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Transition from Shell to Skeleton in Ancient Mediterranean Ship-Construction: analysis, problems, and future research

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During the 1st millennium AD ship-construction changed. Previously, ships were built 'shell-first'—strakes were installed before frames, giving the hull its shape and integrity. About the mid-1st millennium AD the concept and construction of hulls changed to being shaped by transverse frames fixed to the keel, reinforced by longitudinal members. During the transition varying combinations of the two technologies were used. It has been widely accepted that the transition was completed by the beginning of the 2nd millennium. Recent discoveries, mainly in Dor/Tantura lagoon and lately in Yenikapı, analyses of other hulls, and reassessment of evidence, indicate an earlier completion of the transition. Since this process was the result of many factors, including economic and social, and occurred in different areas of the Mediterranean at different times, no simple linear development is suggested, but a more complex process, which raises questions for future research.

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Key words: transition in construction, construction principles, construction methods, Mediterranean, Late Antiquity, Early Middle Ages.

The expression 'transition in construction', referring to changes in shipbuilding technique and tradition, has been reconsidered several times. The conceptual approach to this question was first defined by Hasslöf (1958; 1963; 1966; 1972), who realized that construction methods were not necessarily the result of choosing between carvel or clinker planking-shell, but rather the builder's control of the shape of the hull and of its structural integrity. He thus characterized a hull as being of shell-construction or skeleton-construction. He also suggested expanding the approach to considering traditions, concepts, methods and constructions (Hasslöf, 1972: 42). Casson (1963; 1964a) extended the principles of this new approach to ancient Mediterranean shipbuilding, and concluded that ancient ships were built shell-first. Going a step further, Basch (1972: 15–49) introduced the concept of 'active' or 'passive' frames to explain the differences between shell and skeleton techniques. He interpreted the frames of a shell-constructed hull as 'passive', functioning only as reinforcement; and those of a skeleton-based ship as 'active', giving the hull its shape and its primary strength. 'Passive' frames were not necessarily connected to the keel, whereas 'active' frames were. Basch continued by introducing the term 'intermediary techniques'—or 'mixed construction'—in which active frames were employed together with passive frames in most hulls in different proportions. In his answer to Basch, Christensen (1973: 143) explained the phenomenon of most mixed-construction hulls as a 'shellbuilder's solution to skeleton problems', or *vice versa*.

To extend the discussion, Pomey (1988; 1994; 1998; 2004a) proposed a new approach based on the differentiation between construction principles (the hull-concept) and building methods (the construction-process). In this analysis, he gave a fundamental role to the structural conception of the hull. He defined hull integrity according to several construction features, as being primarily based either on planking, or on frames, with possible mixed solutions. Steffy (1995: 418–19),

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extended this analysis, and suggested abandoning the definition of 'shell-built' or 'shell-first' in favour of 'tenon-built'. He considered the way in which the hull was shaped, and its form based on longitudinal or transverse orientation.

McGrail (1997) explained the alternatives, and suggested the terms 'plank-oriented' and 'frame-oriented' or 'frame-based', and indicated that the majority of hulls were of mixed construction or 'intermediate or alternating forms'. Pomey (1998) and Pomey and Rieth (2005) adopted the new idea for the hull-shape concept, and saved the 'shell' or 'skeleton' definitions for the structural concept: '*conception longitudinale sur bordé*' or '*conception transversale sur couples*'. Lastly, to summarize the question, Hocker (2004: 6) defined three classification criteria: design, assembly-sequence, and structural philosophy; which are equivalent to hull-shape, building-process and structural concept.

The variations are much more than merely technical issues: they are facts, revealing basic changes in the principles of ship-design, hull-structure, and construction-methods. Instead of viewing a ship longitudinally, based on a shell of strakes joined together to determine its form and structural integrity, the concept changed to that of a shape and a structure based on transverse frames. This transition was a process that lasted *c.*1000 years, mainly during the 1st millennium AD. It was influenced by many factors, such as society, economics, geography, and environment; and probably varied from one region of the Mediterranean to another.

The transition is sometimes explained as a reflection of social and economic stresses, such as those which arose in the Byzantine era in the eastern Mediterranean, or after the Islamic conquest (Kreutz, 1976; van Doorninck, 1976: 130; van Doorninck, 1982: 139–40; Casson, 1990; Steffy, 1995: 417; Mor, 2011). However, these factors, and their technical, social and economic consequences, must be better defined in order to determine their effects on the transition process. Similarly, whether the transition was also affected by the 'Barbarian' invaders of the western Mediterranean, such as Vandals, Burgundians, Visigoths and Ostrogoths, is another question for future research. Environmental conditions should also be considered in future studies, as one of the possible influences was climate-change and its ecological effects on forest resources, and therefore on the supply of timber for shipyards.

The technology was combined with the shipwright's basic attitude and his concept of construction, giving the hull its shape, integrity and strength—either a longitudinal strake orientation and a shell structure (shell technique), or a transverse frame orientation and a skeleton structure (skeleton technique). Elements of these two basic methods were often incorporated to different degrees, whether in shaping and reinforcing the hull, or in the sequence of construction (mixed technique). From a structural point of view, the shell technique needed a strong connection between the planks (and the keel) of the hull to maintain its integrity; but not necessarily between the frames and the keel, or between the components of each frame. However, internal longitudinal timbers (keelson, stringers) often reinforced the hull-structure, ensuring a minimum of coherence to the heterogeneous framing.

Because of the close setting of planking-edge fasteners (pegged mortise-and-tenon joints), adjoining connections between the planks, and the high standard of carpentry—sometimes actual carving and sculpting—watertightness was achieved without caulking. However, pitch was applied internally and externally, penetrating into the seams, and sometimes luting was also used (Santamaria, 1995: 149–50). On the other hand, the skeleton technique required integrity of the framing, especially with the keel, but no connections between the planks. However, the absence of connections between the planks required watertightness to be ensured by caulking the plank-seams. This caulking created a mechanical compression of the planks which contributed to the structural integrity of the hull (Coates, 1985a: 15–18; 1985b: 440–41; 2001: 154). In addition, some elements of the longitudinal inner structure, the keelson and stringers in particular, also contributed to the integrity of the framing. The development of the skeleton during the transition shows some identifiable technical characteristics. In order to create a cross-sectional basis for building the hull, frames or, more precisely, some significant frames which determined the transverse geometry of the hull, must have been pre-designed and shaped before they were rigidly installed on the keel to form the skeleton. The longitudinal strength of the hull should be evaluated when considering characteristics of the skeleton concept, in order to understand the different evolutions of the two basic methods of construction.

Steffy (1994) demonstrated the transition in terms of the lessening of the importance of edge-joints between the strakes (Fig. 1), and consequently the reduction of the longitudinal strength of the hull. This approach had been discussed earlier by van Doorninck (1976: 122–3) and Steffy (1982b: 26–8; 1991: 1–2). However, although significant, the evolution of edge-joints is not the only criterion for this change. For example, the role of the frames in the hull changed over the years with the introduction of 'active frames' as described by Basch (1972). In addition, the nailing or bolting of frames to the keel, and eventually to the keelson, also needs further study, as it cannot be interpreted simply.

Nails or bolts connecting frames to keel in vessels of the Hellenistic, Republican, and probably early Roman Imperial periods, were basically reinforcement, as illustrated by La Madrague de Giens and other shipwrecks (Fig. 2) (Pomey, 1978: 77; 1998: 66–7; 2002a); and in the construction of the famous *Syracusia* by Hiero II, which provides the earliest evidence for the use of such bolts (Salviat, 1990). By late Antiquity

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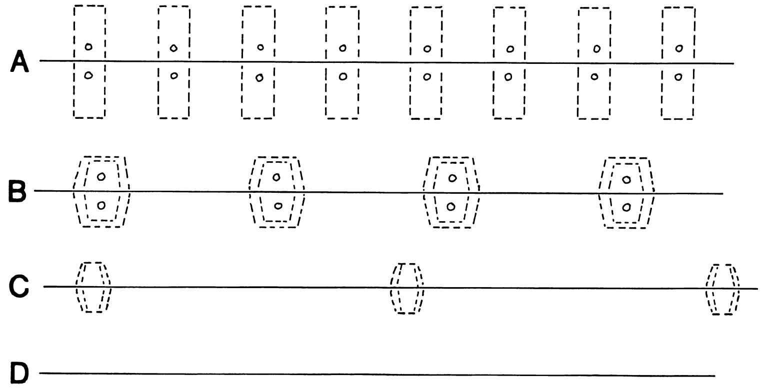

Figure 1. Transition in mortise-and-tenon joinery. A) Kyrenia ship; B) 4th-century Yassıada 2 ship; C) 7th-century Yassıada I ship; D) Serçe Limanı ship. (Steffy, 1994, fig. 4.8, reproduced with permission)

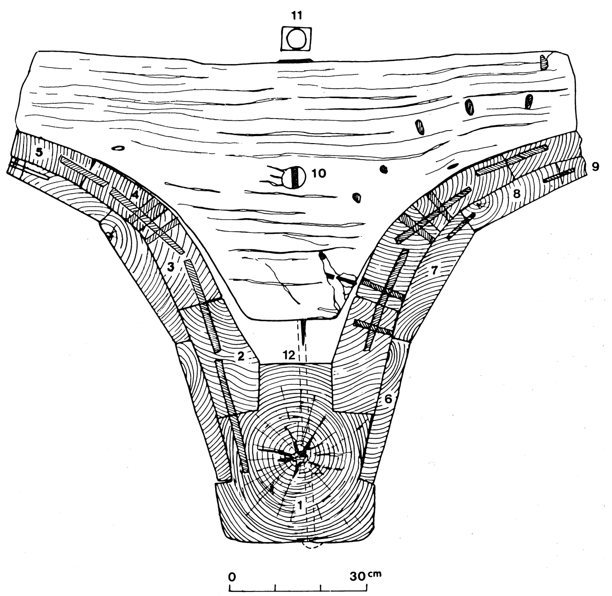

Figure 2. La Madrague de Giens shipwreck. Detail of cross-section at frame M104. Note the bolt connecting the floor-timber to the keel. (Pomey, 1978, fig. 10)

this was a major component of skeleton construction, as described below. In general, the reinforcement of the hull-framing of some vessels of the Roman Imperial period can be considered as a possible stage in the transition process (Pomey, 1998: 68–9; Pomey and Rieth, 2005: 166–71). These vessels belong to a new structural type of the Roman Imperial period developed in the 2nd century AD in the western Mediterranean. This new tradition—western Roman Imperial—is exemplified by several hulls with flat bottom-frames and a round turn of the bilge, and is characterized by bolted frames, overlapping half-frames, a long mast-step/keelson set on two sister-keelsons, and active or partially active frames.

The structural system also has to be considered. The usual discussion concerns the role played by each component of the tripartite structure: longitudinal axial members, planking, and framing, in keel construction. However, recent research has raised the problem of 'keel construction', characterized by a morphological and structural continuity between the bottom and the sides, and of 'bottom-based' ('s*ur sole*') construction, characterized by a morphological and structural discontinuity between the bottom and the sides (Arnold 1998: 76).

Until recently it was widely accepted that the first ship known to have been constructed purely skeleton-first was the Serçe Limanı 'Glass Wreck' of the 11th century AD. Following Steffy's comment that 'we can only hope for an abundance of forthcoming archaeological discoveries' (1994: 91), this paper takes into account several recently-excavated wrecks, mainly from Dor/Tantura lagoon and Yenikapı, Istanbul. Considering these new discoveries in the context of many other wrecks in dealing with the question of transition, an earlier date for the transition, and different possible roots, are suggested. The word 'root' is employed here in the sense of development of a distinctive construction technique, similar to Greenhill's usage of the word (1976: 89). However, this does not lead to a simple solution, but poses several questions, and suggests directions for future research.

Shipwrecks from the western, central and eastern Mediterranean are chosen here to demonstrate the problems, with brief explanations (Figs 3–4). One geographical exception is the County Hall wreck found in London, but built according to the Mediterranean tradition. The Port Berteau 2 shipwreck, from the Atlantic area, is also considered, due to its relevance to the discussion of the origin of some aspects of the transition. Apart from recent discoveries, most of the Mediterranean shipwrecks considered are listed in Parker (1992). The list is not exhaustive, but the examples have been chosen for the importance of their remains, the quality of the evidence, and their relevance to the evolution—even from a negative point of view—towards the complete transition. The shipwrecks are presented in chronological order, and then summarised in Tables 1 and 2.

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Figure 3. Location map of Mediterranean shipwreck sites. Corpus sites: 8, Fiumicino 1, 2, 3; 11, Parco di Teodorico; 14, Pantano Longarini; 19, Akko Marina. Other sites: 23, Mazarrón 1, 2; 24, Binissafúller; 25, Golo; 29, Cala Sant Vicenç; 31, Ma'agan Mikhael; 32, Kyrenia; 34, San Marco Island, Boccalama; 37, Gela 2. (V. Dumas and P. Pomey, Centre Camille Jullian, CNRS)

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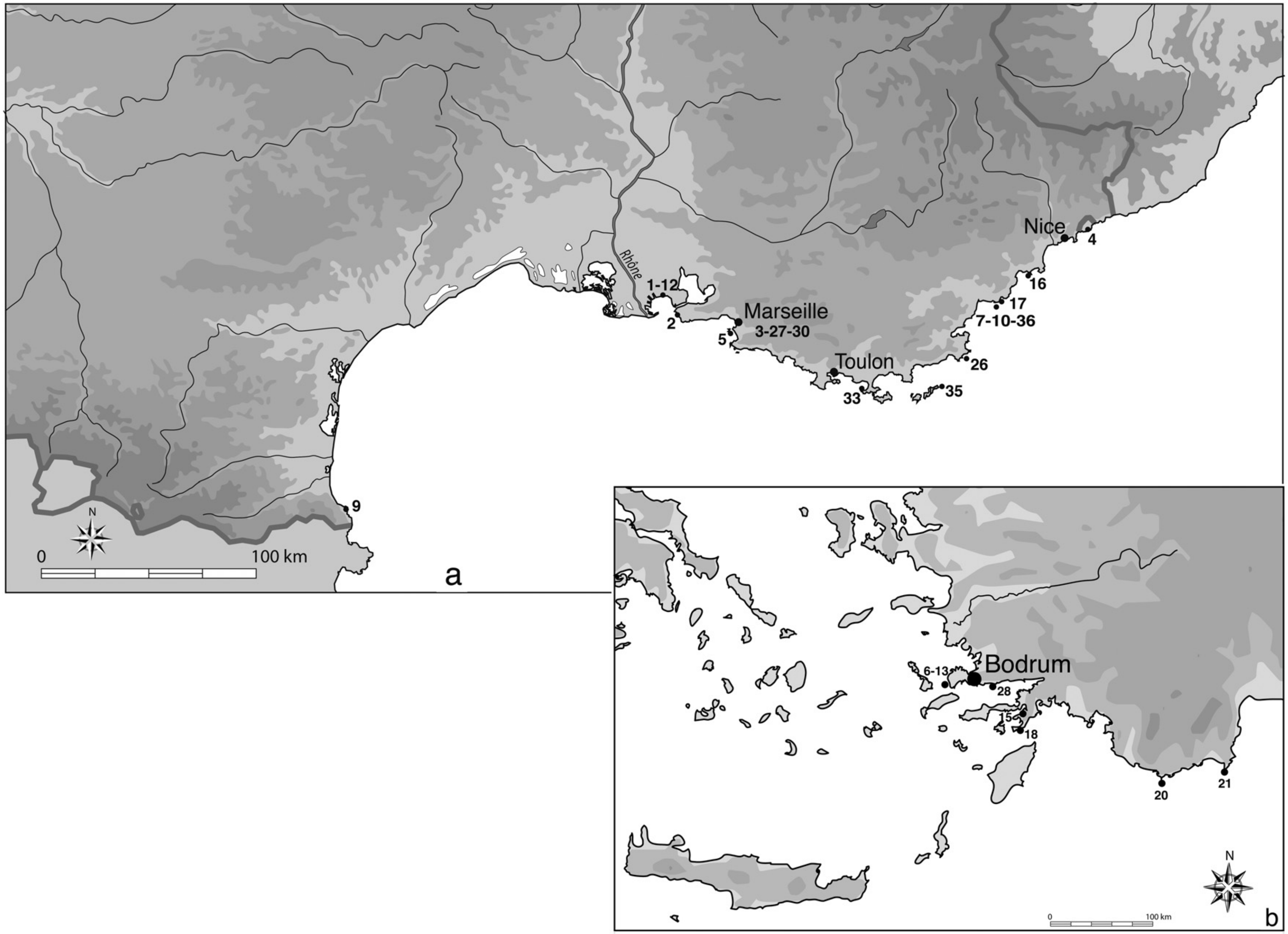

Figure 4. Detailed location map of Mediterranean shipwreck sites: (a) French coast. Corpus sites: 1, Saint-Gervais 3; 2, Laurons 2; 3, La Bourse (Lacydon); 4, Monaco; 5, Pointe de la Luque B; 7, Dramont F; 9, Port-Vendres 1; 10, Dramont E; 12, Saint-Gervais 2; 16, Bataiguier; 17, Agay A. Other sites: 26, Bon Porté 1; 27, Jules-Verne 7, 9; 30, César 1 (Villeneuve-Bargemon 1); 33, La Madrague de Giens; 35, Titan; 36, Dramont A. (b) Turkish coast. Corpus sites: 6, Yassıada 2; 13, Yassıada 1; 15, Bozburun; 18, Serçe Limanı. Other sites: 20, Uluburun; 21, Cape Gelidonya; 28, Pabuç Burnu. (V. Dumas, P. Pomey, Centre Camille Jullian, CNRS)

Saint-Gervais 3

(Pomey, 1987–88: 12–13; Liou *et al.*, 1990: 157–264) (Figs 5–7).

The wreck was found near Saint-Gervais in the Golfe de Fos in southern France, at a depth of 4 m. It was dated by amphoras with *tituli picti* to the mid-2nd century AD. The remains were 14.7 m long and 6.8 m wide. Its reconstructed length was 17 m, and its maximum beam was 7.5 m. The transverse section at the main frame had a flat frame with a round turn of the bilge. The hypothetical reconstruction proposes a concave stem.

The keel was 17 cm sided and 18 cm moulded. It was scarfed to the stem and stern transitional timbers. The keel was chamfered for the garboards, which were up to 75 mm thick next to the keel, to which they were attached by double rows of mortise-and-tenon joints. The planks were 20–30 cm wide and 35–45 mm thick. Planks were connected to each other by closely-set mortise-and-tenon joints. The mortises were 70 mm wide, 7 mm thick, 130 mm deep, and spaced 120 mm apart (centre-to-centre). The pegs were tapered, and generally driven from the inside of the hull. Toward the fore-part, three pegs were driven from the outside at the level of strakes 7 and 8, under a bolted floor-timber

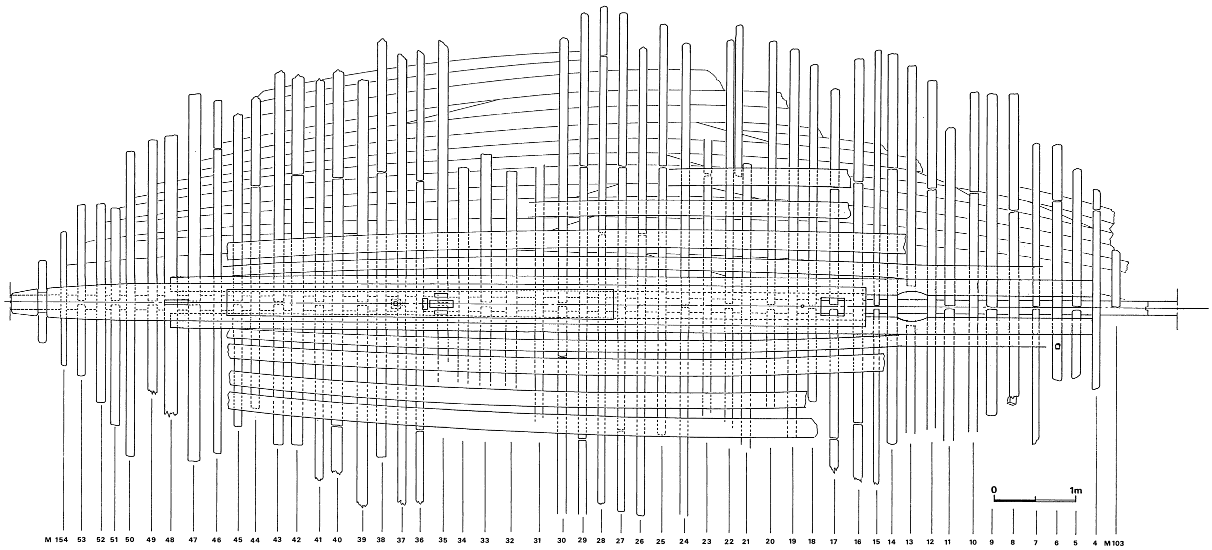

Figure 5. Saint-Gervais 3 shipwreck. Hull plan. (Liou *et al.*, 1990, fig. 80, reproduced with permission)

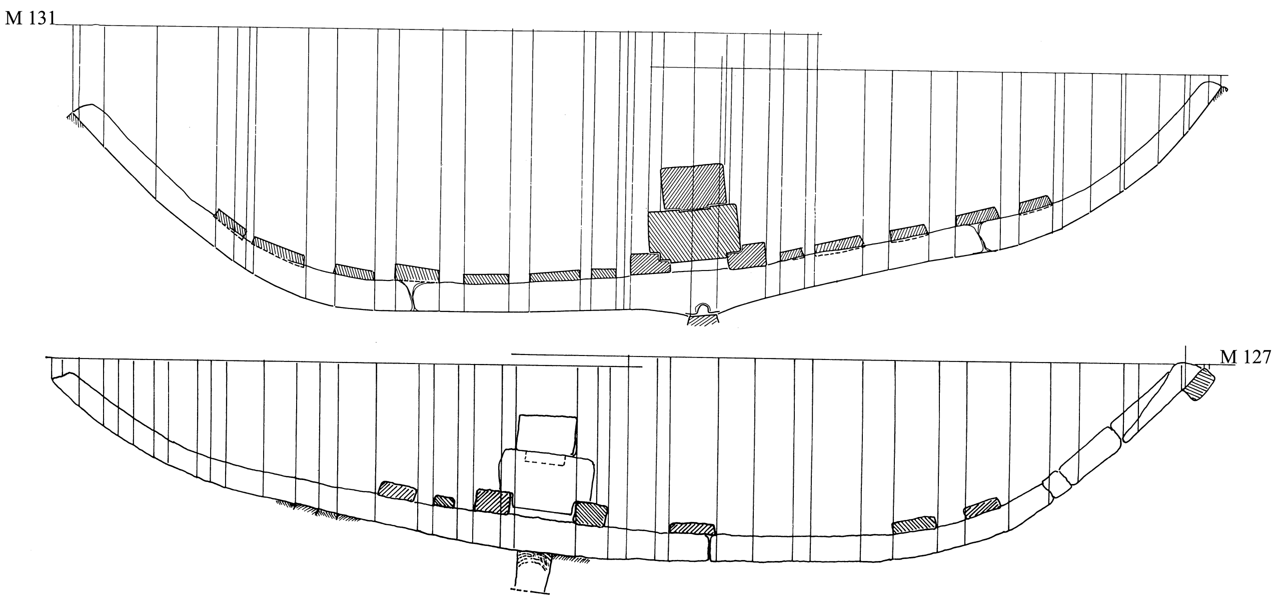

Figure 6. Saint-Gervais 3 shipwreck. Cross-section at frames M127 and M131. (Liou *et al.*, 1990, fig. 86–3, reproduced with permission)

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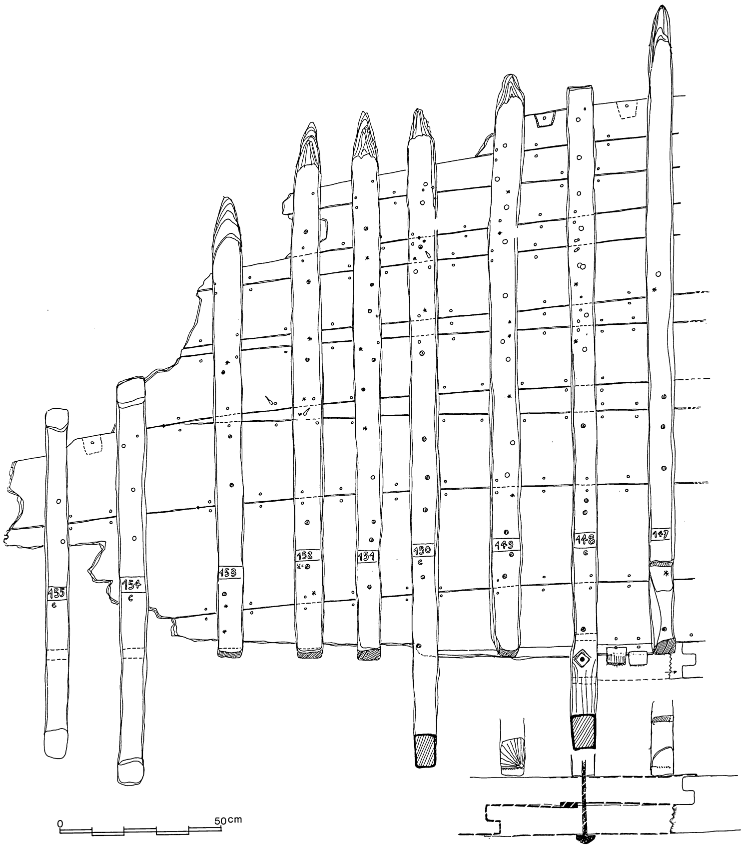

Figure 7. Saint-Gervais 3 shipwreck. Detail of the fore part of the hull. (Liou *et al.*, 1990, fig. 97, reproduced with permission)

(M 148) and a simple floor-timber (M 150) (Fig. 7). This sequence suggests a possible partial role of active frames for these two floor-timbers. Planks were joined with diagonal scarfs to form strakes. One lower wale, 165 mm wide and 90 mm thick, was partially preserved and integrated into the planking. Fifty-five frames survived, on average 14–16 cm sided and 13 cm moulded, with room-and-space of 28–30 cm. They were not connected to the keel, except for three floor-timbers (one over each keel-scarf with the endpost, and one aft), which were fixed by copper bolts. The frames were connected to the planking by pairs of treenails (15 mm diameter), and at the fore extremity by copper nails.

The general framing-pattern was of alternating floor-timbers and half-frames. Some half-frames overlapped amidships, one extremity crossing the keel so that the butt-joint of the two half-frames projected beyond the central axis. This system of half-frames allowed the reinforcement of the hull-framing. The futtocks were not connected to the lower frames. A large keelson, 10.5 m long, 47 cm wide and 27 cm thick, was installed above two sister-keelsons (*carlingots*), 18–20 cm wide and 11–13 cm thick. A mast-step (4.8 m long, 38 cm wide, 21 cm thick) with several recesses for mounting the mainmast was set on the keelson. This is a unique example of such a mast-step timber independent of the keelson. There were numerous stanchion-holes in the longitudinal timbers, and a recess for the foremast toward the extremity of the longitudinal timber.

With flat floor-timbers amidships, overlapping half-frames, and a keelson fitting onto two sister-keelsons—not directly over the floor-timber—this hull is characteristic of the Roman Imperial type found in the western Mediterranean (Pomey, 1998: 68–9; Pomey and Rieth, 2005: 166–71). In comparison with the earlier Hellenistic or Roman Republican type (Pomey, 2004b); the hull was largely reinforced transversely by the framing, and longitudinally by a combined system of keelson and stringers. The hull was made watertight by an internal coat of pitch. The hull-structure was obviously based on a shell concept, and its shape was based on a longitudinal strake-oriented concept. However, the hull-structure showed reinforcement of the framing, and it is possible, although not quite certain, that some partially-active frames were used at the extremities after the assembly of the first seven strakes. This was deduced from the observation of some reverse pegs under a floor-timber (but there were very few, and they could have been the result of a change during construction, or repairs). In this hypothesis, the building process may be considered to be mixed, and the use of some partially-active frames can be considered as a skeleton solution to a shell problem.

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Laurons 2

(Gassend *et al.*, 1984: 75–105; Pomey, 1987–88: 23–5; Pomey, 1988: 406–07; Ximénès, and Moerman, 1991; Pomey, 1992: 24–5; Pomey, 2004a: 32) (Figs 8–9).
The wreck was found in the Anse des Laurons in the Golfe de Fos, southern France, at a depth of 2.5 m, and was dated to the end of the 2nd century AD. (It was recently re-dated to the end of the 3rd century, based on a coin found in the pitch covering the ceiling-planks, and the study of ceramics among the crew's possessions. The identification of the coin is still open, however, and we have retained the traditional dating, which corresponds better to the majority of the artefacts). The remains were 13.3 m long and 6 m wide at the master-frame. The reconstructed dimensions of the hull were 15 m long by 5 m wide. Its main significance is in the surviving remains of the upper part of the hull, the deck and above the bulwark and its stanchions. The transverse section of the hull had flat frames with a round turn of the bilge.

The keel was 8.6 m long, 12 cm sided and 16 cm moulded. It was scarfed to the stem and stern transitional timbers. The keel was chamfered for the garboards, and the endposts were rabbeted. Planks were generally 25 mm thick, except for the garboards, which were 45 mm thick at their keel face, and 14–30 cm wide. They were connected to the keel and to each other by pegged mortise-and-tenon joints. The tenons were 60 mm wide, 10 mm thick, 120–130 mm deep, and spaced at 120 mm. The pegs were tapered, 9–11 mm in diameter, and driven from the inside of the hull, except for strakes 10 and 11, which were replacements. Strakes were made from planks diagonally scarfed with mortise-and-tenon joints, and nailed horizontally at their extremities.

Two wales, 12 cm wide and 8 cm thick, reinforced the planking. Fifty-five frames survived, composed of alternating floor-timbers and half-frames. Some half-frames overlapped. They were 7–9 cm sided and 20–22 cm centre-to-centre. Floor-timbers were moulded 20 cm near the keel and 10 cm elsewhere, while half-frames were mostly 9 cm moulded. There was no connection between the lower frames and the futtocks. Frames were connected to the pre-existing planks by 15-mm-diameter treenails, usually two per frame per plank. Four floor-timbers were connected to keel/endpost timbers by metal bolts, located on the two keel/transitional timber scarfs, on the transitional timber/stem scarf, and on a floor-timber (M 150) astern. Copper (or bronze) nails were used in the attachments of plank-extremities to the endposts, for fixing the lower strakes to frames, and in the stringer-frame connections. The keelson/mast-step timber was set on two sister-keelsons. Transverse beams, preserved in the upper section of the bow and stern, were connected to the wales, not to the frames. Some of the beams were of double thickness over the deck

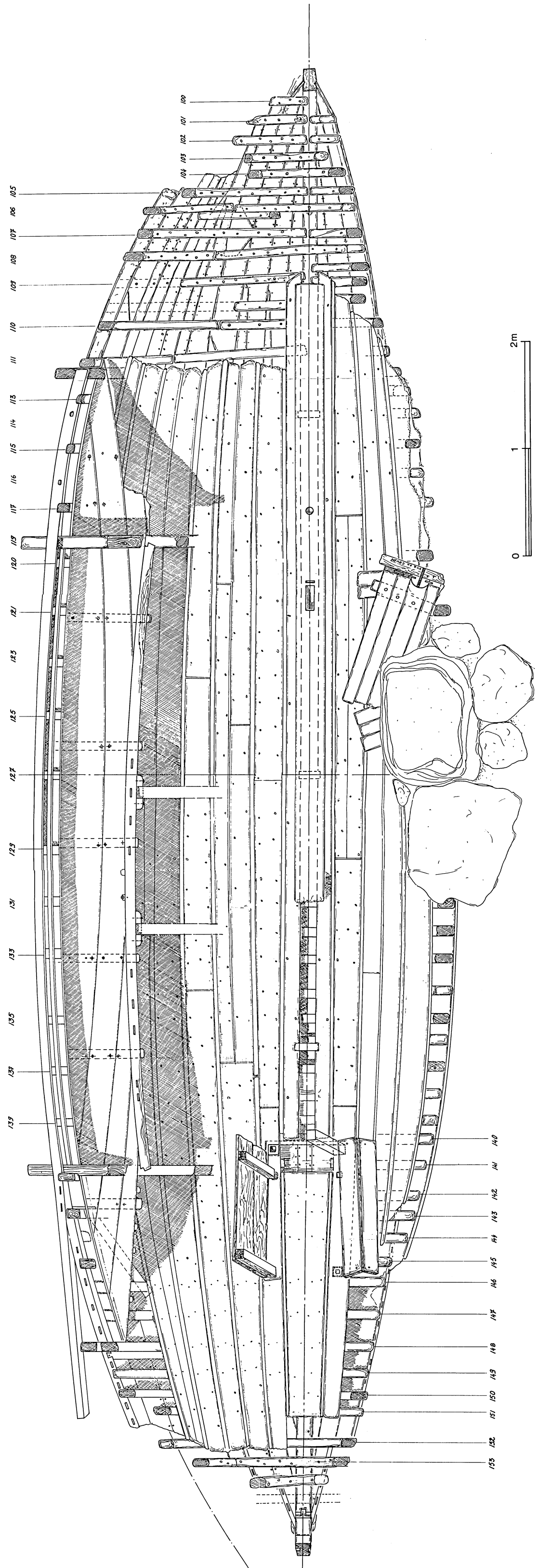

Figure 8. Laurons 2 shipwreck. Hull-plan. (Gassend *et al.*, 1984, fig. 21, reproduced with permission)

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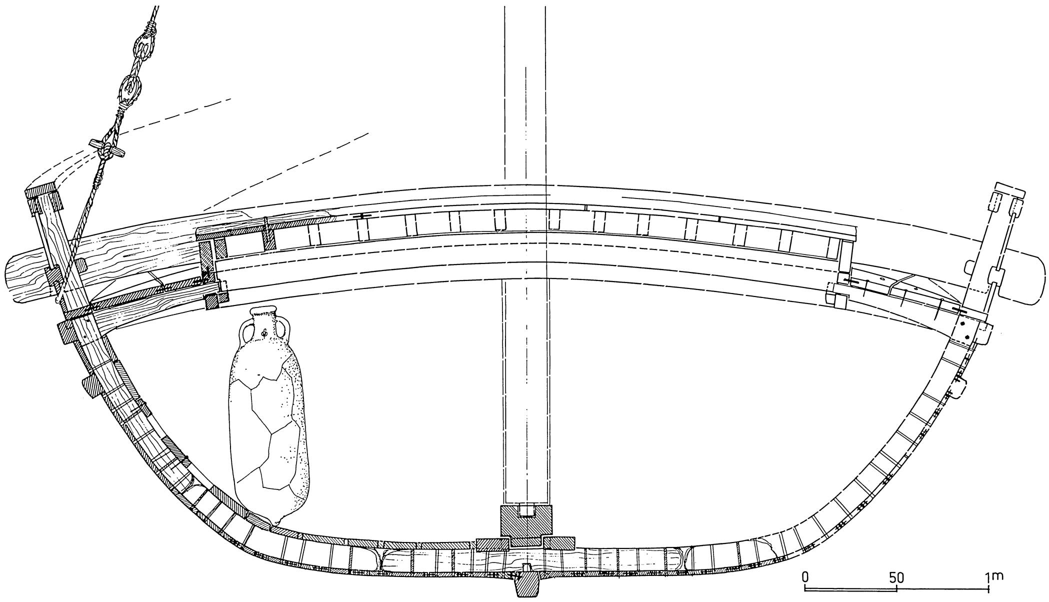

Figure 9. Laurons 2 shipwreck. Cross-section amidships. (Gassend *et al.*, 1984, fig. 17c, reproduced with permission)

(*surbaux*), in order to give additional transverse strength. The hull was made watertight by an internal coat of pitch.

The characteristics of the hull show that it was based on a shell structural concept and longitudinal, strake-oriented hull-shape, rather than having the integrity of a skeleton-based construction. The building process was very probably shell-first. The bolts connecting some floor-timbers were probably for the reinforcement of the hull—three of the four were located on keel/endpost scarfs—and not an indication of active frames, of which there was no evidence. The wreck was re-opened and reconsidered during dendrochronological research in 1994 (Guibal and Pomey, 2009). The planking, mortise-and-tenon joints and the repairs between strakes 10 and 11 were scrutinized in detail. There was no evidence for the hypothesis of an 'alternating construction', a mixed process of skeleton-first, as proposed by Gassend (Gassend and Cuomo, 1982: 272; Gassend and Cuomo, 1985: 350; Gassend, 1989: 118; *cf*. Pomey, 1988: 406–07; Pomey, 2004a: 32). However, the Laurons 2 hull belonged to the new western Roman Imperial type with a flat bottom and reinforced framing.

La Bourse (Lacydon), Marseille

(Gassend, 1982; Gassend and Cuomo, 1982; Gassend and Cuomo, 1985; Pomey, 1988: 407–08; Gassend, 1989; Rival, 1991: 245–65; Pomey, 1998: 68; Pomey, 2004a: 31–2) (Figs 10–13).

This shipwreck was found in the 'Vieux Port' of Marseilles, in the horn of the ancient creek of Lacydon, during the construction of the new Centre de la Bourse. The archaeological remains were 20 m long by 7 m wide, and the reconstructed ship 23 m long by 9 m wide. It was dated to 190–220 AD (Carre, 1998: 101). The hull-section had flat frames and a round turn of the bilge. The trapezoidal keel was 17–28 cm sided and 29 cm moulded, and was chamfered along its entire length. The chamfered corners gradually changed to rabbets in the endposts.

The garboards were attached to the keel by pegged mortise-and-tenon joints, and to the endposts with copper nails. The mortises were 60 mm wide, 10 mm thick and 100 mm deep. The edge-to-edge spacing between adjacent mortises was 12–15 cm. The planks were 18–23 cm wide and 60 mm thick, and were mortise-and-tenon-joined. Tenons were 60 mm wide, 10 mm thick and 120–130 mm long, and were spaced 200 mm centre-to-centre. They were locked in their mortises by tapered pegs 8–15 mm in diameter. The pegs were driven from the inside, except at the level between the 8th and 10th strakes under some frames (M 114, 122, 139), where the pegs were cylindrical and possibly set from the outside (Fig. 12). Strakes were made from planks joined by diagonal scarfs with pegged mortise-and-tenon joints, and nailed horizontally at their ends. One lower wale 14 cm thick was partially preserved, connected to the planking by mortise-and-tenon joints.

The framing-pattern was generally alternating floor-timbers and half-frames. Some half-frames overlapped, crossing the keel. The frames were 8 cm sided and 15 cm moulded, with room-and-space of 25 cm. Frames and planks were connected by 15–20-mm-diameter treenails. There was no connection between the framing elements (floor-timbers, half-frames and futtocks). Eight floor-timbers were connected to the keel by copper bolts 20 mm in diameter. Four of these

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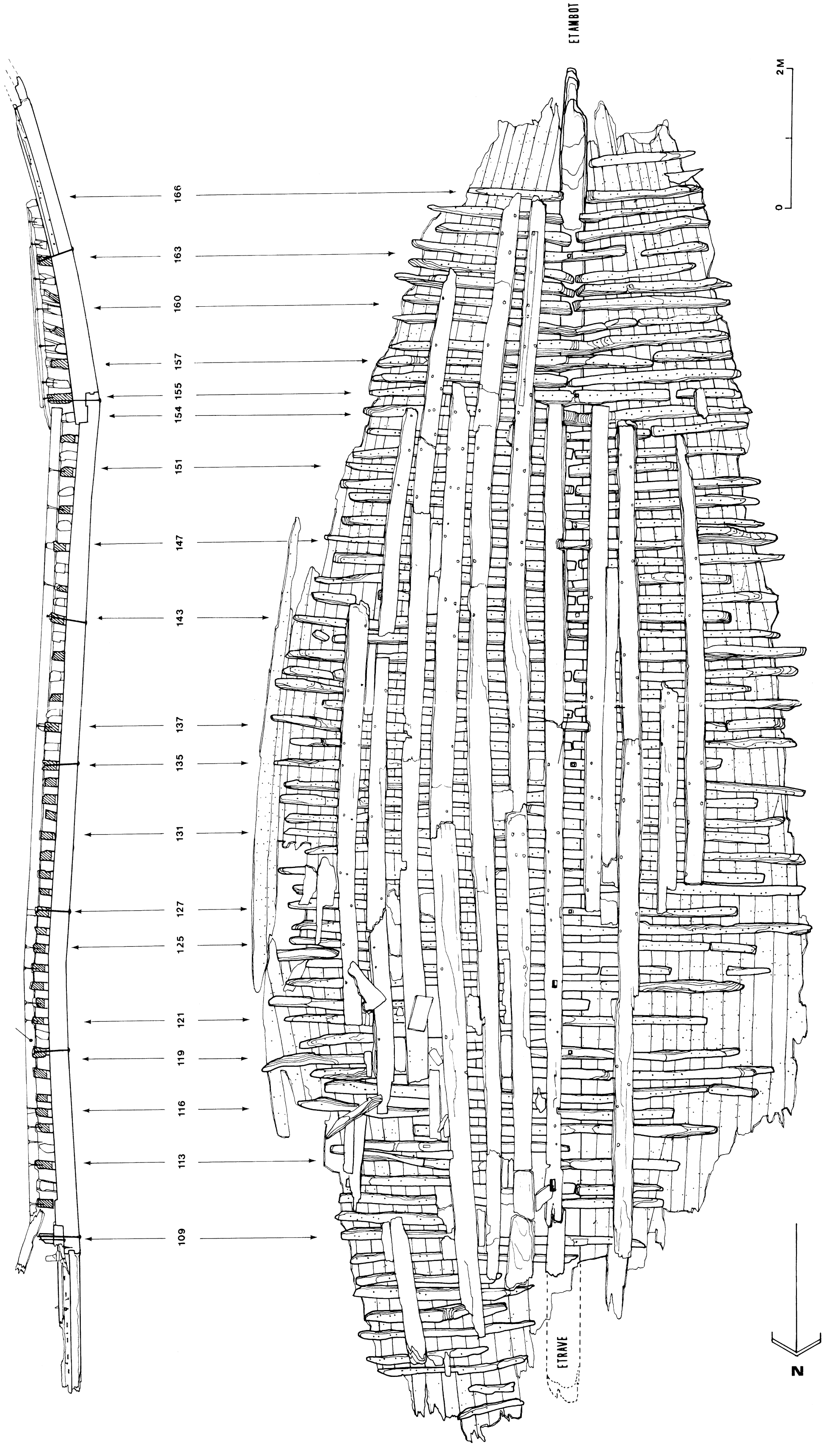

Figure 10. La Bourse shipwreck. Hull-plan and longitudinal section. (Gassend, 1982, fig. 13, reproduced with permission)

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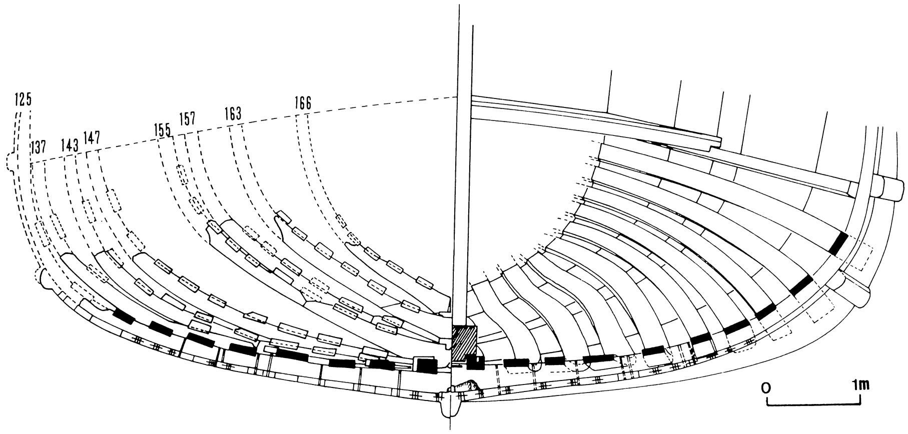

Figure 11. La Bourse shipwreck. Cross-section at amidships. (Gassend, 1982, fig. 19, reproduced with permission)

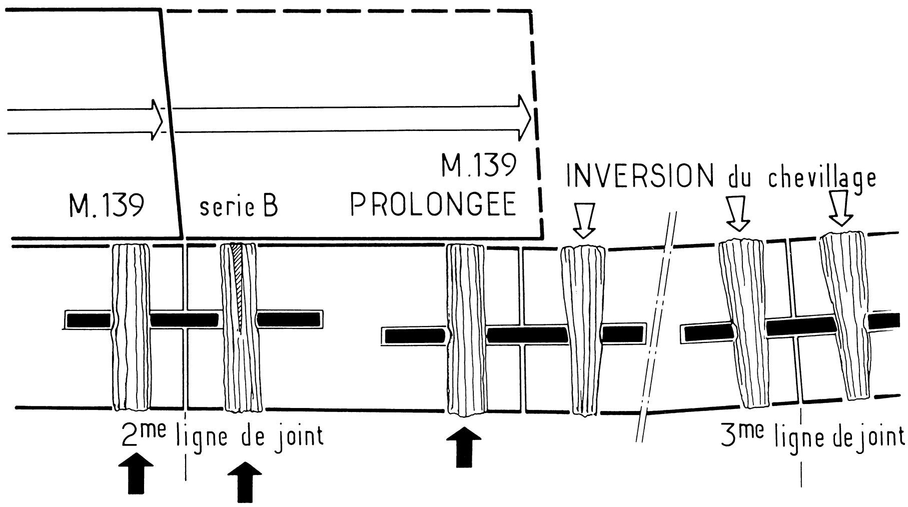

Figure 12. La Bourse shipwreck. Detail of inversion of the pegs locking the tenons at frame 139. (Gassend, 1982, fig. 60, reproduced with permission)

were associated with a scarf between the keel and an endpost, probably to reinforce the joint. Four others were set along the keel every 8th to 10th frame. There were two sister-keelsons, one on each side of the keel. Although the mast-step/keelson timber did not survive, its existence and connections could be reconstructed based on extant marks and assembly evidence. Sections of keelson could be restored on each end of the hull, as an extension of the mast-step, according to long projecting bolts that formed the keel/frame/keelson connection.

The hull cross-section had flat frames and a round turn of the bilge, characteristic of the western Roman Imperial type. The hull was made watertight by internal and external coats of pitch. As to the construction, Gassend and Cuomo (1985) proposed a process of 'alternating construction' (*construction alternée*), where frame-elements always preceded the setting-up of the planking. In this construction-process, the hull-shape was determined by the frames, and the ship was frame-oriented. However, Pomey (1988; 2004a) demonstrated that the application of this process to La Bourse shipwreck was not obvious. In fact, the lack of structural integrity of the framing, associated with a close set of mortise-and-tenon joints for the planking, indicated a shell structural conception. It is possible that there were some active frames, but only a few, and only partially around the 8th to 10th strakes. The hull-shape was mainly determined longitudinally, and strake-oriented, rather than frame-oriented. In conclusion, the Bourse hull was of shell structural concept, and mainly strake-oriented, and built on longitudinal principles. However, the possible presence of a few partially-active frames to help the hull-shaping during the construction, much like a skeleton solution, indicates a mixed building process.

Figure 13. La Bourse shipwreck. Longitudinal view of the hull from the stem scarf. (P. Pomey)

Monaco

(Benoit, 1961: 146; Mouchot, 1968–69; Basch, 1972: 48–50) (Figs 14–15).

The wreck was found in Monaco harbour in 1948, and was partially studied in 1958, and again in 1965. It was dated to the end of the 2nd century or the first half of the 3rd century AD. The remains were about 8.4 m

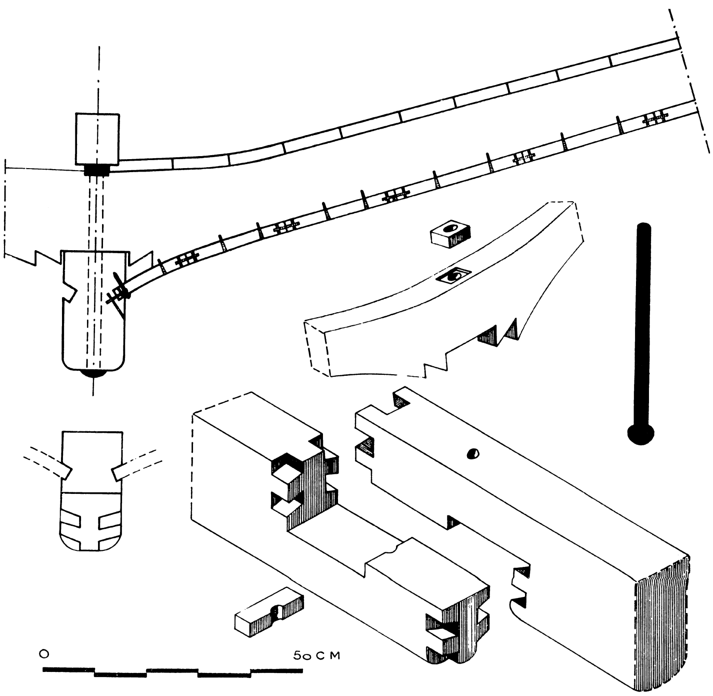

Figure 14. Monaco A shipwreck. Cross-section and scarf detail according to Alinat's drawings. (Benoit, 1961, fig. 79, reproduced with permission)

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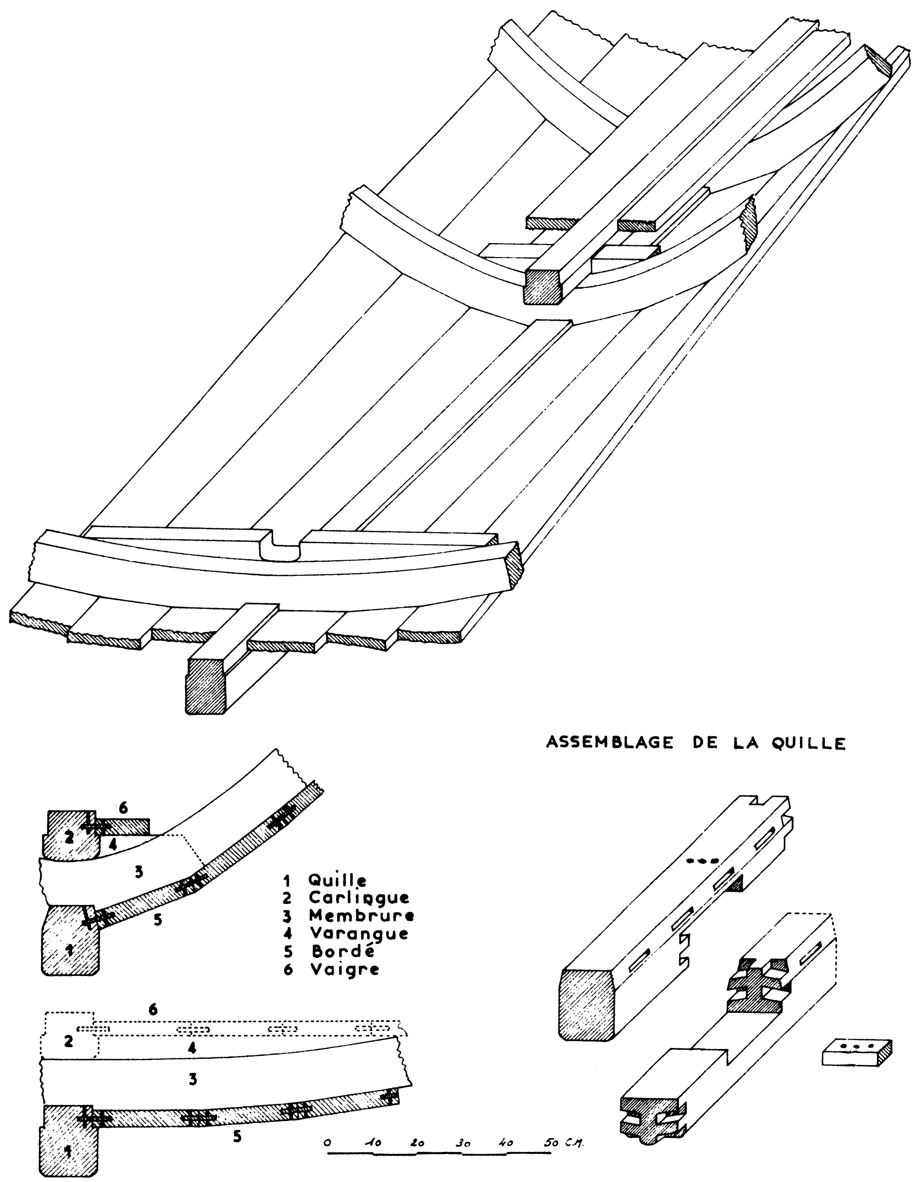

Figure 15. Monaco A shipwreck. Reconstruction drawing of the hull and scarf detail by Mouchot. (Mouchot, 1968, pl. XV, reproduced with permission)

long, in two sections, and 1.2 m wide. The ship was probably not more than 15 m long. The midship section had a flat floor-timber with a round turn of the bilge. The reconstruction proposed after studying the wreck on land in 1965 (Mouchot, 1968–69: pl. XV) raised some questions. For example, the treenails observed in the keel-scarf were not for connecting the elements as proposed, but to reinforce this major joint, as in many other shipwrecks (for example Madrague de Giens, Rival, 1991: 165; Fiumicino 1, Boetto, 2008: 37). The floor-timbers were probably not restored in their correct positions, and the 'keelson' was probably a misplaced fragment of the keel or endpost. Therefore we have considered in this analysis the original drawings made in 1958 by Cdt Alinat during the excavation, and published by Benoit (1961: 146), which present different evidence.

The keel cross-section was 11–14 cm sided and 16 cm moulded (22 cm at one endpost). Keel-elements and endposts were connected by elaborate hook-scarfs. At one endpost the scarf was reinforced by a long copper bolt. The keel was partly chamfered and partly rabbeted along its length, and rabbeted at the endposts. Garboards were tenoned to the keel, and tenoned and nailed on the endpost. The keel mortises were 40–60 mm wide, 6 mm thick, and the edges of adjacent mortises were spaced 60–70 mm. The average centre-to-centre distance between tenons was 125 mm (based on a sketch of the wreck in Mouchot, 1968–9: 201, pl. XV). Tenons were 5–6 mm thick and

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70–80 mm long, and were locked in their mortises by tapered pegs. Hull-planks were 18–27 cm wide and 30–40 mm thick, and were connected by pegged mortise-and-tenon joints.

The framing-pattern was not clear, and seems to have consisted only of floor-timbers (Mouchot reports long frames, crossing the keel, with futtocks, and short floor-timbers. It is possible that there are, in fact, floor-timbers and overlapping half-frames). Frames were on average 65 mm sided and 115 mm moulded, and connected to the hull-planking by treenails. A floor-timber (max. 17 cm moulded), at one endpost scarf, was bolted to the keel. A keelson 15 by 8 cm reinforced the hull. Ceiling-planking was in evidence above frames. Basch (1972: 48–50) considered the floor-timber bolted to the keel as an example of an active frame; but this bolt also connected the endpost scarf, so its function was more probably reinforcement. According to its characteristics, the Monaco hull was built on a longitudinal and shell structural concept. If it had active frames, which is a possibility, the construction-process would have been mixed, with a skeleton solution to the shell-first problem.

County Hall

(Riley and Gomme, 1912; Marsden, 1972; Marsden, 1974; Marsden, 1994) (Figs 16–17).

The shipwreck was found in London on the south bank of the River Thames in 1910, and dated to *c.*AD

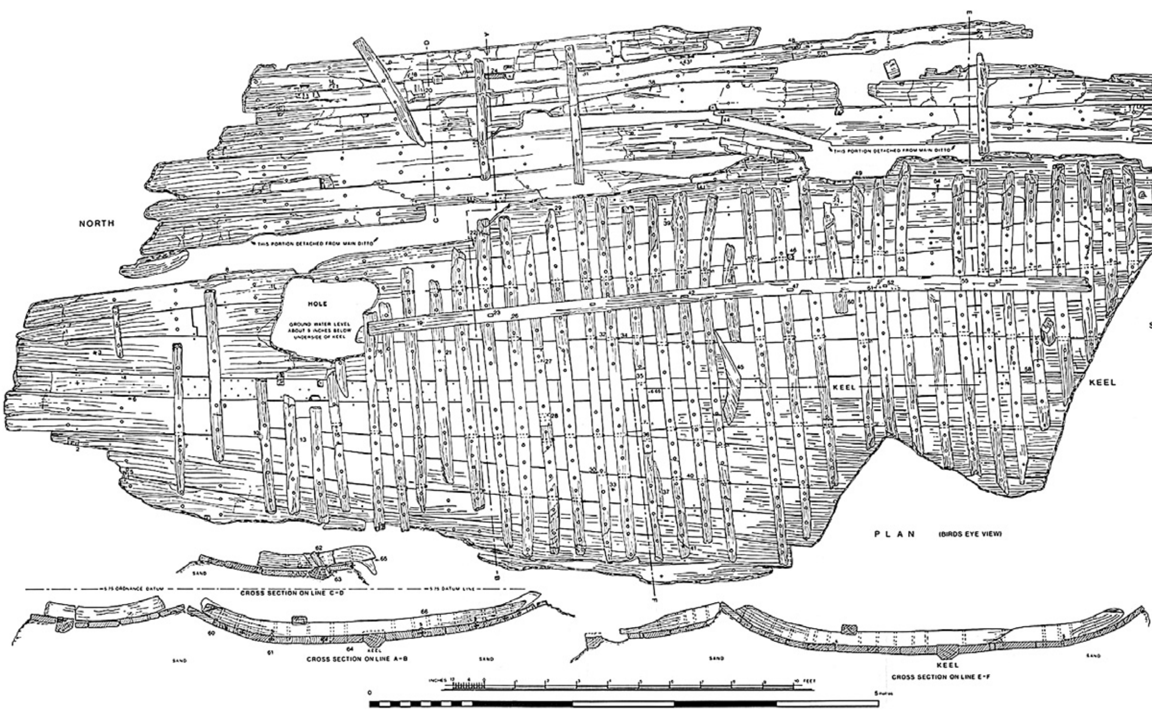

Figure 16. County Hall shipwreck. Hull-plan and cross-sections. (Riley and Gomme, 1912)

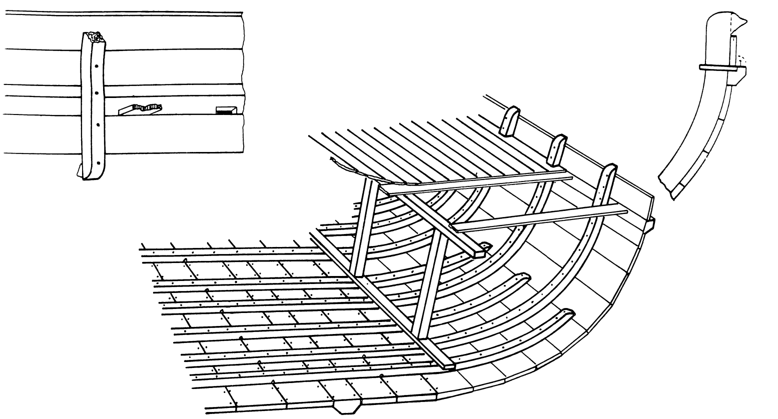

Figure 17. County Hall shipwreck. Reconstruction drawings of the hull. (after Marsden, 1974, figs 4 and 6)

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300. The archaeological remains *in situ* spread over 13 × 5.5 m. The length of the ship was difficult to reconstruct, perhaps 19.1 m long by 5.06 m wide. The hull cross-section was of flat frames with a round turn of the bilge. The keel was 215 mm sided and 165 mm moulded, without garboard rabbets. Planks were 267–381 mm wide, and with variable thickness tapering from 76 mm at the garboard/keel joint to 51 mm.

Planks were fastened to the keel and to each other by pegged mortise-and-tenon joints. Tenons were 64 mm wide, 7 mm thick and 127 mm full length, with pegs 16 mm in diameter. One mortise was 110 mm wide, 7 mm thick and 65 mm deep. The distances between the edges of adjacent mortises were from 152 mm in the keel-garboard joints near the north end of the hull, to 970 mm towards the centre. Plank-scarfs were reinforced with iron nails. One wale was preserved, 152 mm square, with its lower outer corner chamfered off. Frames were 114 mm sided and 165 mm moulded, with room-and-space of 533 mm, which decreased at the end to 254 mm. They were attached to the hull by 32-mm-diameter treenails, but were not connected to the keel.

The remaining section of the hull comprised short flat floor-timbers and longer frames, the latter being curved along the turn of the bilge. As the framing-pattern was not clear, two options have been suggested: either short floor-timbers alternating with longer floor-timbers which extended up both sides of the hull; or each frame started at about the turn of the bilge, and crossed the bottom, with alternate frames extending up opposite sides of the hull. In both options the floor-timbers contributed to the structural reinforcement of the bottom and the sides (Marsden, 1994: 118). A stringer was found at one side (there were apparently at least two), 140 mm wide and 89 mm thick, fixed to the frames with iron nails. The archaeological remains included sparse evidence of cross-beams and a deck. The beams were connected to the wales, and not to the frames, evidence of a shell structure concept.

Although built in Britain, the hull was constructed according to the Mediterranean tradition, although its framing-pattern has, for that period, no Mediterranean parallel. The second option of framing-pattern (frames starting at about the turn of the bilge, crossing the bottom, and extending alternately up opposite sides) is specifically attested in the inland shipbuilding of Romano-Celtic tradition (Arnold, 1992: 81). This hull-concept was of the longitudinal and shell principle and method of construction. The variable and large tenon distances, sometimes unpegged, and the narrow tenon relative to the mortise width, are very probably early evidence of the transition from 'shell-first' to 'frame-first'.

Pointe de la Luque B

(Clerc and Negrel, 1973; Liou, 1973; Negrel, 1973; Liou, 1975; Guibal and Pomey, 2009) (Figs 18–19).
This wreck was found at the south-western end of Pomègues Island, Frioul Archipelago, in the Bay of Marseilles, and excavated from 1970 to 1974. It was reconsidered during the dendrochronological project of October 1992, which provided new unpublished information (Guibal and Pomey, 2009), and dated to the 4th century AD. The dimensions of the surviving forward hull remains were 8 m long and 5 m wide; and the estimated original dimensions of the hull were 20 m long and 6 m wide, with a cross-section of flat frames with a round turn of the bilge.

The keel was 13 cm sided and 17 cm moulded, with a rabbet for the garboard, which was 55 mm maximum thick. Planks were 150–230 mm wide and 30 mm thick, and connected to each other and to the keel by pegged mortise-and-tenon joints. The mortises were 60 mm wide, 7 mm thick and 40 mm deep. Tapered pegs

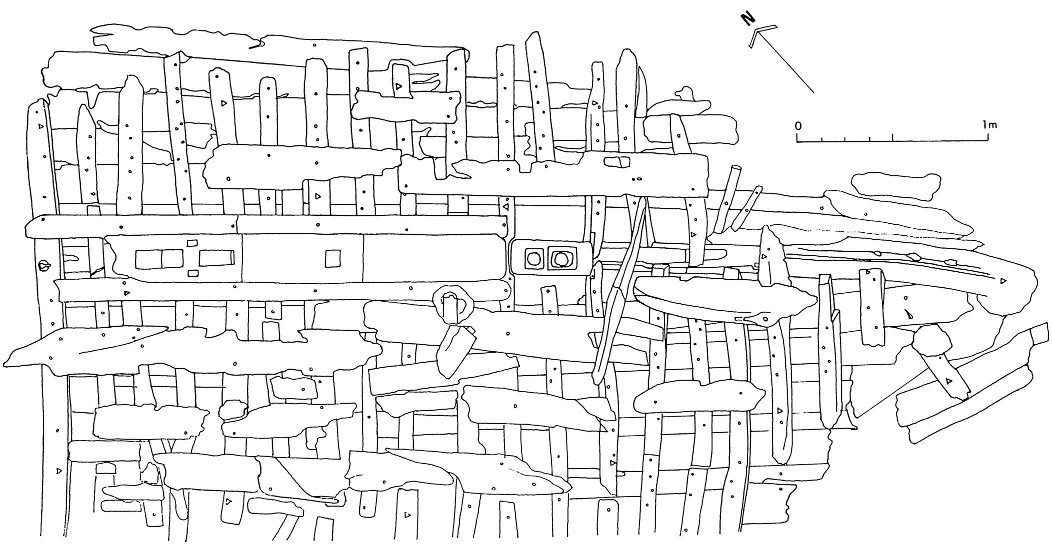

Figure 18. Pointe de la Luque B shipwreck. Hull-plan. (Liou, 1973, fig. 15, reproduced with permission)

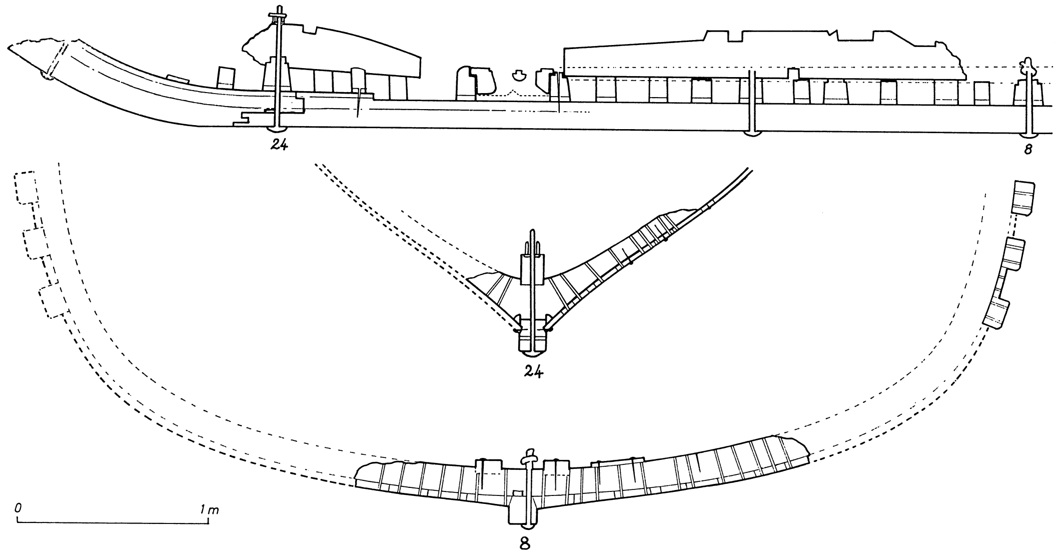

Figure 19. Pointe de la Luque B shipwreck. Longitudinal section and cross-sections at frames 8 and 24. (Liou, 1975, fig. 10, reproduced with permission)

8–11 mm in diameter, spaced 100–120 mm apart, locked the tenons at the keel-garboard joints. The pegs were set from the inside of the hull. Planks were diagonally scarfed with mortise-and-tenon joints and horizontal nails at the ends of the scarf to create strakes. Remains of three wales 145–175 mm wide, 90 mm thick, connected to the planking by mortise-and-tenon joints, were preserved. They contributed to the longitudinal reinforcement of the hull. Frames were irregularly shaped, their maximum dimensions being 13 cm sided and 13 cm moulded, with room-and-space of 12–33 cm. The framing system was alternating floor-timbers with overlapping half-frames. There was no connection between the frame elements. Frames were connected to planks by 10-mm-diameter treenails. Three frames were connected to the keel or endpost by iron bolts. One of the frames, located over the scarf between the keel and the stem, was also bolted to a forward longitudinal timber. The mast-step/keelson was installed on two strong sister-keelsons, which were nailed to the frames. The hull was made watertight by an internal coat of pitch, and is characteristic of the western Roman Imperial type.

Even if some frames were bolted to the keel or end-posts, there was no evidence for the existence of active frames. The floor-timber secured to the fore keelson at the keel-stempost scarf was bolted after the assembly of the fore keelson, probably during a final stage of the building after the construction of the planking. In this case, the bolting of the floor-timber is not a proof of an active frame, but evidence of the reinforcement of the central longitudinal timbers of the hull. On the other hand the mortise-and-tenon arrangement of the planking was strong, and played a major role in the structural integrity of the hull. This ship was of longitudinal and shell principle and construction method. However, like other ships of the western Roman Imperial type, it testifies to an evolution in ship-construction by the reinforcement of the hull by skeleton components.

Yassıada 2

(Bass and van Doorninck, 1971; van Doorninck, 1976; Pomey, 1988: 409; Steffy, 1994: 79–80; Steffy, 2004: 32) (Figs 20–22).

The shipwreck was found about 100 m south of Yassıada ('Flat Island') near Bodrum in southern Turkey, at a depth of 38–42 m, and dated to the 4th century AD. According to the drawings, the overall dimensions of the hull-remains were 16 m long by 5.2 m wide. Its original length was estimated at 20 m, and its beam at 8 m. However, Royal (2002: 207) gives a length of 19 m and a beam of 6.6 m, making a length-to-beam ratio of 2.88. The cross-section of the hull had a wine-glass-shaped bottom (*à retour de galbord*).

The keel was 125 mm sided and 220 mm moulded, and was not rabbeted, except at the forward end. The sternpost was rabbeted, and the garboard was fixed to it with iron nails. Hull-planking varied in width from 110 to 250 mm, and was 42 mm thick, with the garboards 53 mm thick. Planks were connected by mortise-and-tenon joints. Their centre-to-centre spacing varied between 150 and 320 mm. The mortises were 70–90 mm wide, 7 mm thick and 50–55 mm deep. The tenons were 45 mm wide, their total length (from the two sides of the seams) was 85 mm, and they were locked in their mortises by tapered pegs 7–11 mm in diameter driven from inside the hull. Mortises and tenons were tapered; the tenon occupying 50–64% of the mortise width (Fig. 22).

There was evidence of the remains of four wales, typically 160 mm wide and 160 mm thick, connected to

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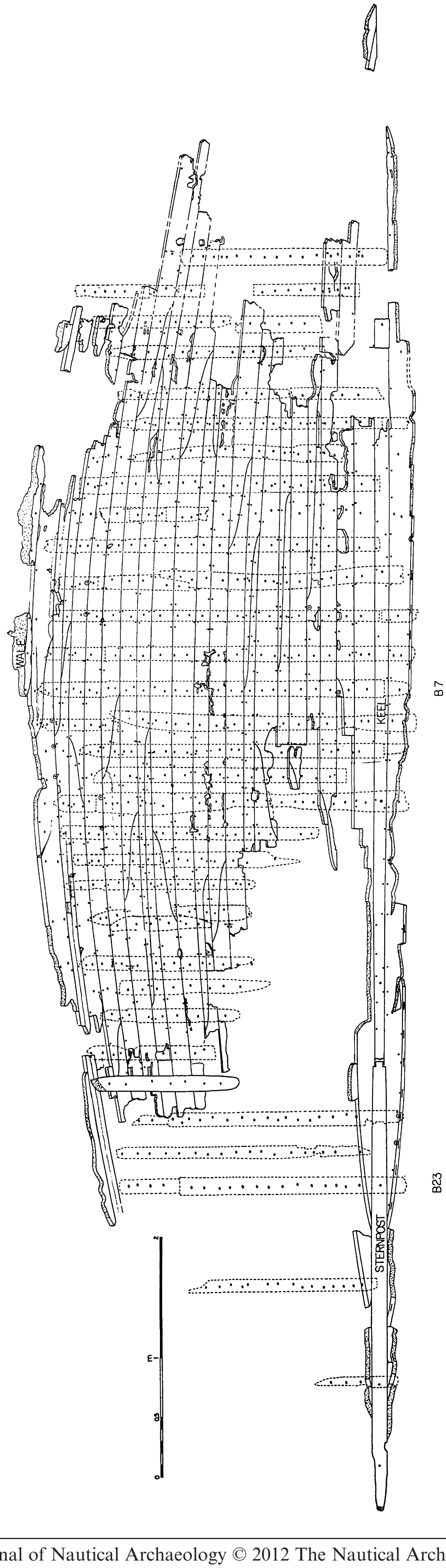

Figure 20. Yassiada 2 shipwreck. Hull-plan. (van Doorninck, 1976, fig. 1, reproduced with permission)

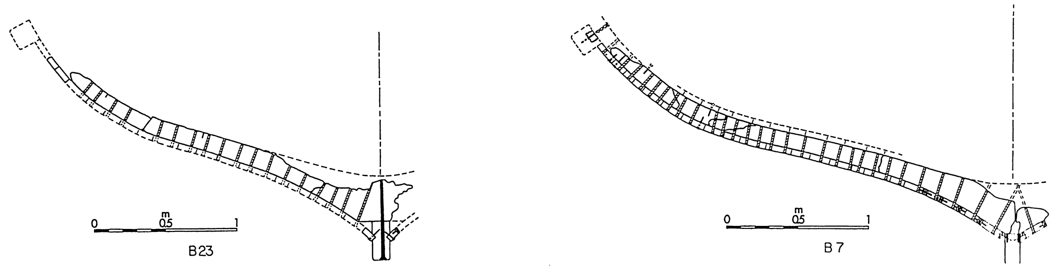

Figure 21. Yassıada 2 shipwreck. Cross-sections at frames B7 and B23. (van Doorninck, 1976, fig. 4, reproduced with permission)

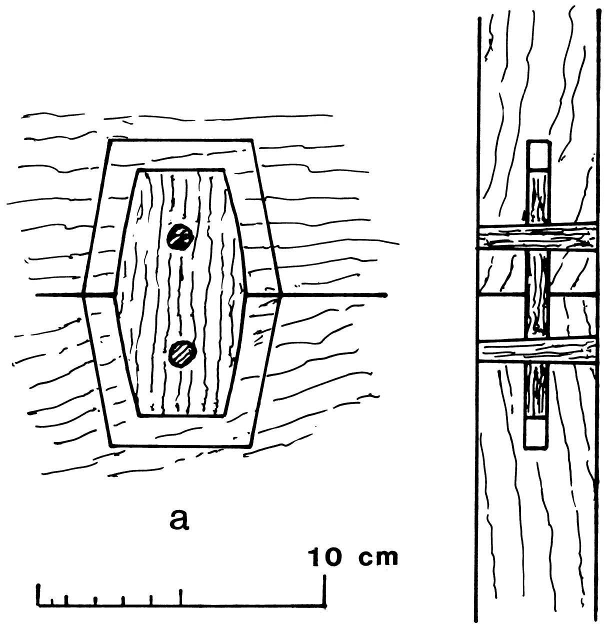

Figure 22. Yassıada 2 shipwreck. Mortise-and-tenon joint. (van Doorninck, 1976, fig. 6, reproduced with permission)

the planking by mortise-and-tenon joints. They contributed significantly to the longitudinal structural integrity of the hull. The frame-pattern was alternating floor-timbers and half-frames. There was no connection between frames and their futtocks. Four frames were fixed with iron bolts to the keel, and three to the sternpost. Floor-timbers were 120–191 mm sided, half-frames 80–150 mm sided. Frames were 125 mm moulded, but above the keel they were *c*.350 mm. Centre-to-centre distance varied between 230 and 300 mm, averaging 270 mm. Treenails 16 mm in diameter connected frames to planks: iron nails were used to secure planks in sensitive places. One partially-active half-frame (B7) was set after the five first strakes. The bolt characteristics suggest the existence of a keelson. The hull was made watertight by an internal coat of pitch.

The hull was of shell concept, based on strakes providing longitudinal shaping and structural strength, but the order of the construction-process was mixed. At least one frame was partially active, giving a skeleton solution to a problem of shell construction. The active frame and the wide spacing of the mortise-and-tenon joints with loose tenons indicate an important step in the transition.

Dramont F

(Joncheray, 1975; 1977) (Fig. 23).

This shipwreck, found west of Cape Dramont, southern France, was the remains of a 10–12-m-long ship dated to the second half of the 4th century AD. Only a section of the hull, 1.10 m long and 2.1 m wide, has been observed and studied. The hull cross-section seems to have had flat floor-timbers and a round turn of the bilge. The keel was trapezoidal, 95 mm sided at the bottom, 105 mm at the top, and 145 mm moulded, with chamfered corners for the garboards.

Mortises were 50–70 mm wide, 7 mm thick and 40 mm deep in the keel, and 58–82 mm wide in the planking. In the keel-garboard attachments they were spaced at 150–230 mm between edges of adjacent mortises (*c.*250 mm centre-to-centre), and in the planking 195–250 mm centre-to-centre. Tenons were 35–55 mm wide, 5–6 mm thick, and their full length was 60–70 mm. They were locked in their mortises with tapered pegs 7–8 mm in diameter driven from inside the hull. The tenons tapered in both their width and thickness, and were fairly loose, occupying about 70% of the mortise. One mortise without a tenon was observed, and at least one plank had no mortises. Frames were square, trapezoidal or rectangular in cross-section, and the general pattern seems to have been of floor-timbers with futtocks without connections, and half-frames beginning far (*c.*1 m) from the keel. They were between 55 and 105 mm sided and 85–110 mm moulded, with room-and-space of 370 mm. They were connected to the planking with tapered treenails 11–14 mm in diameter, generally two treenails per plank per frame. Several iron nails were also found, probably for attaching internal

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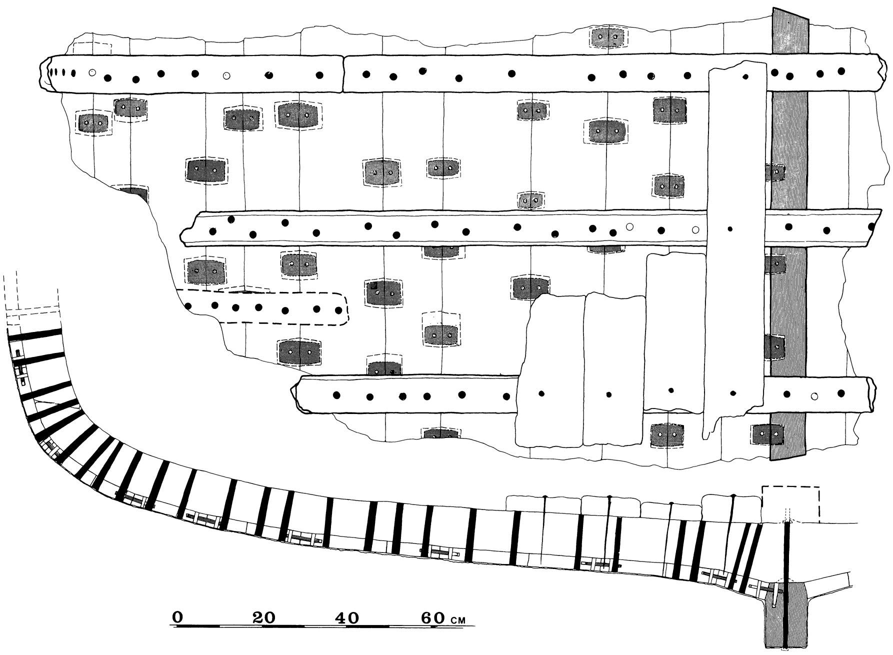

Figure 23. Dramont F shipwreck. Hull-plan and cross-section. (Joncheray, 1975, 126, reproduced with permission)

components, such as ceiling-planking and stringers. An iron bolt connected one floor-timber and probably a keelson to the keel. The hull was made watertight by internal and external coats of pitch.

This hull may be a variation of the western Roman Imperial type. It was of shell concept for the hull-shape and the structure, but a mixed shell-frame construction method was probably used, as is evident from the widely-spaced mortise-and-tenon joints, loose tenons, and their absence in some planking seams.

Fiumicino 1 (Oneraria Maggiore 1)

(Scrinari, 1979; Boetto, 2000; 2003; 2006; 2008) (Figs 24–27).

The Fiumicino 1 shipwreck, its sister-ship Fiumicino 2, and Fiumicino 3 (the same type, but slightly smaller) were discovered in 1960 during the construction of the international airport at Fiumicino, Rome, near the site of the ancient harbour of Claudius. The Fiumicino 1 shipwreck was 13.83 m long by 4.57 m wide, and the

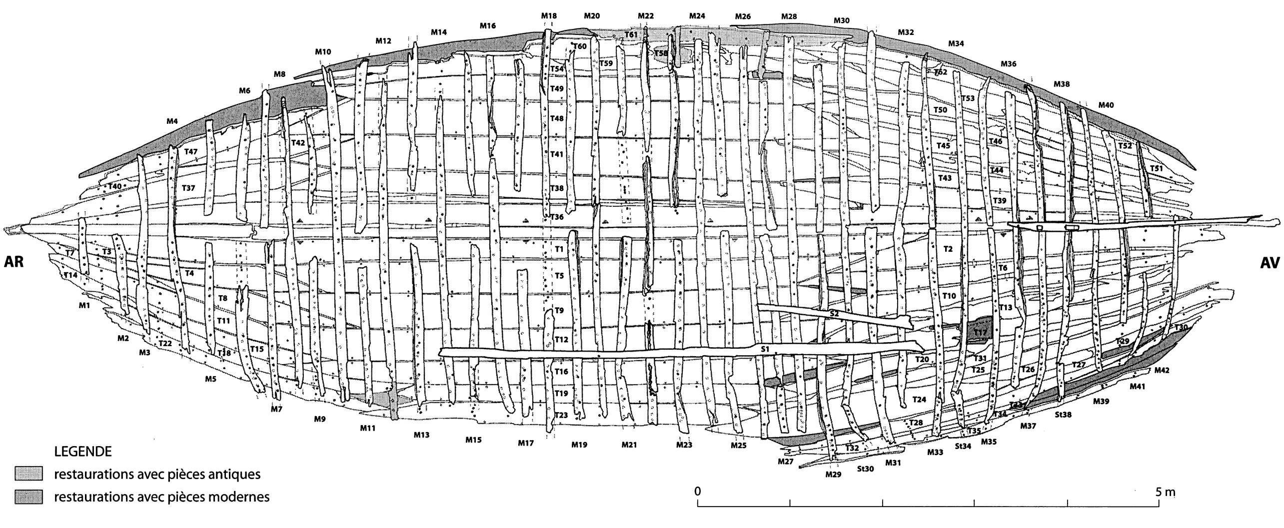

Figure 24. Fiumiucino 1 shipwreck. Hull-plan. (Boetto, 2008, fig. 5, reproduced with permission)

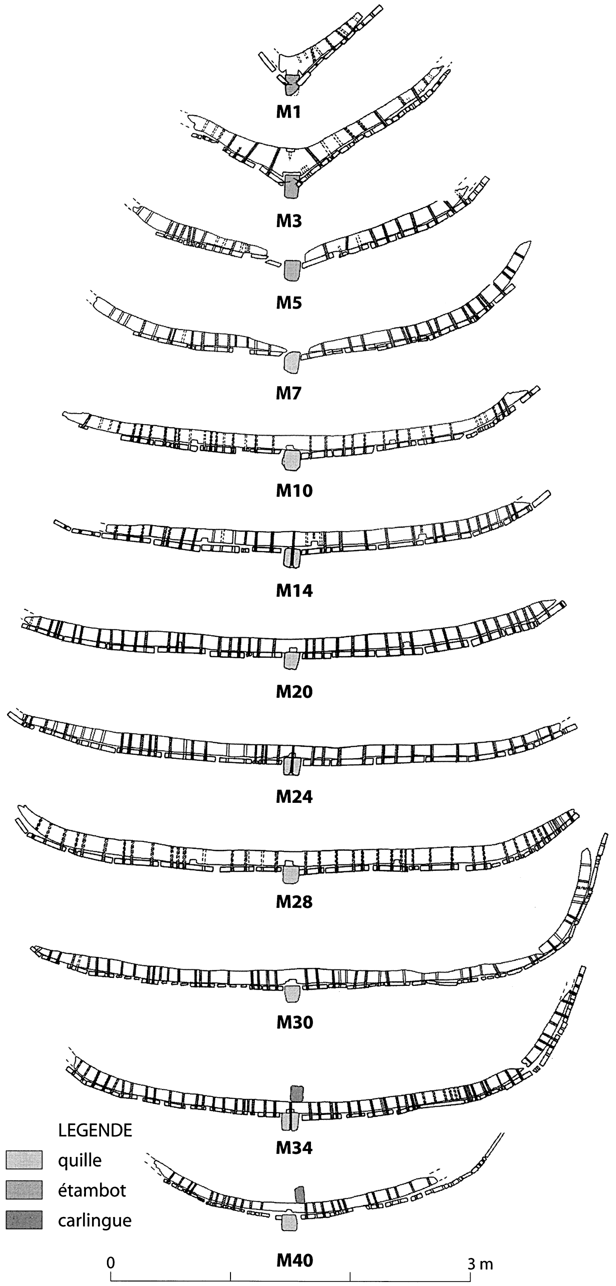

Figure 25. Fiumiucino 1 shipwreck. Cross-sections. (Boetto, 2008, fig. 7, reproduced with permission)

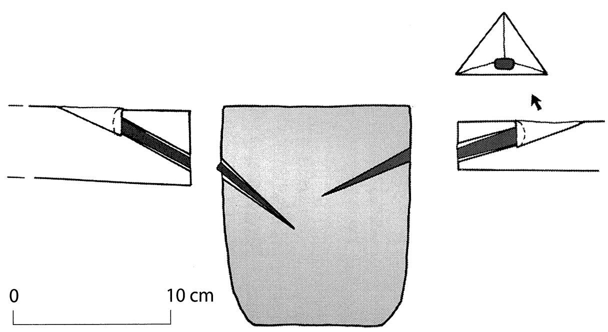

Figure 26. Fiumiucino 1 shipwreck. Tangential iron nails connecting garboard to keel. (Boetto, 2008, fig. 17, reproduced with permission)

reconstructed ship was 17.18 m long (overall) and 5.6 m wide. It was dated to the end of the 4th or the beginning of the 5th century AD. The midships section had flat frames and a round turn of the bilge.

The maximum keel dimensions were 130 mm sided by 170 mm moulded, without a rabbet, except in the transitional stern timber. The garboards were connected to the keel by mortise-and-tenon joints, the majority of the tenons being unpegged. Iron nails, driven tangentially, were also used to connect the garboards to the keel and stem (Fig. 26), and horizontally to the transitional stern timber. Planks had a maximum width of 400 mm and a thickness of 44 mm. Mortise-and-tenon joints, many unpegged, were widely spaced, and tenons only partially filled their mortises. Mortises were 74 mm wide, 7–10 mm thick and 45 mm deep, and tenons were 43 mm wide, 3–6 mm thick and 80–90 mm long. Pegs were driven from the inside. Both mortises and tenons were tapered, and their centre-to-centre spacing was 175–760 mm (average 360 mm). A surviving fragment of wale, 160 mm wide and 90 mm thick, was connected to the planking by mortise-and-tenon joints. The planking was constructed in an unusual way, in three parts: centre, forward and aft. The three planks were connected into strakes by diagonal scarfs, either by mortise-and-tenon joints and horizontal nails, or with nails only, and sometimes without any connection.

Forty-two frames were identified in a general pattern of alternating floor-timbers and half-frames. They were of rectangular or trapezoidal section, 6–12 cm sided, 8–18 cm moulded, with irregular room-and-space varying from 12 to 30 cm, averaging 19 cm. Iron nails connected frames to planks through plug treenails. Six iron bolts connected the keel and floor-timbers, and two of them also connected the keelson/mast-step timber. This mast-step was situated in the fore part of the hull to support the towing-post. Originally, the hull was probably made watertight by an external coat of pitch.

Fiumicino 1, like Fiumicino 2 and 3, was a sea/river boat of the *navis caudicaria* type, which was interpreted as a construction of riverine origin (for example tangential nailing) with some structural influences from a maritime tradition (Boetto, 2008: 50–51). However, the hull-concept was a longitudinal, plank-oriented shell structure. There was no absolute evidence of active frames, and some details of tenoning were the result of later repairs. The decreased strength of the mortise-and-tenon assembly-system may indicate a possible mixed shipbuilding process.

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Figure 27. Fiumiucino 1 shipwreck. General view in the Museo Navi. (Reproduced courtesy of Soprintendenza Speciale per i Beni Archeologici di Roma-sede di Ostia)

Port-Vendres I

(Chevalier and Santamaria, 1972; Chevalier and Liou, 1974; Liou, 1974; Pomey, 1988: 408–09; Rival, 1991: 267–96; Pomey, 2004a: 32) (Figs 28–29).

The wreck was found in the Anse Gerbal at the entrance to the harbour of Port-Vendres, at the south-western end of the French Mediterranean coast. The shipwreck remains were preserved over an area 13.9 m long by 7.5 m wide. Its original length was estimated at 18–20 m, and it was dated to *c.*AD 400. The hull section had flat frames and a round turn of the bilge.

The keel was trapezoidal, 280 mm sided maximum and 350 mm moulded, and rabbeted at the corners for the garboards. The garboards were 60 mm thick, fastened to the keel with mortise-and-tenon joints, and to the endposts with copper nails. Planks were 40 mm thick, and connected to each other by mortise-and-tenon joints spaced 6–15 cm apart, and locked by tapered pegs. Mortises were estimated to average 70 mm wide, according to sketches (Chevalier and Liou, 1974: 54; Liou, 1974: fig. 6). Tapered tenons fitted well within their mortises, although no dimensions were specified. Tapered pegs were mainly driven from the inside, while some were inserted from the outside. The hull was made watertight by an internal coat of pitch. There was luting or a sort of caulking in some planking seams. Santamaria (1995: 149–50), who found the same in the Dramont E wreck,

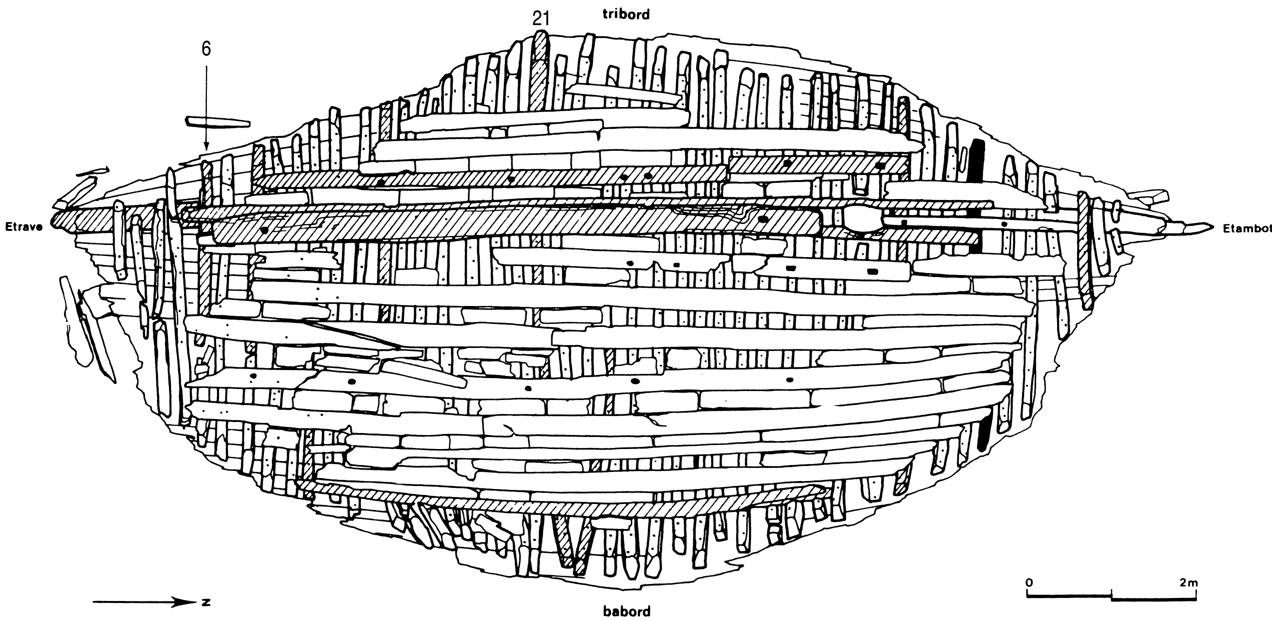

Figure 28. Port-Vendres I shipwreck. Hull-plan. (Rival, 1991, pl. 92, reproduced with permission)

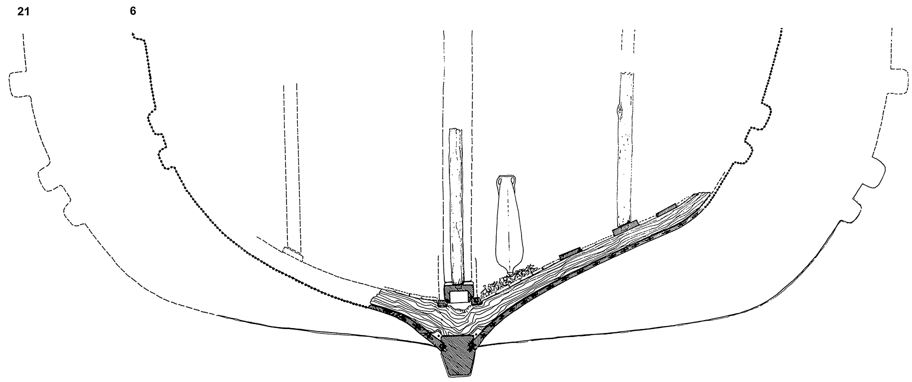

Figure 29. Port-Vendres I shipwreck. Cross-sections at frames 6 and 21. (Rival, 1991, pl. 95, reproduced with permission)

suggested it was a type of luting laid before connecting the planks, for better setting and watertightness.

Planks were diagonally scarfed to create strakes, with mortise-and-tenon joints and horizontal nails in the scarf-ends. Sections of two wales were preserved, 17 cm wide and 21 cm thick, connected to the planking by mortise-and-tenon joints. Forty-seven frames survived, alternating between floor-timbers and half-frames. One half-frame crossed the keel amidships. The futtocks were not connected to the lower frames. They averaged 13 cm sided, 23 cm moulded, with average room-and-space of 25 cm. Seven, or more probably eight, frames were fastened to the keel with iron bolts, but their role is not clear. Some bolts, in the aft part, possibly extended further inside, also connecting the keelson. Frames were attached to the planks by treenails. A long mast-step timber was fitted on two sister-keelsons according to the western Roman Imperial type. A keelson astern, stringers, and ceiling planks were also evident.

The shape and the structure of this relatively-late hull were of a shell concept. However, the hull-framing was reinforced according to the western Roman Imperial type. Perhaps, according to the possible reverse direction of some pegs, some mixed construction-process may have been employed.

Dramont E

(Tchernia, 1969: 470–72; Pomey, 1987–88: 40–41; Santamaria, 1995) (Figs 30–32).

The wreck was found close to Cap Dramont near Saint-Raphaël in southern France, and dated to AD 425–455. Wood-remains spread over 12.84 × 5.54 m, and the original ship was estimated to be 15.5–16 m long. The hull amidships had a gentle wine-glass cross-section and a round turn of the bilge.

A massive keel, generally 22 cm sided and 30 cm moulded, was found scarfed to the forefoot and sternpost. The keel was chamfered along most of its length, gradually changing to rabbets at the ends, and continuing in the endpost members. Remains of 18 or 19 strakes were preserved to starboard, including two wales, and 14 to port. Planks were diagonally scarfed with mortise-and-tenon joints to create strakes. They were 30–50 mm thick, and maximum 240 mm wide. The planks were connected with mortise-and-tenon joints of varying dimensions and patterns. In the endpost areas, mortises were 65–70 mm wide, spaced 100–140 mm edge-to-edge, with tenons 60 mm wide, 8–9 mm thick and 100 mm total length. In the keel-garboard joint, mortises were 100–110 mm wide, with tenons 90–100 mm wide and 11–14 mm thick, with a total

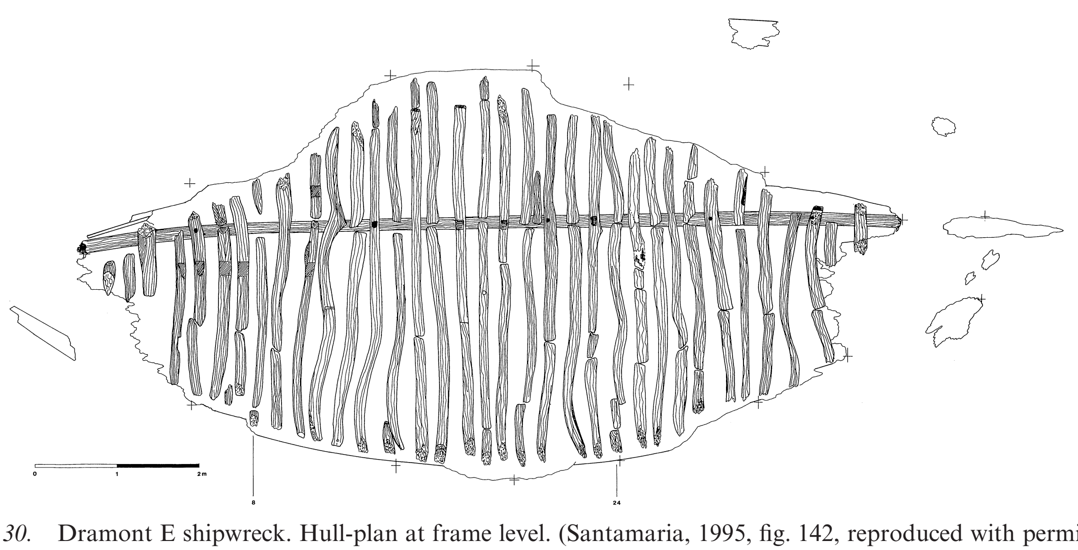

Figure 30. Dramont E shipwreck. Hull-plan at frame level. (Santamaria, 1995, fig. 142, reproduced with permission)

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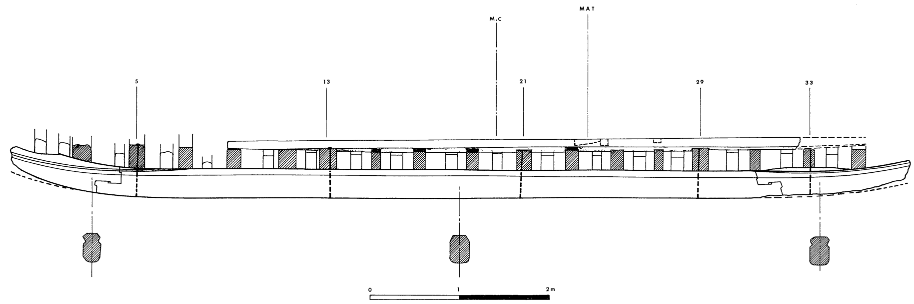

Figure 31. Dramont E shipwreck. Longitudinal section. (Santamaria, 1995, fig. 132b, reproduced with permission)

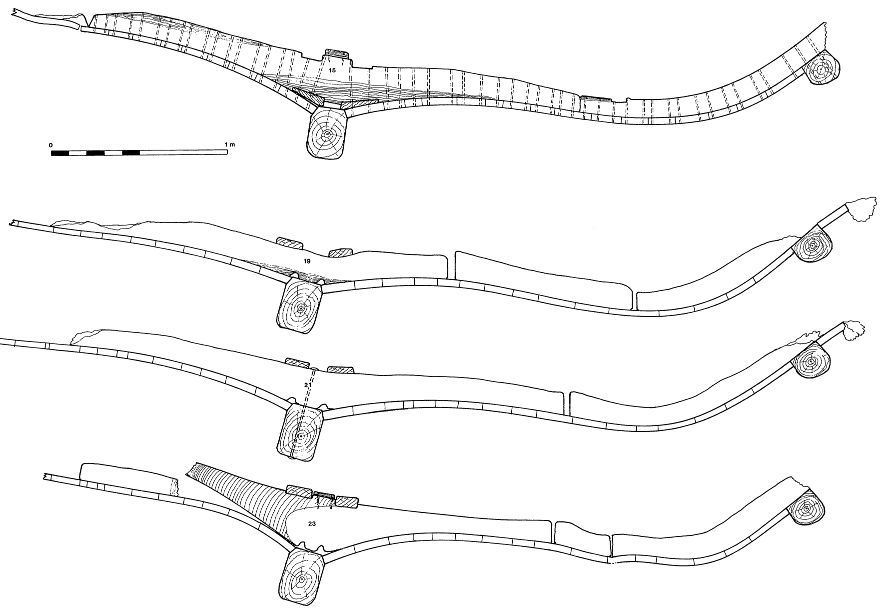

Figure 32. Dramont E shipwreck. Cross-sections at frames 15, 19, 21 and 23. (Santamaria, 1995, pls XIX, XX, reproduced with permission)

length of 120 mm. They were spaced 80–90 mm edge-to-edge close to the bow, and 260–310 mm amidships.

For fitting the garboards to the keel, mortises were wider in the garboard than their corresponding tenons by *c*.30–40 mm. Tapered pegs 8–12 mm in diameter locked the tenons in their mortises (Santamaria, 1995: pl. XVI, 3). Tapered pegs were driven from the inside, even those found under the frames and their futtocks up to the first wale. In some exceptional, but self-explanatory, cases, the pegs were driven from the outside, for example in the tenons between the keel and the garboard (Santamaria, 1995: 143, 145 fig. 4). In a few instances, tenons were secured only at the lower side of the seam, while on the upper side tenons were left unpegged. The lower wale, 20 cm wide and 16 cm thick, was partially preserved and connected to the planking. The second-wale remains were poorly preserved. Floor-timbers and half-frames were produced from naturally-curved tree sections, and were therefore irregularly shaped. The framing-pattern was generally of alternating floor-timbers and half-frames, some of which overlapped slightly. The futtocks, not connected to frames, were 10–15 cm sided, 10–18 cm moulded, and spaced at an average of 27 cm centre-to-centre. Except for five floor-timbers which were fixed to the keel with iron-bolts, but with no relation to the keel-scarfs, frames were not connected to the keel. Generally each frame was connected to each strake by two 15–17-mm-diameter treenails. The hull was made watertight by an internal coat of pitch. However, luting was found in a few seams for better adjustment of the planks and for watertightness. A long mast-step/keelson timber, 7.14 m long, 237 mm maximum wide, and 150 mm thick, was mounted on two sister-keelsons.

According to Santamaria's meticulous study, none of the bolted floor-timbers were active frames. The longitudinal shaping and structure of this 5th-century-AD hull were therefore, without doubt, of shell concept. The construction method was also shell-first. However, some weaknesses in the mortise-and-tenon system and a reinforcement of the hull's internal structure were noted.

Parco di Teodorico, Ravenna

(Medas, 1999; 2001; 2003) (Fig. 33).

This is a late-Roman 5th-century-AD wreck, found in Parco di Teodorico, Ravenna, Italy. The archaeological

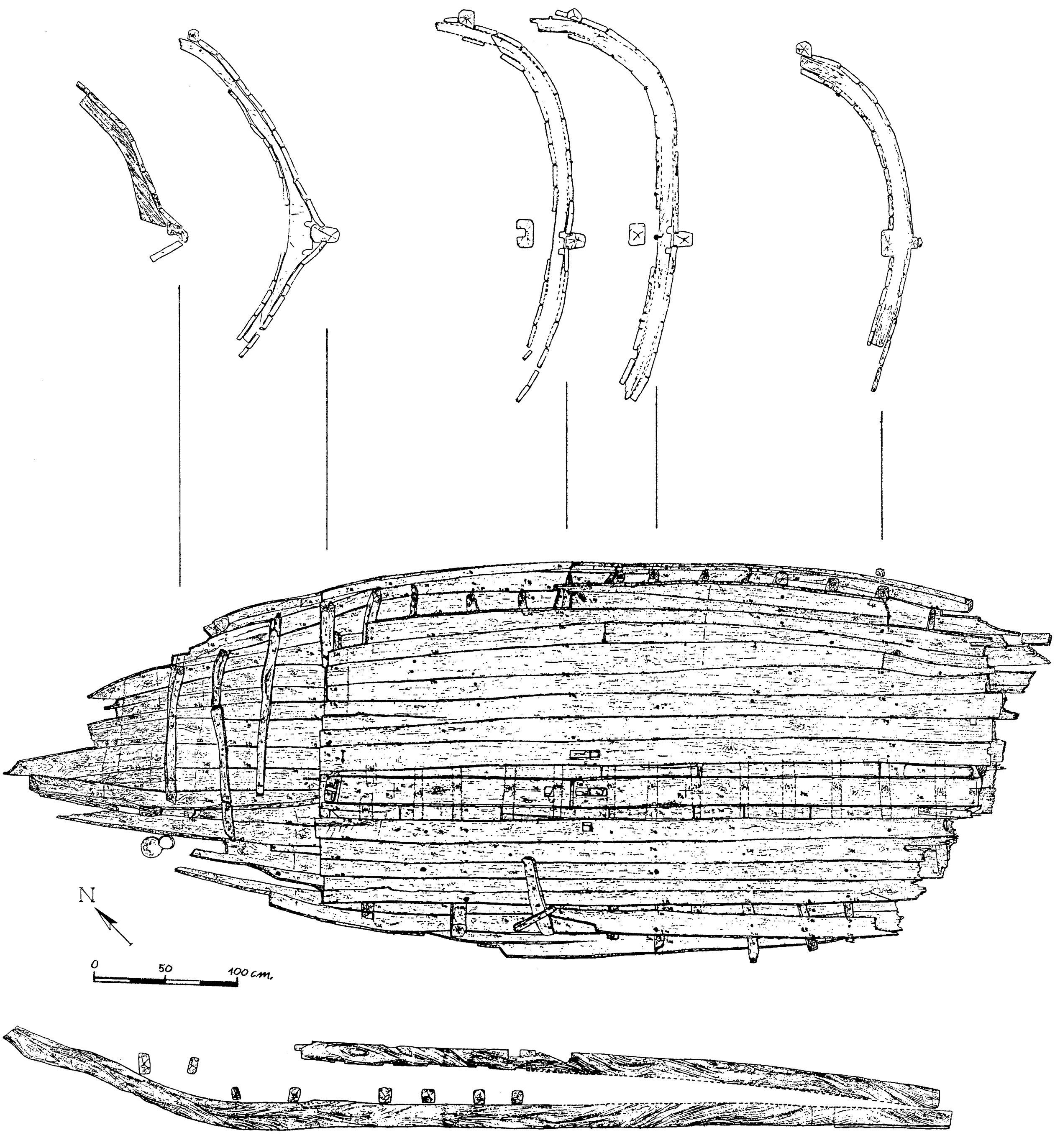

Figure 33. Parco di Teodorico shipwreck. Hull-plan, longitudinal and cross-sections. (After Medas, 2003, fig. 9.2)

remains spread over 7.22 × 2.75 m, and the length of the original vessel was estimated to have been 9 m. The midships cross-section had flat floor-timbers with a round turn of the bilge.

The hull-remains included keel, keelson, frames and planking. Unpegged mortise-and-tenon joints for the planking were widely spaced (*c.*80 cm), with tenons occupying only part of their mortises. The garboard was simply fixed to the keel with iron nails, and inside the stem rabbet. The frames were composed of floor-timbers, with room-and-space of 33 cm, and some high framing-timbers toward the extremity. Some of the floor-timbers were fixed to the keel with iron nails. Planks were connected to frames by iron nails and treenails. The keelson/mast-step timber was fitted directly onto the floor-timber. Ceiling planks were joined to frames with iron nails. No caulking was found in planking-seams, and watertightness was ensured by an external coat of pitch.

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The hull was built according to a shell concept for the shape, and a structural concept on frames. This wreck is a good example of the combination of a mixed transitional concept and technique that still employed plank-oriented principles and shell-first construction method, with frames providing the hull integrity, but not yet full skeleton construction.

Tantura A

(Kahanov and Breitstein, 1995a; 1995b; Kahanov and Royal, 1996; Wachsmann and Kahanov, 1997; Kahanov, 2001; Kahanov *et al.*, 2004; Kahanov, 2011a; 2011b) (Figs 34–36).

This wreck was discovered in the shallow Dor/Tantura lagoon, Israel, *c.*50 m from the modern shoreline (Fig. 34). The archaeological remains spread over an area of 9.02 × 1.75 m on the sea-bed. It was apparently a small coaster *c.*12 m long, and 4 m wide. Abundant pottery sherds were found on the site: however, due to the nature of Dor/Tantura Lagoon, where storms disturb the sea-bed, a wary and conservative approach was taken to accepting these as *in situ* ceramics. Based on ^{14}C and tentative ceramic analysis, it was dated to the end of the 5th/beginning of the 6th century AD. The hull cross-section was of flat frames with a round turn of the bilge.

The pine keel-remains were 5.2 m long, with a rectangular cross-section, 11 cm sided and 18 cm moulded.

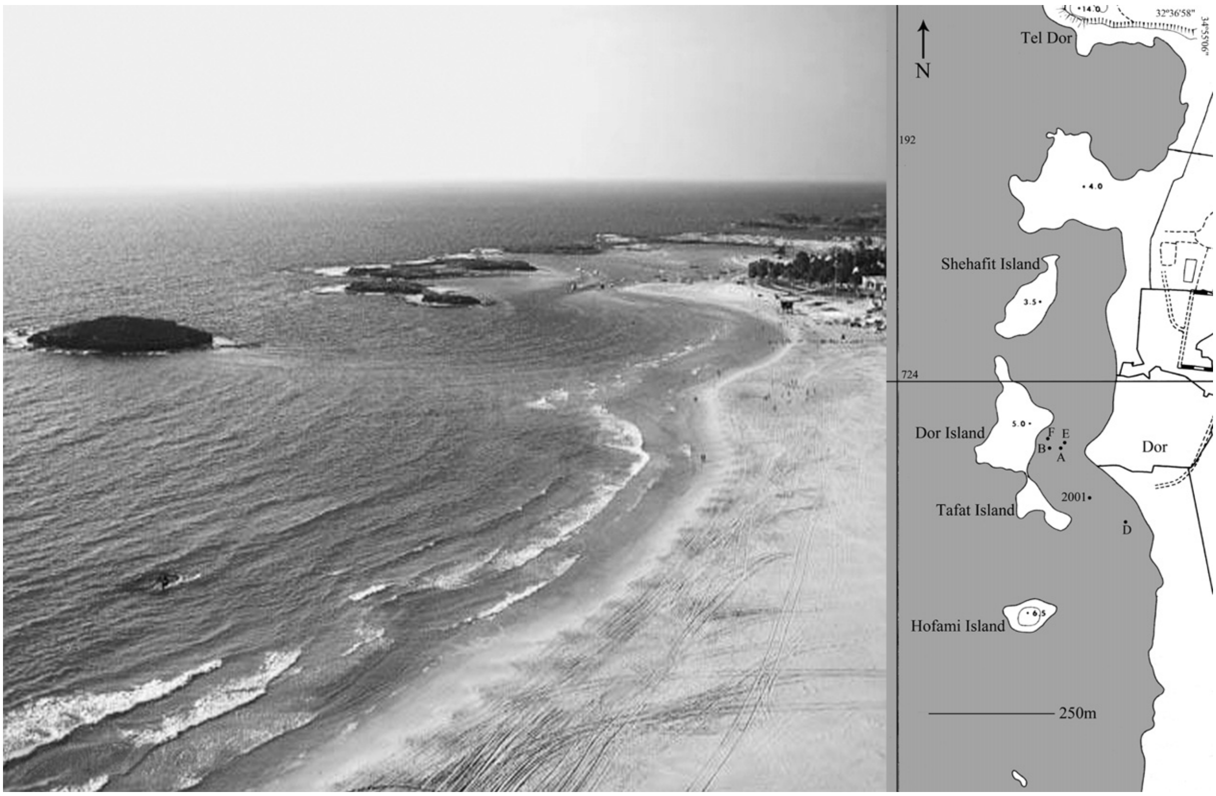

Figure 34. Dor lagoon, showing locations of shipwreck sites. (Reproduced by kind permission of I. Grinberg and A. Tako, M. L. Sneh Ltd, Haifa)

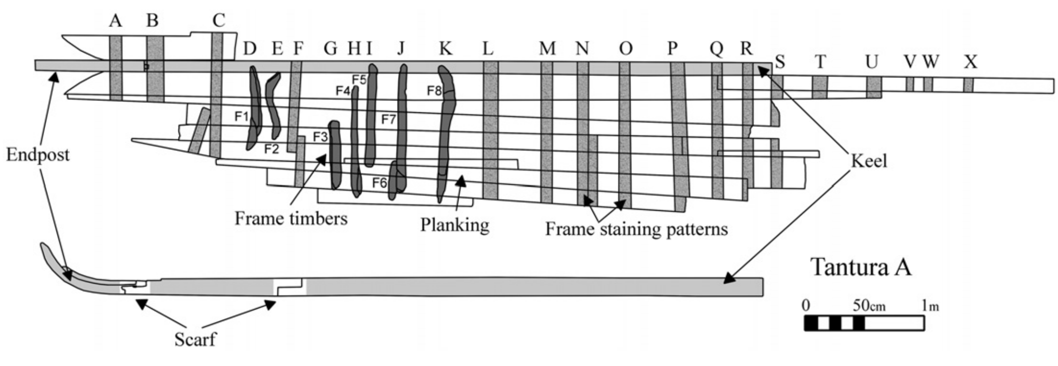

Figure 35. Tantura A shipwreck. Timber remains. (P. Sibella)

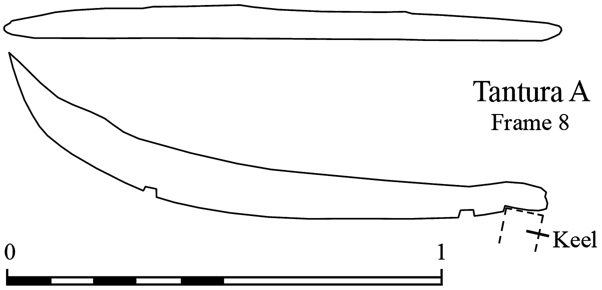

Figure 36. Tantura A shipwreck. The longest extant frame (frame 8) determines the turn-of-the-bilge. (P. Sibella)

There were no keel rabbets or chamfered edges for the garboards, nor was a false keel discovered. The keel was hook-scarfed to an endpost timber, which rose at an angle of *c*.55°, with a total curved length of 1.32 m over its upper surface. The endpost had a rabbet 50 mm deep and 12 mm wide, beginning 140 mm outward from the keel-post scarf. The garboards were nailed to the endpost.

Fragments of eight frames at seven frame-stations were found, together with staining-patterns and nail-holes indicating 17 additional frame-stations whose timbers did not survive. Average frame dimensions were 90 mm sided and 95 mm moulded, with an average centre-to-centre spacing of 324 mm. The longest framing-timber survived to a length of 1.31 m from the keel to the turn of the bilge. The frames were fixed to the keel with iron nails. Remains of eight pine strakes were discovered on one side, and two on the other. One of the garboards survived to a length of 8.78 m, and neither was connected to the keel. The planks were 25 mm thick and 38–260 mm wide, and were fixed to the frames with iron-nails.

Tantura A, although thoroughly scrutinized, showed no indications of mortises or tenons, or any other method of joining planking-edges. On the other hand, it revealed frames nailed to the keel, planking nailed to frames and butt-jointed at frame stations, garboards unconnected to the keel, and caulking in the seams. This combination of features indicates frame construction principles and methods, although no solid skeleton was archaeologically evident—perhaps this hull-type did not need such reinforcement. Tantura A thus displayed an early stage of the transition in ship-building in the eastern Mediterranean.

Dor 2001/1

(Mor, 2003; 2004; 2005; Kahanov and Mor, 2006; Mor and Kahanov, 2006; Basch, 2008; Rieth, 2008; Kahanov and Mor, 2009; Mor, 2010a; Mor, 2010b; Kahanov, 2011a; Kahanov, 2011b) (Figs 37–39).
This wreck of a coaster loaded with building-stones was discovered in Dor/Tantura lagoon 70 m offshore,

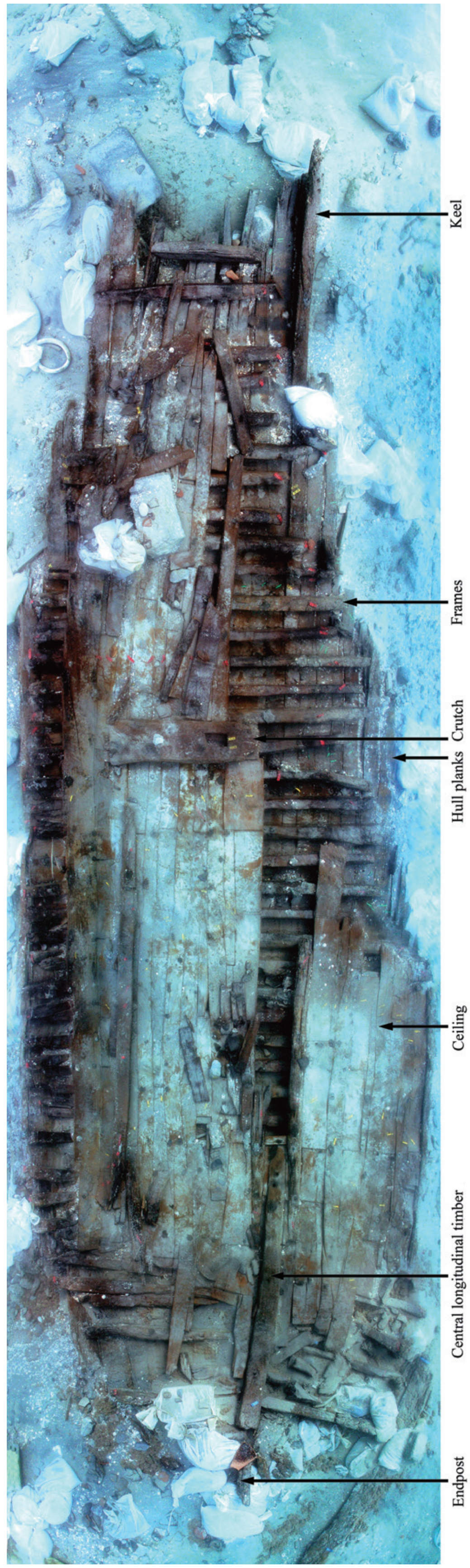

Figure 37. Dor 2001/1 shipwreck. Top view of the hull, after removing the cargo. (S. Breitstein)

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Figure 38. Dor 2001/1 shipwreck. Half-frame at the chine. (S. Breitstein)

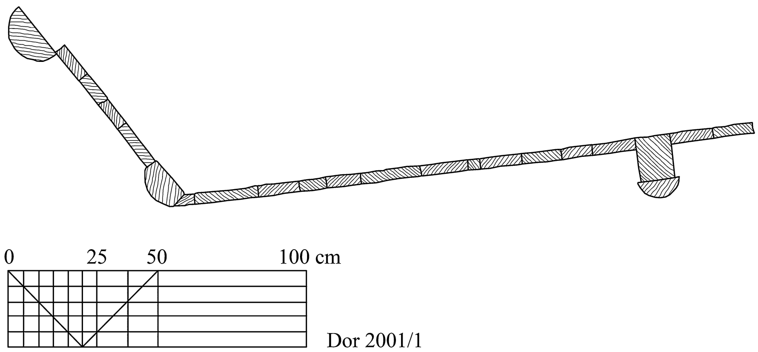

Figure 39. Dor 2001/1 shipwreck. Planking cross-section amidships after remains of wale 2 and the strake beneath it were removed. (C. Brandon)

at a water-depth of 1.5 m, buried under 1.5 m of sand (Fig. 34). The wreck was spread over 11.5 × 4.5 m, and the hull's original dimensions were estimated at 16.9 m long by 5.4 m wide. Although abundant 4th–7th-century-AD pottery sherds were found on the site, a wary approach in accepting these as *in situ* ceramics led to dating the wreck by ^{14}C analysis, to the beginning of the 6th century AD (wiggle-matching by Professor Sturt Manning, director of the Tree-Ring Laboratory at Cornell University, USA, has provided a *terminus post quem* of AD 494–535 (2 SD)).

The hull-remains included keel, false keel, frames, planking, chine-strake, wales, ceiling-planking, stringers, part of the mast-step assemblage, and a central longitudinal timber. The cross-section of the hull was of flat frames and sharp turn of the bilge (hard chine), with straight sides. The keel was made of cypress, 11 cm sided and 15 cm moulded; and an oak false keel 11–13 cm wide and 5–9 cm-thick was fixed to its underside with iron nails. No keel rabbet was found, but a rabbet was found in an endpost.

The framing-pattern was of alternating floor-timbers and pairs of half-frames. Futtocks extended the frames over the bilge to the sides, but most were not connected to the floor-timbers. The turn of the bilge was shaped and maintained by half-frames, each made of a single piece of naturally-curved timber, comparable to knees of inland boats built 'bottom-based'. The frames were typically 75–90 mm sided, 85–120 mm moulded, with room-and-space of 240 mm. Almost all frames were nailed to the keel by iron nails 6 × 6 mm square. At one of the ends an oak central longitudinal timber 2.55 m long survived, 150 mm sided and 180 mm moulded. It was placed above the frames on the longitudinal axis similarly to a keelson (the term 'central longitudinal timber' as an inference of the timber's function was suggested by J. R. Steffy).

Sections of 29 strakes were exposed, their width varying between 50 and 206 mm, and thickness between 20 and 33 mm. The garboards were not connected to the keel, but were connected to the endpost. Two wales were identified, made of half-logs; the lower 220 mm wide by 105 mm maximum thickness, and the upper 200 × 80 mm. The planks were connected to the frames by square, tapered iron nails driven from the outside. Their cross-section near the head was 7.3 mm, and at the inner face of the plank, where they entered the frames, 6.2 mm. Neither mortise-and-tenon joints, nor any other type of planking-edge joints, were found anywhere in the hull. Planks were joined to strakes by butt-joints at frame-stations. Caulking was found in planking seams.

This concept of the hull and its method of construction were based on frames and longitudinal reinforcements in the form of stringers, a central longitudinal timber (which was evident at one end, and probably existed in the original ship at the other end, but did not survive), a foot-wale, chine strakes and two wales. The planking attachment to frames, planking butt-joints at

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frame-stations, and caulking were typical of frame construction. No evidence of a continuous massive keelson/mast-step was found, nor evidence for connections of the mast-step to stringers or frames, but the mast-step could have been fitted within and above the two sister-keelsons but, however, not necessarily connected (see Tantura F below). Apparently, this type of hull did not need additional longitudinal strengthening.

This hull-construction demonstrates a new and different building technique in the Mediterranean—flat frames amidships, hard chine and straight sides—and therefore warrants special attention. As to the tradition behind this hull, Rieth (2008) proposed a protected water/river construction tradition and origin, and further suggested the Nilotic/Egyptian tradition. Basch (2008) supported the idea of an Egyptian origin, from the particular use of caulking, and extended this idea slightly further by locating it specifically in Alexandria. Kahanov (2011b) further developed this idea, strengthening the possibility of the Egyptian origin of this tradition.

Dor D

(Kingsley and Raveh, 1996; Kahanov and Royal, 2001; Kingsley, 2002; Kahanov, 2003; Royal and Kahanov, 2005) (Figs 40–41).

Dor D was a shallow site in Dor/Tantura lagoon, 4 × 6 m in area, 30 m from the shore (Fig. 34). The wreck consisted of the remains of about 30 planks in a poor state of preservation, scattered on the sea-bed. It was impossible to reconstruct a cross-section. Since ceramic analysis for dating in Tantura lagoon is suspect, its dating was based on ^{14}C results, which give a range of AD 350–621. (Two analyses were made: RT-1539, AD 539–621 (calibrated) (Kingsley and Raveh, 1996: 65); and RT-4613, AD 350–370 (3.5%),

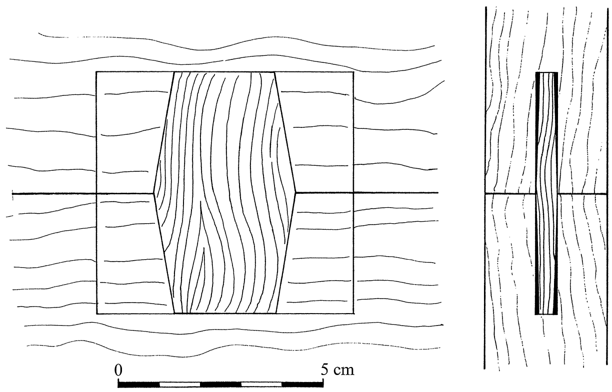

Figure 41. Dor D shipwreck. Typical mortise-and-tenon joint. (S. Haad)

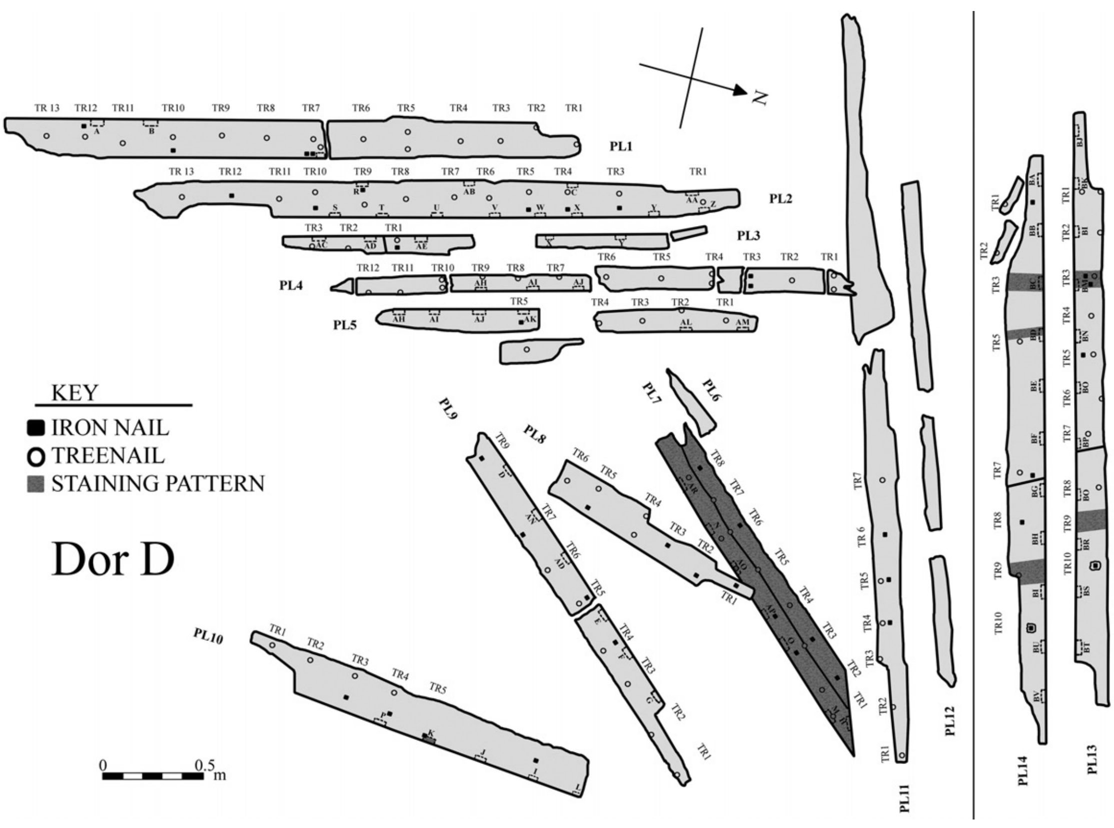

Figure 40. Dor D shipwreck. Site-plan. (S. Haad)

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380–440 (56%), 450–530 (8.4%) (calibrated) (Boaretto, 2004).

Plank fragments included evidence of unpegged mortise-and-tenon joints, but with a single pegged tenon close to a scarf. Planks were generally 30 mm thick, and some were more than 200 mm wide. Mortises averaged 63 mm wide, 5 mm thick and slightly more than 30 mm deep. Their spacing-pattern was inconsistent, with an average centre-to-centre distance of 29 cm, the widest being nearly 62 cm. Oak tenons were tapered, with an average width of 35 mm, thus occupying about 60% of the mortise width. Tenon lengths were equal to their combined mortise depths. Frames appear to have been *c.*100–110 mm sided, with a typical centre-to-centre spacing of *c.*230 mm. Plank-frame attachments showed evidence of oak treenails, with a maximum 15 mm hexagonal cross-section, and some also contained remnants of 5×5 mm square iron nails. It seems that mortise-and-tenon joints assisted in aligning the planks. Once planks were in place, iron nails fastened them to a few of the frames, and later they were secured to each frame by treenails.

Dor D thus could indicate a shell longitudinal conception for the shape, but a structural conception with mixed shell-skeleton construction methods.

Port Berteau 2, Charente-Maritime, France

(Rieth *et al.*, 2001) (Figs 42–45).

This shipwreck was found upside-down, at a depth of 7 m, 64 km upstream in the estuary of the River Charente, on the Atlantic coast, within the active-tidal zone. It was a coaster and river freighter, dated by dendrochronology to AD 599–600. The archaeological remains spread over 13.10×4 m, and the original ship was estimated to have been 14.3 m long, with a beam of 4.8 m, and a maximum burden of 10 tons. The midship cross-section had flat floor-timbers, a well-rounded bilge, and straight sides. *Quercus* sp. of regional origin was the only timber identified in the hull.

The keel was not preserved. The carvel planks were nailed to the stem- and sternposts, and connected to the frames by 25-mm-diameter treenails. Neither mortise-and-tenon joints, nor any other type of plank-edge fasteners, were found anywhere in the hull. Planks were on average 30 mm thick and 100–220 mm wide. Five wales (55 mm thick, 70–200 mm wide) were connected to the frames by treenails. The planking-seams were caulked with pitch mixed with

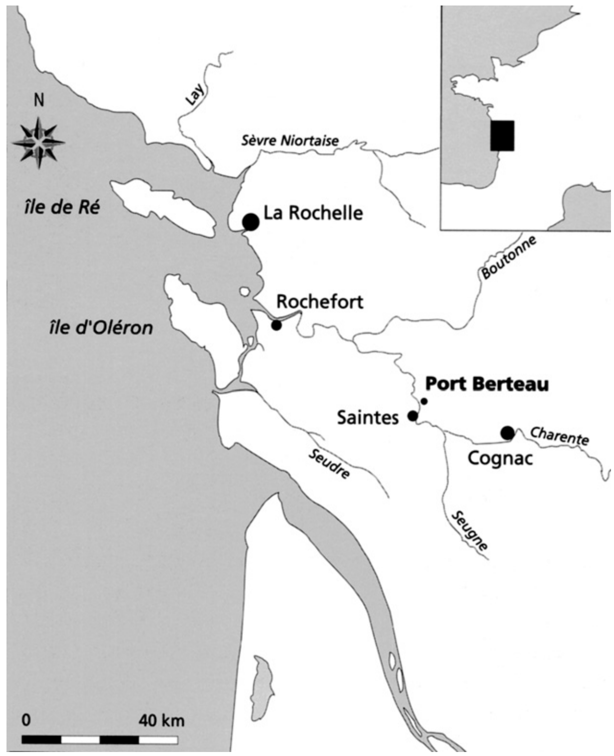

Figure 42. Port-Berteau 2 shipwreck. Location of the shipwreck-site. (Rieth *et al.*, 2001, fig. 1)

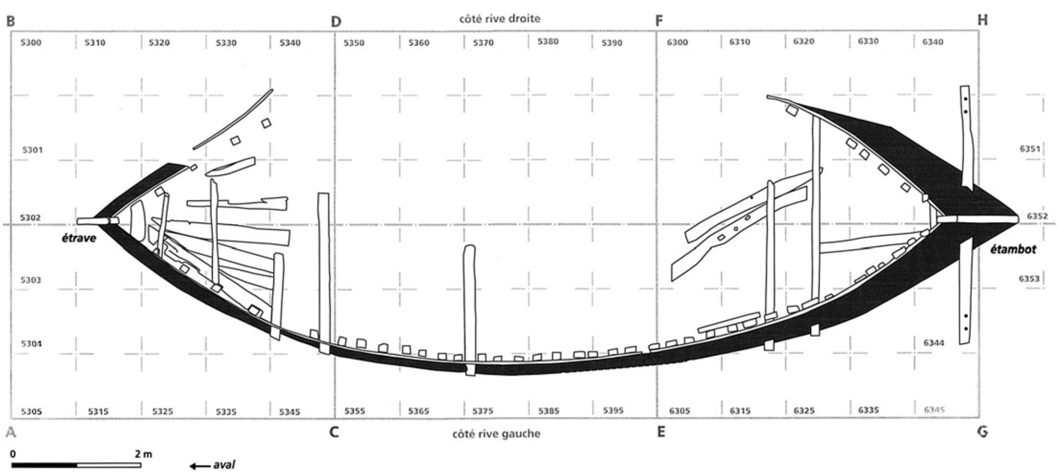

Figure 43. Port-Berteau 2 shipwreck. Wreck-plan. (Rieth *et al.*, 2001, fig. 29)

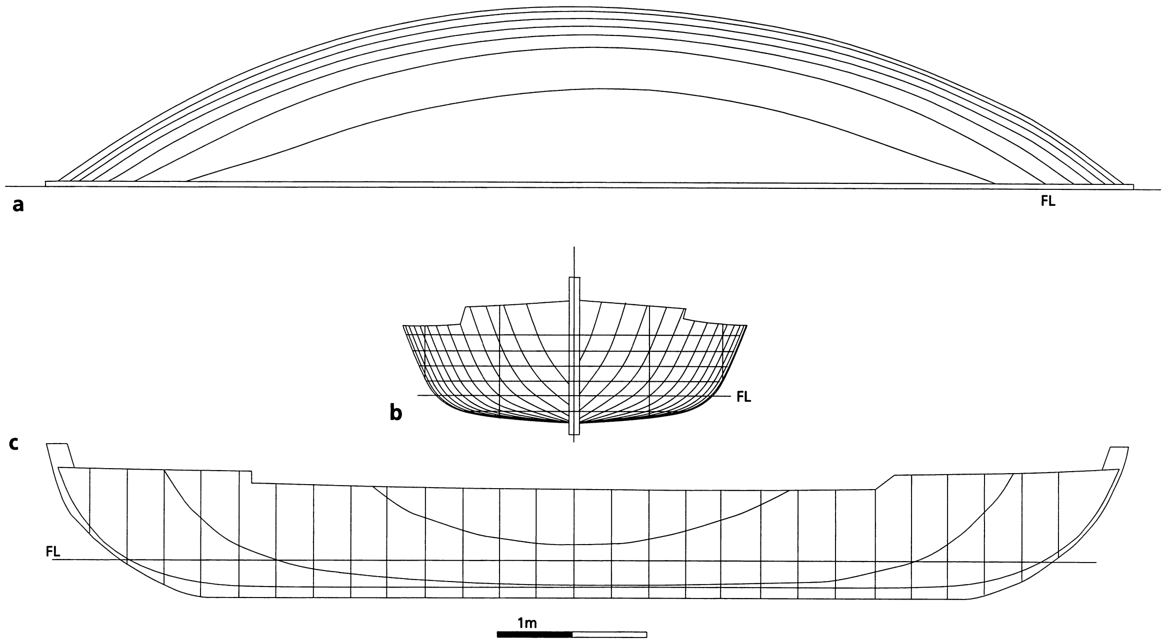

Figure 44. Port-Berteau 2 shipwreck. Reconstruction of the hull-lines. (Rieth *et al.*, 2001, fig. 106)

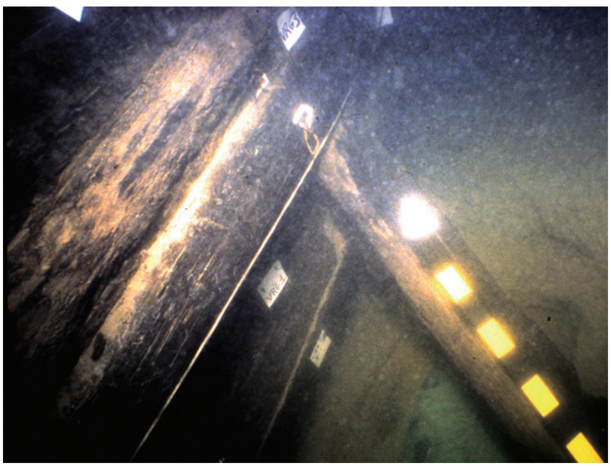

Figure 45. Port-Berteau 2 shipwreck. Detail view of the aft extremity of the overturned hull: the starboard side with one half of the steering beam. (Reproduced courtesy of E. Champelovier)

twigs and stems. Frames were on average 140 mm sided and 95 mm moulded, with an average room-and-space of 190 mm.

The concept and construction method of this hull were based on frames.

Saint-Gervais 2

(Jézégou, 1983; Carre and Jézégou, 1984; Jézégou, 1985; Pomey, 1988: 410–11; Jézégou, 1989; Jézégou, 1998; Pomey, 2004a: 33) (Figs 46–48).

The wreck was found near Saint-Gervais in the Golf de Fos, southern France, at a depth of 2.5 m. It was dated to the 7th century AD, during the Merovingian period; thus a Merovingian origin can be considered. According to the latest study of the material, the wreck should be dated later than first thought, perhaps up to the second half of the 7th century. The cargo was African, and the crew's artefacts were from Africa or the south of France, with the exception of one amphora and two bowls from the eastern Mediterranean (Jézégou, 1998: 343–50, 418). Hull-remains were 9.5 m long and 4.5 m wide. The ship's original length was estimated to have been 15–18 m. The midship cross-section had a wine-glass shape, a round turn of the bilge, and straight sides.

The aft part of the keel, 3.9 m long, was preserved. It was 90–150 mm sided and 200–240 mm moulded, with a rabbet. The garboards were not connected to the keel. In the centre part, a mast-step/keelson, surviving to a length of 4 m, 320 mm wide and 200 mm thick was fitted onto a double sister-keelson, 90 mm wide, 190 mm thick. Towards the stern, it stopped at the bilge-pump. Abaft the pump, in the aft part of the hull, a keelson (200–220 mm wide, 400 mm thick and 4 m long,) was directly set on the floor-timbers. This central longitudinal timber was bolted to the keel at each floor-timber, except the last one at the extension of the piece. In the fore part there was also a central longitudinal timber, which was not preserved, but marks of its setting on the floor-timbers were still visible. Stringers were nailed to the frames. These internal axial components, with a central keelson/mast-step mounted on sister-keelsons and its extension toward each

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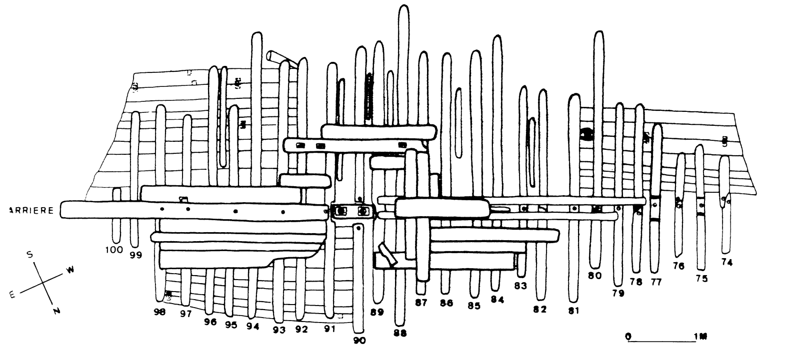

Figure 46. Saint-Gervais 2 shipwreck. Hull-plan. (Jézégou, 1989, fig. 2, reproduced with permission)

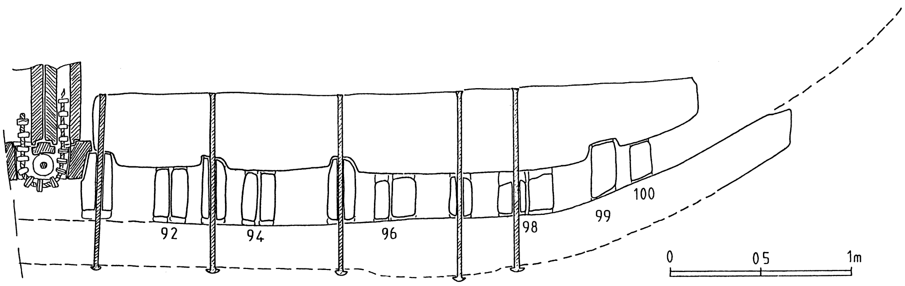

Figure 47. Saint-Gervais 2 shipwreck. Longitudinal section of the after part. (Jézégou, 1989, fig. 3, reproduced with permission)

extremity, are similar to that of the western Roman Imperial type. They were also similar to that of Tantura F, and perhaps to Dor 2001/1, which was only partially preserved.

Planks were *c*.25–30 mm thick, the garboard being 40 mm, and 70–260 mm wide. On the inside the hull-planking was covered by a thick coat of pitch (belonging to the cargo, originally stored in amphoras) making it impossible to make any observations. In the parts of the shipwreck where the pitch did not prevent examination, fewer than ten widely-spaced (over 1 m) mortises were identified toward the extremities. Some did not have a corresponding mortise in the adjacent strake and did not have tenons. In the others, tenons were unpegged. Neither pattern nor system could be identified in the tenon locations: no doubt, they were of no importance in ensuring the integrity of the planking, perhaps being used for aligning planks during construction, or indicating secondary use. The few mortises were on average 70 mm deep; tenons were 28 mm wide, occupying about 40% of the mortise width, and with a half-length of 44 mm. Iron nails and treenails were used to attach planks to frames and other hull-members. Planking-seam caulking was evident.

The framing-pattern was of alternating floor-timbers and half-frames. All floor-timbers, except the last one at the aft extremity (M 99), were fastened to the keel by long iron bolts. Slightly towards midships, one floor-timber (M 93) rested on the keel. The question is whether the floor-timbers which were bolted to the keel were pre-erected. This could only be examined at the aft part, where the keel still survived. In this part, floor-timber M93 certainly touched the keel, but there is no certain evidence regarding other frames. Five pairs of half-frames were nailed together and bolted to the keel. Floor-timbers were 120–200 mm sided and 220–400 mm moulded. Half-frames were 100–150 mm sided and 100–270 mm moulded. Room-and-space varied between 150 and 360 mm, averaging 250 mm (Jézégou, 1983: 34). A section of the starboard side was preserved, with two wales, 110 mm wide and 90 mm thick, which were not integrated into the shell-planking, but treenailed over the planking to the frames.

Due to the lack of plank-edge joints, apart from the few mortise-and-tenon joints, and on the other hand, the strong connection of the frames to the keel, where about two-thirds of the frames (floor-timbers and half-frames) were bolted, and the importance of the longitudinal strengthening timbers, this hull was probably conceived on frame principles for the hull-shape, and certainly based on a frame structure. The construction method was probably frame-skeleton first. Thus, the transition from shell to skeleton appears to have been complete, even if a mixed process cannot be totally

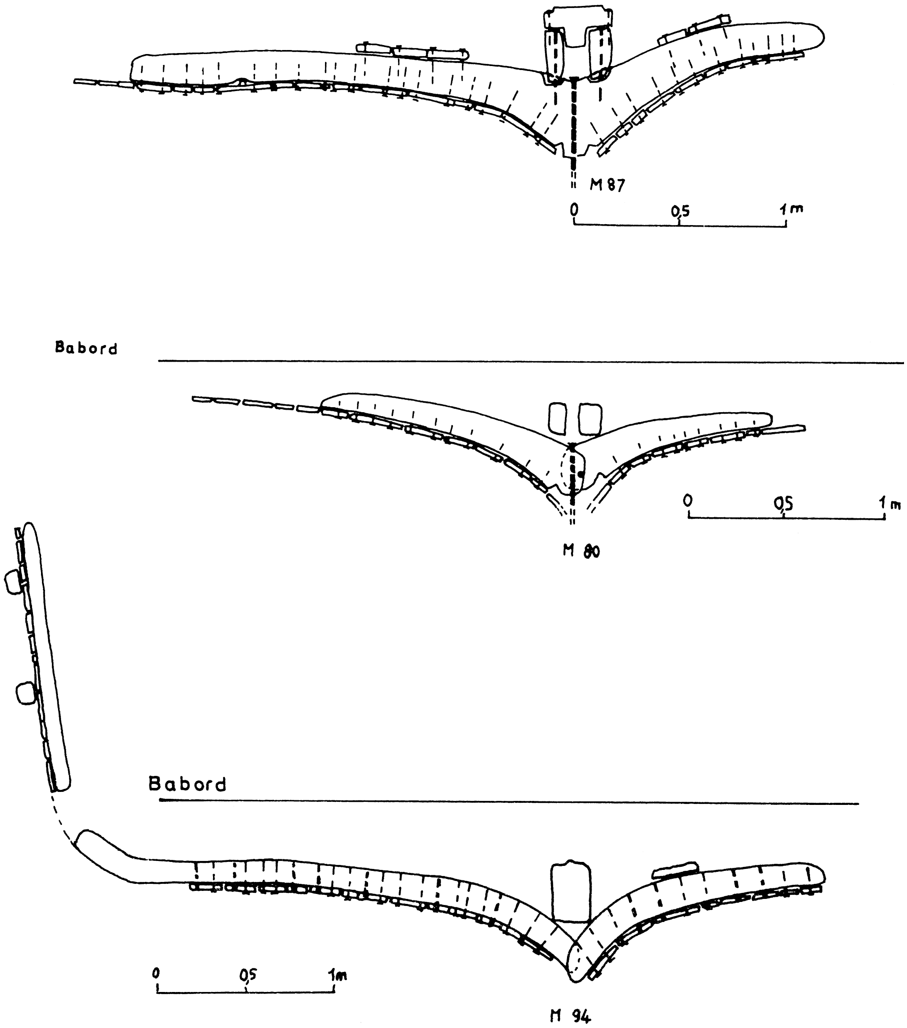

Figure 48. Saint-Gervais 2 shipwreck. Cross-sections at frames 80, 87 and 94. (Jézégou, 1989, fig. 4.6, reproduced with permission)

excluded. This was one of the earliest vessels in the Mediterranean, and the first in the western part, constructed on frame-skeleton principles, although some relics of mortise-and-tenon joints were present.

Yassıada 1

(van Doorninck, 1972; Steffy, 1982a; van Doorninck, 1982; Pomey, 1988: 409–10; Steffy, 1994: 80–85; Pomey, 2004a: 32–3) (Figs 49–52).

This Byzantine shipwreck was found 80 m from the southernmost point of Yassıada, southern Turkey, at a depth of 32–39 m, and dated to *c.*AD 625, during the reign of Honorius. The archaeological remains spread over 15 × 6.3 m. Its reconstructed dimensions were 20.52 m long on deck, 5.2 m maximum beam, 2.25 m depth in hold, and 72.86 tons displacement. It had a wine-glass transverse cross-section amidships, with a round turn of the bilge.

The keel was 220 mm sided and 355 mm moulded. The false keel did not survive, but its reconstructed thickness was 45 mm. Garboards were fitted into the keel rabbet with unpegged mortise-and-tenon joints, and held with iron nails. The strakes varied in width from 130 to 250 mm, and in thickness from 35 to 42 mm. The first 16 strakes were aligned by using unpegged mortise-and-tenon joints during construction (Fig. 51). These mortises were 50 mm wide, 5 mm thick and 35 mm deep, and tenon length was equal to the combined mortise depth: however, they were only 30 mm wide, thus occupying only 60% of the mortise width. Centre-to-centre mortise spacing was *c.*2250 mm along the garboards, 350–500 mm in the stern area, and *c.*900 mm in the middle of the hull. The planks and frames, as well as the other hull-components, were attached by iron nails, spikes, and bolts of different sizes. Four wales, essentially 20-cm-diameter half-logs, were bolted to frames and clamps and stringers.

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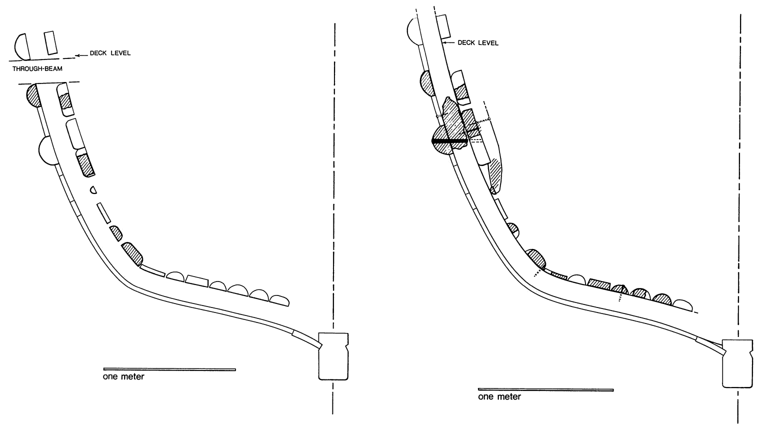

Figure 49. Yassıada 1 shipwreck. Cross-sections between frames 32 and 33 (midships) and at frame 29. (Steffy, 1982a, figs 3.15–3.16, reproduced with permission)

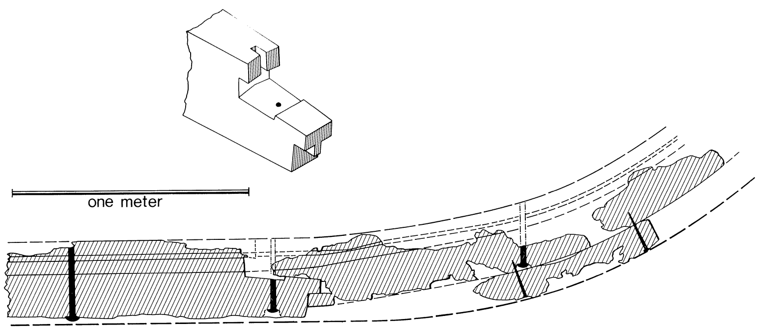

Figure 50. Yassıada 1 shipwreck. Detail of the keel and of the scarf joint. (Steffy, 1982a, fig. 3.26, reproduced with permission)

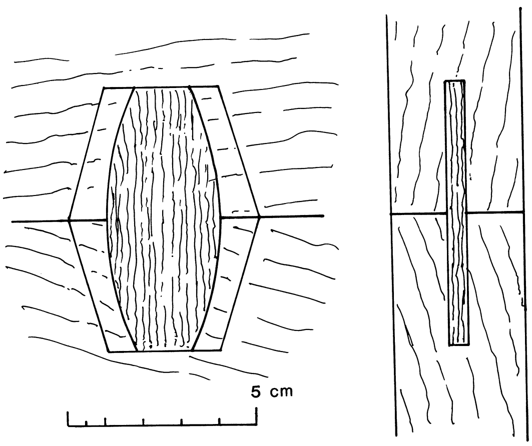

Figure 51. Yassıada 1 shipwreck. Typical mortise-and-tenon joint. (Steffy, 1994, fig. 4.4, reproduced with permission)

The framing system was fairly elaborate, consisting of short floor-timbers, long floor-timbers, overlapping half-frames, futtocks, and top-timbers. Frames were, on average, 140 mm square, with room-and-space of *c*.300–350 mm (based on Reassembly Drawings I and II in Steffy, 1982a, and pers. comm., and see Casson, 1995: 216, based on unpublished information). One out of four frames was connected to the keel by long bolts, while almost all the others were attached by a single iron nail. Even though no wood survived, it was hypothesized by Steffy (1982a: 77) that the keelson and inner posts were bolted to the keel and the framing. Although only unpegged loose mortise-and-tenon joints existed between the first 16 strakes, this hull was still built according to strake principles for the determination of the bottom hull-shape (at least up to the 16th strake). These strakes were secured in place and reinforced by frames. Framing timbers based on the hull served as supports for higher side-planking, where from the 17th strake and upwards no mortise-and-tenon joints were evident. From this level upwards, the hull was built according to frames. After the framing had been completed, and before the ceiling-strakes were installed, a thick coating of resin pitch was applied to both the interior and the exterior of the hull, at least to the level of the waterline. Although no caulking was reported to have been found in the seams of the first 16 strakes, which would have been very difficult as they had mortise-and-tenon joints, a caulking-iron for sealing leaks was found. At the next stage, the keelson and ceiling strakes (stringers and clamps) were fitted and nailed.

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This process shows that the transition in construction towards frame-orientation and skeleton construction was well in progress by the beginning of the 7th century. The main strengthening of the hull was based on frames and longitudinal members, although the shipwright still employed the mortise-and-tenon joint for aligning the planking. This ship, therefore, was an example of mixed construction, in both principle and method, and was thus a significant step in the transition from shell to skeleton construction.

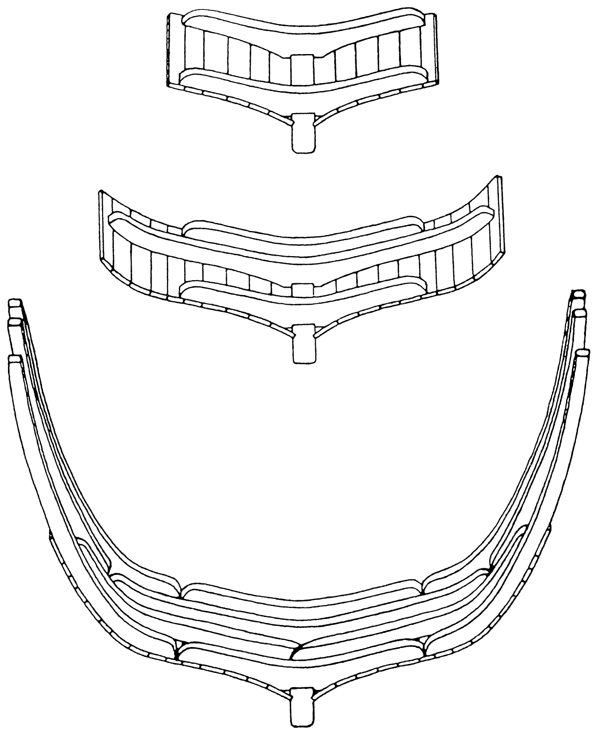

Figure 52. Yassıada 1 shipwreck. Framing and planking sequence. (van Doorninck, 1976, fig. 13, reproduced with permission)

Pantano Longarini

(Throckmorton and Kapitän, 1968; Throckmorton and Throckmorton, 1973; Kampbell, 2007) (Fig. 53). The wreck was found on land, in the Pantano Longarini marsh, near Pachino, west of Capo Passaro in south-eastern Sicily. It was dated by ^{14}C and partial ceramic re-assessment to the early-7th century AD. The archaeological remains which were studied were *c*.9.1 m of the starboard side of the stern above the waterline, while *c*.15 m of the wreck had been destroyed earlier by local workers. The updated reconstruction suggested that it was a large barge 31.5 m long and 10.25 m wide, designed for transporting heavy cargoes, perhaps *c*.300 tons. Both suggested reconstructions of the hull (by Throckmorton and Throckmorton, 1973: 258; and Kampbell, 2007: 66) suggested a round turn of the bilge. There was no agreement on the reconstruction of the bottom, and Kampbell ruled out a wine-glass cross-section.

Unpegged widely-spaced (up to 1 m) mortise-and-tenon joints served to align the planks, and then frames were fastened to the hull by iron nails. Planks were 140–540 mm wide, and 50 mm thick on average (based on drawings in Throckmorton and Throckmorton, 1973: 250 fig. 9, 254 fig. 13, 256–7 fig. 15). Planks were joined into strakes by diagonal, ‘S’ and ‘Z’ scarfs. The framing-pattern was closely-set alternating floor-timbers and half-frames. The frames were massive natural-grown timbers, 180–250 mm average sided and moulded, with average room-and-space of 350 mm. The hull had five wales, made of half-logs: three were heavy, *c*.500 mm wide and almost 250 mm thick; and two were lighter, *c*.200 mm wide and 100 mm thick (based on drawings, see above). They were nailed to the frames.

Given the unpegged mortise-and-tenon joints, the ship was probably built on mixed strake-and frame-principle

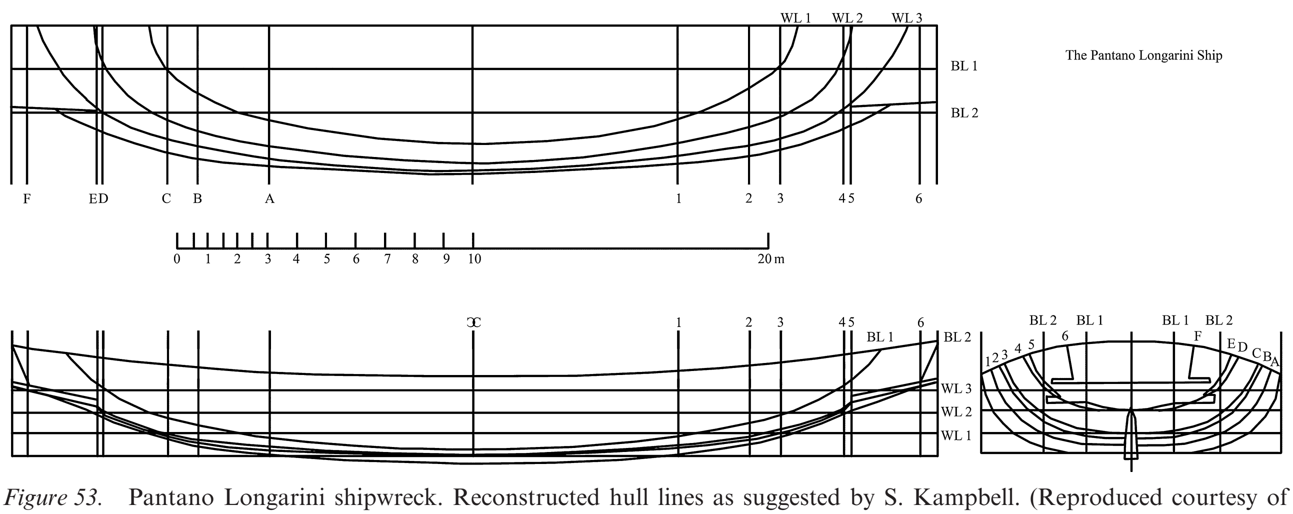

Figure 53. Pantano Longarini shipwreck. Reconstructed hull lines as suggested by S. Kampbell. (Reproduced courtesy of S. Kampbell)

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and methods. In the absence of evidence of a connection between the keel and the frames, it appears that a great part of its integrity for the upper part was based on five wales and a stringer. Researchers suggested that this hull-construction demonstrated a stage of transition and of abandonment of the shell-first technique.

Tantura F

(Wachsmann *et al*., 1997, Trench X; Barkai and Kahanov, 2007; Barkai, 2009; Barkai, 2010; Barkai *et al*., 2010; Eliyahu *et al*., 2011; Kahanov, 2011a; Kahanov, 2011b) (Figs 54–55).

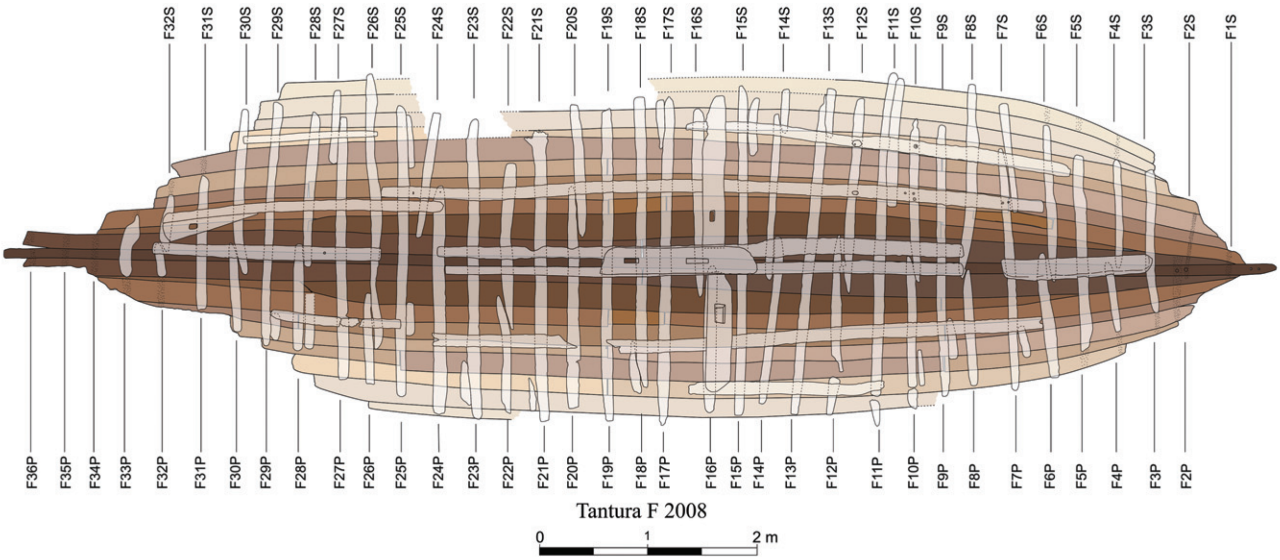

Figure 54. Tantura F shipwreck. Top view of timber remains. (C. Brandon, S. Haad and N. Yoselevich)

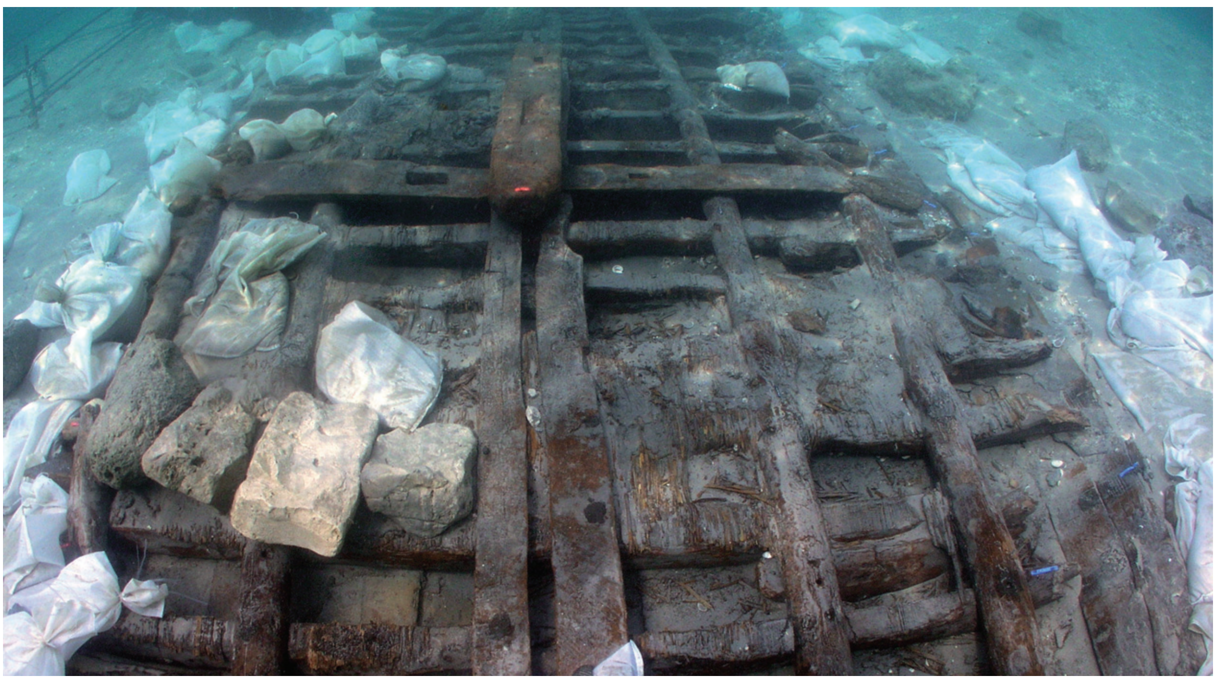

Figure 55. Tantura F shipwreck. General view, note the flat frames and the turn of the bilge (bottom right-hand corner). (S. Breitstein)

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Tantura F, in Dor/Tantura Lagoon, Israel, was first surveyed in 1996, and was excavated over five seasons between 2004 and 2008 (Fig. 34). It was dated to between the mid-7th and the end of the 8th century AD. The archaeological remains spread over 12 × 4 m, and the original ship was estimated to have been 15.7 m long, with a beam of 5.2 m. The shape of its cross-section amidships was of flat frames with a round turn of the bilge.

The measurable dimensions of the keel were 104 mm sided and 120–168 mm moulded. No rabbet or chamfered corners for fitting the garboards were evident, but rabbets were identified at its ends and in the bow and stern transitional timbers.

Thirty-one extant frame-timbers were exposed, including floor-timbers, pairs of half-frames, futtocks, and long/short-armed frames. Generally the framing-pattern was of alternating floor-timbers and half-frames, except under the mast-step, where a series of floor-timbers and futtocks only was identified. The frames, of variable length, were on average 95 mm sided by 120 mm moulded, with room-and-space of 315 mm. Nearly all were connected to the keel by iron nails. Futtocks were fixed to the floor-timbers randomly on the fore or after side. In the archaeological remains only one nail per futtock was found, except in one futtock, where two nails connected it to the floor-timber.

Planks were up to 235 mm wide, and their average thickness was 25 mm. They were connected to the frames by square iron nails of 5 mm average side, one or two nails connecting each plank to each frame, depending on plank-width. Planks were butt-jointed to strakes at frame-stations. No planking-edge joints were evident anywhere. Caulking was found in the seams, and also used for repairs and filling gaps.

At the ends of the hull two central longitudinal timbers were evident. The bow timber was 2.03 m long, maximum 132 mm sided, and 159 mm moulded. The stern timber was 1.42 m long, maximum 142 mm sided, and 145 mm moulded. At the centre of the hull two sister-keelsons supported the mast-step, which fitted into a space between the stringers that was shaped for it, but was not connected to the stringers. It was 1.45 m long, 260 mm maximum sided, and 200 mm moulded. This system of longitudinal components resembles similar installations in St-Gervais 2 and in one end of Dor 2001/1.

This hull was based on keel, frames and longitudinal reinforcing members, to which planks were nailed and caulked. The concept and construction method of Tantura F were based on frames.

Tantura E

(Wachsmann and Kahanov, 1997; Royal and Kahanov, 2000; Planer, 2007; Kahanov *et al*., 2008; Kahanov, 2011a; Kahanov, 2011b) (Figs 56–57).

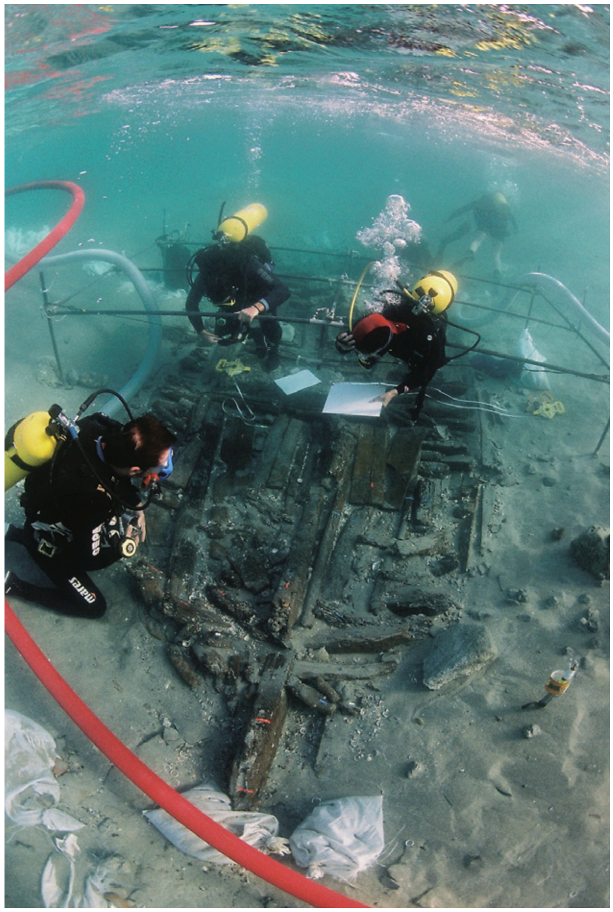

Figure 56. Tantura E shipwreck. General view. (I. Grinberg)

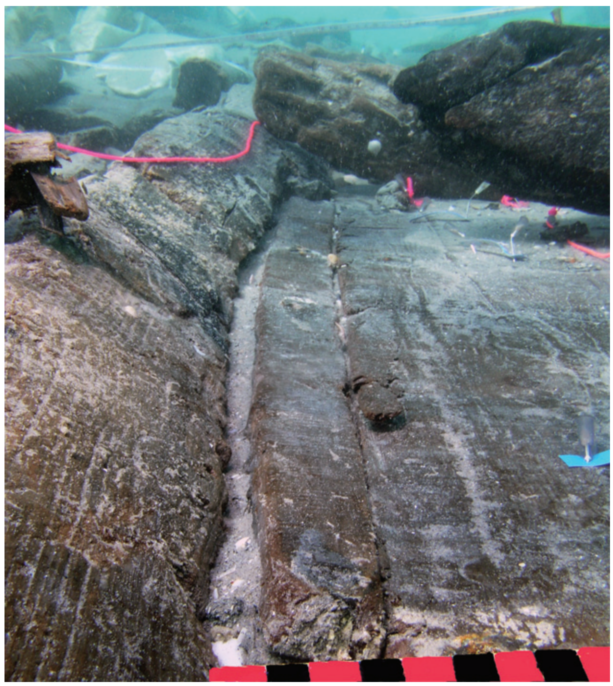

Figure 57. Tantura E shipwreck. Planking at the turn of the bilge (chine) on the western side. (A. Yurman)

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The Tantura E shipwreck was discovered in Dor/Tantura lagoon in 1995, and excavated systematically in 2006, 2007 and 2008 (Fig. 34). The wood-remains spread over an area of 7.6 × 3.1 m, but its original size has not yet been determined. It was dated to between the 7th and 9th centuries AD. Its cross-section was of flat frames, with a sharp turn of the bilge.

A 7.6-m section of the cypress keel, transitional timber and a fragment of the endpost survived. The keel had a rectangular cross-section, 100 mm sided and 170 mm moulded, and was rabbeted along its entire length. Wood-remains and nail-holes indicated the existence of a false keel, *c.*45 mm thick.

Remains of 44 framing-timbers were recorded in 24 frame stations, comprising floor-timbers, pairs of half-frames and futtocks. The framing-pattern, with a few exceptions, was of alternating floor-timbers and half-frames. Most of the frames were attached to the keel by iron nails. The frames were on average 100 mm sided and 120 mm moulded, with average room-and-space of 260 mm.

Sections of 23 strakes of pine and cypress survived, 13 on the western side and 10 on the eastern side of the keel. The planks, up to 210 mm wide, and 22–28 mm thick, were connected to the frames by between one and three iron nails, depending on the plank-width, and were butt-jointed at frame-stations. The planks were exceptionally short; the longest being only 3.1 m, and showed many repairs. Remains of caulking were found in many plank-seams, and also for repairs and filling gaps, parallels to which were found in both Tantura F and Tantura B.

A central longitudinal timber was found in the northern area of the wreck, above the frames, 2.14 m long, 100 mm sided, and 150 mm moulded on average. No evidence of its being a full-length keelson was found, and there was no evidence of a mast-step. Sections of seven stringers, a bulkhead-support, and a stanchion were found. A mortise containing a tenon was found in one ceiling-plank, the only example of this technology found in Tantura E, and was in an internal component, not a hull-plank.

The hull of Tantura E was based on keel, frames and longitudinal reinforcing members, to which planks were nailed and caulked. Its concept and construction method were based on frames.

Tantura B

(Wachsmann *et al.*, 1997, Trench XIII; Kahanov, 2000; Kahanov *et al.*, 2004; Kahanov, 2011a; Kahanov, 2011b) (Figs 58–59).

The remains of this wreck were found in Dor/Tantura lagoon, spread over an area of 12 × 3 m (Fig. 34). Analysis of the finds and ^{14}C results dated it to the beginning of the 9th century AD. The ship was *c.*18–23 m long, 5 m wide, with a flat and constant hull cross-section over a significant length, and a round turn of the bilge.

The oak keel, 104 mm sided and 95 mm moulded, survived to a length of 9.8 m. Except for a short rabbet close to the endpost, there were no rabbets or chamfered edges in the keel, and there was no evidence of a false keel. The keelson was chamfered on both its upper and lower faces, and its underside was notched for fitting onto the frames. Iron nails *c.*10 mm square connected the keelson and the floor-timbers.

Thirty articulated pine frames were preserved, forming a pattern of alternating floor-timbers and half-frames. Evidence of nine additional frames was identified. Floor-timbers were 96 mm sided and 97 mm moulded; and half-frames were 87 mm sided and 91 mm moulded, with average room-and-space of 260 mm. Some frames were preserved to the turn of the bilge. Both floor-timbers and half-frames were fastened to the keel with a single nail, and further reinforced by the keelson from above, although the half-frames were not cross-nailed to each other. The largest preserved floor-timber was 2.48 m long, and extended 1.43 m outwards from the centreline of the keel. No futtock timbers survived. However, several fastener concretions indicated the existence of futtocks, but the impression was not of strong connections. The pine keelson, 122–202 mm sided, 157–180 mm moulded, and 7.84 m long, stretched along most of the length of the shipwreck, from the surviving end to the point where it was broken. It was hook-scarfed from two components, and the scarf had been reinforced from above by another timber. It served as a mast-step, having a recess for the mast-heel in its upper surface.

Remains of 12 strakes survived, five on one side and seven on the other. Planks were pine, with one exception, between 40 and 360 mm wide, and with an average thickness of 30 mm. The sixth strake on the western side was of oak, 100 mm wide and 85 mm thick: apparently this was the bilge-keel or a wale. Strakes were not connected to the keel, apart from one strake on either side fitting into a short rabbet in the keel-end. Planks had butt-joints and L-shaped joints at frame-stations. Square iron nails of 5-mm cross-section were used to connect planks to frames. No planking-edge joints were discovered anywhere in the hull. Caulking was found in planking seams and filling gaps.

Tantura B thus presents a frame concept and construction method, and a developed longitudinal backbone. Although this hull included keel, keelson and sister-keelsons, it perhaps needed more longitudinal strengthening.

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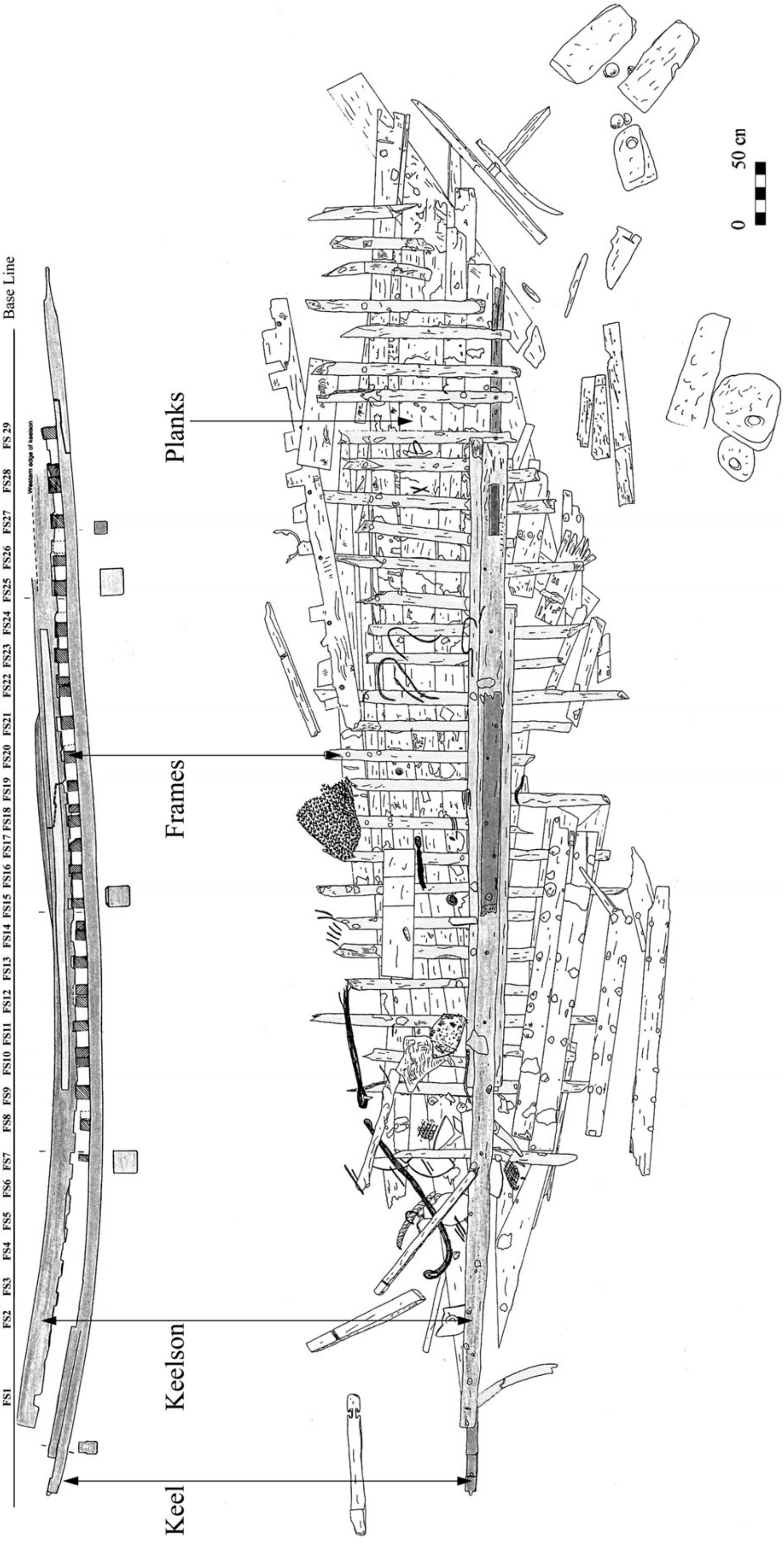

Figure 58. Tantura B shipwreck. Site-plan and longitudinal section. (P. Sibella)

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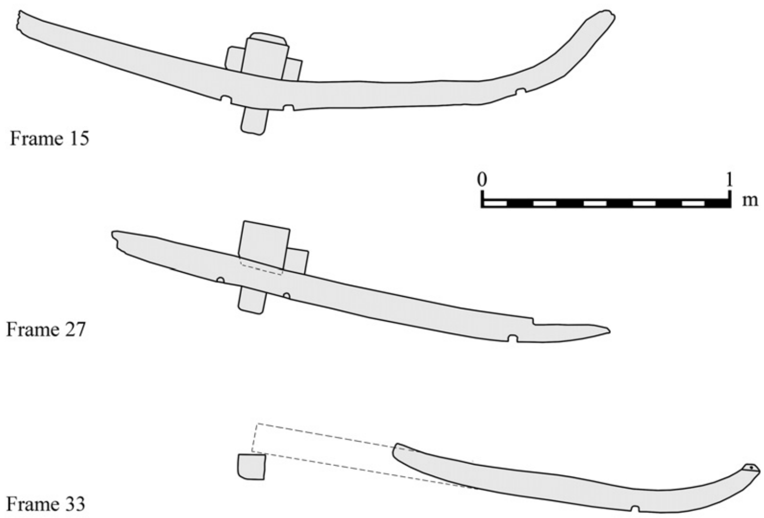

Figure 59. Tantura B shipwreck. Cross-sections at frames 15, 27 and 33. (P. Sibella, adapted by H. Itzcovitch)

Bozburun

(Harpster, 2002; 2005a; 2005b; 2006; 2009) (Figs 60–61).

The shipwreck was found near Selimiye/Bozburun, southern Turkey, and dated by dendrochronology to AD 874. The archaeological site consisted of a mound of amphoras spread over an area 20 × 8 m. The original vessel was estimated to have been 14.3 m long and *c*.5 m wide. Among its remains (only 30% of the hull survived) were keel, endposts, planks, frames and stringers. The hull had a shallow wine-glass cross-section. The keel protruded downwards, the garboard emerged at a considerable angle upwards, but from the third strake the bottom was flat and the turn of the bilge was round.

The oak keel was maximum 180 mm sided and 290 mm moulded. It had flanges along both of its upper edges, the garboards abutted the undersides of the flange, and it was nailed and treenailed to the keel. Oak planks were straight- or diagonally-scarfed into strakes, and had a maximum thickness of 40 mm. They were connected to the frames by 13-mm polygonal treenails and 4–7-mm square iron nails. No mortises and tenons were observed in the hull. However, edge-joints in the form of polygonal treenails (‘coaks’) were extensively used. They had a cross-section of *c*.10–13 mm, and penetrated *c*.50 mm into the plank-edges. The framing-system consisted of floor-timbers, half-frames and futtocks, the majority of pine, but several of oak. Floor-timbers were 120–170 mm sided, 140–220 mm moulded, and were spaced 300–400 mm apart. They were each fixed to the keel with one 10-mm-square iron nail. Futtocks were connected to floor-timbers by short L-shaped scarfs in the vertical plane, cut through the thickness of the timbers. In one oak floor-timber the remains of a nail securing the scarf survived. Evidence of futtocks, dubbed floor-timbers from the side, was also found. Remains of ceiling-planking, a stringer, and possibly a keelson, were also identified. Caulking was preserved along the edges of some of the planking fragments, and internal pitch was found only on one fragment of the keel.

The construction sequence was of alternating frames and planks with edge-joints. Frames were installed

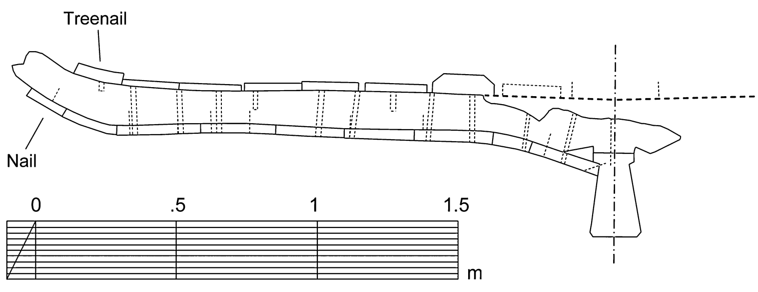

Figure 60. Bozborun shipwreck. Cross-section of the hull at floor-timber 1. (Reproduced courtesy of M. Harpster)

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first, giving the hull its shape, while planks were edge-joined to each other by means of dowels (or coaks) before being connected to frames with nails and treenails. The design and shape of the midships section of this hull were based transversally on frames. Its structural integrity was also partially based on the framing. Harpster (2005b: 466 fig. 5–26, 471–479; 2006) suggests a compromise between the desire to keep the wide and flat hull-shape based on frames, and the planking constraints of the rising and narrowing of the hull towards the ends. The use of a set of moulds has been proposed (Harpster 2009: 302–312). The construction-process was thus of mixed frames and planks, with the use of active strakes as a shell solution to a skeleton problem.

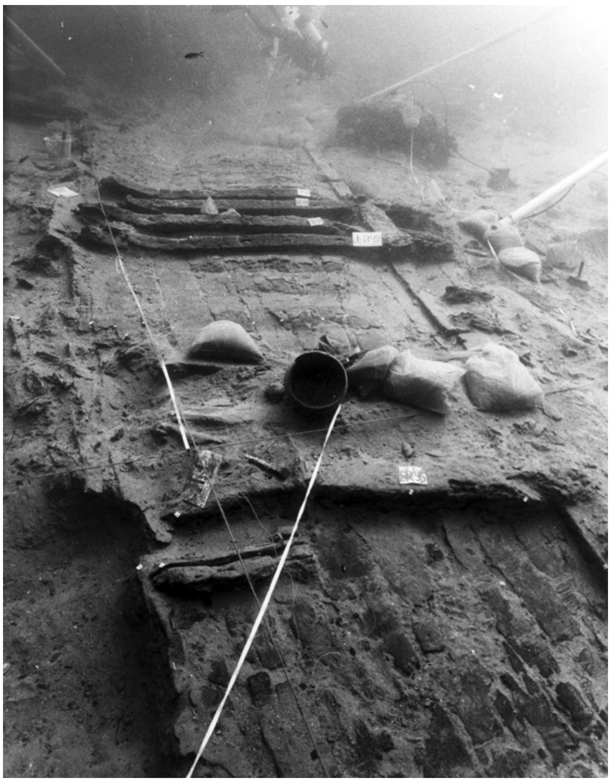

Figure 61. Bozborun shipwreck. General view. (Don Frey, reproduced courtesy of INA)

Bataiguier

(Joncheray, 2007a) (Figs 62–63).
The wreck was found in 1973 off the coast near Cannes (Alpes-Maritimes, France), and dated to the 10th century. The ceramics in its cargo presented similarities with products of the south-east of Caliphate Spain, North Africa, and Sicily. The wreck was that of a merchant ship preserved to 11.35 m of its length, from one end of the hull to the area of the master-frame, with an estimated maximum beam of 4.3 m. The original length of the hull was *c*.20 m. The cross-section amidships had a flat floor-timber, a sharp turn of the bilge (*c*.140° inner angle), and probably straight sides.

The garboards were not connected to the keel. Planking was nailed to the frames without planking-edge joints. Planks were 160–300 mm wide and 40 mm thick. Their interior and exterior faces were payed with a thick layer of pitch. The discovery of a piece of leather between the outer face of the planking and the pitch layer led to the hypothesis of leather sheathing. Some fragments of an inner planking layer 50 mm thick were found. The keel, 100 mm sided, 190 mm moulded, had no rabbet for the planking, but was only chamfered. The frames were preserved only to the level of the floor-timbers, and were nailed to the keel. The floor-timbers were *c*.180 mm sided and 200 mm moulded, with an average edge-to-edge spacing between adjacent frames of 100–130 mm. It seems that the framing-pattern

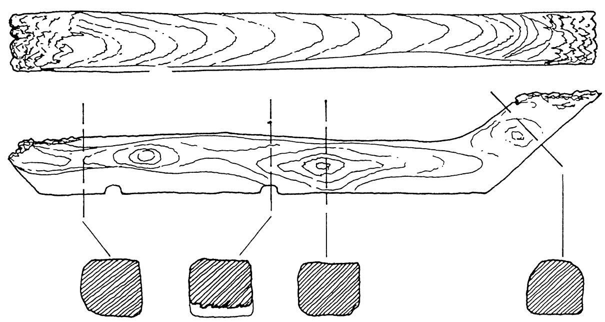

Figure 63. Bataiguier shipwreck. A frame. (Joncheray, 2007a, p. 220, reproduced with permission)

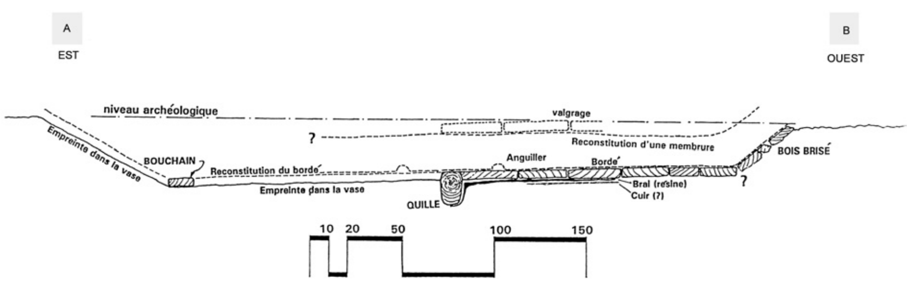

Figure 62. Bataiguier shipwreck. Cross-section amidships. (Joncheray, 2007a, p.220, reproduced with permission)

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was long-armed floor-timbers alternating to port and starboard.

The concept and construction method of this hull were based on frames.

Agay A

(Joncheray, 2007b) (Figs 64–66).

The wreck was found in 1963 off the coast near Cap Dramont (Var, France). Like the Bataiguier wreck, the Agay A shipwreck is famous for the Saracen origin of its cargo, dated to the 10th century. Some of the ceramics in the cargo would seem to be associated with production originating in North Africa, but the exact origin of the cargo (ceramics, and copper and bronze cauldrons and rods) still raises questions. The wreck is of a merchantman, of an estimated length of 20–25 m. The cross-section amidships was of flat floor-timbers, a rounded bilge, and straight sides.

Tree-species analysis revealed that only black pine (*Pinus nigra* L.) was used for longitudinal components, transverse timbers and planking. The keel was 100 mm sided and 175 mm moulded. All frames were fixed to the keel with one or two iron nails. The garboards were not connected to the keel, which was chamfered. Planking was nailed to the frames without planking-edge joints. The carvel planks were 190 mm wide and 20–26 mm thick. A thick layer of pitch was payed on their interior and exterior faces. No remains of keelson or stringers were found. Only a longitudinal inner ceiling, of which some remains were preserved, covered the frames.

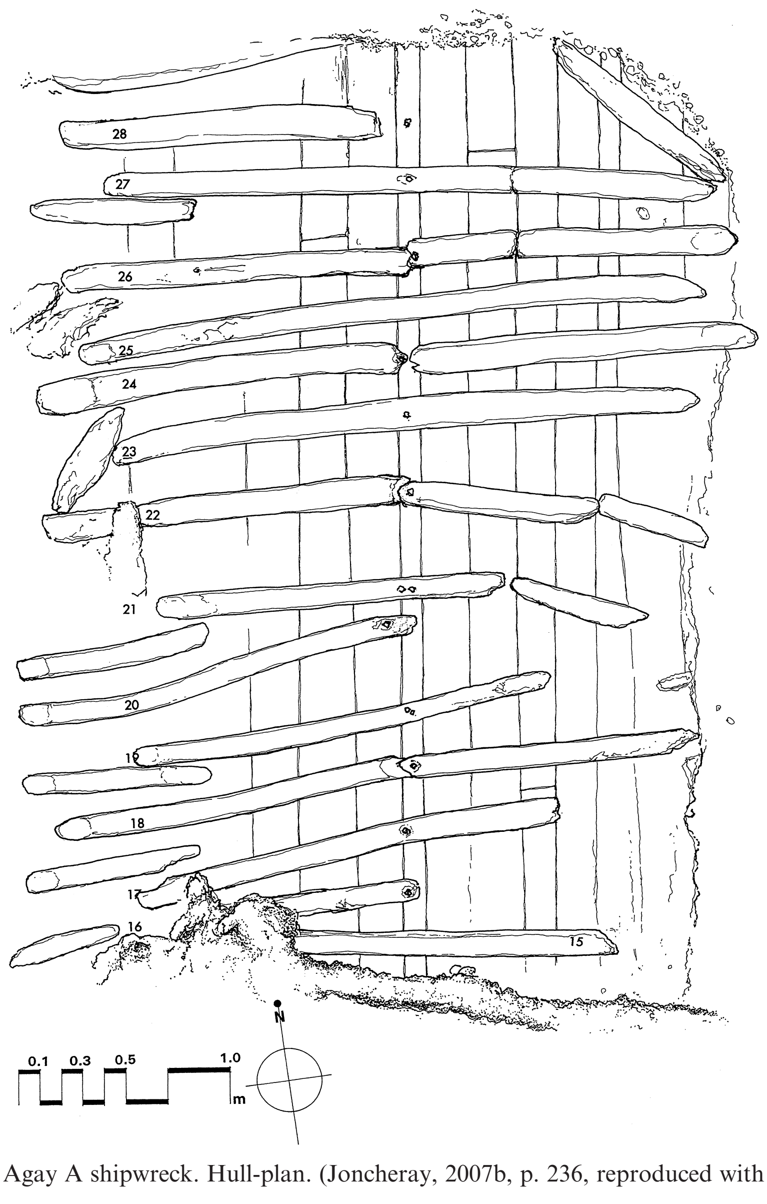

Figure 64. Agay A shipwreck. Hull-plan. (Joncheray, 2007b, p. 236, reproduced with permission)

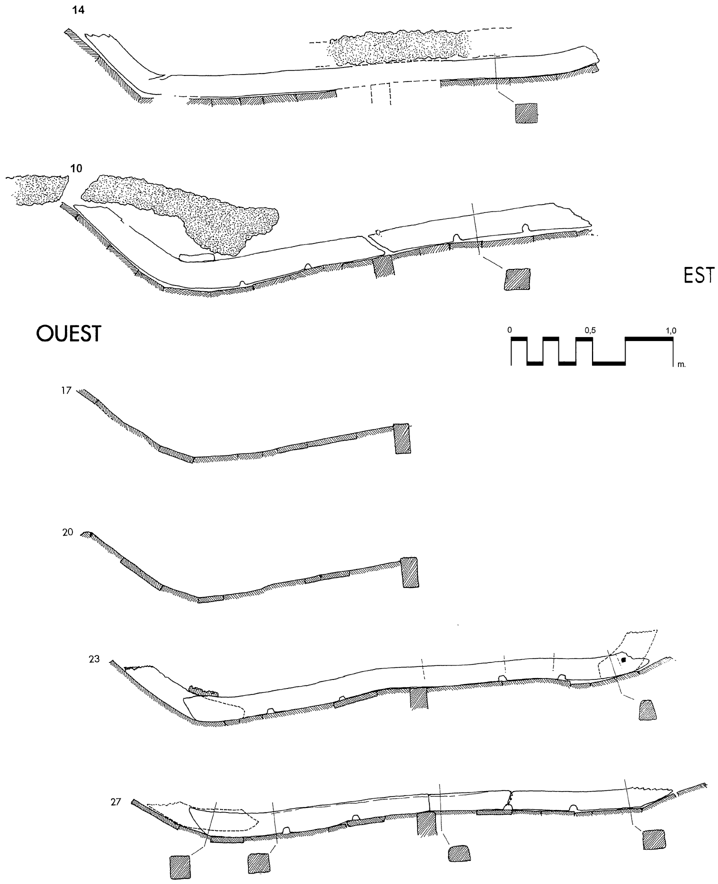

Figure 65. Agay A shipwreck. Cross-section at frames 10, 14, 17, 20, 23 and 27. (Joncheray, 2007b, p. 237, reproduced with permission)

Figure 66. Agay A shipwreck. View of the west side of the hull. (Reproduced courtesy of J-P. Joncheray)

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The framing system was composed of alternating floor-timbers and half-frames and futtocks. Frames were 125–145 mm sided and 100–130 mm moulded, with edge-to-edge spacing between adjacent frames of 140–230 mm. The half-frames were joined together by a diagonal scarf in the vertical plane, and fixed to the keel by a single nail. Futtocks and floor-timbers overlapped side-by-side, and were fixed to the keel by one or two nails.

Both the concept and the construction method of the hull were based on frames.

Serçe Limanı

(Steffy, 1982b; Pomey, 1988: 411; Steffy, 1994: 85–91; Matthews and Steffy, 2004: 81–122; Steffy, 2004: 153–69; Pomey, 2004a: 33–4) (Figs 67–70).

The wreck was found in Serçe Limanı Bay on the south-west coast of Turkey. It was dated to AD 1025, and its reconstructed dimensions were 15.66 m long, 5.2 m wide, with an estimated burden of 35 tons. Its cross-section amidships had a flat bottom, with a sharp turn of the bilge and straight sides, which seems to be similar to the Dor 2001/1, Bataiguier, and perhaps also Tantura E shipwrecks.

Its elm keel, to which all the frames were attached, was 120 mm sided and 160 mm moulded. The garboards were not connected to the keel, except at their ends, which were nailed to the side of the keel. Planking was nailed to the frames without planking-edge joints. Treenails were also found in plank-frame attachments, apparently in repairs. Planks were on average 40 mm thick, and typically 240 mm wide, joined into strakes by 'Z' scarfs which were not fastened to each other except at their tips, and by butt-joints.

The framing-system was composed of one full midship frame, long-armed floor-timbers alternating to port and starboard, a few half-frames, V-shaped tail-frames, and futtocks. Futtocks were scarfed and nailed to the floor-timbers. All floor-timbers were nailed to the keel with a single iron nail. The nails were tapered, with a *c.*12-mm-square cross-section. Frames were on average 120 mm sided and 160 mm moulded, with average room-and-space of 330 mm. Although less than 3 m of the keelson survived, it has been assumed that it extended to the ends of the ship. It was 200 mm sided and 180 mm moulded, and was bolted between the frames to the keel. Together with three stringers and two wales, the hull was reinforced longitudinally. Pitch remains were found on plank and wale surfaces, both inside and outside. Evidence for driven caulking was the remains of fibrous material in seams, and the existence of caulking-irons in the tool-kit remains.

The concept and construction-method of this hull were based on frames with longitudinal reinforcements. The hull-shape was predetermined by the midship-frame and five other frames. Similarly to Bozborun, the use of two moulds (one midships-mould and one rising-mould for the determination of fore floor-timbers and two tail frames) has been proposed (Harpster, 2006: 44–50).

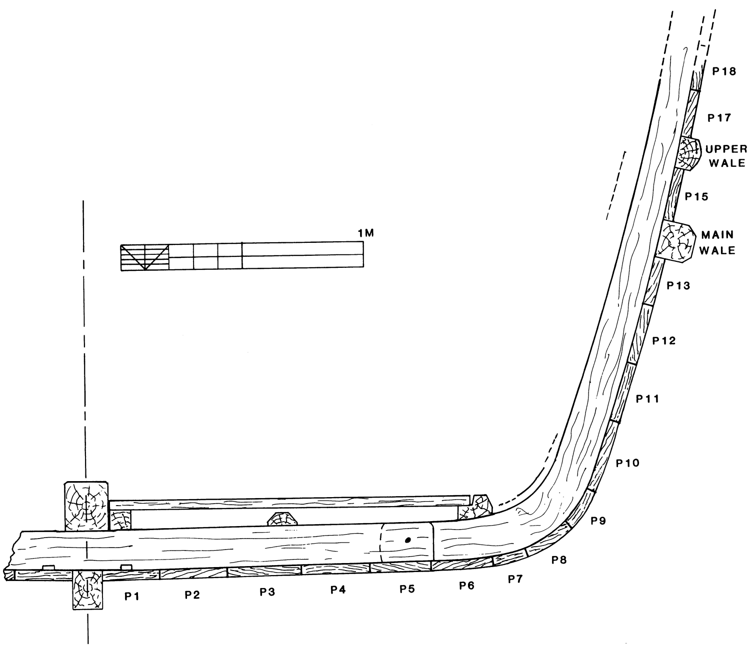

Figure 67. Serçe Limanı shipwreck. Midship section. (Steffy, 1994, fig. 4.10, reproduced with permission)

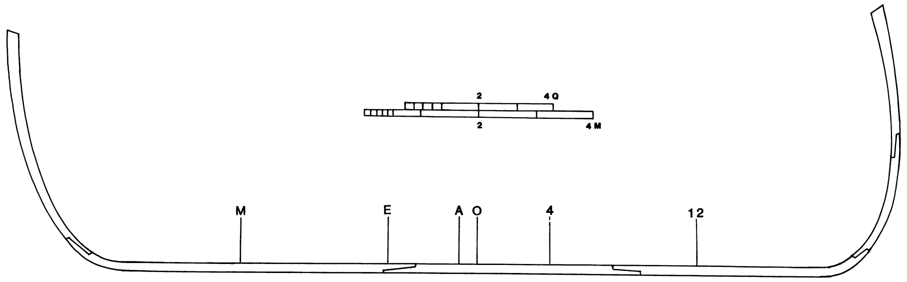

Figure 68. Serçe Limanı shipwreck. Longitudinal section with predetermined frame-locations. (Steffy, 1994, fig. 4.11, reproduced with permission)

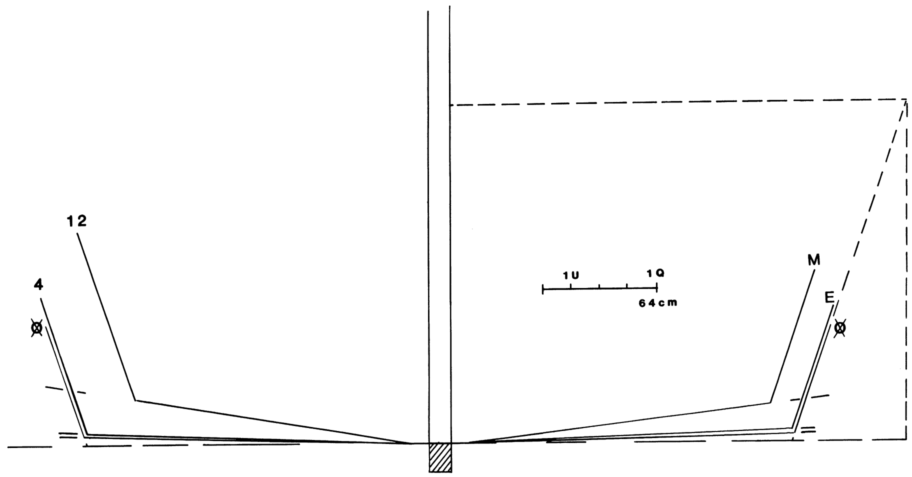

Figure 69. Serçe Limanı shipwreck. Projections of six predetermined stations. (Steffy, 1994, fig. 4.16, reproduced with permission)

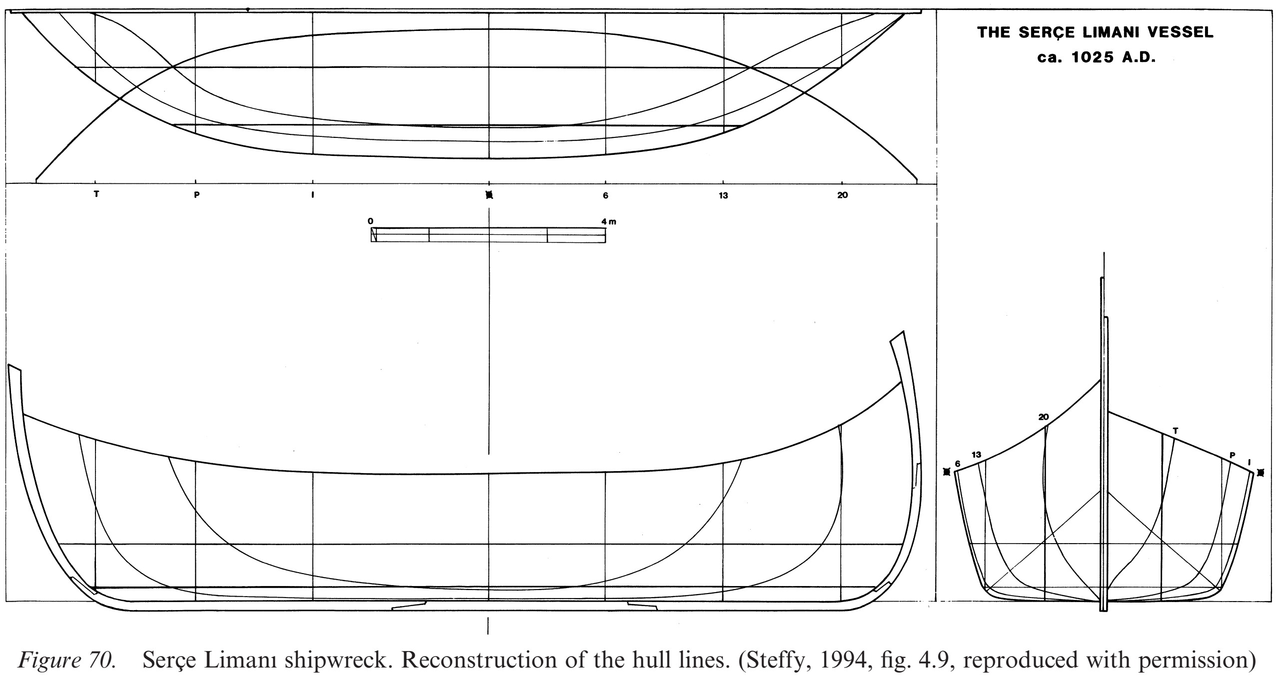

Figure 70. Serçe Limanı shipwreck. Reconstruction of the hull lines. (Steffy, 1994, fig. 4.9, reproduced with permission)

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Yenikapı

(Pulak, 2007; Özsait-Kocabaş and Kocabaş, 2008; Kocabaş, 2009; Türkmenoğlu, 2009; Günsenin, 2010; Ingram and Jones, 2010; Kocabaş and Özsait-Kocabaş, 2010) (Figs 71–88).

Thirty-six shipwrecks have been discovered on land in the Theodosian (Byzantine) harbour of Istanbul, Turkey, in the district of Yenikapı. The excavation was initiated by two development projects for improving transportation in Istanbul: Marmaray—extending the Turkish State Railways, and Metro—extending the city's metro system. As work is ongoing, the number of wrecks may increase as the project continues. The first shipwrecks were found during a rescue excavation by Istanbul Archaeological Museums, which started in 2004. They were exposed in 2005, and most of them are still being studied. Information about the shipwrecks is based on several publications and several oral presentations (Pulak, 11th ISBSA, Mainz 2006; Pulak, International Round Table, Institut Français d'Etudes Anatoliennes, Istanbul, 2007; Pulak, Tropis 10, Hydra, 2008; Pulak, Archaeological Institute of America, Philadelphia, 2009; Günsenin, Kocabaş, Özsait-Kocabaş, and Türkmenoğlu, all at 12th ISBSA, Istanbul, 2009).

Shipwrecks of various types and sizes were excavated (Fig. 71). Based on the artefacts within the same

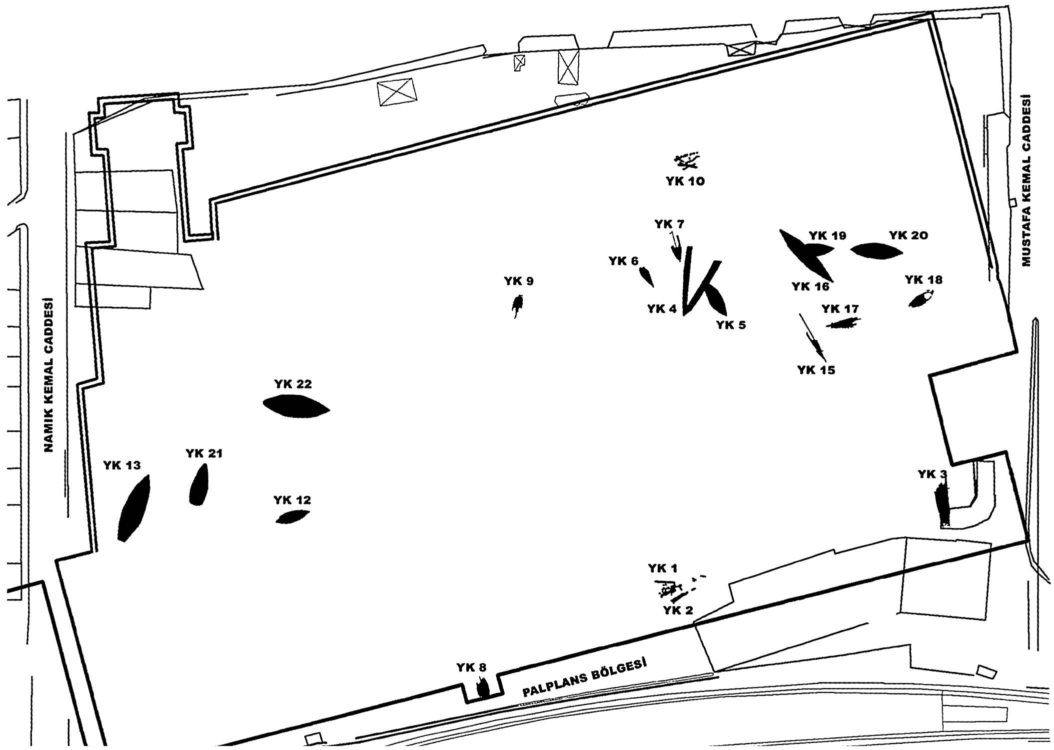

Figure 71. Yenikapı shipwrecks. Locations of shipwrecks at Yenikapı excavation area. (After Kocabaş and Özsait-Kocabaş, 2010, fig. 12)

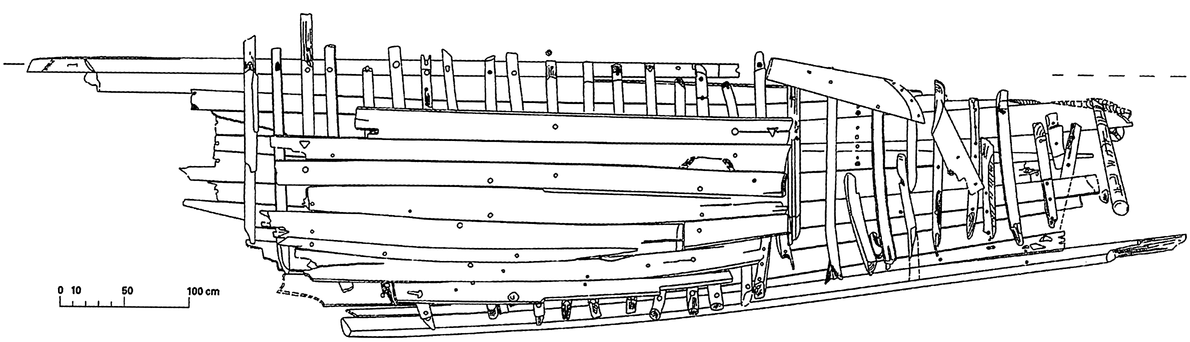

Figure 72. Yenikapı 3 shipwreck. Hull-plan. (After Kocabaş and Özsait-Kocabaş, 2010, fig. 18)

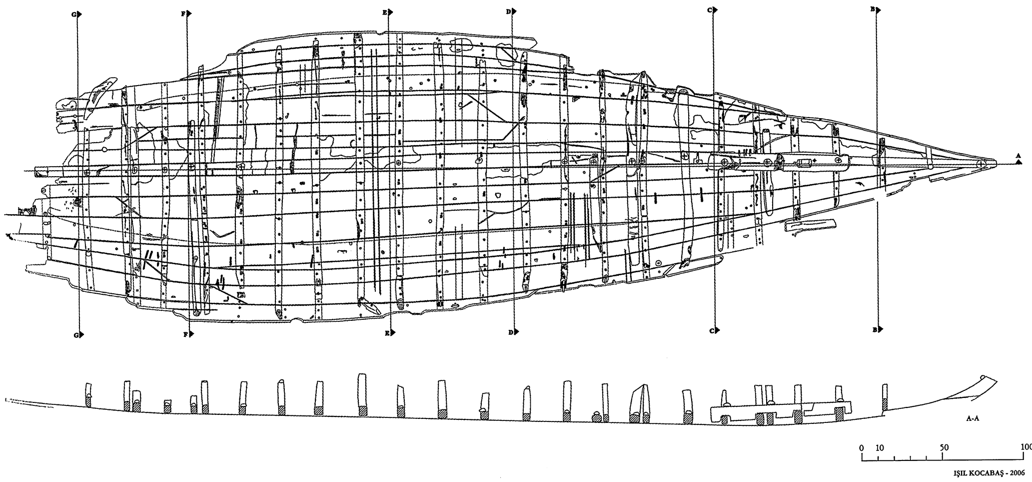

Figure 73. Yenikapı 6 shipwreck. Hull-plan and longitudinal section. (After Özsait-Kocabaş and Kocabaş, 2008, 49, fig. 1)

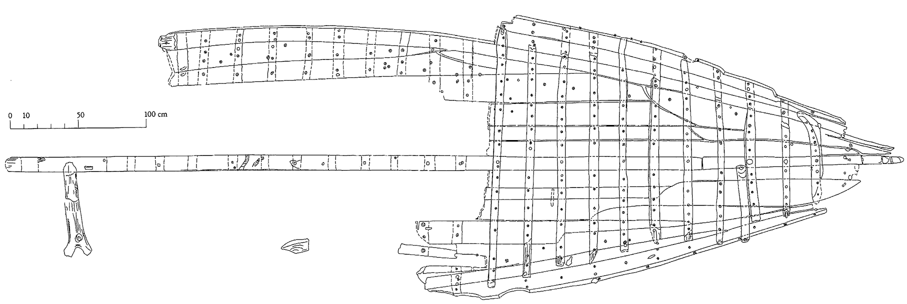

Figure 74. Yenikapı 7 shipwreck. Hull-plan. (After Özsait-Kocabaş and Kocabaş, 2008, 133, fig 7)

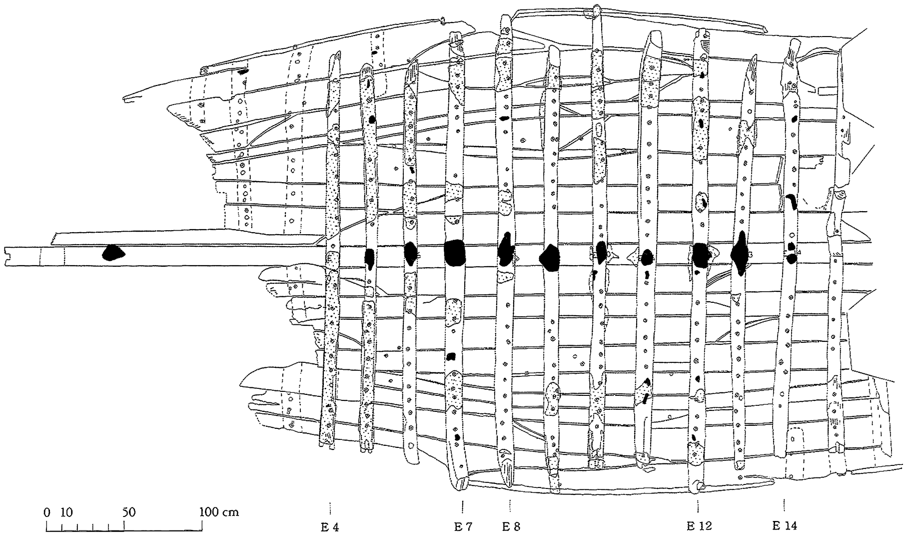

Figure 75. Yenikapı 8 shipwreck. Hull-plan. (After Özsait-Kocabaş and Kocabaş, 2008, 149, fig. 10)

stratigraphical context, the shipwrecks were preliminarily dated to between the 5th and 11th centuries AD. The recording and retrieval of the shipwrecks was shared: Yenikapı 3, 6–9, 12–13, 15–18, 20, 22, 25, 31, 35 and 36, by Istanbul University's Department of Conservation of Marine Archaeological Objects (Figs 72–80); and Yenikapı 1, 2, 4, 5, 11, 14, 23, and 24 by the Institute of Nautical Archaeology at Texas A&M University

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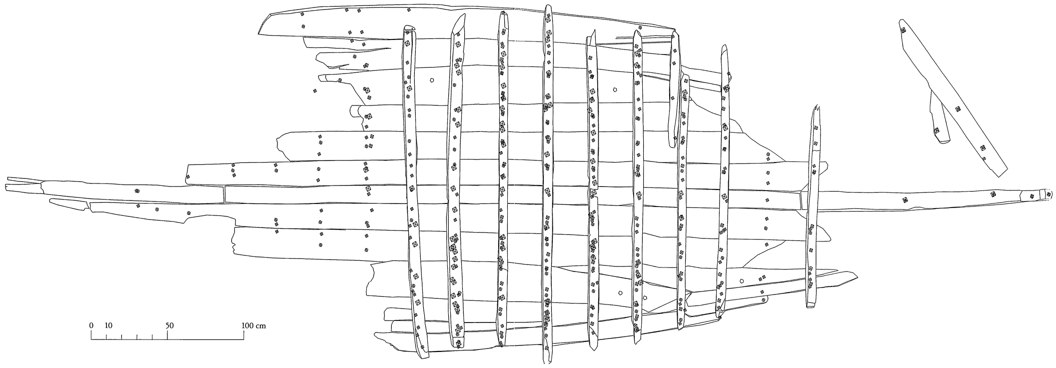

Figure 76. Yenikapı 9 shipwreck. Hull-plan. (After Özsait-Kocabaş and Kocabaş, 2008, 128, fig. 5)

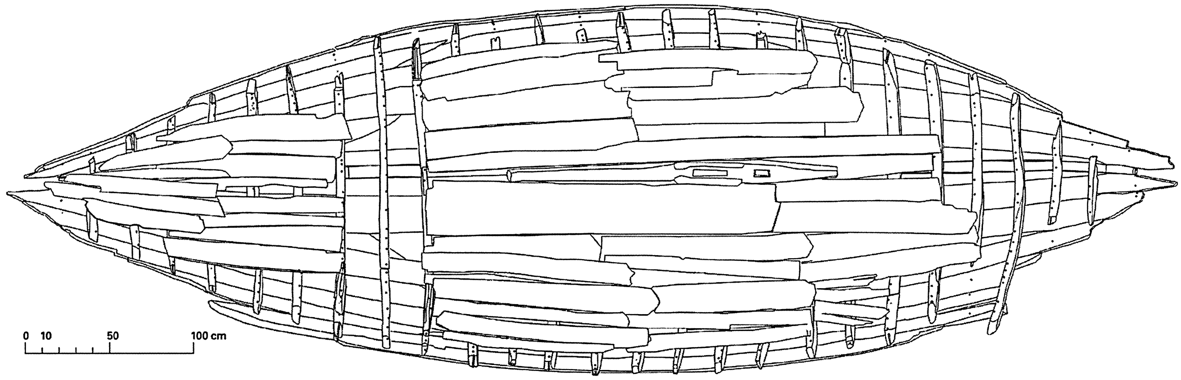

Figure 77. Yenikapı 12 shipwreck. Hull-plan. (After Kocabaş and Özsait-Kocabaş, 2010, fig. 14)

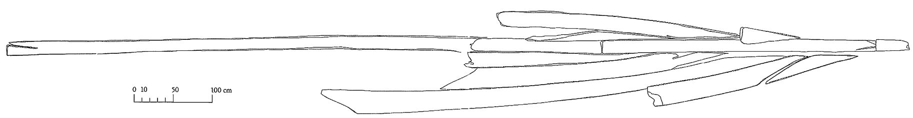

Figure 78. Yenikapı 15 shipwreck. Hull-plan. (After Özsait-Kocabaş and Kocabaş, 2008, 165, fig. 13)

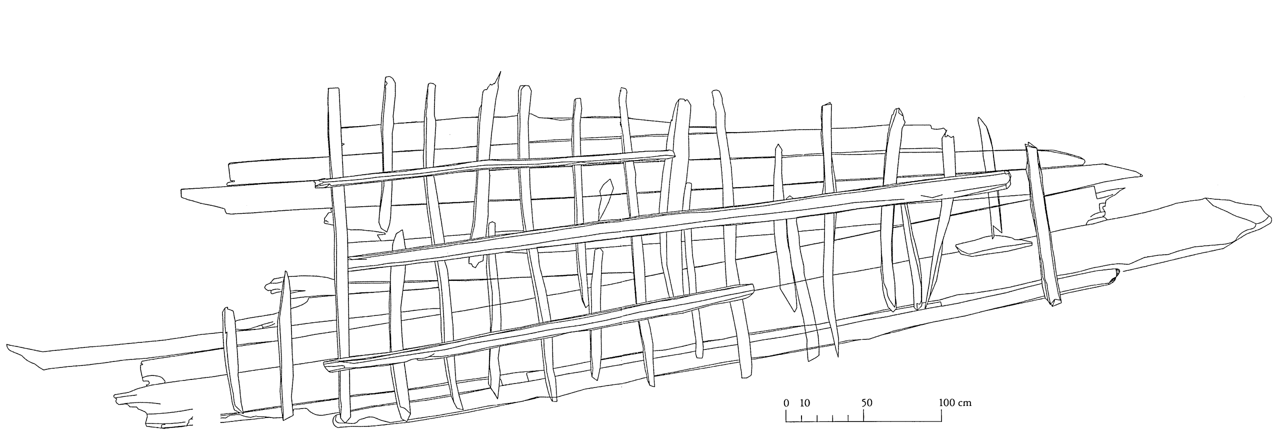

Figure 79. Yenikapı 17 shipwreck. Hull-plan. (After Özsait-Kocabaş and Kocabaş, 2008, 170, fig. 15)

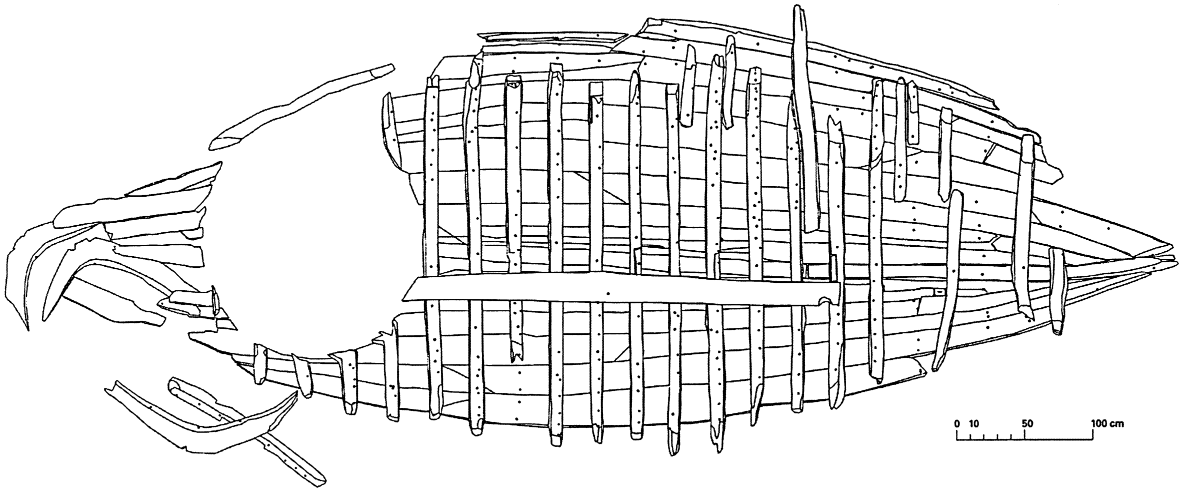

Figure 80. Yenikapı 18 shipwreck. Hull-plan. (After Kocabaş and Özsait-Kocabaş, 2010, fig. 16)

Figure 81. Yenikapı 1 shipwreck. General view of the hull. (Reproduced courtesy of C. Pulak, INA)

(Figs 81–84). All the shipwrecks were cargo ships of different sizes, or fishing boats, except for five galleys (Yenikapı 2, 4, 13, 16, and 25), of which only Yenikapı 16 will be discussed here, the others being still under study.

The most significant feature in their construction, relevant to the present discussion, was the use of dowels (coaks) (Fig. 85), as edge-joints between the planks in all shipwreck remains except one (Yenikapı 17). One wreck (Yenikapı 11) was built using planks edge-joined with unpegged mortise-and-tenon joints (Ingram and Jones, 2010: 13). Although most of the evidence was of the underwater section of the hulls, the

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Figure 82. Yenikapı 5 shipwreck. General view of the hull. (Reproduced courtesy of C. Pulak, INA)

Figure 83. Yenikapı 14 shipwreck. General view of the hull. (Reproduced courtesy of C. Pulak, INA)

dowels (coaks) were evidence of the hulls being built at least partially by a shell-first process. Additionally, in the majority of the shipwrecks, diagonal or S planking-scarfs—evidence of shell-first construction—were identified. Many floor-timbers were connected directly to the keel, mainly by iron nails, sometimes complemented by treenails. Generally, preserved futtocks were found connected to floor-timbers either at their ends, or side-by-side. The entire structure of some hulls, built on a skeleton principle, was reinforced in some cases by the mast-step timber or keelson (Yenikapı 6, 12, 16, and18), bilge-keels (Yenikapı 6 and 7), bilge-stringers (Yenikapı 16), wales (Yenikapı 1, 3, 12, 16 and 18) or strong ceiling-planks (Yenikapı 3, 12 and 18). Finally, in most hulls, seam-caulking was identified, with additional putty that was added from the interior of the hull. In Yenikapı 6, the detailed examination of the caulking has shown that it was in fact luting put in the seams before the assembly of the planks (Kocabaş, 2008: 103).

Except for Yenikapı 15, 17, 22 and 29, all these shipwrecks were built according to a mix of a shell-built process at the bottom of the hull and a general skeleton concept of the structure. They were dated to

Figure 84. Yenikapı 24 shipwreck. General view of the hull. (Reproduced courtesy of C. Pulak, INA)

the 9th–10th and the 10th–11th centuries AD. They can be divided into two different constructional types, according to the transverse cross-section at the main frame: one, with flat floor-timbers and a fairly sharp chine at the turn of the bilge (Yenikapı 5–9, 12 and 14) (Figs 86–88); and the other with a gentle wine-glass cross-section and a round turn of the bilge (Yenikapı 3, 16 and 18) (Figs 72 and 80), of which Yenikapı 16 was probably a galley.

In one shipwreck, Yenikapı 17 (Fig. 79), dated to the 8th–9th centuries AD, no edge-joints were detected during the initial study and *in situ* recording or preliminary observations, but caulking has been found in the planking-seams. The floor-timbers were fixed to the keel and the planking with iron nails. The internal structure was reinforced by bilge-stringers which had been nailed to the frames similarly to the wales. Unfortunately, the structural type was not clear, but according to its characteristics it may be considered that it was built based on frames. According to preliminary results three additional shipwrecks, Yenikapı 15, 22, and 29, were built 'with skeleton-first technique' (Kocabaş, 2009, and pers. comm.; Türkmenoğlu, 2009; Kocabaş and Özsait-Kocabaş, 2010). However, in Özsait-Kocabaş and Kocabaş (2008: 164), referring to YK 15 (Fig. 78), dowels (coaks) between some planks are mentioned. Strangely, these shipwrecks were from the lower layers, dated to between the 5th and 9th centuries, while shipwrecks from upper layers, dated to between the 9th–11th centuries AD, were built with edge-fasteners.

Major construction features of the Yenikapı shipwrecks, relevant to this paper, as far as they are available, are described in Table 3.

Figure 85. Yenikapı 14 shipwreck. Detail view of the coaks *in situ*. (Reproduced courtesy of C. Pulak, INA)

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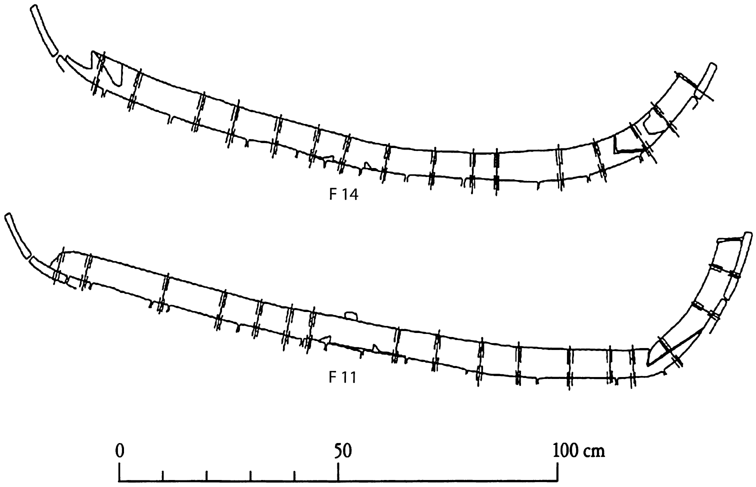

Figure 86. Yenikapı 6 shipwreck. Cross-sections. (After Özsait-Kocabaş and Kocabaş, 2008, 53, fig. 2, left)

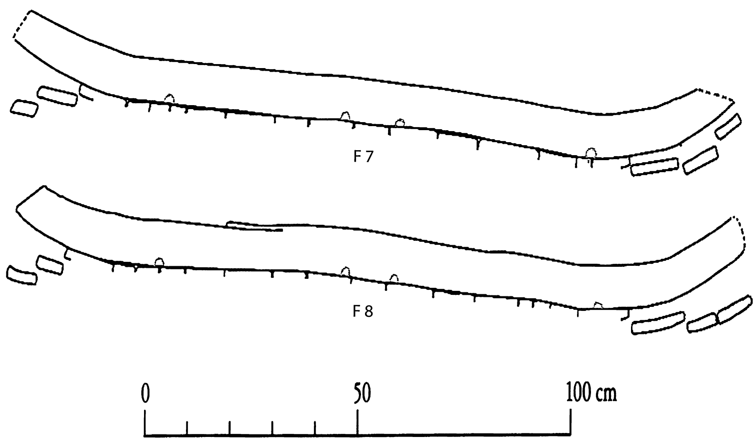

Figure 87. Yenikapı 8 shipwreck. Cross-sections. (After Özsait-Kocabaş and Kocabaş, 2008, 53, fig. 2, right)

Figure 88. Yenikapı 14 shipwreck. Detail view of the hull-bottom with the turn of the bilge. (Reproduced courtesy of C. Pulak, INA)

Table 1. *Summary of construction details*

Vessel	Date (AD)	General construction	Cross-section amidships	Original length (m)	Keel dimensions (sided, moulded, mm)	Keel rabbet	Garboard-keel attachment	Plank dimensions (width, thickness, mm)	Wales: number, width, thickness (mm)	Central longitudinal timbers (length: m, width, thickness: mm)
St-Gervais 3	Mid-2nd c.	Shell concept, perhaps mixed construction	Flat frames, round bilge	17	170 × 180	No keel rabbet, only chamfered	Double, pegged mortise-and-tenon	200–300 × 35–45 garboard 75 near keel	One, 165 × 90	Keelson (10.5 m, 470 × 270 mm) + 2 sister-keelsons + mast-step
Laurons 2	End 2nd c.	Shell concept and construction	Flat frames, round bilge	15	120 × 160	No keel rabbet, only chamfered, rabbeted endposts	Pegged mortise-and-tenon	140–300 × 25	Two, 120 × 80	Keelson/mast-step (7.75 m, 260–280 × 220 mm) + 2 sister-keelsons
Bourse (Lacydon)	End 2nd/ beginning of 3rd c.	Shell concept, probably mixed construction	Flat frames, round bilge	23	170–280 × 290	Chamfered keel, rabbeted endposts	Pegged mortise-and-tenon. Nails in endposts	180–230 × 60	Section of the lower wale 140 thick	Keelson/mast-step (reconstructed) + central longitudinal timber at the ends (reconstructed) + 2 sister-keelsons
Monaco	End 2nd/ first half of 3rd c.	Shell concept, perhaps mixed construction	Flat floor-timbers, round bilge	15	110–140 × 160 (220 mm at one endpost)	Keel rabbet, chamfer in endposts	Pegged mortise-and-tenon	175–270 × 30–40		Keelson (? × 150 × 80 mm)
County Hall	*c.*300	Shell concept and construction	Flat frames, round bilge	19.1	215 × 165	No	Pegged mortise-and-tenon	267–381 × 51–76	One, 152 square, chamfered.	No (side stringers)
Pt. de la Luque B	4th c.	Shell concept and construction	Flat frames round bilge	20	130 × 170	Keel rabbet	Pegged mortise-and-tenon	150–230 × 30 garboards 55 thick	Three, 145–175 × 85	Keelson/mast-step + 2 sister-keelsons + central timber in fore part
Yassıada 2	4th c.	Shell concept, mixed construction	Wine-glass	20	125 × 220	No keel rabbet except forward end and sternpost	Pegged mortise-and-tenon. Iron nails in sternpost	110–250 × 42–53	Four, 160 × 160	Existence of keelson (suggested)
Dramont F	2nd half of 4th c.	Shell concept, mixed construction	Flat floor-timbers, round bilge	10–12	95–105 × 145	Chamfered keel	Pegged mortise-and-tenon (with exceptions)	—		Keelson (reconstructed)
Fiumicino 1	End 4th/ beginning of 5th c.	Shell concept, probably mixed construction	Flat frames, round bilge	17.18	130 × 170	No keel rabbet, rabbeted sterngripe	Mortise-and-tenon (majority unpegged) + iron nails	400 × 44	Fragment, 160 × 90	Fore keelson/ mast-step (2.75 m, 50–100 × 150)
Port-Vendres 1	*c.*400	Shell concept, perhaps mixed construction	Flat frames, round bilge	18–20	280 (max.) × 350	Rabbet in keel and endposts	Pegged mortise-and-tenon + copper nails	? × 40–60	Two, 170 × 210	Keelson/mast-step (7.16 m long, 285 × 190–230) + 2 sister-keelsons + central longitudinal timber astern
Dramont E	Second 1/4r of 5th c. (425–455)	Shell concept and construction	Wine-glass, round bilge	15.5–16	220 × 300	Chamfered keel, rabbeted endposts	Pegged mortise-and-tenon. Bronze nails in endposts	240 (max.) × 30–50	Two, the 1st 199 × 160	Keelson/mast-step (7.14 m × 237 × 150 mm) + 2 sister-keelsons
Parco di Teodorico, Ravenna	5th c	Mixed concept, and construction	Flat floor-timbers, round bilge	9	?	?	Unpegged mortise-and-tenon, garboard nailed to keel	?		Keelson fitted on frames
Tantura A	End 5th/ beginning of 6th c.	Frames concept and construction	Flat frames, round bilge	12	110 × 180	No keel rabbet, rabbeted endpost	Not connected	38–260 × 25	—	No

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Dor 2001/1	Beginning of 6th c.	Frames concept and construction	Flat frames, sharp bilge, straight sides	16.9	110 × 150	No keel rabbet, rabbeted endpost	Not connected	50–206 × 20–33	Two, 220 × 105, 200 × 80	Central longitudinal timber at the end (2.55 m, 150 × 180 mm) + 2 sister-keelsons
Dor D	350–621	Shell hull concept, mixed structural concept and construction	—	15–20	—	—	—	200 × 30	—	No
Port Berteau 2	599–600	Skeleton concept, based on frames	Flat frames, round bilge, straight sides	14.3	—	—	—	100–220 × 30	Five, 70–200 × 55–65	
St-Gervais 2	7th c.	Skeleton concept and construction, based on frames	Wine-glass, round bilge, straight sides	15–18	90–150 × 200–240	No	Not connected	70–260 × 25–40	Two, 110 × 90	Central longitudinal timber aft (4 m, 200–220 × 400 mm), fore central longitudinal timber (reconstructed), keelson/mast-step (4 m, 320 × 200), + 2 sister-keelsons
Yassıada 1	625	Mixed concept and construction	Wine-glass, round bilge	20.52	220 × 335	Keel + endposts rabbet	Unpegged mortise-and-tenon + iron nails	130–250 × 35–42	Four, half logs 200 (diameter)	Reconstructed keelson (220 × 220) + inner posts
Pantano Longarini	Early 7th c.	Mixed concept and construction	Round bilge	31.5	—	—	—	140–540 × 50	Five, half logs, three heavy 500 × 250, two lighter 200 × 100	—
Tantura F	Mid-7th–end 8th c.	Skeleton concept based on frames and construction	Flat frames, round bilge	15.7	104 × 120–168	No, only at ends	Not connected, only at ends	80–235 × 25		Mast-step + 2 sister-keelsons + Two central longitudinal timbers (Bow, 2.06 long, 140 × 120. Stern, 1.42 long, 140 × 155)
Tantura E	7th–9th	Skeleton concept and construction based on frames.	Flat frames, sharp bilge	—	100 × 170	Full rabbet along entire keel	Iron nails	100–210 × 22–28	—	Central longitudinal timber 2.14 m, 100 × 150
Tantura B	Beginning of 9th c.	Skeleton concept and construction based on frames,	Flat frames. round bilge	18–23	104 × 95	No, only at end	Not connected	40–360 × 30	One, bilge keel 100 × 85	Keelson (7.84 long, 122–202 × 157–180)
Bozburun	874	Frames concept, mixed construction	Shallow wine-glass	14.3	180 × 290	Flange	Iron and treenails	3–4 × 40	Two	—
Bataiguier	10th c.	Skeleton conception and construction	Flat floor-timbers, sharp bilge, probably straight sides	20	100 × 190	No keel rabbet, only chamfered	Not connected	160–300 × 40	—	—
Agay A	10th c.	Skeleton conception and construction	Flat floor-timbers, round bilge, straight sides	20–25	105 × 175	No keel rabbet, only chamfered	Not connected	190 × 20–26	—	—
Serçe Limanı	1025	Skeleton conception and construction	Flat floor-timbers, sharp bilge, straight sides	15.66	120 × 160	No keel rabbet, rabbeted sternpost	Not connected except nails at ends	240 × 40	Two, 160 × 160, 145 × 131	Keelson from bow to stern 200 × 180
Akko Marina	147–540	Mixed construction		—	—	—	—	—	—	—

Table 2. *Summary of mortise-and-tenon joints and frame details*

Vessel	Mortises and tenons					Frames				Treenail diameter (mm)	Metal fasteners		Watertightness and caulking
	Mortise dimensions (width, thickness, depth, mm)	Centre-to-centre mortise distance (mm)	Tenon dimensions (width, thickness, half-length, mm)	Tapered peg diameter (mm)	Tenon width/ mortise width (%)	Pattern	Sided (mm)	Moulded (mm)	Room-and-space (mm)		Metal	Type and dimension (mm)	
St-Gervais 3	70 × 7 × 130	120	Very slightly less than mortises	5/6–12	Well fitted	Alt. floor-timbers & half-frames (some overlapped)	140–160	130	280–300	15	Copper	3 bolts and nails	Internal coat of pitch
Laurons 2	60 × 10 × 120–130	120 (edge-to-edge)	Similar to mortises	9–11	Well fitted	Alt. floor-timbers & half-frames (some overlapped)	70–90	100–200 (floor-timbers) 90 half-frames	200–220	15	Copper or bronze	4 bolts and nails	Internal coat of pitch
Bourse (Lacydon)	60 × 10 × 100 (keel)	200	60 × 10 × 120–130 (planks)	8–15	Well fitted	Alt. floor-timbers & half-frames (some overlapped	80	150	250	15–20	Copper	8 bolts, 20 mm diameter	Internal and external coat of pitch
Monaco	40–60 × 6 × ? (keel)	60–70 (edge-to-edge, keel)	? × 5–6 × 35 (keel)	Used	—	Floor-timbers (& half-frames overlapped [?])	65	115	—	Used	Copper	One bolt (observed)	—
County Hall	110 × 7 × 65	152–970 (edge-to-edge)	64 × 7 × 65	16	58 (one example)	Alternating short/long floor-timbers, or extending opposite bilge	114	165	254–533	32	Iron (limited)	Nails	—
Pt. de la Luque B	60 × 7 × 40	100–120	—	8–11	—	Alt. floor-timbers & overlapping half-frames	130	130	120–330	10	iron	3 bolts (observed)	Internal coat of pitch
Yassıada 2	70–90 × 7 × 50–55	150–320	45 × ? × 42.5	7–11	50–64	Alt. floor-timbers & half-frames	Floor-timbers 120–191, half-frames 80–150	125 and 300 above keel	230–300, average 270	16	Iron	7 bolts + some nails	Internal coat of pitch
Dramont F	50–82 × 7 × 40–55	195–250 average 224	35–55 × 5–6 × 30–35	7–8	70	Floor-timbers and half-frames	55–105	85–110	370	11–14	Iron	One bolt (observed) and nails	Internal and external coat of pitch
Fiumicino 1	74 × 7–10 × 45	175–760 average 360	43 × 3–6 × 40–45	7–13 and also unpegged	58	Alt. floor-timbers & half-frames	60–120	80–180	Average 190	Plug treenails	Iron	6 bolts and nails	External coat of pitch (?)
Port-Vendres 1	Est. 70 wide	Est. average 150	—	—	Well fitted	Alt. floor-timbers & half-frames (one overlapping)	130	230	250	Used	Iron and copper (bronze)	7/8 iron bolts, copper nails	Internal coat of pitch & traces of luting
Dramont E	65–110	80–310 edge-to-edge	60–100 × 8–14 × 50–60	8–12	90, a few in garboard 70	Alt. floor-timbers & half-frames	100–150	100–180	270	15–17	Iron and maybe bronze	5 iron bolts (22 mm diam.) & iron (bronze ?) nails	Internal coat of pitch & traces of luting
Parco di Teodorico, Ravenna	?	*c.*800 mm	?	Unpegged	Tenons occupied only part of the mortise	Floor-timbers	—	—	330	Used	Iron	Nails	External coat of pitch
Tantura A	No mortise or tenon, frame-based construction	—				—	90	95	324		Iron	Nails	Seam caulking
Dor 2001/1	No mortise or tenon, frame-based construction	Alternating floor-timbers & half-frames				—	75–90	85–120	240		Iron	Bolts and nails (several sizes)	Seam caulking

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Dor D	50–90, average 63 × 5 × 30	286 average	35 × 3–5 × 30	Unpegged except for one 10 mm diameter peg	60	—	100–110	—	230	15	Iron	Nails (5 × 5)	—
Port Berteau 2	No edge joints, frame-based					Floor-timbers, futtocks	85–280 (average 140)	115–260 (average 95)	115–260 (average 190)	25	—	—	Seam caulking
St-Gervais 2	—	No pattern	—	Unpegged	40, only few	Alt. floor-timbers & half-frames	Floor-timbers 120–200, half-frames 100–150	Floor-timbers 220–400, half-frames 100–270	150–360, average 250	Used	Iron	Bolts and nails	Seam caulking
Yassıada 1	50 × 5 × 35	350–2250	30 × ? × 35	Unpegged	60	Alternating short and long floor-timbers, half-frames, futtocks and top-timbers	140	140	300–350	—	Iron	Bolts and nails	Internal and external coat of pitch (bottom) + possible caulking?
Pantano Longarini	—	1000	—	Unpegged	Loose	Alt. floor-timbers & half-frames	180–250	180–250	350	—	Iron	Nails	?
Tantura F	No mortise or tenon, frame-based					Alt. floor-timbers & half-frames	95	120	315		Iron	Nails (several sizes)	Seam caulking
Tantura E	No mortise or tenon, frame-based					Alt. floor-timbers & half-frames	100	120	260		Iron	Bolts and nails (several sizes)	Seam caulking
Tantura B	No mortise or tenon, frame-based					Alt. floor-timbers & half-frames	Floor-timbers 96, half-frames 87	Floor-timbers 97, half-frames 91	260		Iron	Nails (10–12 square, and 5 square)	Seam caulking
Bozburun	Polygonal treenails (coaks) *c.*10–13 mm penetrated some plank edges *c.*5 cm.					Floor-timbers, half-frames and futtocks	120–170	140–220	300–400		Iron	Nails (10, 7–4)	Seam caulking
Bataiguier	No edge joints, frame-based, skeleton-constructed					Long-armed floor-timbers alt. port/starb	180	200	100–130 (edge-to-edge)		Iron	Nails	Internal and external coat of pitch, leather sheathing (?)
Agay A	No edge joints, frame-based, skeleton-constructed					Alt. floor-timbers, half-frames, futtocks	125–145	100–130	140–230 (edge-to-edge)		Iron	Nails (5 square)	Internal and external coat of pitch
Serçe Limanı	No edge joints, frame-based, skeleton-constructed					Long-armed floor-timbers alt. port/starb	120	160	330	Used in repairs	Iron	Bolts (keelson) + nails (several sizes)	Seam caulking, Internal and external coat of pitch. Caulking irons
Akko Marina	59 × 7 × 47	118–260, average 163	54 × 5 × ?	Unpegged	93	—	70	—	218	17	Copper & bronze	Nails (square, 5)	—

Table 3. *Major construction features of the Yenikapı shipwrecks*

Shipwreck				Floor-timbers			Frame-plank fasteners		Frame-keel fasteners			Cross-section	Wales (number)	Plank edge-joints	Construction method	Notes
INA	Istanbul University	Type of vessel	Date (century AD)	Average sided (cm)	Average moulded (cm)	Average room & space (cm)	Iron nails	Treenails	Iron nails	Treenails	Not connected					
YK 1		Small, cargo	End of 10th	—	—	—	+	–	–	–	–	Flat floor-timbers	—	Dowels (coaks)	Mixed	~~Bilge keel~~
	YK 3	Large, cargo	10th–11th	7–12	10–12	25	+ From outside	+	+ Some with plug treenails	–	+	Wine-glass	1	Dowels (coaks)	Mixed	Keel rabbetted, garbord nailed, caulking
YK 5		Medium, cargo	10th	6.5	11	27	–	–	–	–	–	Flat floor-timbers	—	Dowels (coaks)	Mixed	—
	YK 6	Small, cargo or fishing	10th–11th	3–5	6	25	+ From outside	+	+	+	+	Flat floor-timbers	_	Dowels (coaks)	Mixed	Caulking (luting) + putty, mast-step, bilge keel
	YK 7	Medium, cargo	10th–11th	6–7	7.5–8	23	+ From outside	+	+	+	+	Flat floor-timbers	—	Dowels (coaks)	Mixed	Caulking + putty, bilge keel
	YK 8	Medium, cargo	10th–11th (7th?)	8–11	12	26	+	+	+	no	+	Flat floor-timbers	—	Dowels (coaks)	Mixed	Caulking
	YK 9	Small, cargo or fishing	10th–11th	4–6	6–9	29	+	+	+	no	+	Flat floor-timbers	—	Dowels (coaks)	Mixed	Caulking + putty
YK 11		Small, boat	—	—	—	—	–	–	–	–			—	unpegged tenon	Mixed	—
	YK 12	Small, cargo	9th–10th	4–7	9–10	—	+	+	+	+	+	Flat floor-timbers	1	Dowels (coaks)	Mixed	Mast-step/ keelson
YK 14		Medium, cargo	Late 9th–early 10th	—	—	—	–	–	–	–	–	Flat floor-timbers	—	Dowels (coaks)	Mixed	—
	YK 15	Large, cargo	8th–9th	—	—	40	+	+	+	–	–	—	—	Dowels (coaks)	Mixed	Garbord nailed, planking with dowels (coaks)
	YK 16	Galley	Middle Byzantine	5	6	16–20	+	+	–	–	–	Wine-glass	2	Dowels (coaks)	Mixed	Keelson, bilge stringer, putty
	YK 17	Large, cargo	8th–9th	5–11	10	32	+	No	+	–	–	—	2	No dowels	Skeleton (?)	Caulking, bilge stringer
	YK 18	Medium, cargo or fishing	10th–11th	6.5–10	5–11	29	+	+	+	No	+	Soft chine (?)	1	Dowels (coaks)	Mixed	Garbord nailed
	YK 20	Small	—	—	—	—	–	–	–	–	–	—	—	Dowels (coaks)	Mixed	—
	YK 22	Large cargo vessel	5th–7th	—	—	—	–	–	–	–	–	—	—	—	Mixed	—
YK 23	—	—	—	—	—	—	–	–	–	–	–	—	—	Dowels (coaks)	Mixed	—
YK 24		Medium, cargo	Early 9th	—	—	—	–	–	–	–	–	Straight, not flat, with angle of deadrise	—	Dowels (coaks)	Mixed	—
	YK 29	—	End 7th-early 8th	—	—	—	–	–	–	–	–	—	—	—	Skeleton (?)	—
	YK 31	—	—	—	—	—	–	–	–	–	–	—	—	Dowels (coaks)	Mixed	—
	YK 32	—	—	—	—	—	–	–	–	–	–	—	—	Dowels (coaks)	Mixed	—
	YK 33	—	—	—	—	—	–	–	–	–	–	—	—	Dowels (coaks)	Mixed	—
	YK 34	—	—	—	—	—	–	–	–	–	–	—	—	Dowels (coaks)	Mixed	—
	YK 35	—	—	—	—	—	–	–	–	–	–	—	—	—	—	—
	YK 36	—	—	—	—	—	–	–	–	–	–	—	—	—	—	—

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Figure 89. A timber from Akko Marina. (J. J. Gottlieb and H. Itzcovitch)

Akko Marina, Israel

(Galili *et al.*, 2002: Galili *et al.*, forthcoming) (Fig. 89). About 25 ships' timbers were retrieved by a dredger while deepening the anchorage of the small modern marina in Akko (Acre) in 1992–93. The evidence must be evaluated with reservations because of the broken, distorted and out-of-context nature of the find. Analysis by ^{14}C dating of wood samples gave dates from 147 to 540 AD. (The tests were: RT-2517: AD 147–250; RT-2519: AD 249–372 (Segal and Carmi, 2004: 127); RT-4386: 420–470 (26.3%), AD 480–540 (39.9%) (Boaretto, 2004). However, due the doubtful context, these timbers are reported here and not in chronological order (Fig. 89).

Twelve unpegged mortise-and-tenon joints were evident. The mortises were on average 59 mm wide, 7 mm thick, 47 mm deep, and spaced 163 mm centre-to-centre. Tenons were 54 mm wide and 5 mm thick, with maximum preserved length of 40 mm. The tenons occupied an average 93% of the mortise width and 72% of the mortise thickness. Nine square tapered copper nails were found, the longest being 145 mm. Their average head-diameter was 17 mm, and the cross-section was 5 mm. At least 39 treenails were evident. They had an average diameter of 17 mm, and fitted well into their holes. Although no framing timbers survived, evidence of plank-frame attachments and traces of five frames were found. These indicated that the frames were sided *c.*7 cm. The centre-to-centre distance between frames ranged between 160 and 275 mm; 218 mm on average. Frames and planks were fastened together by bronze nails and treenails (the metal nails were analysed by Prof. Shalev of the Leon Recanati Institute for Maritime Studies, University of Haifa).

These timbers revealed the use of relatively closely spaced unpegged mortise-and-tenon joints between the planks which are connected by frames. Whether an earlier date, or the latest ^{14}C date (mid-6th century) is considered, they are therefore possibly among the earliest evidence of the use of this combination of ship-building techniques in the eastern Mediterranean. These features point to an early stage of the transition and a hull of mixed construction. It is very unlikely, however, that all the timbers from Akko Marina were components of a single shipwreck, and they might even be parts of a harbour installation.

Discussion

Until now, discussion of the question of the transition from the shell concept and construction-method (strake-oriented) to the skeleton concept and construction-process (frame-based) has followed the theory postulated by van Doorninck (1976) and Steffy (1994: 84). The evolution had been based on the criterion of the mortise-and-tenon joint, from its progressive weakening until its complete disappearance. This theory of hull-concept and construction-process was extended by Pulak (2007), and is well established to present a comprehensive process of transition (Fig. 90). It started at the end of the 14th century BC with Uluburun, and ended in the 11th century AD with Serçe Limanı, and includes, among other shipwrecks, Bozburun and some from Yenikapı. In this transition theory the sole criterion is planking-edge fasteners. This question of planking-edge fastening remains fundamental, but the complexity of the transition phenomena suggests considering other factors, such as the development of internal framing and the structural type. All these aspects, in the light of the above corpus of shipwrecks, will be discussed below.

Mortise-and-tenon joint evolution

In the last 20 years, several traditions of ship-construction have come to light in the Ancient Mediterranean. From the earliest wooden hull of a shipwreck discovered in the Mediterranean, Uluburun (*c.*1320 BC, Turkey), hulls were probably built using a shell-concept and process. In the absence of framing-elements, the Uluburun hull was designed strake-oriented: planks were connected by well-fitted long, robust, pegged mortise-and-tenon joints, which gave the hull its basic integrity (Pulak, 1999; 2002; 2003; 2008). It should, however, be noted that, 'The Uluburun ship's mortise-and-tenon joints were more widely spaced and more robust than those of later Greek and Roman hulls of similar size' (Pulak, 2003: 29) (Fig. 90). The later Cape Gelidonya shipwreck (*c.*1200 BC, Turkey), also demonstrated evidence of the use of mortise-and-tenon joints (Bass, 1967; 1989; 1999). These two ships not only plied the eastern Mediterranean, but apparently belonged to eastern Mediterranean maritime cultures and construction traditions. Probably, following these traditions, two shipwrecks discovered at Mazarrón (mid-7th century BC, Spain), demonstrated pegged mortise-and-tenon planking-joints associated with frames lashed to the planking (Negueruela *et al.*, 1994; Nieves, 1994; Negueruela, 2004; Negueruela, 2005). This combination was also found in the later Binissafúller shipwreck (4th century BC, Balearic Islands) (De Juan *et al.*, 2010), and very likely in the Golo shipwreck (Archaic period, Corsica)

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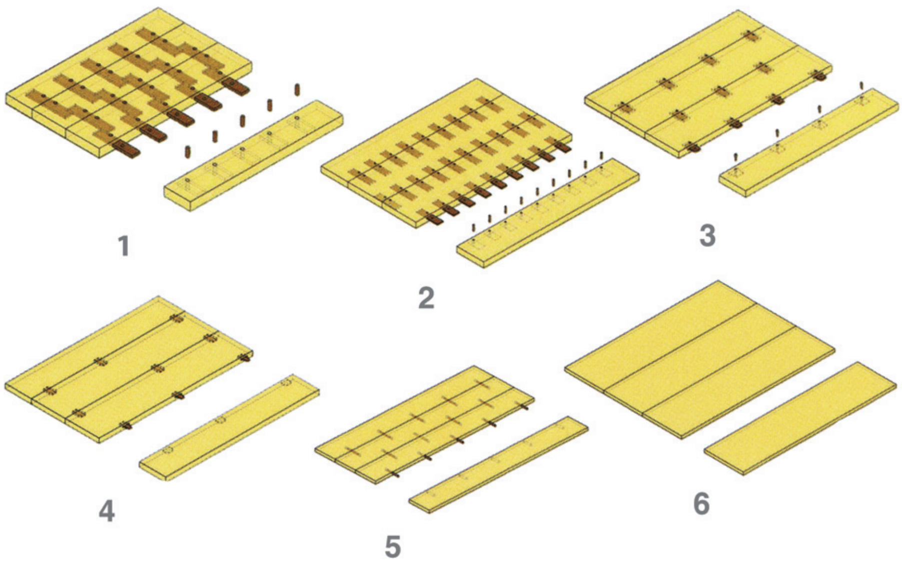

Figure 90. Mortise-and-tenon-joint evolution from its progressive weakening until its complete disappearance. (1. Uluburun, *c.*1325 BC; 2. Kyrenia, late-4th century BC; 3. Yassıada 2, 4th century AD; 4. Yassıada 1, 7th century AD; 5. Yenikapı 14, *c.*900 AD; 6. Serçe Limanı, *c.*1025 AD. Reproduced courtesy of C. Pulak, INA)

(Pomey, 2012). The Mazarrón wrecks were identified as Punic ships by Negueruela, but because of their local origin and the fact that this tradition lasted until at least the 4th century BC, Pomey (2012) suggests an Iberian shipbuilding tradition with Punic influence.

Mortise-and-tenon joints were characterized by Cato (*De Agricultura* XXI, 18.9) as *punicana coagmenta*, 'punic joints' (Sleeswyk, 1980). This text is, however, about a millennium later than the Uluburun and Cape Gelidonya shipwrecks. Considering the geographical origin and proposed cultural construction tradition of these shipwrecks, together with Cato's terminology, and the date and the archaeological context of the Mazarrón shipwrecks, a Phoenician origin for this technology cannot be ruled out.

From the beginning of the 6th century BC, another tradition, of sewn ships of Greek construction, appeared all around the Mediterranean (Pomey, 1997; Kahanov and Pomey, 2004; Pomey, 2010). The sewing technique had been used in the Aegean since the Archaic Greek period, and probably in Homeric times, as interpreted from Homer (see *Iliad* 2.135), and was still in use in the Classical period according to Aeschylus (*Suppliants*, 134–5) (Morrison and Williams, 1968: 50, 199; Pomey 1981: 237; Pomey, 1985: 35–48; Casson, 1995: 10 n.1., 27–8). Moreover, Mark (1991; 1996; 2005) considers, probably rightly in our opinion, that Odysseus' craft (Homer, *Od.* 5.244–53) was sewn, *contra* Casson (1964b; 1992) (on this question, cf. also Tchernia, 2001; Kahanov, 2009).

In this tradition, the planking was sewn, and the frames were lashed to the planking, as evidenced by the majority of the preserved and characteristic shipwrecks, such as Bon Porté 1 and Jules-Verne 9 (Pomey, 1981; 1999) (Fig. 91). However, planking-sewing was never used alone, but always with additional pre-assembling and reinforcing components, such as dowels (coaks). Unusually, unpegged tenons were found in the Pabuç Burnu shipwreck (2nd quarter of the 6th century BC, Turkey) (Greene, 2003; Greene *et al.*, 2008: 700; Polzer, 2010), and on the Cala Sant Vicenç wreck (last third of the 6th century BC, Balearic Islands), where the unpegged tenons were used combined with dowels (Nieto and Santos, 2008; 2010). But the remains of Pabuç Burnu are fragmentary, and the original arrangement of the unpegged tenons is not known. In the Cala Sant Vicenç wreck the combination of unpegged tenons and cylindrical dowels is due to major repairs (Nieto and Santos, 2008: 48–52; Nieto and Santos, 2010: 48–9).

Towards the end of the 6th century the Jules-Verne 7 and César 1 (Villeneuve-Bargemon 1) wrecks (both Marseilles, France) testify to an important step in the evolution of this Greek sewn tradition (Pomey, 2001; Kahanov and Pomey 2004; Pomey, 2010): the floor-timbers were fastened with iron nails, and the top frames were treenailed and lashed at the foot to the hull-planking. The planking was mainly assembled with pegged mortise-and-tenon joints, whereas the sewing was used only on keel extremities, endposts, and also for repairs (Fig. 92). The sewing system was similar to the former technology (Bon-Porté 1 and Jules-Verne 9), with cylindrical treenails for pre-assembly. The Jules-Verne 7 shipwreck illustrates the introduction of the systematic use of pegged mortise-and-tenon joints in the Greek sewing tradition. However, the pattern of pegged tenons was not very closely-spaced (Fig. 93), and the repairs were not made with tenons, but always by sewing.

These characteristics can be considered as Archaic. The next significant transitional step is evidenced in the

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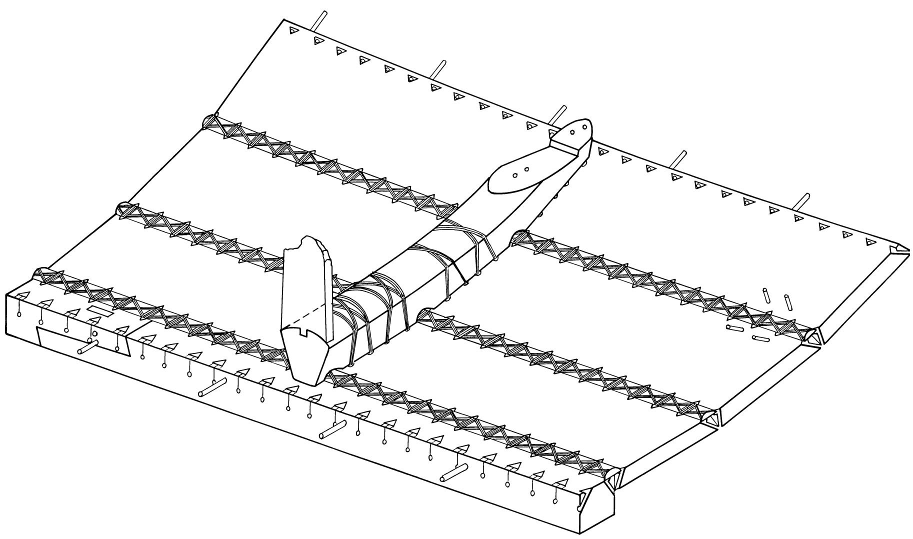

Figure 91. Jules-Verne 9 shipwreck. Sewing system of assembly. (M. Rival, Centre Camille Jullian, CNRS)

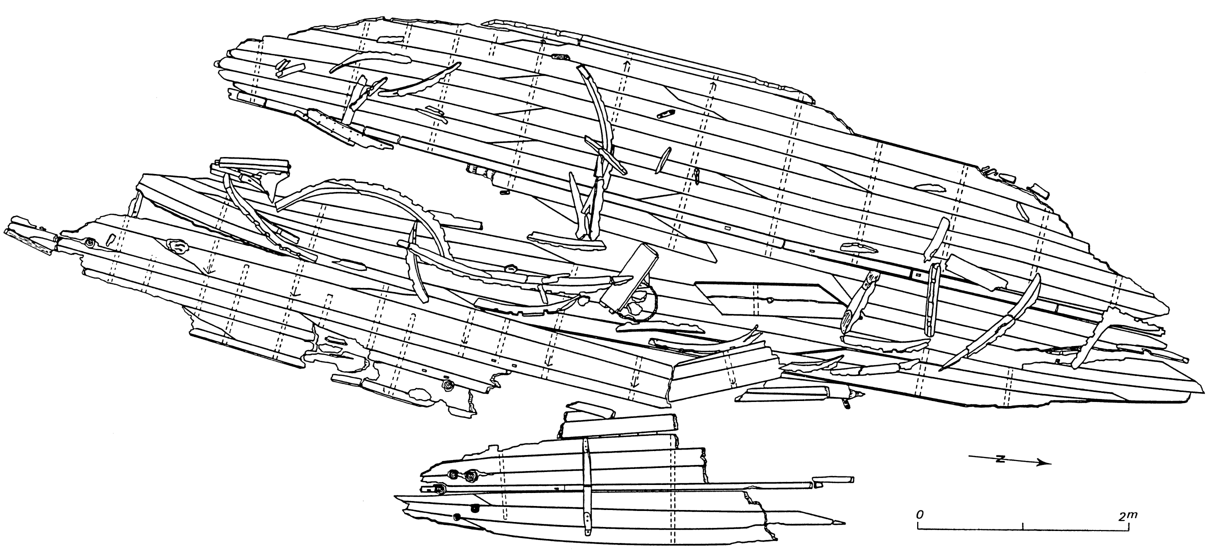

Figure 92. Jules-Verne 7 and 9 shipwrecks. Plan of the hull remains. (M. Rival, Centre Camille Jullian, CNRS)

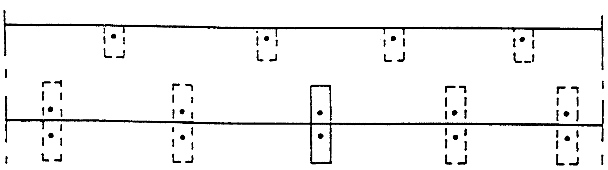

Figure 93. Jules-Verne 7 shipwreck. Mortise-and-tenon-joint pattern. (M. Rival, Centre Camille Jullian, CNRS)

Ma'agan Mikhael shipwreck (end of 5th century, Israel), which is also considered to have been built in this Greek tradition, and where the sewing is limited to the extremities (Kahanov and Linder, 2004: 245; Kahanov and Pomey, 2004; Stieglitz, 2006). The final transition would be completed in the Greek Kyrenia ship (end of 4th/beginning of 3rd century BC, Cyprus) (Steffy, 1985; Steffy, 1994: 42–59; Katzev, 2005: 72; Polzer, 2011: 365). In Kyrenia the planking showed closely-spaced mortise-and-tenon joints (Fig. 90), except for one ceiling-plank, which was a re-use of a sewn plank (Steffy, 1985: 95; Kahanov and Pomey, 2004: 23). While repairs were made with the same technology (contrary to Jules-Verne 7, César 1), sewing and lashing fell into disuse in this tradition. Kyrenia can be considered as the ultimate step of evolution from sewing to mortise-and-tenon joints; and at the same time, due to structural considerations, as the beginning of the Graeco-Roman tradition of shipbuilding based on pegged tenons (Pomey, 1997; Kahanov and Pomey, 2004; Pomey, 2010) (Figs 94–95). However, other

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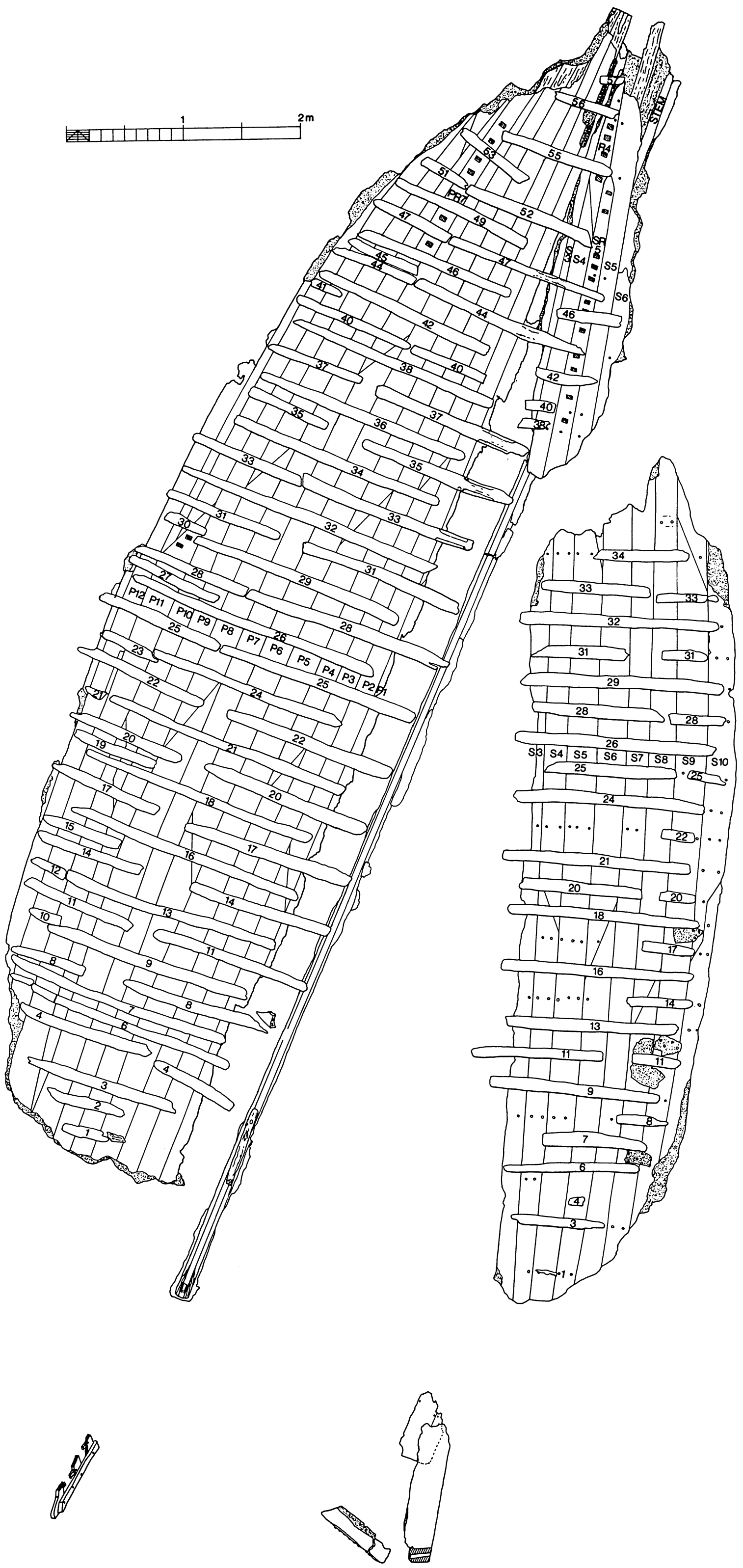

Figure 94. Kyrenia shipwreck. Hull-plan. (Steffy, 1994, fig. 3.23, reproduced with permission)

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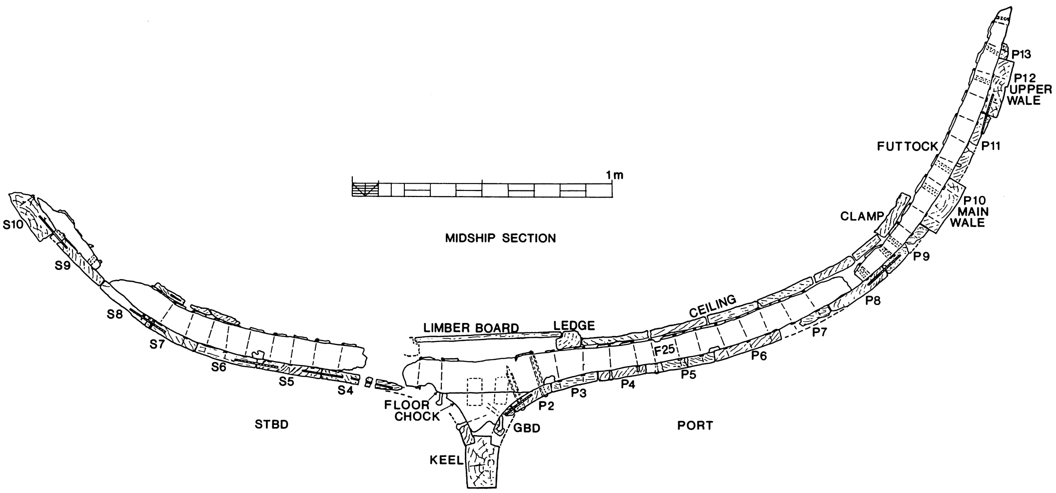

Figure 95. Kyrenia shipwreck. Cross-section amidships. (Steffy, 1994, fig. 3.31, reproduced with permission)

construction traditions did employ sewing during Antiquity in the Mediterranean, but in different historical and geographical contexts (Pomey, 1985; Bonino, 1985; Pomey, 2002b; Kahanov and Linder 2004: 66–76, Marlier, 2005).

The introduction of pegged mortise-and-tenon joints into the Greek sewing technique might have been a consequence of Phoenician (or Punic) influence and diffusion of technology, as a result of contacts between Greeks and Phoenicians during the colonization of the western Mediterranean (Pomey, 1997; Kahanov and Pomey, 2004; Pomey, 2010). Nevertheless, Polzer (2010: 33–4; 2011: 368–9), referring to Pabuç Burnu, suggested that the development from unpegged dowels and sewing, through unpegged rectangular tenons and sewing, to pegged mortises and tenons, was a natural development within the Greek technology, rather than an importation of Phoenician technology. However, it should be noted that rectangular tenons were used with cylindrical dowels in the Cala Sant Vicenç wreck, and that dowels were used still later, for the sewing in Jules-Verne 7 and César 1 (Villeneuve-Bargemon 1) wrecks, where most of the planking was assembled with pegged mortise-and-tenon joints. The rectangular tenons thus do not appear to be a transitional stage of evolution, and may be an idiosyncrasy or the fingerprint of a particular shipyard.

The Kyrenia shipwreck and the new Graeco-Roman shipbuilding technology introduce the theory of 'Transition in Construction' in Late Antiquity, as has been stated by van Doorninck (1976: 122–3), Steffy (1982b: 26–8; 1991; 1994: 83–85 and Pulak (2007), and as discussed in the introduction to this article, and recently reconsidered by Dell'Amico (2002: 71–7), and revised by Pomey and Rieth (2005: 171–2, 175–80) (Fig. 96) and Kahanov (2010).

Of the above corpus of shipwrecks, the Roman ships dated from the end of the 2nd to the end of the 3rd centuries AD—St-Gervais 3, Laurons 2, La Bourse and Monaco—were built on shell principles with well-fitted mortise-and-tenon joints. Thus, their conception was based on longitudinal, strake-oriented, hull-shape and shell structural concepts. Even if in some cases (St-Gervais 3, La Bourse), the building-method had been partially of mixed process, these were typical skeleton solutions for supporting the hull-construction. In the 4th century AD pegged tenons, occupying only part of their mortises, with larger spacing, were used in some ships, such as County Hall, Yassıada 2 and Dramont F. From the end of the 4th century to the beginning of the 7th century, unpegged mortise-and-tenon joints became more frequent, and even a common technique, in Fiumicino 1, Parco di Teodorico, Dor D, St-Gervais 2 and Yassıada 1. It is thus evident that the change in

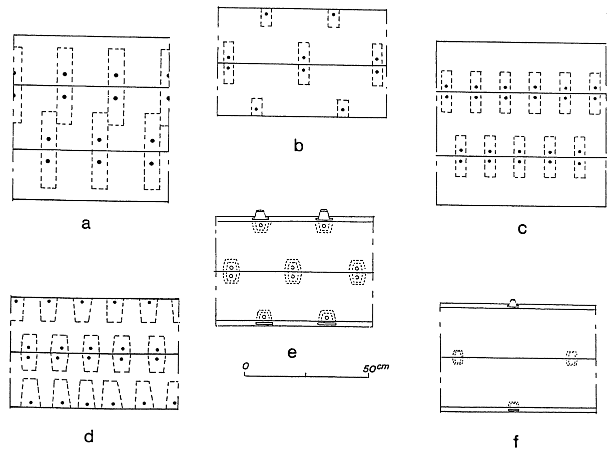

Figure 96. Mortise-and-tenon-joint evolution, after Pomey and Rieth, 2005, fig. p.117. a. Uluburun, *c.*1325 BC; b. Jules-Verne 7, late-6th century BC; c. Kyrenia, late-4th century BC; d. La Madrague de Giens, 1st century BC; e. Yassıada 2, 4th century AD; f. Yassıada 1, 7th century AD. (M. Rival, Centre Camille Jullian, CNRS)

the function of mortise-and-tenon joints, from being the main element in a strake-oriented hull and shell structure, to being used for aligning planking in mixed strake-and-frame construction-methods, was completed within less than five centuries. Henceforth, the unpegged mortise-and-tenon joints had lost their conceptual function, and were restricted to a practical role of pre-assembly.

However, no simple linear development is postulated; and no clear specific criteria, nor any single construction element, can define this transition. During the same period, the Pointe de la Luque B (4th century), Port-Vendres 1 (*c*.400 AD) and Dramont E (5th century) had been built with a strong arrangement of pegged mortise-and-tenon joints. So apparently more than one shipbuilding tradition can be traced.

About two centuries of transition are evident in shipwrecks found in the western Mediterranean. On one hand Port-Vendres 1 and Dramont E extended hull-shape concept and structure, based on shell strake-oriented and mortise-and-tenon joints until the 5th century, with a full shell-first construction-process in Dramont E. In Port-Vendres 1, some of the pegs were driven from the outside instead of the inside, and are possibly an indication of a mixed process of construction. However, there is insufficient information about this phenomenon to be totally certain and to be able to draw a conclusion. On the other hand, St-Gervais 2, which was not only based on frame principles, but may be considered as a frame-skeleton-construction-method hull, was about two centuries later. This suggests that two different traditions were followed in the western Mediterranean, although 200 years is not a short period. St-Gervais 2 is an example of the complexity of the process of transition. The presence of some relics of mortises and tenons in this wreck suggests that the previous tradition of strake-orientation with mortise-and-tenon-jointed planking had not been completely forgotten. However, there are cases of both traditions being in use simultaneously in the same location (see for example Yenikapı below).

The places of construction of these ships are unknown. But all three ships sank when sailing off the south coast of France. In spite of their African cargo, their wreck-sites and dimensions do not rule out a western Mediterranean origin. No solid evidence for the transition in construction exists in Port-Vendres 1, and absolutely none in Dramont E, while the transition is practically complete in St-Gervais 2. In this light, Dramont F, a small vessel with pegged, widely-spaced, and sometimes missing, mortise-and-tenon joints, presents an intermediate stage in the transition between the Port-Vendres 1 and Dramont E of less than a century later, and St-Gervais 2 of two and a half centuries later.

In the Adriatic, in the central Mediterranean, the 5th-century-AD Parco di Teodorico wreck in Ravenna exhibits an early use of widely-spaced unpegged mortise-and-tenon joints and a mixed concept and process of construction. This being a common type of plank-joint can be supported on both sides of the Mediterranean by Fiumicino 1 (partially) and by the Akko Marina timbers (despite their problematic context), and Dor D. It re-dates the common chronology of the technique from the beginning of the 7th century to the 5th century (if not slightly earlier), thus confirming the testimony of Procopius about the skeleton construction of Aeneas' Ship (*Bell. Goth.* 8.22: 7–17; Basch, 1985).

At the eastern end of the Mediterranean, if Dor D presents unpegged mortise-and-tenon joints in a mixed strake-and frame-oriented hull and a mixed shell and skeleton process, the earlier Tantura A and Dor 2001/1, evaluated based on the fact that mortise-and-tenon joints were totally absent from their hulls, had completed the transition, and were completely frame-based; thus being of both frame concept and construction method. However, a century later Yassıada 1, with unpegged mortise-and-tenon joints at the bottom, was still built according to a mixed shell and skeleton concept and process of construction. A similar chronological complexity occurs in Yenikapı, where most of the wrecks between the 9th and 11th centuries AD had planking with dowels (coaks) instead of mortises and tenons, which corresponds to a mixed process of construction, while other wrecks dated to between the 5th and 9th centuries were built frame-based. On the same site there is evidence of an earlier transition, and late evolution.

All the different technologies and stages are demonstrated within a short period, 5th–7th century, throughout the Mediterranean. In the west, Port-Vendres 1 (largely) and Dramont E (fully) were shell-constructed with mortise-and-tenon joints, while St-Gervais 2 was skeleton-built. In the western, central and eastern Mediterranean, Fiumicino 1, Parco di Teodorico, Dor D, Yassıada 1 and Pantano Longarini were mixed strake-and frame-based construction, using partially or totally unpegged widely-spaced tenons; and at the eastern end of the Mediterranean Tantura A and Dor 2001/1 were frame-based. A similar phenomenon is demonstrated in the 8th–9th centuries by Tantura F, Tantura E, Tantura B, and Bozburun. Until the 11th century Bozburun and many Yenikapı wrecks relied, at least partially, on plank-edge joints (coaks), which indicate a partial mixed process. Tantura F, Tantura E, Tantura B, and Yenikapı 17 and 29 were built based on frame principles and construction-method, with no planking-edge fastening.

Other factors that were part of the mortise-and-tenon-joint system, and further elements, can also be used as indicators for the transition process. The most significant characteristic is the density of the mortise-and-tenon pattern, as calculated by the ratio between the space between two adjacent mortises and the width of the mortises (which depend on the dimensions of the plank, and consequently the hull). In the period under discussion, mortise spacing gradually increased. Close

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spacing of up to 20 cm was found in wrecks dated between the mid-2nd century and the 3rd–4th centuries AD (St-Gervais 3, Laurons 2, La Bourse, Monaco, Pointe de la Luque B). In all these wrecks the distance between two mortises never exceeds 2.3 × mortise width, and is very frequently more-or-less equal to it. Spacing became greater, *c.*30 cm and more, in later wrecks dated between the 4th and 5th centuries AD (Yassıada 2, Akko Marina, Dramont F, Fiumicino1). In Dramont E the mortise spacing varies, depending on their position on the hull, from a very tight pattern to a wide one. The largest spacings of *c.*1 m were evident in 7th-century wrecks (St-Gervais 2, Yassıada 1, and Pantano Longarini). The County Hall vessel is exceptional, with spacing of 97 cm, at the turn of the 3rd century AD.

The tenon to mortise width ratio corresponds to the transition stage. The vessels with a high ratio (above 90%) are earlier (St-Gervais 3, Laurons 2, La Bourse), while those with a smaller ratio (*c.*60%–70%) are later (County Hall, Yassıada 2, Dramont F, Fiumicino 1, Parco di Teodorico, Dor D, St-Gervais 2, Yassıada 1). But despite the general tendency, Port-Vendres 1, Dramont E, and the Akko Marina timbers have high percentages, and are dated among the latter group, the first two being built with a shell concept and process.

Unpegged mortise-and-tenon joints made their appearance at the end of the 4th or the beginning of the 5th century AD, as demonstrated by Fiumicino 1 and Parco di Teodorico. This technique later appeared systematically in hulls (Dor D, St-Gervais 2, Yassıada 1, and Pantano Longarini).

Other planking aspects

The change in metal used for nails, from copper to iron, parallels the transition process from shell to skeleton. However, during the Greek Archaic period, iron nails were in use, for example in the Jules-Verne 7 wreck, to fix the floor-timbers to the planking (Pomey, 1999: 152). But at the same time the mortise-and-tenon pattern was looser than during the Hellenistic and Republican periods. During the transition process three stages can be identified. The earliest (St-Gervais 3, Laurons 2, La Bourse) had copper nails (in Laurons 2 nails were of copper or bronze). In the intermediate transition stage, lasting about two centuries, copper and iron nails were used (Monaco, copper; County Hall, iron; Yassıada 2, iron; Akko Marina, copper, Fiumicino 1, iron; Port-Vendres 1, iron and copper; Dramont E, iron, and perhaps bronze). In the last stage only iron nails were used (Tantura A, Dor 2001/1, Parco di Teodorico, Dor D, St-Gervais 2, Yassıada 1, Pantano Longarini, Tantura F, Tantura E, Tantura B, Bozburun, Yenikapı, and Serçe Limanı).

In the Graeco-Roman tradition based on a shell concept (shape and structure) and construction-process of the hull, a thick coat of pitch was applied to the internal and external faces of the planking. This traditional technology was identified in St-Gervais 3, Laurons 2, La Bourse, Pointe de la Luque B, Yassıada 2, Dramont F, Port-Vendres 1, Dramont E, and Parco di Teodorico. In these shipwrecks, mortise-and-tenon joints (sometimes unpegged) were used. Moreover, a sort of luting in some seams is attested in Port-Vendres I and Dramont E. Luting or caulking was identified in some of the Yenikapı shipwrecks, where dowels were used as edge-fasteners. Driven caulking has been found in later wrecks (Tantura A, Dor 2001/1, St-Gervais 2, Tantura F, Tantura E, Tantura B, and Serçe Limanı) which were built on frames. This seam-caulking with its double watertightness and structural function is a significant archaeological fingerprint of a frame-based hull. Although the caulking was a characteristic of a frame construction, it would not have excluded the traditional use of a coat of pitch, as testified by Bataiguier, Agay A and Serçe Limanı.

The use of butt-joints of planks at frame-stations is another good indication of a frame-based hull. It occurred in Tantura A, Dor 2001/1, Tantura F, Tantura E, and Tantura B. Intriguing is the Serçe Limanı shipwreck, where in addition to two butt-joints, there were several 'Z' scarfs. This is difficult to explain; in Steffy's words, 'Why three-planed scarfs were used, rather than plain butt-joints, is a mystery to me'. The latter joints, however, were apparently without edge-fasteners (Steffy, 2004: 162). This may possibly have been a relic of an old shipyard tradition (Harpster, 2005b: 506–08).

Shaping the keel with rabbets or chamfers for attaching the garboard became less common with the years, and is partially correlated with the transition. The relation between the keel and the garboard and their attachment is fundamental in determining the bottom-shape of the hull in the shell concept, and consequently in the shell-first process used in shell or mixed construction (Pomey, 1998: 59–61). On the other hand it loses its significance in the frame-oriented skeleton construction, with the predetermination of some frames. In hulls built according to a shell process, strake-oriented at the bottom, thus including various mixed process, the keel was rabbeted or chamfered for connecting the garboards (St-Gervais 3, Laurons 2, La Bourse, Monaco, Pointe de la Luque B, Dramont F, Port-Vendres 1, Dramont E, Yassıada 1, and Yenikapı 3). In hulls built according to a skeleton frame-oriented process, keels were generally not shaped to fit the first strakes, and in several shipwrecks planks were not connected to the keel (Tantura A, Dor 2001/1, St-Gervais 2, Tantura F, Tantura B, Serçe Limanı). Endposts continued to have rabbets (County Hall, Yassıada 2, Fiumicino 1, Tantura A, Dor 2001/1, St-Gervais 2, Tantura F, Tantura B, Serçe Limanı), but this feature, which facilitated the connection of strakes to the endpost, was evident throughout all periods and systems of construction, and so cannot serve as a typological criterion. However, there were exceptions. In the County Hall vessel, built on a shell concept and process, and the Yassıada 2, built on a shell concept

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and a mixed process with the setting of the five first strakes, the keel was not shaped. In the frame-based ships Bataiguier and Agay A, the keel was chamfered, and in Tantura E, the keel had a rabbet along its entire length and endpost, and the garboard was nailed into it. It is thus an exception to the other Dor/Tantura shipwrecks. Bozburun's keel had an arrangement for the garboard in the shape of a flange, which was well-known in Viking ships, unlike the contemporary Tantura F and Tantura B. In this way, the relation between the keel and the first strakes can serve to some extent as an indication of a strake or frame-construction method, and is to some degree correlated with the transition.

Structural evolution

In the transition, in addition to the evolution of mortise-and-tenon joints, the evolution of the hull-structure, mainly the internal framing, is a fundamental question. The first test can be the plank-thickness. This parameter is also not clear-cut, as plank-thickness was also a function of hull-size. However, if until the 5th century plank-thicknesses were seldom less than 40 mm, from the 6th century they were usually *c*.30 mm for an equivalent hull-size. Similarly, the wale was a significant factor in determining the structural concept of a hull. In a shell structural concept the wales were part of the planking, connected by mortise-and-tenon joints, constituting a strong longitudinal reinforcement. Such wales were found in hulls built in a shell structural concept (St-Gervais 3, Laurons 2, La Bourse, County Hall, Point de la Luque B, Yassıada 2, Port-Vendres 1, and Dramont E). On the other hand, in hulls built in a skeleton structural concept, wales were connected directly to the frames (Dor 2001/1, St-Gervais 2, Tantura B, Yenikapı 17, Serçe Limanı). In the mixed building concept of Yassıada 1 and Pantano Longarini, where the upper part of the planking was connected to frames, the wales were also nailed directly to the frames.

In frame-based construction, parallel to the disappearance of plank-edge joints, hulls were strengthened, and derived their integrity mainly from frames, and their attachment to the keel was a fundamental criterion. Nevertheless, internal longitudinal reinforcement components, such as keelson, central longitudinal timber, mast-step, sister-keelson and stringers played an important role.

The first point is the general attachment of the frames to the keel. Until the beginning of the 5th century AD, frames were only sporadically bolted (or nailed) to the keel (St-Gervais 3, Laurons 2, La Bourse, Monaco, Point de la Luque B, Yassıada 2, Dramont F, Fiumicino 1, Port-Vendres 1, Dramont E). All these hulls were of a shell concept, sometimes with a mixed process. This nailing reinforced the hull, but was not a basic essential in the hull construction, or a clear indicator of frame-based construction. It has been shown that a bolted frame was not always a pre-erected active frame (Pomey, 1998: 66–7). Bolted floor-timbers were mentioned in the 3rd century BC *Syracusia* ship (Athenaeus, *Deipnosophists*, 5.207b). The first archaeological evidence was found in La Madrague de Giens of the 1st century BC, which was built according to a shell concept and construction-process (Pomey, 1998: 66–7) (Fig. 2). Pomey (2002a) has shown that these floor-timbers were bolted to the keel in order to compensate for the weakness of the keel in the hull-type with a wine-glass cross-section. In Yassıada 2 (4th century) the partially-active frame B7 was not a floor-timber, but a half-frame not connected to the keel (Fig. 21).

From the 5th century, frames were generally nailed to the keel (Dor 2001/1, Tantura A, St-Gervais 2, Tantura F, Tantura E, Tantura B, Bozburun, Bataiguier, Agay A, Yenikapı 17, Serçe Limanı). All these wrecks were built in a skeleton concept. As in other analyses, the process was slightly more elaborate, as demonstrated by Yassıada 1, which was of typical mixed concept and construction-process. Although it is dated later than Tantura A and Dor 2001/1, and was roughly contemporary with St-Gervais 2, only a quarter of the frames were connected to the keel, similar to earlier wrecks. In the Yenikapı wrecks of the 9th–10th centuries built in a mixed construction-process (Yenikapı 3, 6–9, 12, 15, 18), most, but not all, of the frames were nailed (sometimes treenailed) to the keel.

The framing-pattern is also an important parameter in determining the architectural type and its structural integrity. In the Graeco-Roman construction method, the main framing-pattern used during the Hellenistic and Republican period was of alternating floor-timbers and half-frames (Pomey, 1998; Pomey, 2004b; Pomey and Rieth, 2005) (Fig. 97). In the western Mediterranean, from the 2nd century AD, a new ship-type was the western Roman Imperial (Fig. 98). Its characteristics were a flat bottom and flat floor-timbers amidships, with a round turn of the bilge. It presented a different framing-pattern, characterized by alternating floor-timbers and half-frames, which often overlapped the keel axis (Pomey, 1998; Pomey and Rieth, 2005). These overlapping half-frames obviously reinforced the framing system, and contributed to its strength. It was found in St-Gervais 3, Laurons 2, La Bourse, Monaco (?), Pointe de la Luque B, and Port-Vendres 1, which were built according to a shell concept and a shell or mixed process.

However, alternating floor-timbers and half-frames were evidenced in Fiumicino 1 and Dramont E, which belonged to a different hull-type: a riverine influence and mixed process in the first one; and shell concept and process in the second. On the other hand, County Hall, Dramont F, and Parco di Teodorico present a specific framing-pattern, where floor-timbers dominated. If the County Hall expressed possible river influence, but a shell concept and process, the other two presented an important step in the transition, especially Parco di Teodorico of mixed concept and construction, in which the framing had an important role. St-Gervais 2 is a special case: the

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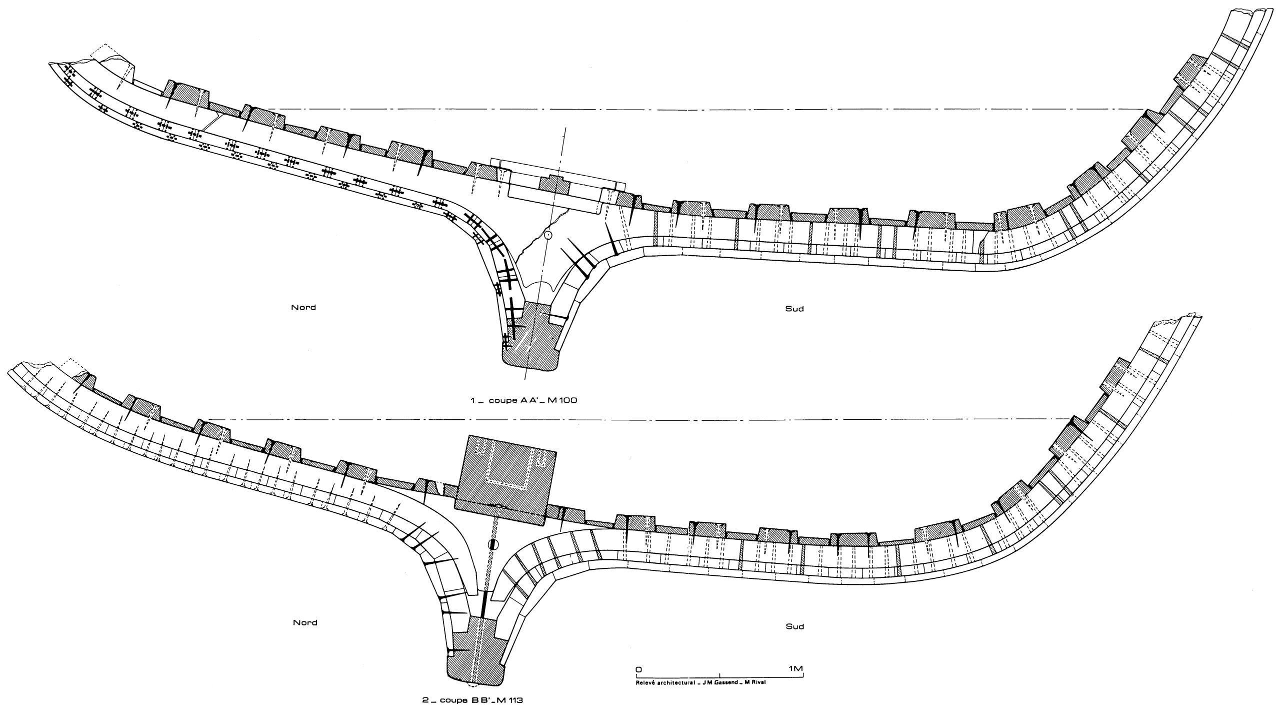

Figure 97. Madrague de Giens shipwreck. Cross-sections amidships with alternating floor timber and half-frame. (J-M. Gassend and M. Rival, Centre Camille Jullian, CNRS)

framing-pattern was of alternating floor-timbers and half-frames, with the inner ends of the half-frames connected to each other by horizontal nails, above the keel axis. This was an unusual feature, which increased the strength of the framing.

In the eastern Mediterranean, several framing-patterns were encountered. In the early-transitional Yassıada 2 and the later Pantano Longarini there was a classical alternation between floor-timbers and half-frames, and on the mixed ship Yassıada 1 the framing-pattern was more elaborate: alternating long and short floor-timbers, half-frames, all with futtocks and top-timbers. Moreover, several framing-patterns were also in evidence in frame-based hulls. In Dor 2001/1, Tantura B, E, F, and Agay A alternating floor-timbers and half-frames with futtocks appeared. But in Bozburun, Bataiguier, Yenikapı 3 and 12, and Serçe Limanı the framing was mainly made of floor-timbers, with a characteristic system of long-armed floor-timbers alternating to port and starboard.

Another significant point regarding the transition, concerning the framing system, was the integrity of the skeleton and the framing components, considering not only the connection of the framing with the keel, but also the connection between floor-timbers or half-frames and their futtocks. However, futtocks were preserved, although their connection with floor-timbers or half-frames could be observed only in Tantura F, Yenikapı 3, 6, 7, 9, 12, Serçe Limanı, and Bataiguier, which probably had the same framing-system as Serçe Limanı. Absence of a connection between these framing components and the lack of integrity of the framing-system were the essential features of construction based on a shell structural concept, expressing the lesser importance given to the framing system, from a conceptual and structural point-of-view (Steffy, 1994; Pomey, 1998; Pomey and Rieth, 2005). This was also the case in the mixed constructions, where the integrity of the hull was obtained by a mixture of shell and framing structure; and longitudinal components, such as keelson, stringers and wales, played an important role. It is of major interest in ships built in a frame-oriented concept and process, where the hull integrity was based on the skeleton. In the frame-based wreck Dor 2001/1, where there was no connection between floor-timbers or half-frames and futtocks, part of the hull's integrity was achieved by longitudinal components and connecting framing-timbers, such as stringers, clamps, wales and ceiling-strakes. In the mixed-construction Bozburun, a similar problem was resolved by adding planking-edge fasteners (coaks).

Thus the function of the longitudinal backbone, or longitudinal reinforcing components, and their importance in the transition, should be reconsidered. This question may be directed to the function of the keelson, which, according to the definition of the *Dictionnaire de la marine à voile* (Bonnefoux and Pâris, 1848: 148), is 'to complete the connection of the floor-timbers with the keel and the upper false keel'. In other words, there seems to have been a logical architectural association between the two

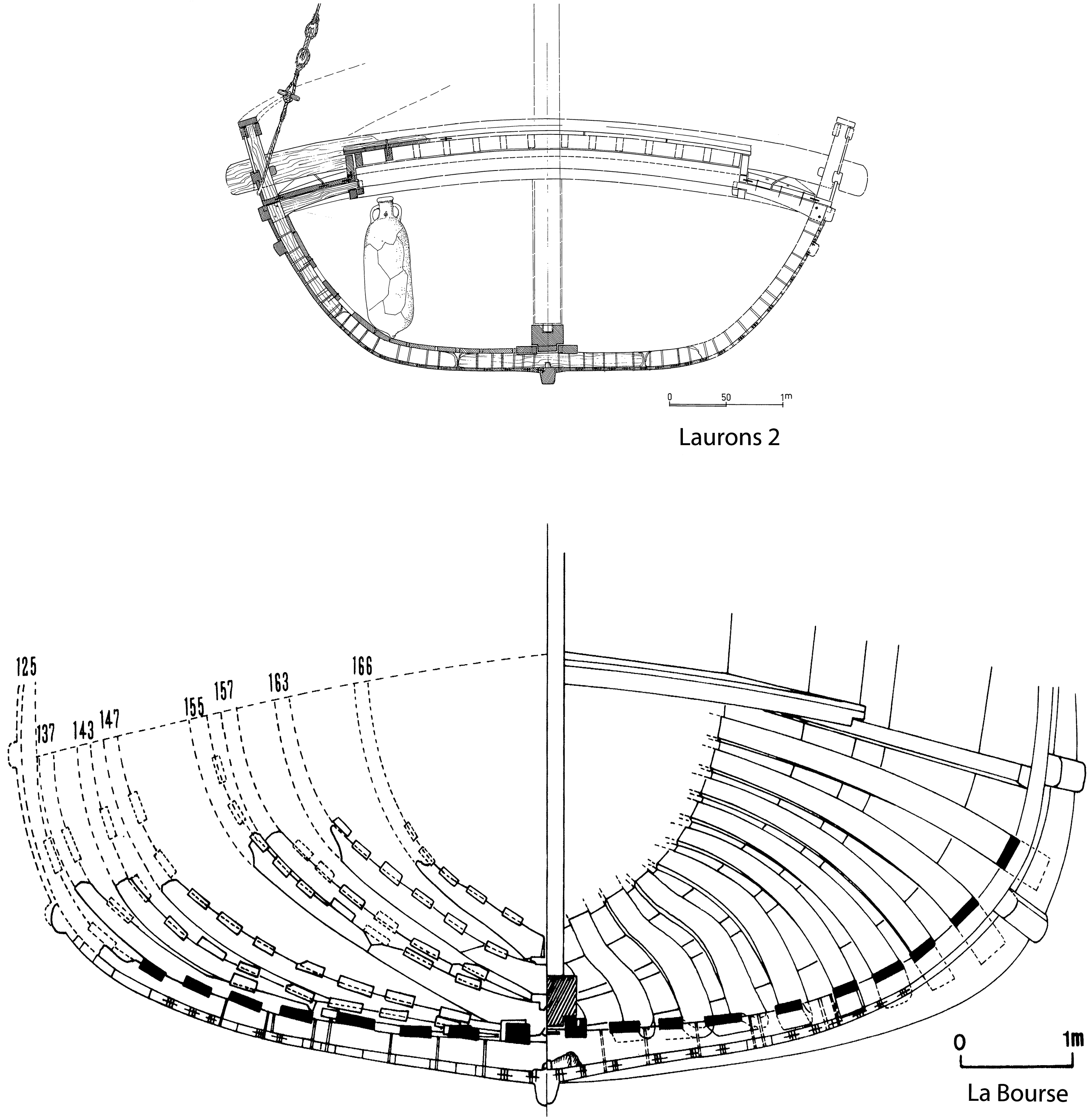

Figure 98. Two characteristic examples of the western Roman Imperial type: Laurons 2 and La Bourse shipwrecks. (P. Pomey, Centre Camille Jullian, CNRS)

main elements of the longitudinal structure of the hull: keel and keelson (with or without false keel).

In the western Roman Imperial type, the longitudinal components were made of two central sister-keelsons, connected by transverse braces, and fitted on the floor-timbers, supporting a long and large keelson/mast-step timber, and prolonged at each end by a central longitudinal timber. This system considerably reinforced the longitudinal axis of the hull and the integrity of the framing. It was found in St-Gervais 3, Laurons 2, La Bourse, Monaco (?), Point de la Luque B and Port-Vendres 1, all belonging to this hull-type. Perhaps a similar system, with some alternatives, is evident in Dramont E, where the keelson/mast-step was fitted on two sister-keelsons and floor-timbers; and in St-Gervais 2, where the scantlings of the longitudinal timbers are significant.

Alternatively, both the latter shipwrecks belonged to a different type, as, instead of flat floor-timbers, their midships cross-section was of a wine-glass shape. The

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County Hall vessel and Fiumicino 1 were particular cases, characterized by the absence of longitudinal axial components, except for the small forward keelson of Fiumicino 1, which was a towing-post-step. This particular feature may perhaps have been the result of riverine influence: both wrecks were of sea-river vessels. In the Parco di Teodorico shipwreck, there was a long keelson/mast-step timber which fitted directly onto the floor-timbers, as in the ancient Graeco-Roman system of the Hellenistic or Republican period, although the hull had a flat bottom, not a wine-glass cross-section. This ancient system, with a keelson and inner posts directly fitted on the floor-timbers and bolted to the keel, was found on the transitional mixed ship of Yassıada 1, the hull of which had a wine-glass cross-section.

Referring to the Tantura shipwrecks, the question of the necessity of a strong longitudinal backbone in a frame-based hull and a skeleton construction is relevant. Dor 2001/1, Tantura A, Tantura B, Tantura F, and Tantura E show the transition. All five demonstrate a clear frame-construction tradition, where planks were nailed to pre-existing frames, with planking butt-joints at frame stations, and later caulked. However, except for Tantura B, they lacked the remains of a strong keelson. In Tantura A no internal longitudinal components were found, but in Dor 2001/1, Tantura F, and E, longitudinal reinforcing components were evident. Perhaps the central longitudinal timbers, combined with stringers and other longitudinal components, were deemed to be strong enough. All these five Tantura shipwrecks could have been associated with a specific architectural tradition, with a riverine origin of 'bottom-based' construction, as discussed below. An important characteristic must be underlined: in the 'bottom-based' construction, there is neither keel nor continuous keelson between the two extremities of the hull. Apparently, therefore, the Tantura wrecks did not require a strong longitudinal backbone. But Tantura B and, some centuries later, Serçe Limanı, did have a keelson. The flat-bottomed Yenikapı 1, 6 and 7 had bilge-keels, which is a solution for the structural reinforcement of such a hull-type. Both ships of the 10th–11th century were built in a mixed process.

On the other side of the Mediterranean, St-Gervais 2 belonged to a different ship-type, and can be associated with a different architectural origin from the Tantura shipwrecks. It presented longitudinal components, which were not continuous (mast-step/keelson on sister-keelsons and central longitudinal timbers at the ends), similar to Tantura F, and of which Dor 2001/1 and Tantura E have similar elements. In this regard, the archaeological remains of mortises and tenons in St-Gervais 2 did not play any structural role, and may apparently be ignored.

To summarize: in frame-based construction, hulls with keel, frames, and full or partial axial longitudinal members, could well be additionally reinforced by chine-strakes, stringers, foot-wales, clamps and massive wales, as in Dor 2001/1, St-Gervais 2, Yassıada 1, Tantura F, Tantura E, and Yenikapı 17. According to Christensen, these additional longitudinal reinforcements are 'shellbuilder's solutions to skeleton problems'. On the other hand, the 14th-century galley at St Marco Island, Boccalama, Venice, which was *c*.38 m long, 5 m beam, with relatively small skeleton elements, should be included, and the skeleton question re-examined (D'Agostino and Medas, 2002; 2003). Regarding the relatively small skeleton elements of medieval and post-medieval galleys, two architectural characteristics must be noted: the use of strong stringers ('*escoues*') at the level of the joints between floor-timbers and futtocks (Fennis, 1995: 843–5); and, referring to the planking, the use of particular strakes (*fils endentés*), which were notched in the outer face of the frames (Fennis, 1995: 921–2). In the architecture of galleys, these longitudinal inner and outer reinforcements had a key structural role. In this respect the opposite argument should not be misinterpreted: a strong skeleton does not necessarily mean a frame-based hull. Ships of the Roman Republican period had a large keel and keelson with an elaborate stringer system and wales, as for example in La Madrague de Giens (Pomey, 1978; 2004b), or Titan and Dramont A (Gianfrotta and Pomey, 1981: 237–8) (Fig. 99): all were shell-constructed. In the same way, ships of the Roman Imperial type, of which more examples are presented in the wrecks reported above, presented a strong skeleton and important longitudinal reinforcement, while being built in a shell concept.

These data and elements have to be considered with respect to the hull's structural strength. Casson (1963; 1995: 201, 207) refers to skeleton as made only of keel and frames. The keelson itself and the longitudinal backbone are only one factor in the development of the integrity of the internal framing towards the transition to frame-based or skeleton-built ships.

The different roots of transitions

The study of the evolution of mortise-and-tenon joints and of the hull-structure suggests that hulls built in a frame concept and construction-method were found in both western and eastern Mediterranean shipwreck-sites from about the 6th–7th century AD. Analysis of the Tantura A and Dor 2001/1 wrecks and of St-Gervais 2, in light of the various terms describing the transition above, leads to the conclusion that the transition in construction had been more or less completed in these vessels. Obviously, these wrecks were of different types of ships, so it is very likely that this transition occurred in different geo-historical contexts, various shipbuilding traditions, and different structural families of boats and ships. Until now, the transition has been discussed from architectural aspects (principle and method of shipbuilding). The following discussion suggests an additional approach, based on the characteristics of ship-types, mainly the geometry

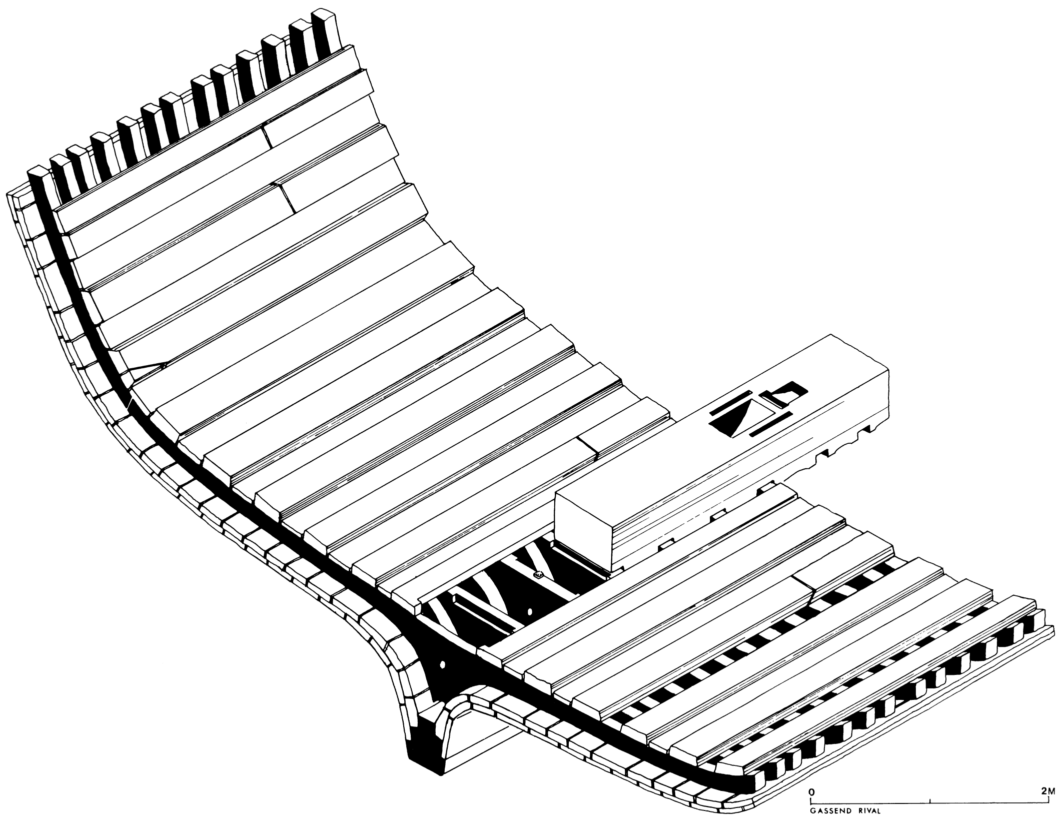

Figure 99. A characteristic example of the Hellenistic type: the Madrague de Giens shipwreck (axonometric view). (J-M. Gassend, Centre Camille Jullian, CNRS)

of the hull cross-section as proposed by Rieth (2008). It also explains the roots, which define the various construction traditions. These roots originated in different geographical locations and different cultural contexts within the Mediterranean, and perhaps even beyond.

This analysis begins with shipwrecks of the south-western Mediterranean French coast of the western Roman Imperial tradition, Root 1, characterized by a flat floor-timber and a round turn of the bilge at the main frame. The framing was strengthened by overlapping half-frames and some bolted floor-timbers. In addition, longitudinal components, such as a long mast-step/keelson installed on sister-keelsons, sometimes continued to the ends of the ship, and in several cases prolonged to the extremities by central longitudinal timbers (Pomey and Rieth, 2005: 165–7). This strong structure, together with a tight mortise-and-tenon system, may be a first stage towards the transition (Pomey, 1998: 68–9). In this ship-type, which was of a shell concept, the first evidence of possible partially-active frames and a limited mixed process of construction are found, for example, in St-Gervais 3, La Bourse, Monaco (?), and perhaps Port-Vendres 1.

The next step in the evolution in this ship-type is difficult to determine conclusively. However, it is possible that Dramont F and Parco di Teodorico belonged to the same tradition, and represent a late evolution of this western Roman Imperial type (with their flat floor-timbers, a round turn of the bilge, a framing-system based on floor-timbers—and a strong axial longitudinal timber—a possible evolution of the alternating floor-timbers and overlapping half-frames). If so, there were two more intermediate steps of evolution leading progressively to a mixed process of building: Dramont F (second half of the 4th century), with its widely-spaced mortise-and-tenon joints and loose tenons; and then the mixed concept and process of construction in Parco di Teodorico (5th century), with unpegged mortise-and-tenon joints. It is also quite possible that the County Hall vessel and Fiumicino 1, in spite of their particular sea-river characteristics, with flat-floor-timber-bottom hulls built in a Mediterranean technique, and widely-spaced and even unpegged mortise-and-tenon joints, are parallels in this evolution. Nevertheless, this root of evolution was not linear, considering the Laurons 2 and Pointe de la Luque B wrecks, which belonged to the western Roman Imperial ship-type, which showed none of this evidence of the evolution, and which were still built in the shell concept and process.

In the 5th century, another tradition must be considered, represented by the ship-type of Dramont E, with a master-frame of a gentle wine-glass

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cross-section and a round turn of the bilge, and a framing-pattern of the classical alternating floor-timbers and half-frames, both characteristics similar to the earlier Hellenistic type. It is possible that we have a long evolution of this tradition in the western Mediterranean. However, the elaborate central longitudinal timbers had similarities with the western Roman Imperial type. This ship was entirely shell-built, which indicates that the evolution toward transition was not systematic, and did not include all ship-types, or all shipyards.

Some centuries later, St-Gervais 2 (600–625 AD) was very probably built in a frame-oriented concept and a process of construction based on frames. Therefore, it marked a significantly advanced step, which almost completed the transition. The ship-type was characterized by a wine-glass-section master-frame, a round turn of the bilge, alternating floor-timbers and half-frames, and strong axial longitudinal components—similar to the western Roman Imperial type. This ship-type presents many similarities with Dramont E, and, particularly in its cross-section geometry, with the Hellenistic type. However, technically there is a discrepancy between the shell-built Dramont E and the frame-built St-Gervais 2. The absence of a direct link, in the present database, between St-Gervais 2 and Dramont E, is problematic, and leads to the consideration of an external influence on this old tradition. Although the ship-types were quite different, the importance of the framing, mainly the internal central longitudinal components, which were similar to the western Roman Imperial type, may suggest a possible influence on this type, and perhaps its evolution. At least the existence of a process of evolution as demonstrated by Dramont F, Fiumicino 1 and Parco di Teodorico in the western and central Mediterranean, could have been a favourable context for such a radical evolution, possibly under external influence. St-Gervais 2, therefore, very probably belonged to a second root—Root 2—of evolution towards the transition.

In the eastern Mediterranean two different traditions were represented by two different ship-types: (a) with a wine-glass cross-section, and a round turn of the bilge, as in Yassıada 2 (4th century), Yassıada 1 (7th century), Bozburun (9th century) and the 10th–11th centuries Yenikapı 3, 16 and 18; and (b) with flat frames and a hard chine, as in the Dor/Tantura wrecks. The Bataiguier, Agay A and Serçe Limanı shipwrecks should be included in the second tradition. Regarding Pantano Longarini, it is debatable whether the bottom had a wine-glass section, which is ruled out by Kampbell, (Kampbell, 2007: 70) or flat floor-timbers.

The first tradition recalls the Hellenistic type, from which it was probably descended. In this tradition, Yassıada 2 presents a first step of evolution, characterized by widely-spaced, loosely-pegged mortise-and-tenon joints and a partially-active frame, which indicate a shell concept, but a mixed process of building. About three centuries later, Yassıada 1, with unpegged mortise-and-tenon joints, demonstrates a typical example of a mixed concept and process. Assuming an advanced step in the evolution in this tradition had occurred by the 7th century, this indicates a third root—Root 3—which was still not completed.

It is quite possible that the next step is represented by Bozburun (9th century). The ship had a shallow wine-glass section with a round turn of the bilge, which reflects the origin of its tradition. There were no mortise-and-tenon joints, which were replaced by polygonal coaks, and the sequence of construction was frame-first. The hull-concept was frame-oriented and frame structural principles, and the construction-process was of a mixed frame and plank method with the use of active strakes. One or two centuries later, Yenikapı 3, 16, and 18—according to preliminary research—presented the same characteristics: dowels (coaks) as planking-edge fasteners, and full floor-timbers, the majority nailed to the keel and planking. They were still built in a mixed construction-process in the 10th–11th centuries AD. It demonstrates the permanence, and consequently the adoption, of this tradition in the Byzantine context, in a period when skeleton construction was largely used elsewhere (the shipwrecks Yenikapı 22 (5th century) and 29 (8th century) are considered to be built on frames, but we do not yet have enough details to classify their type). The transition, as described by van Doorninck and Steffy, and extended by Pulak, corresponds mainly to this particular tradition, with the exception of Serçe Limanı, which belongs, in our point of view, to another tradition.

The second tradition, in the eastern Mediterranean, included the Dor/Tantura shipwrecks, which were built on frames, both in concept and process. The absence of a heavy keelson, which existed in Tantura B, raises a question about the other Tantura ships. Frames nailed to the keel fixed the shape of the hull, and served as the basis for planking. Contributing to the longitudinal integrity were the keelson and wale in Tantura B, and central longitudinal timbers, stringers, foot-wales, clamps and wales in others. This group represents a fourth root of evolution in transition—Root 4.

Dor 2001/1 is key in analysing the cross-section geometry of the hulls. It is one of the two oldest eastern Mediterranean archaeological examples of a frame-skeleton hull, and can be regarded as the archetype of a family of geometrical hull-shapes. Its characteristics amidships were flat and horizontal frames, a hard chine and oblique sides—three characteristics of a pure ‘box-shaped’ master-frame. This specific geometrical family of hull was of those of the ‘bottom-based’ built ‘*sur sole*’ inland vessels, which were characterized by ‘three plane surfaces, the flat bottom and the two sides’ (Beaudouin, 2000: 41). The geometry of its cross-section was different from that of the two first families of hull-shapes described above. The earlier was built ‘on keel’, and shaped with a wine-glass bottom and a round turn of the bilge. This was first attested in the 5th

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century BC in Gela 2 (Sicily) (Benini, 2001) and Ma'agan Mikhael (Israel), of the sewn Greek family, and later at the end of the 4th/beginning of the 3rd century BC in the Kyrenia ship (Cyprus), in the new Graeco-Roman tradition of mortise-and-tenon joints. It developed in the Hellenistic and Roman Republican periods into the Hellenistic type, which defined its main characteristics, as in the 1st century BC Madrague de Giens (France) (Pomey, 2004b) (Fig. 99). It continued until the second quarter of the 5th century AD (Dramont E, France).

The second, later, group was built 'on keel', with flat frames and a round turn of the bilge. It appeared in the western Mediterranean in the 2nd century AD (St-Gervais 3, France), during the Roman Empire, and was accordingly termed the Western Roman Imperial type (Fig. 98), and continued until the 5th century AD (Parco di Teodorico, Ravenna, Italy). This type of maritime origin should not be confused because of its flat frames with the box-shaped midships section type represented by Dor 2001/1.

Both geometrical families of hull-shapes: wine-glass, and flat frames with round bilge, were not limited to ancient times and the shell concept and construction method. They also occurred in the mixed concept and construction method (Yassıada 1, Parco di Teodorico); the frame concept and mixed construction-process (Bozburun); and the skeleton concept and construction method (St-Gervais 2). The shipwrecks of Hellenistic and western Roman Imperial traditions, with similar families of hull-shapes—wine-glass or flat frames—but with different concepts and construction methods, demonstrate a long, complex process of evolution from shell to skeleton construction. Three cultural roots associated with the Graeco-Roman World have been suggested, one of them perhaps under external influence.

Almost certainly there was another long, complex and non-linear process of evolution to the skeleton concept, linked to a different origin. It was not connected with sea-going vessels built 'on keel', but associated with a flat 'bottom-based' tradition of inland boats built 's*ur sole*'. In this respect Dor 2001/1 can represent the maritime archetype of this lineage, Root 4, of a skeleton concept and construction method of shipbuilding. It was linked to a shallow-water, riverine construction tradition; specifically Nilotic (Rieth, 2008). Basch (2008) supported the idea of an Egyptian origin, from the aspect of the use of caulking, and extended this idea by pointing specifically to Alexandria. Kahanov (2011b) suggested the consideration of the idea of the Nilotic origin of the Dor/Tantura shipwrecks under discussion here, specifically Dor 2001/1.

The two 'Saracen' shipwrecks, Bataiguier (Joncheray, 2007a: 131–222) and Agay A (Joncheray, 2007b: 223–48), discovered on the southern coast of France, and dated to the 10th century, present similar characteristics. They obviously represent an extension of the Dor/Tantura type. It is suggested that the tradition crossed the Mediterranean with the Islamic conquests (Rieth, 2008). Moreover, it is likely that this tradition also penetrated the Byzantine world, as is evident from the similar cross-section of Serçe Limanı (Steffy, 2004: 156–60). Built according to a skeleton concept and method of construction, this 11th-century-AD shipwreck presently marks the completion of the transition process.

The Yenikapı 6, 7, 8, 9 and 12 ships had flat frames and a hard chine, sometimes reinforced by a bilge-keel (Yenikapı 1, 6, 7). They present many similarities with the tradition of the flat-framed hulls of the Dor/Tantura type. However, they were built in the 9th–11th centuries in a mixed technique, which used dowels between the bottom planks for preliminary assembly. This mixed construction was a kind of shell solution to skeleton problems. So the question is whether Yenikapı 6, 7, 8, 9 and 12 belonged to the same tradition of flat-framed hulls as Dor/Tantura, but with a strong influence of the shell tradition due to a specific context (Byzantine shipyards of the Portus Theodosiacus?). In this case, there was a specific branch of this tradition representing a branch of Root 4. Alternatively, the Yenikapı 6, 7, 8, 9 and 12 ships belonged to another tradition of flat-framed ships, similar to the one encountered in the western Mediterranean. This tradition was thus specific to the eastern Mediterranean, and represented another tradition, a fifth root—Root 5—or perhaps it is the eastern branch of the same original tradition as the western one, which represents a branch of Root 1. The answer may be clarified when more information from the Yenikapı becomes available.

In the discussion above regarding St-Gervais 2, the possibility of an external influence was raised. It seems that the shipbuilding traditions in NW Europe have also become of major interest. In the Romano-Celtic era of NW Europe, the group of vessels used in the estuaries and along the coasts (Atlantic, Channel, North Sea) comprises three shipwrecks (McGrail, 2001: 200; 2008: 625–7): Blackfriars 1 (Marsden, 1994; McGrail, 1995), St Peter Port, Guernsey (Rule and Monaghan, 1993), and Barland's Farm, Wales (Nayling and McGrail, 2004), all dated from between the middle of the 2nd century AD to *c*.AD 300. According to McGrail, these vessels were frame-based and built 'framing-first' (McGrail, 1997; 2001: 200; 2008: 626–7). In this perspective, the transition to skeleton could have been under way in NW Europe as early as the 2nd century AD.

However, the design and construction of these Romano-Celtic vessels raise some questions. The vessels were not built 'on keel', but on a flat bottom, which has morphological and structural similarities with 'bottom-based' ('s*ur sole*') hulls. Therefore, the possibility that the vessels were 'bottom-based' to some extent means that the concept of the hull was determined by the bottom planks, and must be considered (Arnold, 1998; Pomey and Rieth, 2005: 174–5). This

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'bottom-based' process of design does not exclude, however, the possibility of a 'proto-frame-based' method of building, as a practical solution, in which some framing elements could be used (Pomey and Rieth, 2005). This construction method would be another possible, but extra-Mediterranean, way to transition. However, some influence of NW European ship construction technology on the Mediterranean methods must be considered.

Another question is raised by the five Romano-Celtic wrecks found on the ancient bank of the Rhine in Mainz, Germany in 1981–82, and dated to the late 4th century AD (Höckmann, 1982; 1997; McGrail, 2001: 204; Bockius, 2006). These river-vessels—oared military craft and state-inspection sailing vessels—are considered to have been designed and built on keel (wreck 5) and keel plank with transverse moulds or templates according to a 'proto-frame-based' so-called "mould construction" method (Bockius, 2006: 191–194; 2009: 86–91). In this possible transverse design of the hull, some temporary moulds could have been used to build the carvel planking before the erection of frames.

So another question arises: was there technological transfer between NW Europe and the Mediterranean in the late Roman era? Historical evidence, according to Procopius (*Bell. Goth*., 4.22.5–17) as interpreted by Lucien Basch (1985: 23–7), confirms the use of a frame-based hull as early as the 6th century. The so-called 'ship of Aeneas' described by Procopius was in a ship-house in the middle of Rome on the bank of the Tiber, and was probably built contemporaneously. In the context of the 'Great Invasions' characterized by significant immigration of the so-called 'Barbarian populations' to the western Mediterranean, the possible influence, or partial transfer, of the NW European native shipbuilding traditions (inland and maritime) to Mediterranean shipyards should be considered. The notoriousVandals had significant maritime experience and numerous fleets in the 5th century. With reference to this complex historical problem, influence, and transfer of technology, the Port Berteau 2 shipwreck should be considered with two main questions in mind.

Firstly, what kind of relations could have existed between the architecture of the Port Berteau 2 wreck and the Romano-Celtic tradition of shipbuilding? In spite of an absence of wrecks dated between the 4th (Barland's Farm) and 7th centuries (Port Berteau 2) in the Atlantic nautical space, an 'architectural memory' or 'influence' of the Romano-Celtic tradition of shipbuilding during the Merovingian period can be hypothesised. From an architectural point of view, no technical rupture seems to have been existed.

Secondly, from the point of view of the transition in construction, how could the historical contexts of the Merovingian wreck of Port Berteau 2 on the Atlantic side, and the possible Merovingian wreck of St-Gervais 2 on the Mediterranean side, be interpreted? Were these isolated processes, or were they related to a possible diffusion from the Atlantic to the Mediterranean? There is no simple answer, as two different ship types are considered: an Atlantic sea-river-vessel with flat floor-timbers—Port Berteau 2—and a Mediterranean sea-going vessel with a wine-glass cross-section—St-Gervais 2. However, regarding St-Gervais 2, due to evolution in the maritime context, in addition to the Graeco-Roman influence, an additional external influence can, on its own, explain the apparent break in the evolution of the transition process of this ship-type in the western Mediterranean. Thus the hypothesis of a Merovingian influence is meaningful, and the link with Port Berteau 2, even if it is not evident, becomes at least indirectly possible. The main characteristics of the different Mediterranean roots are summarized in Table 4.

Conclusions

The transition in ship-construction in the Mediterranean, from the shell concept and construction-method (or strake-oriented) to the skeleton concept and construction-process (or frame-based), appears to be a long and complex evolutionary phenomenon. The linear process, suggested by van Doorninck and Steffy more than 20 years ago, was based on a limited number of shipwrecks from the eastern Mediterranean. Evidently the transition was more complex, comprising several roots. The corpus chosen for this analysis has grown considerably, to 27 shipwrecks, to which may be added the Yenikapı group, which is still under study. Moreover, the present corpus spans chronologically nine centuries (2nd–11th century AD), and extends geographically throughout the eastern, central and western Mediterranean, also including a few shipwrecks from northern Europe. Consequently, it is not surprising that the transition has become more complex, while becoming more accurate and detailed.

Thus, if the evolutionary basis of the mortise-and-tenon, proposed by van Doorninck and Steffy, and recently extended by Pulak, gradually weakening to the point of losing its structural function, remains a decisive and fundamental criterion, it is no longer the only one. The evolution of the framing-system and the longitudinal strengthening components appears quite as significant as the analysis of the architectural system in relation to the morphology of the hull. This last criterion proved to be fundamental in determining and distinguishing the various traditions of construction in which the transition took place.

The transition appears first, naturally, on a chronological scale. It apparently began in the Mediterranean earlier than envisaged. Perhaps its early emergence can be identified in the second half of the 2nd century AD. This is evident, with as yet very partial mixed processes, in the contemporary shipwrecks of St-Gervais 3 and La Bourse. In these hulls belonging to the structural system of the western Roman Imperial type, the internal framing was more important than in the earlier Hellenistic type. At the same period a sort of

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Table 4. *Summary of the characteristics of the suggested roots of the transition in Mediterranean ship-construction*

Root	Origin	Original construction	Date (century AD) of main steps	Evolution	Examples of shipwrecks
1. Western Roman Imperial	Western Roman Imperial type	Shell concept and process. Flat frames, round bilge. Overlapping half-frames, bolted floor timbers, longitudinal components. Tight mortise-and-tenon joints.	2nd to 5th	From shell concept and process to shell concept with partially mixed processes (2nd c. AD); then to entirely mixed concept and process (5th C. AD). Loosening of mortise-and-tenon joints, then unpegged tenons. Strong framing and longitudinal components.	St-Gervais 3, La Bourse Dramont F Fiumicino, Parco di Teodorico
2. Western with Continental influence	Western Hellenistic/ Roman Republican type	Shell concept and process. Wine-glass cross-section, round bilge. Alternating floor-timbers and half-frames. Central longitudinal timbers. Tight mortise-and-tenon joints.	5th to 7th	Late evolution of the framing and longitudinal timber under western Roman Imperial type influence (5th c. AD); then sudden evolution (break) to frame concept and process under possible continental influence (7th c. AD). Disappearance of mortise-and-tenon joints.	Dramont E St-Gervais 2
3. Byzantine	Eastern Hellenistic type	Shell concept and process. Wine-glass cross-section, round bilge. Alternating floor-timbers and half-frames. Central longitudinal timber. Tight mortise-and-tenon joints.	4th to 7th, 9th to 11th	From shell concept and process to shell concept with mixed processes (4th c. AD), to mixed concept and process (7th c. AD), then to frame concept with mixed process (9th c. AD). Loosening of mortise-and-tenon joints until unpegged tenons or coaks.	Yassıada 2 Yassıada 1 Bozburun Yenikapı 3, 16 and 18
4. Eastern Riverine	Riverine/Nilotic tradition (?)	Bottom-based construction (?). Flat floor-timbers, hard chine, rectilinear sides.	End of 5th/ beginning of 6th 10th to 11th	Frame concept and process. Flat floor-timber cross-section with keel, sharp turn of bilge and rectilinear sides. Longitudinal timbers. No mortise-and-tenon joints (or coaks).	Dor/Tantura (Dor 2001/1) Bataiguier, Agay A Serçe Limanı
5. Eastern Flat-Bottomed	Unknown	Flat-bottomed	9th to 11th	Frame concept and mixed process. Flat floor-timbers, hard chine. Coaks.	Yenikapı 6–9, 12
***Or* 5a (?) Eastern Branch of Root 1**	Sub-root of 1	*cf.* Root 1	9th to 11th	As above	Yenikapı 6–9, 12
***Or* 5b (?) Byzantine Riverine**	Sub-root of 4	*cf.* Root 4	9th to 11th	As above	Yenikapı 6–9, 12

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transition to skeleton could have been under way in NW Europe according to the 'proto-frame-based' method of building used in the 'bottom-based' Romano-Celtic shipwrecks.

In addition, the degree of evolution of the transition varied with time and area. It appeared relatively advanced in the central Mediterranean, with the unpegged tenons of the 5th century Parco di Teodorico ship, whereas at the same time the Dramont E vessel, in the western Mediterranean, presented no sign of evolution, and was built according to a shell concept and process. Moreover, the transition was completed barely a century later, at the beginning of the 6th century, in the eastern Mediterranean with Tantura A and Dor 2001/1, which show 'the procedure and character of skeleton-building technique' (Hasslöf, 1972: 41), whereas it would occur only one century later in the western Mediterranean, in the 7th century St-Gervais 2. At the same time, the 7th century Byzantine Yassıada 1 was still built according to a mixed concept and construction-process, and the 9th–11th century Bozburun and Yenikapı 3, 6, 7, 8, 9, 12, 15, 16, and 18 show that the transition was still not totally completed nor adopted. Thus, if the first steps of the evolution appeared precociously, the transition was also completed, in some cases, as early as the 6th–7th century, well before the 11th century Serçe Limanı, which for a long time was considered the hull marking the conclusion of the transition.

The above diversities or even disparities can be explained by the analyses of the construction systems, and of the morphological characteristics of ships' hulls. These analyses allow the definition of various types related to different architectural traditions of various origins. However, within these different traditions, the evolution took place in dissimilar technological backgrounds, and in different historical and environmental contexts. Therefore, the evolution did not progress at the same pace in all areas. In certain cases, the transition could have appeared rapid, whereas in others it could have been accelerated by external influences, and finally, in some other cases, it was slower, and even incomplete. Therefore, examples of mixed concepts or mixed construction-processes, and in a skeleton concept based on frames, frequently coexist.

In the above corpus, at least four evolutionary roots towards the transition, corresponding to four different groups of architectural traditions, can be identified. The first—Root 1—concerns the architectural type termed the western Roman Imperial. This type's midships cross-section was characterized by flat frames, a round turn of the bilge and well-developed internal longitudinal strengthening components. It comprises mainly western Mediterranean shipwrecks. In this type the first indications of the evolution appear with partially-active frames (St-Gervais 3, La Bourse), following a loosening of the mortise-and-tenon arrangement (County Hall, Dramont F), and unpegged tenons (Fiumicino 1, Parco di Teodorico). Thus it developed gradually from the 2nd to the 5th centuries from a shell concept with partially-mixed construction-processes, to an entirely mixed concept and process. This can be identified as the 'western Roman Imperial root'.

However, within this architectural type in the Mediterranean, the evolution was not systematic: Laurons 2 (2nd century) and Pointe de la Luque B (4th century) still testify to traditional practices of construction entirely based on shell, both in the concept and the process. The completion of the transition in this tradition has not yet been clearly established. Perhaps it continued in the eastern Mediterranean with some of the Yenikapı vessels (Yenikapı 6–9, and 12) of the 9th–11th centuries, which were always of mixed construction. One hypothesis, given the location of these shipwrecks, can consider them as the 'eastern branch' of Root 1 (Table 4). This tradition of flat-bottomed hulls could have had a similar parallel in the Atlantic, according to Port Berteau 2 (7th century).

The second root—Root 2—was confined to the western Mediterranean. The architectural type was characterized by a wine-glass cross-section, a round turn of the bilge, and a framing-pattern of alternating floor-timbers and half-frames. This type would have been a late evolution directly from the Hellenistic or Roman Republican type. In the Dramont E wreck (5th century) this type appears to have been influenced by the western Roman Imperial type, from which it borrowed the structure of the internal longitudinal components, based on a massive keelson/mast-step supported on two sister-keelsons. Although the internal structure was strongly reinforced, however, the principle and the method of construction were still of shell concept and process.

Two centuries later, St-Gervais 2 testified within this architectural type to a well-developed stage of the evolution, indicating a practically complete transition, where the concept and process were based on frames. With the influence of the western Roman Imperial type, as demonstrated by the framing-pattern, and in view of the evolutionary context of Root 1, the hull of St-Gervais 2 indicates a sudden evolution, actually a sort of break. In the absence of any milestone it is difficult to explain this change. Therefore, taking the context into account, the assumption of an external influence within Root 2 was raised. The Merovingian wreck Port Berteau 2 could be an indirect reflection, because it belonged to a different type (flat-bottomed), but built on frames. This Root 2 can be termed 'western with Continental influence', or perhaps even be a clue to a connection to the Merovingian culture.

The third root—Root 3—in the eastern Mediterranean, always corresponded to the Hellenistic or Roman Republican architectural tradition, but seems to have had a different evolution. The first evidence of this evolution appeared in Yassıada 2 (4th century) with the recourse to a mixed process within a shell concept. This evolution continued with the Byzantine wreck Yassıada 1 (7th century), where the concept and the process were mixed. Later, in Bozburun (9th century), a mixed process was applied in a frame concept. Yenikapı 3, 16 and 18 (10th–11th century) were similar, whereas the transition was completed elsewhere, in a Byzantine context, particularly in an early form in Yenikapı 17, 22, and 29, and at the same time in Serçe Limanı. Root 3 may be termed the 'Byzantine root' (Table 4).

The fourth root—Root 4—is fully expressed in the Dor/Tantura shipwrecks, specifically in Dor 2001/1. It can be the archetype, with its flat-bottomed cross-section, sharp turn of the bilge, and rectilinear sides. The principle and the method of construction were based on frames. The frames were reinforced by longitudinal strengthening components. This assumes that skeleton construction does not necessarily mean a heavy keelson, and that longitudinal integrity can be achieved using other hull-members. Within this tradition, the transition appears to have been completed at the end of the 5th–beginning of the 6th century AD. This type of construction, resulting from a flat frame construction, probably had a riverine origin, in this case apparently Nilotic. It is possible that the maritime diffusion of this type occurred in an Alexandrian context, where the process of evolution could have developed at an earlier date than the Dor/Tantura shipwrecks. This type diffused thereafter throughout the Mediterranean; westward with the Arab conquests (Bataiguier and Agay A), and eastward into the Byzantine world (Serçe Limanı). This Root 4 may be termed the 'eastern riverine root' (Table 4).

Yenikapı 6–9 and 12 (9th–11th century) were of mixed construction. According to one hypothesis they could have represented a specific branch within this tradition: flat frames amidships, characterized by the use of treenails (coaks) for the pre-assembly of the planking, in a concept of flat frames and skeleton tradition. In this case, it would be a branch of Root 4, termed the 'Byzantine riverine root' (Table 4). Finally, the last hypothesis concerns Yenikapı 6–9 and 12. Assuming they were of a tradition peculiar to the eastern Mediterranean, without relationship to the preceding ones, they would constitute a 5th root, which can be called the 'eastern flat-bottomed root'—Root 5 (Table 4).

This new hypothesis of evolutionary processes with several roots is valid in theory, as well as being feasible. It is based on various clear criteria, and is supported particularly by the architecture, based on the geometry of the hull's cross-section. However, it does not explain all aspects of the problem, and many questions remain open. For example, in Root 2, the Merovingian influence, or more generally the continental influence, which was assumed in the transition process evidenced by the St-Gervais 2 wreck, remains a hypothesis which has to be further examined. According to the different interpretations of the maritime Romano-Celtic tradition of NW Europe, the transition in these regions had been completed or was under way as early as the 2nd century AD, long before it occurred in the Mediterranean. Similarly, in Root 4, the process of evolution and the suggested hypothetical role of Alexandria according to the Nilotic origin, also deserve further research. Finally, Yenikapı 6–9 and 12 need further research in order to identify their tradition and to confirm or refute the hypotheses suggested about them.

Another field of questions remains the relations and the interactions which could exist between these various roots. Above all, a major difficulty or even impossibility, with rare exceptions, is to locate precisely the places of construction and origin of shipwrecks. To overcome this difficulty, a large geographical area has been proposed for each ship, taking into account the specific areas of navigation. This, however, does not rule out errors, which may put certain classifications into question. As it is quite impossible to identify the places of construction and origin of shipwrecks, we do not know the locations of each root. Therefore, there remains hope that new discoveries—with the present exceptional richness of Yenikapı—will enlarge the corpus of shipwrecks for study. This new hypothesis will be refined, developed and corrected. In this respect, the contributions of dendrochronology and tree-species identification may be fundamental to the determination of the origin of timbers, and consequently of areas or even places of construction (for example the dendrochronological programme of the ancient shipwrecks of the French Mediterranean coast, Guibal and Pomey, 2009). Finally, as is underlined in the introduction, it remains to relate these various architectural traditions to precise historical, economic, and social contexts, and to evaluate their consequences.

Undoubtedly it remains accepted that the transition in construction from shell construction to skeleton construction was a long and complex process, implementing various technical solutions with advances, regressions, and failures. It was a non-linear process lasting several centuries, probably starting from several different origins throughout the Mediterranean basin, each one undoubtedly evolving at different levels and contexts. Let us hope that these new explanations of the transition reflect at least a part of the truth of this long process, and will lead to new research.

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