with at least two oppositely oblique treenails (Pomey 1999: 150). The frames were lashed to the planking at wide intervals but were never attached to the keel, perhaps reflecting the need for easy disassembly of the hull for regular maintenance and retightening of the ligatures (Pomey 1997: 195; for an account of maintening and replacing ligatures on a similar type boat, see Hornell 1941: 62). Frames lashed to a hull would also be able to give slightly to accommodate flexing of the hull and help reduce deformations of the planking joints (Coates 1985: 11). The frames were distinct in their shape, having a trapezoidal cross-section with a wide, rounded top and a narrow foot, and notches along their underside where they crossed over the planking seams. This morphology allowed the frames to be cinched tightly to the hull without damaging the ligatures and wadding (Pomey 1999: 150). The single frame of the Pabuç Burnu ship for which we have evidence was sided 7.0 cm along its base (Table 2). This dimension is larger than that of the Bon Porté (Joncheray 1976: 26-27), Cala Sant Vicenç (Nieto et al. 2002: 22), and Place Jules-Verne 9 (Pomey 1999: 150) vessels, and may indicate that the Pabuç Burnu ship itself was larger as well. On the upper sides of the hull, rectangular-sectioned top-timbers were inserted between the frame futtocks and attached to the strakes with both ligatures and wooden treenails (Pomey 1999: 149; Kahanov and Pomey 2004: 15). The treenails were needed to hold the timbers in their vertical position and prevent them from sliding down the hull. Plank UM1 from the Pabuç Burnu ship comes from the upper side of the hull and bears the ligature and treenail holes (1.2 cm in diameter) where three top-timbers were attached (Fig. 3). The timbers were spaced 84 cm apart (between centers) and their sided dimensions measured 15.3 cm. This also may provide some idea of the top sided dimension of the made-frames, which would seem to be in line with that of the Bon Porté (Joncheray 1976: 26-27), Cala Sant Vicenç (Nieto et al. 2002: 22), and Place Jules-Verne 9 (Pomey 1999: 150) ships.

After the framing was installed, the interior of the hull was smeared with a thick coating of tar or pitch, a common practice in antiquity that helped waterproof the planking and protect the seam ligatures and wadding from rot (Casson 1995: 211-212). The inboard surfaces of the Pabuç Burnu planking fragments are bespattered with reddish-brown tar made from Aleppo pine (*Pinus* sp.).[2] Likewise, the inner surfaces of the Giglio (Bound 1991b: 31), Cala Sant Vicenç (Nieto et al. 2004: 203), Place Jules-Verne 9 (Pomey 1999: 149), Grand Ribaud F (Long et al. 2001: 39), and Gela 1 (Panvini 2001: 23, fig. 16) hulls were all coated with tar.

The builders of the Pabuç Burnu ship deviated from so-called standard Greek laced construction by employing rectangular tenons rather than cylindrical dowels as coaks between the planks. Planks UM1 and UM5 were fitted with tenons made from Kermes oak (*Quercus coccifera*) and a species from subgenus *Sclerophyllodrys* (Fig. 4), suggesting that these shipbuilders were aware of the value of using edge fittings that were harder than the wood surrounding them, and that these tenons were more than mere plank aligners. Their mortises were cut from the center of the plank edges and are roughly staggered along one edge of the plank from those in the opposite edge. The mortises in UM5 are slightly smaller than those in UM1, reflecting the slighter dimensions of the plank itself (Table 3). Preserved corners of the mortises are sharp and precisely cut, with no evidence of pre-drilling.

Dowels were used in the hull as well, but apparently not in its original build. Planks UM3 and UM6 have oblique dowel holes measuring 1.2-1.4 cm in diameter. The dowel holes in UM3 are spaced irregularly along its preserved edge, with distances between centers varying widely from 12-44 cm. The holes were drilled at an angle from the plank's edge and emerge through its inboard face 6-12 cm from the

2) The tar was identified tentatively as made from Aleppo pine (*Pinus halepensis*) by Curt Beck at the Amber Research Laboratory of Vassar College.

edge (Fig. 5). Plank fragment UM6 contains a single preserved dowel hole that was drilled to the plank's exterior surface and retains a portion of the original dowel. These coaks were fashioned from branches of oleander (*Nerium oleander*), common troughout the Mediterranean basin in both tree and shrub form.

The oblique application and irregular spacing of these dowels indicates that the planks are replacement pieces used in repair of the hull. In order to replace a plank in an edge-joined hull, the coak holes along at least one edge of the new plank had to be made obliquely and open at the plank surface so that once the repair piece was fitted between the existing strakes the shipwright could insert the coaks and lace up the new assembly. The oblique holes would have been drilled preferentially to the inboard side of the repair plank, but where a frame or other obstacle prevented this, they were drilled to the outer face. The choice here to use flexible branches for dowels may well have been intentional, as they would be better able to bend from the angled holes of the replacement plank into the straight holes in the original strakes. This repair treatment is virtually identical to repairs made to the Kyrenia hull, though there pegged tenons were employed rather than coaks and lacing (Steffy 1994: 54-57).

The hull remains from the Cala Sant Vicenç shipwreck at Majorca exhibit strikingly similar features. The wreck is dated to the last third of the VIth century and is believed to be Greek in origin, sailing from Massalia or perhaps Emporion on the northeastern Iberian coast (Nieto *et al.* 2005a: 49-50). The ship's builders joined the strakes of the hull with tenon coaks and pegged lacing (Nieto *et al.* 2004: 202, 222 fig. 4). However, between the keel and garboard strakes the builders inserted cylindrical dowels diagonally from the inboard surface of each garboard through their edge and into the sides of the keel (Nieto et al. 2004: 202, 222 fig. 3). They may have applied the dowels in this manner in order to penetrate deeper into the keel and in this way effect a stronger join, or perhaps they too represent some type of repair or retrofit. Wreck 1 at Gela also appears to have been assembled with lacing and a combination of dowels and tenons. Dowels were used between the first three bottom strakes in the normal fashion (Panvini 2001: 21, 22 fig. 13). In the strakes above, however, dowels and tenons alternate between plank edges, at least in certain areas of the hull (Panvini 2001: 21, 22 fig. 15, 26 fig. 22). Unfortunately, the remains have not been well documented and published reports do not allow for a full evaluation of the ship's joinery.

The coaks of the Pabuç Burnu hull represent the earliest archaeologically attested use of tenons in Greek boatbuilding. Shipwrights in Egypt had utilized tenons and lashings to join hull planks and frames since at least the Old Kingdom. As in the Pabuç Burnu hull, these tenons were freestanding, but by at least 500 B.C. Egyptian boat builders were joining the strakes of their hulls with tenons locked into mortises with wooden pegs (Haldane 1996: 242). The earliest archaeological evidence for pegged mortise-and-tenon joinery in Mediterranean seagoing ships is found in the Late Bronze Age Syro-Canaanite ship excavated at Uluburun, Turkey (Pulak 1999). This type of edge joinery does not appear in the existing archaeological record of Greek shipbuilding until the latter VIth century B.C., in the Place Jules-Verne 7 hull (525-510 B.C.) excavated at Marseille (Pomey 1995: 476-477).

Indeed, a number of shipwrecks from the late VIth and Vth centuries B.C. demonstrate the early use of pegged mortise-and-tenon joinery in Greek shipbuilding. These include the aforementioned wreck 7 at Place Jules-Verne, the contemporary but smaller César 1 shipwreck from Place Villeneuve-Bargemon in Marseille, the Grand Ribaud F wreck (510-490 B.C.) from near Toulon, and wreck 2 at Gela (450-425 B.C.). The two ships from Marseille were abandoned in the last third of the VIth century and exhibit the same hull shape and construction techniques in their remains as the much larger Grand Ribaud F wreck (Pomey 2001: 429-430; Pomey and Rival 2002). They had rounded hulls with sharp, angled extremities and planking strakes joined with tenons locked into their mortises with wooden pegs (Pomey 1999: 150-151). The tenons are small and widely spaced (Table 3). The frames of these ships still have the same rounded trapezoidal shape as laced boats and they still have notches cut into their underside where they crossed over planking seams, despite the fact that they were nailed to the hull and there was no seam lacing to protect (Table 2) (Pomey 1999: 152). However, the traditional lacing technique (with tetrahedral notches, edge dowels, and pegged ligatures) was still used in the Marseille vessels to attach the ends of the strakes to the keel, stem, and sternpost, and also to make repairs in the hull planking (Pomey 1999: 151-152).

The presence of these wrecks alongside that of Place Jules-Verne 9 testifies to the early adoption of mortise-and-tenon joinery in Greek shipbuilding. The rudimentary nature of this technique is obvious from the fact that the ships' builders had to revert to lacing in difficult areas of the hull where severe curvatures and in situ fitting of planks proved too challenging for their proficiency with the new method (Pomey 1999: 151). Three quarters of a century later, little had changed in the hull joinery of the Gela 2 wreck (Benini 2001: 104), but Greek shipwrights had begun to realize and take advantage of some of the benefits of their new construction method. The ship's hull sported a wineglass shape, which provided it with a stronger spine and thus made it sturdier and longer lasting, and also gave it better sailing characteristics (Benini 2001: 106). The Ma'agan Mikhael ship that sank a few decades later (400 B.C.) shows further improvements. Its hull also had a wineglass shape, but now vestiges of the lacing technique were further diminished (Kahanov 2003: 54). Lacing through tetrahedral notches —but without coaks— was employed at the extremities, but only to attach the strake ends to the keel, end posts, and reinforcing knees that served as the main support elements of the end assemblies (Kahanov 2003: 64-69). Additionally, the frames were no longer notched for laced seams (Kahanov 2003: 92).

It would take another century, however, before Greek shipwrights mastered their new techniques. The well preserved hull remains of the Kyrenia ship, which wrecked around 295-285 B.C. after a long service life, testify to a ship in which all the hallmark traits of Greco-Roman ship construction were manifest. The hull had a more pronounced wineglass shape and rockered keel, a much denser network of pegged mortise-and-tenon joints, stronger framing with floor timbers and alternating half-frames nailed to the strakes through treenails, and a complete absence of lacing (Steffy 1994: 52-54). Even the numerous repairs made to the hull during its many years at sea were realized with specially shaped tenons (Steffy 1994: 56-57). The recent demise of laced joinery, or at least what vestiges of it that remained, is poignantly revealed in the discovery that planks from a laced boat had been trimmed of their ligature holes and reused as ceiling planking within the Kyrenia's hull (Steffy 1985: 95).

Even though the development of mortise-and-tenon construction in Greek shipbuilding is quite well attested in the shipwreck record (Fig. 6), the questions of when and how this process began —and why— remain. The contemporaneous nature of the Place Jules-Verne 9 and 7 and César 1 shipwrecks has prompted some scholars to conclude that the adoption of pegged mortise-and-tenon joinery into Greek boatbuilding occurred at the end of the VIth century B.C. in a wholesale manner that was rapid and inclusive of all types of vessels (Pomey 2001: 431). Many also assume that the Greeks acquired the new joint from the Phoenicians; that pegged mortise-and-tenon joinery was transferred from Phoenician shipbuilding into the Greek tradition (Bass 2006: 14; Kahanov and Pomey 2004: 24-25; Mark 2005: 35, 67-68; Pomey 1997: 201; Wachsmann 1998: 241). However, it would be quite remarkable for Greek shipwrights to so readily abandon their lacing technique and wholly adopt an entirely new type of joinery, given the conservative nature of these artisans (Mark 2005: 16; 60-62 for a good discussion of the conservatism of seamen and shipwrights). Nevertheless, some type of Phoenician influence does seem likely. Pegged mortise-and-tenon joinery had been used in Phoenician (and Proto-Phoenician) shipbuilding for at least eight centuries, as evidenced in the Uluburun (ca. 1305 B.C.), Cape Gelidonya (ca. 1200 B.C.), and Mazarrón (650-600 B.C.) shipwrecks. Roman writers later attributed the joint to the Phoenicians by calling it *coagmenta punicana* (Sleeswyk 1980). The Greeks were greatly stimulated by cultures with which they came in contact and traded, and orientalizing influences can be found in all facets of East Greek life at this time (Akurgal 1962: 374). But the early Phoenician role in this process and Greek-Phoenician interactions are difficult to quantify, though undoubtedly they did exist (Boardman 1999: 37-53; Markoe 2000: 172-174). The question is to what extent did Phoenician practices influence Greek shipbuilding and how was that influence manifested: as a direct transfer of new technology or as a stimulus for its development.

Pursuant to this question, one might ask whether a case can be made for an independent —or at least a more natural— development of mortise-and-tenon construction within a Greek laced tradition? Such developments in shipbuilding typically unfold gradually over time as shifting socio-economic forces and other influencing factors change the underlying circumstances within which the shipwrights operate (Steffy 2000). Indeed, the evidence from Pabuç Burnu, Cala Sant Vicenç, and Gela suggest that this was the case with mortise-and-tenon hull joinery. The use of tenon coaks in the hulls of these ships would appear to represent a higher level of sophistication within Greek laced construction than lacing with dowel inserts, not merely a variation of the technique. Cutting and fitting tenons and mortises is more difficult and time consuming than drilling holes and shaping dowels (see Steffy 1985: 90 for a description of cutting mortises). This is well illustrated in the case of one particular coak hole in plank UM5, where evidently the shipwright forgot to cut a mortise before he added the strake onto the hull during construction. He must have realized the omission only when he began inserting tenons in preparation for adding the next strake. Instead of taking the time to cut a mortise and shape a tenon, he chose instead simply to drill a hole and insert a dowel (Fig. 2).

Of course, Greek boat builders would not have switched from dowels to tenons had there not been significant benefit. Tenons provide greater resistance than dowels to normal stresses exerted against the seam joints and they impart greater longitudinal stiffness to the hull, which helps prevent sliding between planks (Coates 1985: 18). Greek shipwrights must have recognized this advantage, prompting them to integrate tenons into their hulls to make them stronger. This may be the point where a Phoenician influence interjected and provided the impetus for employing tenons in ship construction. Regardless, the Greeks did not convert to the Phoenician pegged tenon joint, rather they incorporated tenons into their hulls in the only manner they knew: as coaks. At this stage, the builders were not thinking fundamentally differently about hull design or construction, they were not yet using the tenons themselves as joints, and they were not intentionally developing a new method of hull construction. However, this change to tenon coaks was the necessary step required for eventual progression to pegged mortise-and-tenon joinery. Due to their shape, cylindrical dowels could not easily be pegged and therefore would never likely have evolved to take the place of lacing in edge joinery. The wider and flat tenon, however, could. It is not difficult to imagine a scenario wherein shipwrights familiar with inserting tenons into their planks, lacing them up, and pegging the ligatures finally realized that they could simply peg the tenons instead and eliminate the lacing altogether (Wachsmann 1998: 241).

Mark (2005: 62) asserts that similarities between pegged lacing and pegged mortise-and-tenon joinery are superficial, and that more would be require than merely learning how to fashion a new type of joint for shipwrights to start building hulls with the latter. Broadly speaking, this may be true, but it denies a role for innovation and experimentation. Furthermore, Greek boat builders did not simply start building their vessels with new joinery overnight; the evidence suggests that the process evolved more gradually. Once Greek shipwrights began using tenons in their laced boats, it could only have been a matter of time before they realized that they could combine the two separate elements of their joinery —tenon coaks and pegged lacing— into one integrated joint —the pegged tenon. Within decades of converting to tenon coaks, Greek shipwrights were constructing vessels such as those at Marseille, Grand Ribaud, and Gela with predominantly pegged mortise-and-tenon joinery. They were still working within the familiar confines of laced shipbuilding, but had changed the primary type of joinery that they employed. This is evident in the fact that this change was not accompanied initially by a significant modification of other elements of laced construction —namely hull shape, joint density, and frame morphology and spacing— and suggests strongly that Greek mortise-and-tenon construction evolved from and within the laced tradition.

Mark's assessment is correct in that the implications of the introduction of this new type of joinery into laced boatbuilding were far reaching. The adoption of any new technology always comes with a period of learning, experimentation, adaptation, and implementation. All of the intricacies that shipwrights building laced vessels had mastered over generations had to be relearned with this new method. Such challenges were encountered immediately in planking the bow and stern areas of the hull and in retrofitting damaged joints or planks. In these cases, the builders reverted to edge lacing with dowel coaks, techniques that were familiar and perhaps considered more trustworthy (Pomey 1995: 478-479). A similar reversion to a simpler and established technique is seen in the repairs of the Pabuç Burnu hull and confirms the relative newness of its original construction employing tenon inserts.

As Greek shipwrights and sailors became more experienced building and sailing ships assembled with pegged tenons, they adapted their designs and techniques to exploit the capabilities of the new joinery. The rigid joints, including a change to nailed frames, allowed for stiffer hulls that lasted longer and required less maintaining, which translated into greater economy of ownership over the life of a vessel. Mortise-and-tenon joinery allowed shipwrights to build hulls with more complex curvatures and produce ships that were more capable, that were better able to sail in adverse weather conditions, and that could carry greater loads, all of which again made them more economical (for an opposing view, see Mark 2005: 54-57). Vestiges of lacing were still present in the Ma'agan Mikhael ship built a century or so after the Jules-Verne 7 vessel, and it was not until the end of the IV$^{\text{th}}$ century B.C., as seen in the Kyrenia ship, that the new method was completely mastered. Thus, while it took perhaps only 50 years or so (one generation) to move from tenon coaks to pegged tenon joints, another two centuries were required for the full development to Greco-Roman mortise-and-tenon construction.

A full and convincing argument for why this change occurred has yet to be put forth. Mark attributes the replacement of lacing with pegged mortise-and-tenon construction to the increased transport of bulk cargoes in amphoras (Mark 2005: 63-66), and believes the transition was accelerated by the rapid buildup of state-supported naval fleets (Mark 2005: 68; concerning Aegean naval power and warships in the VI$^{\text{th}}$ century B.C., see Davison 1947; Dillon and Garland 2000: 48-49; Huxley 1966: 122-150). One other aspect of mortise-and-tenon joinery that is seldom discussed but that was an inherent advantage is that all of its constituent elements —mortises, tenons, and pegs— are located within the thickness of the hull planks and are thus well protected. By contrast, the wadding and much of the ligatures of laced joinery lie exposed on the interior of the hull. Shipwrights did what they could to minimize this exposure by coating the seam lacing thickly with pitch and using tetrahedral notches and oblique holes to keep the ligatures within the confines of the plank wood as much as possible, especially on the hull exterior. When ligature holes —whether for seam lacings or frame lashings— did not line up precisely, they cut a groove between the holes to keep the ligatures flush with the plank surface. Such efforts, however, could do only so much; lacing was inherently an exposed joinery vulnerable to heavy cargo items and the pointed toes of amphoras, particularly in rough seas when such items were most likely to shift. Sailors did their best to protect hulls and stabilize cargoes by spreading brushwood or other dunnage over the planks, but even this could snag and damage the seam and frame lacings. Pegged tenons were not only stiffer joints, they were less vulnerable to wear and damage than pegged lacing.

Whatever the exact causes of the transition, it is not surprising to find this technological advancement taking place largely in the VIth century and in an East Greek context. This was a time of tremendous innovation in all facets of Greek society, from city planning and architecture to science, philosophy, and the arts (Akurgal 1962: 376-379). Shipping and commerce were no less affected (Roebuck 1984: 133-134). The Greek cities of western Asia Minor were in the forefront of all of these advances, spurred on by geopolitical conditions that also stimulated colonization on a grand scale and, in turn, generated large international trade (Akurgal 1962: 372-374; Roebuck 1984: 124). These processes would have placed challenges on seafaring and demanded larger, stronger, and more capable ships (Roebuck 1984: 134-137). Thus, this dynamic time saw technological ingenuity and socio-economic incentives come together to provide the necessary conditions for advancements in ship construction.

As limited as the archaeological data is, especially from the Pabuç Burnu wreck, there is sufficient evidence to make a plausible case for a Greek development of pegged mortise-and-tenon joinery within laced construction. The original impetus for this evolvement in merchant ships remains open to debate, but undoubtedly it involved a need for ships that could carry greater burdens and comprised increasingly of amphora cargoes; that could sail farther distances; and that could better handle adverse sailing conditions. A growing demand for new warships with stronger and sturdier hulls that could withstand the tremendous stresses of ramming another vessel and that, in turn, could survive a similar blow, may well have accelerated, if not initiated, this innovation and development in Greek shipbuilding. An external technological influence, in particular a Phoenician one, cannot be ruled out, but the precincts of technology are never entirely limited to existing knowledge and materials —experimentation and invention obviously did occur, owing to the ingenuity of the shipwrights themselves (Steffy 2000: 265-266). The motive, opportunity, and certainly technological capability were all present within an East Greek milieu in the VIth century B.C. for a natural development of mortise-and-tenon construction from lacing, rather than a wholesale exchange of techniques. Ultimately, the ingenuity and mechanical ability of the shipwrights themselves more than any other factor enabled them to develop pegged mortise-and-tenon joinery from their pegged lacing method with tenon coaks, which in turn lead eventually to the evolution of a new shipbuilding tradition that would dominate ancient hull construction for at least 800 years. Final confirmation of how and why this process began must await the discovery and study of additional hull material from shipwrecks of this period —whether Greek, Phoenician, or others.

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Table 1. Maximum Preserved Dimensions of the Hull Fragments

Fragment No.	Length (m)	Width (cm)	Thickness (cm)
UM 1	2.24	30.5	4.5
UM 2	0.28	15.2	4.2
UM 3	1.86	27.8	4.1
UM 4	0.38	17.4	3.8
UM 5	1.72	20.2	3.2
UM 6	0.45	12.2	3.5

Table 2. Frame Dimensions and Spacing

Shipwreck	Type	Attachment Method	Sided (cm) Top	Sided (cm) Base	Molded (cm)	Spacing (cm)	Morphology
Giglio			18.0	—	12.3	—	
Pabuç Burnu	made-frames	lashing	—	7.0	—	—	trapezoidal
	top-timbers	lashing and treenails	—	15.3	—	81.8	rectangular
Bon Porté	made-frames	lashing	10-12	2-3	11-14	92-100	trapezoidal, rounded top, notched base
Cala Sant Vicenç	made-frames	lashing	20	4	—	90-100	trapezoidal, rounded top, notched base
Jules-Verne 9	made-frames	lashing	8.5	3.0	10	96	trapezoidal, rounded top, notched base
	top-timbers		—	—	—	96	rectangular
Jules-Verne 7	made-frames	double-clenched nails	—	—	—	98	trapezoidal, rounded top, notched base
	top-timbers	lashing and treenails	4-5	8	—	98	rectangular
César 1	made-frames	double-clenched nails	—	—	—	—	trapezoidal, rounded top, notched base
Grand Ribaud F	made-frames	double-clenched nails	19-20	5	26	82	trapezoidal, rounded top, notched base
Gela 1	made-frames	double-clenched nails	—	—	10-14	84	trapezoidal, rounded top, notched base
Gela 2	made-frames	double-clenched nails	—	—	—	60-70	trapezoidal, rounded top, notched base
Ma'agan Mikhael	made-frames	copper nails	14.2	6.2	11.4	75	trapezoidal, rounded top, limber holes
	top-timbers		—	—	—	75	
Kyrenia	floors and half-frames, detached futtocks	copper nails, double clenched	9	9	9	25	square, limber holes

Table 3. Mortise Dimensions and Spacing

Shipwreck	Plank Thickness (cm)	Mortises (cm) Width	Thickness	Depth	Spacing
Pabuç Burnu					
Plank UM1	4.5	3.3	1.0	6.0	28.7
Plank UM5	3.2	3.1	0.7	5.6	31.1
Cala Sant Vicenç	4.5	2.5	—	7.0	22.5-32.5
Jules-Verne 7	3.0	3.0	0.5	7.0	20.0
César 1	—	—	—	—	—
Grand Ribaud F	3.5	4.5	—	6.0	20.0
Gela 2	4.5	—	—	—	20.0
Ma'agan Mikhael	4.4	4.1	0.8	8.2	13.0
Kyrenia	3.7	4.5	0.55	8.0	11.7

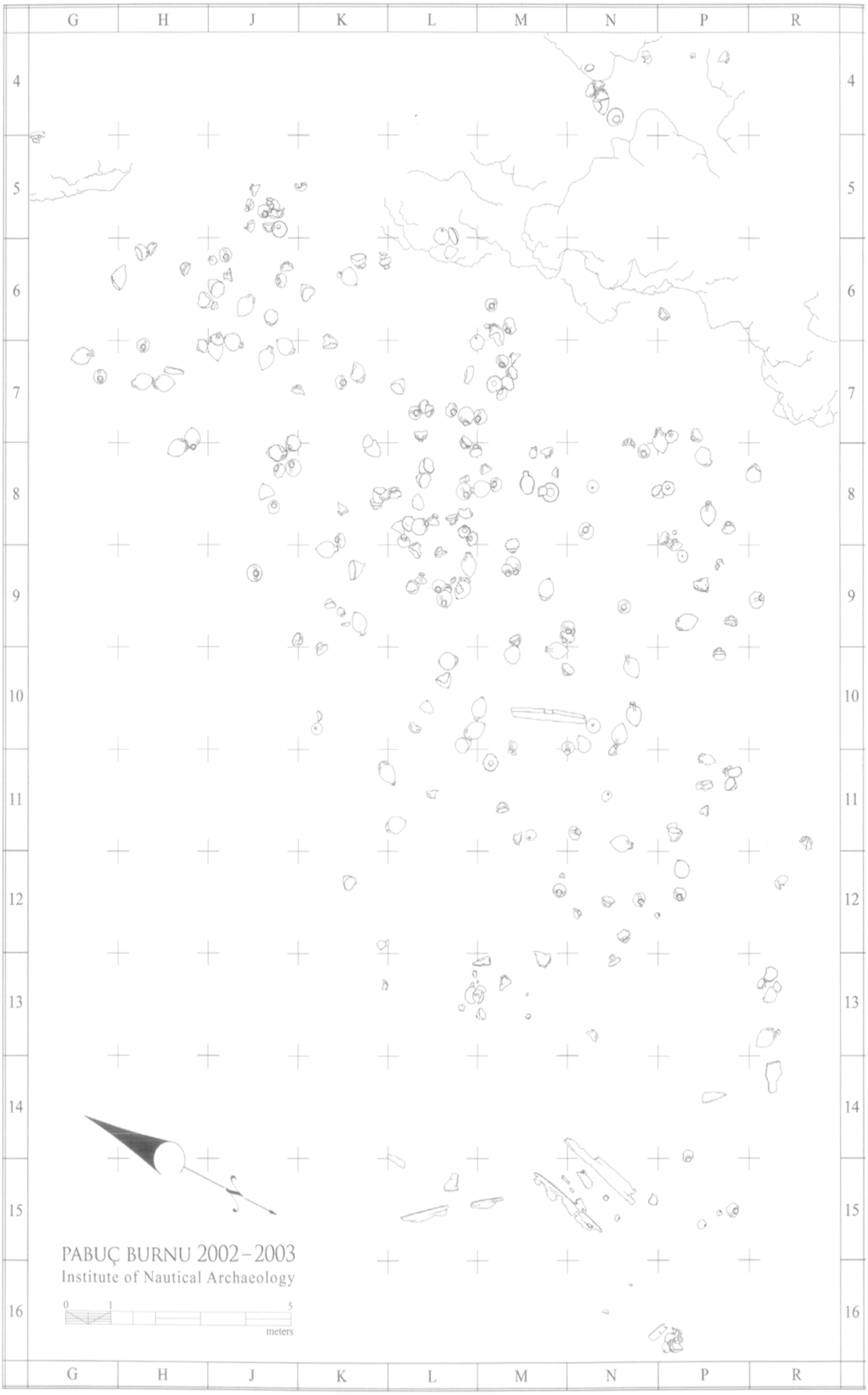

Fig. 1 : The Pabuç Burnu shipwreck site plan. (Drawing S. Matthews and M. Polzer).

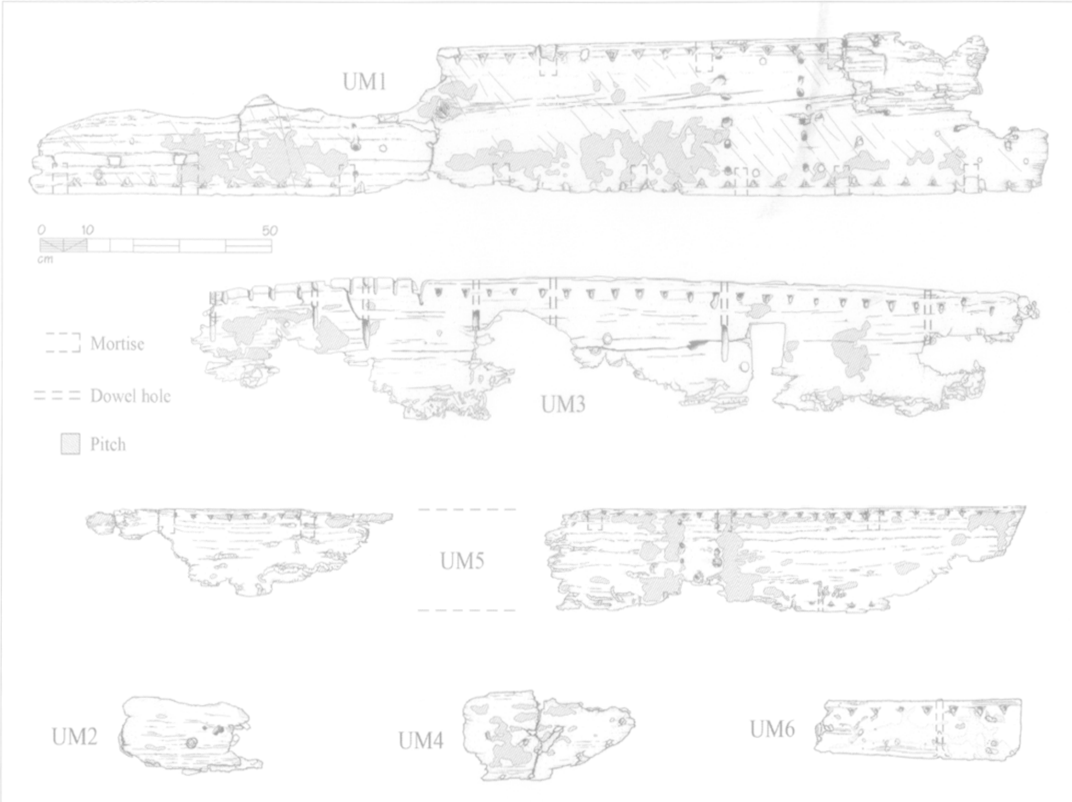

Fig. 2 :
Planking fragments recovered from the Pabuç Burnu shipwreck. (Drawing M. Polzer).

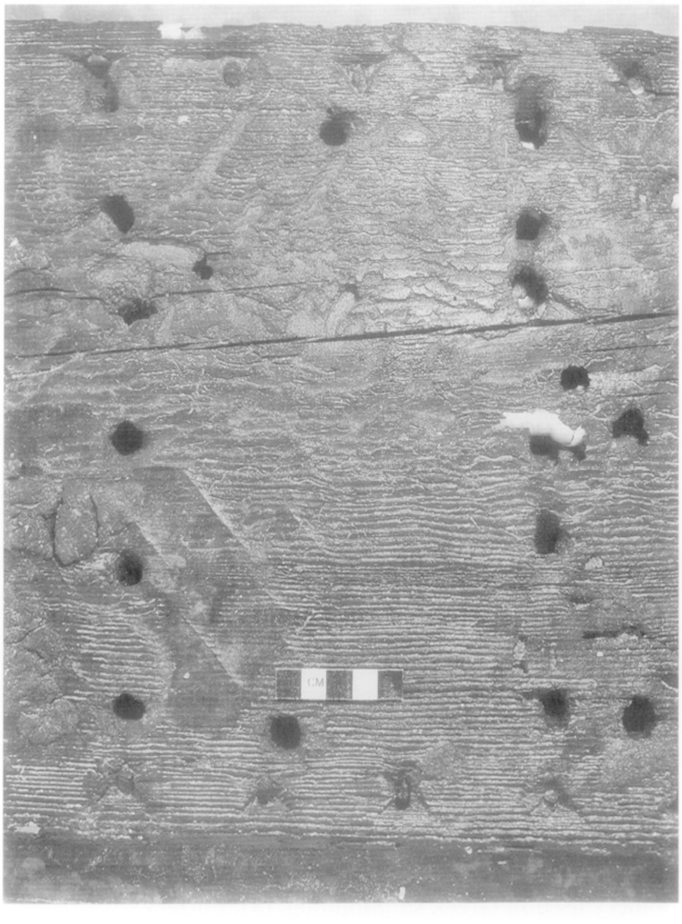

Fig. 3 :
Fastening holes for a top-timber in fragment UM1. (Photo M. Polzer).

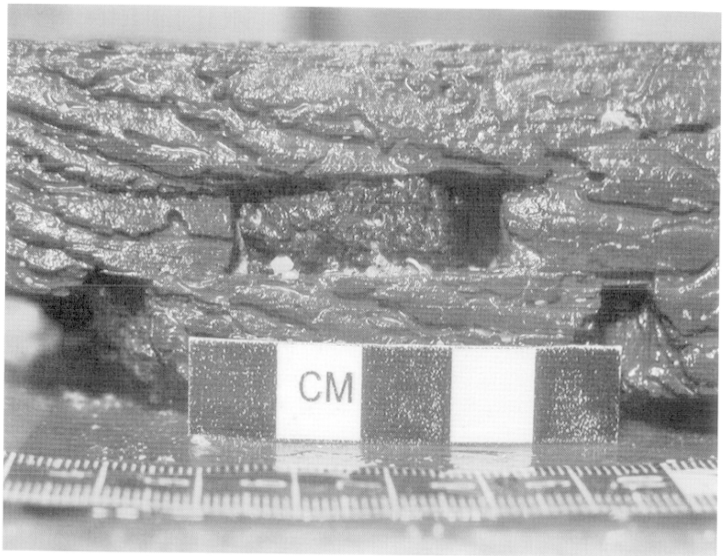

Fig. 4 :
Preserved mortise and half a tenon coak in fragment UM1. (Photo M. Polzer).

Fig. 5 :
Repair dowel hole in fragment UM3. (Photo M. Polzer).

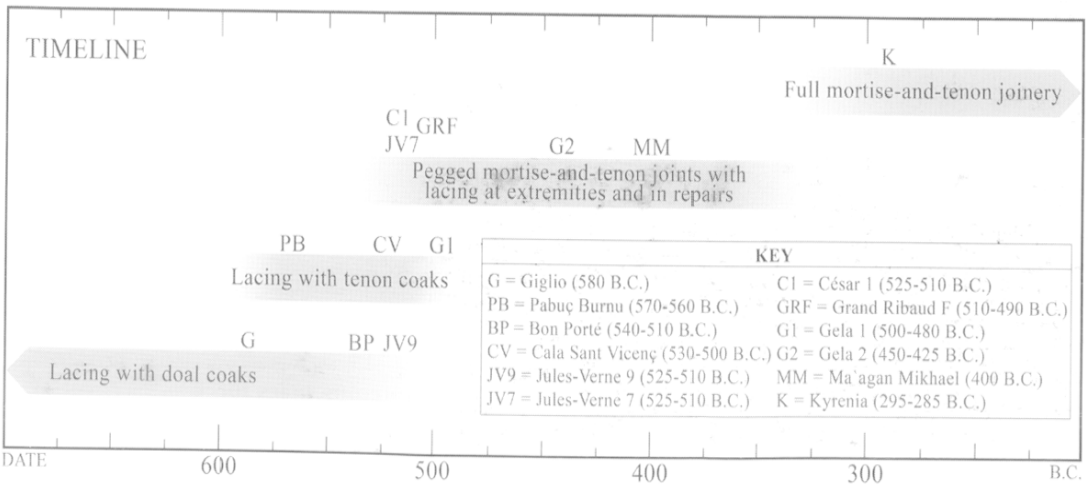

Fig. 6 : Timeline of edge joinery used in Greek shipbuilding. (M. Polzer).