

Ma'agan Mikhael B, Israel: a preliminary report of a Late Byzantine–Early Islamic period shipwreck

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The Ma'agan Mikhael B shipwreck was found in 1.5m of water, beneath 1.5m of sand, 70m off the Mediterranean coast of Israel. The hull remains are in a good state of preservation, comprising the endposts, aprons, framing timbers, hull planks, stringers, and bulkheads. The finds comprise rigging elements, wooden artefacts, organic finds, animal bones, glassware, coins, bricks, stones, ceramic sherds, and complete amphoras. The shipwreck was dated to the 7th–8th centuries AD; which makes it an exceptional source of information regarding various aspects of ship construction, seamanship, and seafaring in the area in Late Antiquity.

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During the second half of the 1st millennium AD, a fundamental change occurred in shipbuilding methods—the transition from ‘shell-first’ to ‘frame-based’ construction. How, why and when this process of ‘transition in ship construction’ happened, has been one of the main issues in the history of shipbuilding for over 70 years (Pomey *et al.*, 2012). Therefore, each shipwreck of this period can provide valuable new insights into this process.

Kibbutz Ma'agan Mikhael is located on the Mediterranean coast of Israel, about 35km south of Haifa (Fig. 1). In 1985 the site became known as a result of the discovery of the 400 BC Ma'agan Mikhael shipwreck (Linder, 2003; Kahanov, 2011a). At a distance of about 150m south of the Ma'agan Mikhael shipwreck, the naturally exposed remains of another wooden ship were discovered in 2005 by two kibbutz members returning from a recreational dive. They reported seeing framing timbers, ceramic sherds, and stones. The location was verified by a sub-bottom profiler survey conducted in 2015, and consequently, a water-jetting survey was conducted in August of the same year. The water-jetting survey exposed wooden fragments of two different tree species, a 180mm-long piece of rope, and a pine cone. The shipwreck was designated as Ma'agan Mikhael B (Cvikel *et al.*, 2017).

A single wooden fragment and a sample of the rope were dated by ¹⁴C AMS analysis to the range 650–885 AD, which includes the late Byzantine and early Islamic periods in the region. This preliminary dating of the Ma'agan Mikhael B shipwreck was a strong incentive to excavate the shipwreck to evaluate

its significance in the period of transition in ship construction.

The underwater excavations

Three underwater excavation seasons were conducted in May and December 2016 and September 2017 by the Leon Recanati Institute for Maritime Studies of the University of Haifa. The shipwreck is located about 70m off the shoreline, at 32°33'18.7"N; 34°54'16.1"E, in 1.5m of water, buried under 1.5m of sand. Excavation at the site is challenging due to a small island that creates a disturbed sea at the meeting point between the offshore (south-west) current and a local (north-west) current in all but calm weather. Of 44 potential excavation days, work was possible on only 21 days.

The shipwreck is 19.6m long between its extremities, and maximum 4.9m wide. Its longitudinal axis is on compass bearing 110°–290°. Among the hull remains, which are in a good state of preservation, are endposts, aprons, framing timbers, hull planks, stringers, and bulkheads (Fig. 2): the keel has not yet been exposed. At this stage it is too early to determine which end is the bow and which is the stern of the ship. All wood species were identified by S. Wicha, at Archéobois, Marseilles.

The hull and its nearby surroundings contained a wide variety of finds: rigging elements, wooden artefacts, glassware, copper-lead alloy coins, bricks, stones, and ceramic ware, sherds and complete amphoras, and organic finds such as food remains, rope, and animal bones. The finds were documented on site, and after careful consideration, some were retrieved for further study.

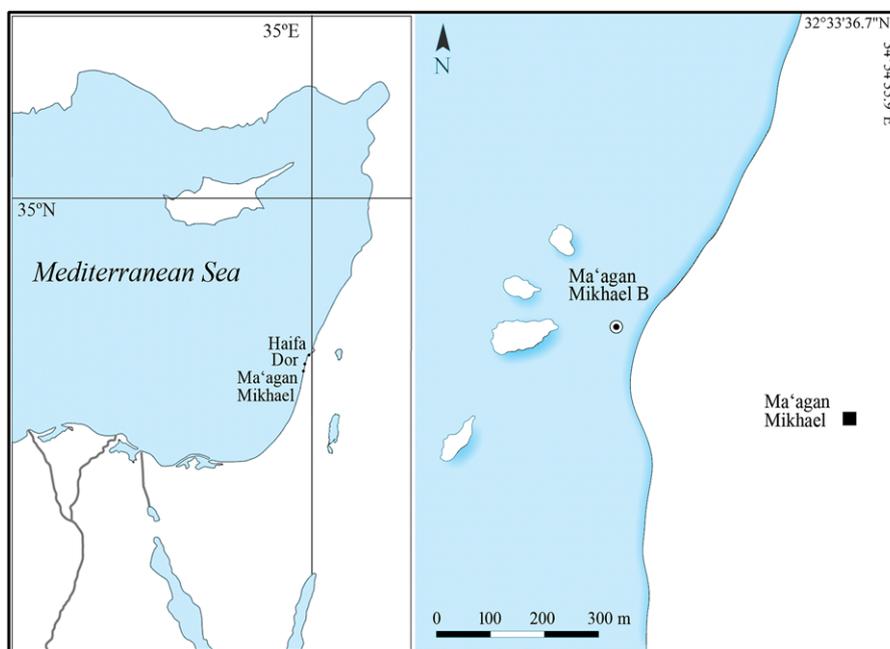


Figure 1. Location of Ma'agan Mikhael and the Ma'agan Mikhael B shipwreck site (Drawing: N. Yoselevich).

The hull remains

The endposts

The two endposts of the ship survived at its eastern and western ends. The eastern endpost is composed of two timbers connected by an elaborate scarf that resembles the *trait de Jupiter* (complex keyed hook scarf) (Fig. 3a–b), an example of which was found in the Roman period Grado shipwreck (Beltrame and Gaddi, 2007: 138), the Tantura F shipwreck (Barkai and Kahanov, 2016: 8), and Yenikapı 12 (Özsait-Kocabaş, 2018: 360). Traces of iron concretion show that the scarf was also fastened by iron nails.

The upper timber of the eastern endpost, which was broken at the top, survived to a length of 360mm, and is made of *Pinus halepensis* or *Pinus brutia* (Aleppo pine or Turkish pine). It is maximum 125mm sided (minimum 90mm) and typically 235mm moulded. The lower timber, 1.50m of which was exposed, is made of *Juglans regia* (walnut). Similarly to the upper timber, it is typically 125mm sided and 235mm moulded.

The upper timber of the western endpost is missing. The lower timber, of *Juglans regia*, was exposed to a length of 224mm (Fig. 3c). This timber is 130mm sided and moulded 119mm at the lowest exposed point, tapering to 100mm at the top end.

The aprons

Timbers attached to each endpost appear to be aprons (Steffy, 1994: 267). Although their relation to the keel is as yet unknown, these timbers were definitely internal reinforcements. The eastern apron (Fig. 4a), made of *Juglans regia*, exposed to a length of 400mm, was typically 240mm sided and 220mm moulded. It was

bolted to the endpost. The western apron (Fig. 4b), also of *Juglans regia*, was exposed to a length of 490mm. It seems to have an almost round cross-section of 80mm diameter. On its eastern side (facing the interior of the hull) a large concretion was visible, perhaps indicating its fastening to the endpost.

The framing timbers

During the excavations, 56 framing timbers were exposed on the southern side of the hull (Fig. 5a), and 63 on its northern side, comprising at least 30 frame-stations. The frames were made of *Juglans regia*, except for two (F96 and F121), which were made of *Quercus ilex* (holly oak) and *Abies* sp. (fir) respectively. Both exceptional frames were found on the southern side of the hull, perhaps being repairs. The framing timbers have various cross-sections—some made of partially worked thick branches, others being trapezoidal or rectangular (Fig. 5b–c). The faces that were connected to an adjacent frame or to a hull plank were carefully worked, and on some timbers tool marks are visible, possibly of an adze (Fig. 5c). In a few places remains of bark were found, as well as evidence of sealing material.

The framing timbers were exposed to a length of about 1m, and it was noticeable that their moulded dimension increased with depth. The timbers are 50–230mm sided, with an average of 133mm, and 95–145mm moulded, averaging 123mm. The average room and space, measured at the top of the exposed frames, is 440mm. The western face of three abutting frames is 9.24m from the eastern endpost. The rigging elements were found nearby, perhaps indicating the location of the mast step.

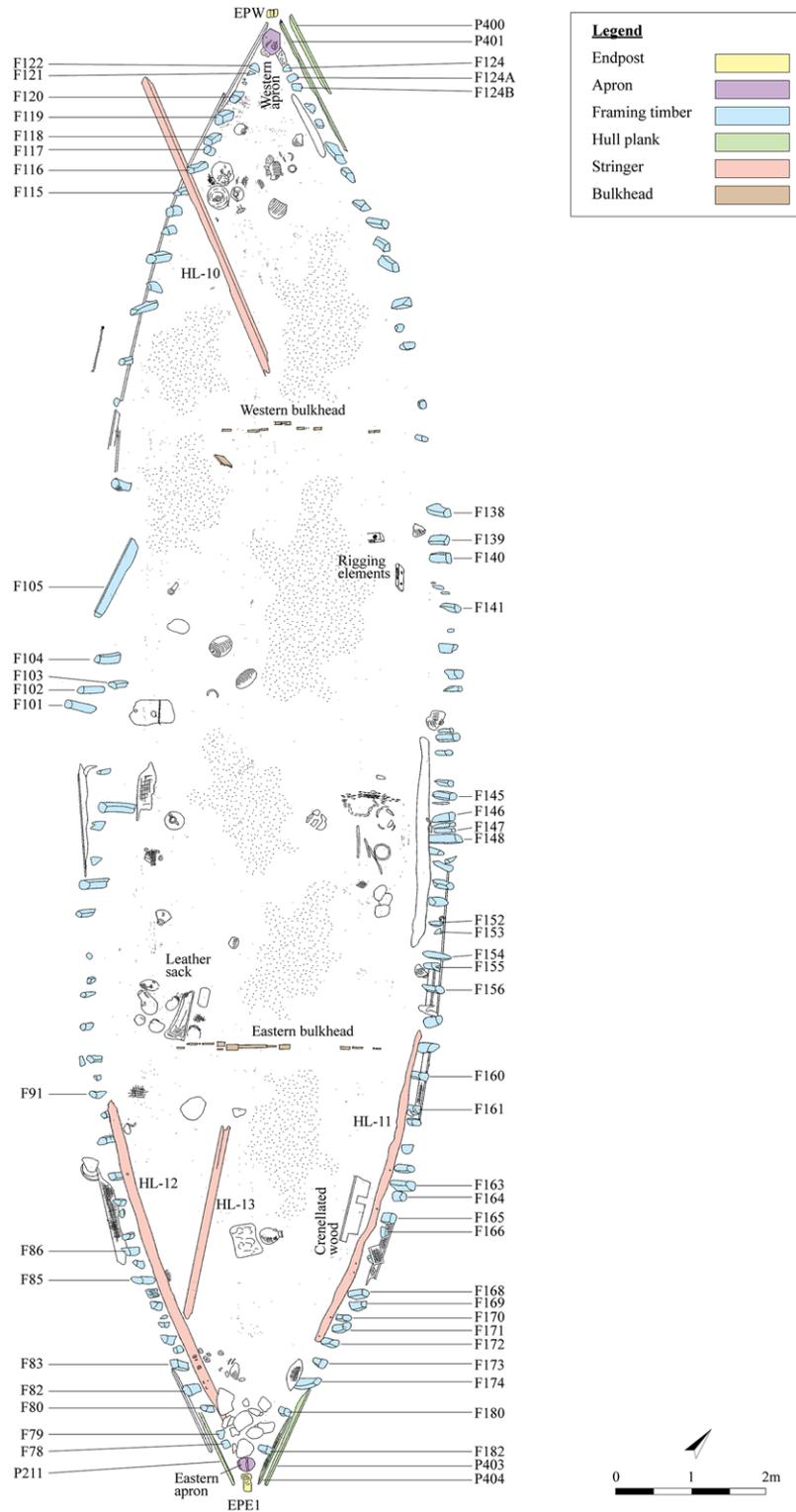


Figure 2. Plan of the Ma'agan Mikhael B shipwreck (Drawing: P. Sibella, adapted by K. Asuli).

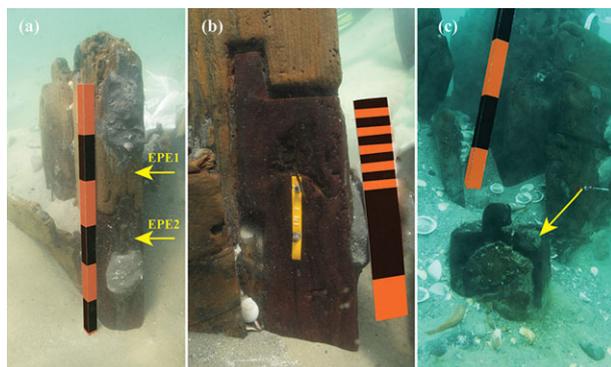


Figure 3. The endposts: *a*) the eastern endpost looking west; *b*) a closer view of the scarf looking north; and *c*) the lower timber of the western endpost (yellow arrow) (Photos: A. Yurman).

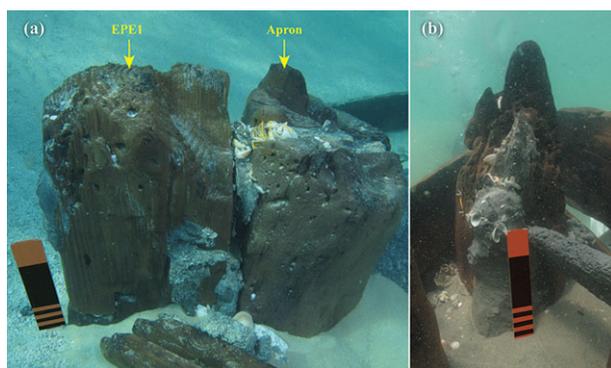


Figure 4. The aprons: *a*) the eastern apron looking south; and *b*) the western apron looking west (Photos: A. Yurman).

The hull planks

Thirteen hull planks were exposed on the southern side of the shipwreck and three on the northern side (Fig. 6a). Six hull planks were documented and studied. They were made of *Abies* sp., which is easily sawn, making it suitable for plank production (Giachi *et al.*, 2003: 275). The longest measured plank is 1.88m, but other planks are longer and were not fully exposed. On average the hull planks are 176mm wide (maximum 280mm) and 31.5mm thick (maximum 42mm). In addition, a cross is incised in a plank at the northern side of the hull. It is similar to the three marks found in the Dor 2006 shipwreck (Navri *et al.*, 2013: 311). It seems that two iron nails were used to connect each hull plank to each framing timber. A single butt-joint was found near the eastern end of the hull, with traces of two iron nails on each side.

Closer to the two endposts, planks have scorch marks on their inner surface (Fig. 6b), which might indicate bending through a heating process, known as 'char-bending' (Greenhill, 1957: 115; de Zeeuw, 1967: 154). Similar char-bending traces were also found in Dor shipwrecks (Dor D, Tantura A, Dor 2001/1, Dor 2006, Tantura F, Tantura E) and in Yenikapı (YK 1, YK 3, YK 5, YK 11, YK 14, YK 17, YK 23) (Wachsmann

et al., 1997: 6; Steffy, 1999: 403; Kahanov *et al.*, 2004: 118; Kocabaş, 2008: 163, 171; Türkmenoğlu, 2012; Kahanov and Mor, 2014: 49, 51; Jones, 2017: 261; Ingram, 2018: 115).

The stringers

On the north and south-eastern sides of the hull, three timbers made of half-logs of *Abies* were accessible for documentation. The maximum length measured was 4.94m, but one of these timbers continued well into the sand, and two were broken. They were on average 183mm wide and 100mm thick. One of these timbers on the south-eastern side (HL-13) was considerably narrower, at 135mm wide. Scorch marks were visible on their worked faces; and tool marks, apparently of an adze, were especially apparent on the chamfered edge near the eastern endpost. On the round face, facing the interior of the hull, were remnants of branches, most probably removed using an axe (Meiggs, 1982: 332), and a thick layer of sealing material (Fig. 7a). Because of their location and shape (half-logs), it can be postulated with caution that these timbers served as clamps or stringers, providing longitudinal reinforcement to the hull (Steffy, 1994: 269; Kocabaş, 2015: 33).

The stringers were nailed to the frames from the inside of the hull using iron fasteners (see Fasteners below). Evidence for the use of a drill can be seen in the nail holes (Fig. 7b). The stringer on the south-eastern side of the hull (HL-12), has two Greek letters, Π (Pi) and Μ (Mu), (Fig. 8a); and three unidentified letters or symbols (Fig. 8b) cut into it. The purpose of these marks is not known; perhaps they are initials of the carpenters, or shipwrights, or crew members.

Another stringer, 3.9m in length, was recorded on the south-western side of the hull. It also extends into the sand, and seems to have been displaced during the wrecking event. It is on average 242mm wide and 90–110mm thick.

The bulkheads

There are two sets of transverse vertical planks inside the hull, assumed to be bulkheads (Fig. 2). The eastern bulkhead is located 13.8m from the western apron, and the western bulkhead is at a distance of 5.5m from the western apron. These measurements were taken from the inboard face of the top of the apron. The planks comprising the bulkheads were exposed to a maximum length of 0.54m, but are longer. They are on average 149mm wide and 36mm thick. The planks composing the western bulkhead and those of the eastern bulkhead have not yet been identified. The bulkheads created separate compartments on the ship (Steffy, 1994: 268); the cargo hold and spaces for storing equipment.

Fasteners

The fasteners used in the construction of the ship were square cross-section iron nails and bolts. The appearance of concretions, and the fact that very little remains of the metal, indicate the use of iron

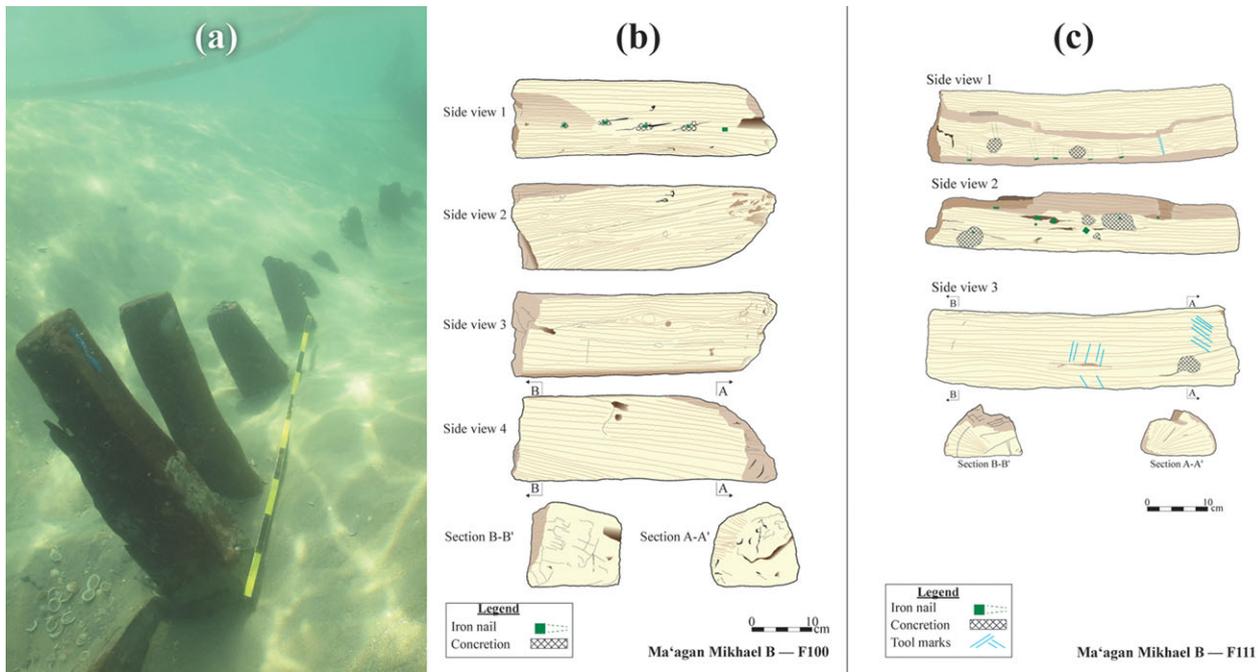


Figure 5. Framing timbers: a) on the southern side of the hull (Photo: A. Yurman); b) a section of framing timber F100, rectangular cross-section; and c) a section of framing timber F111, made from a partially worked thick branch (Drawings: K. Asuli).

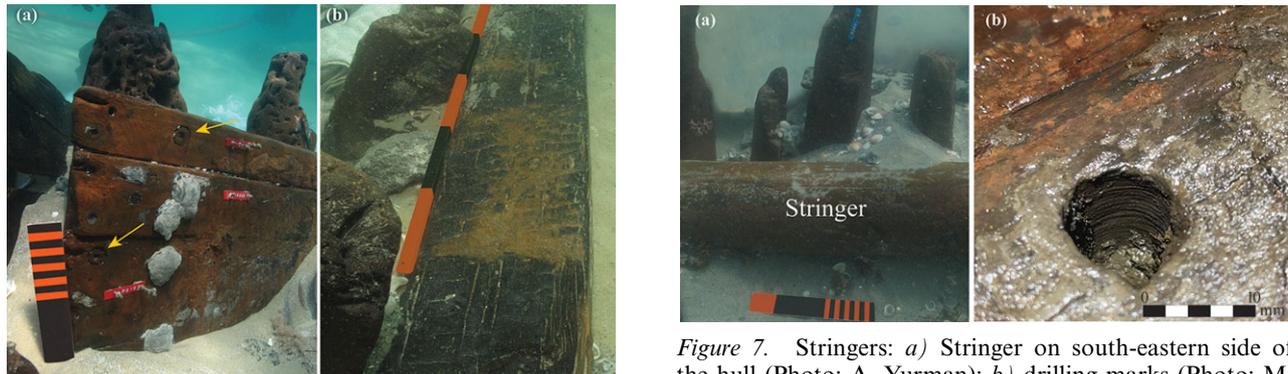


Figure 6. Hull planks: a) planks on the south-western side of the hull. The arrows indicate the imprint of the nail heads; and b) scorch marks (Photos: A. Yurman).

Figure 7. Stringers: a) Stringer on south-eastern side of the hull (Photo: A. Yurman); b) drilling marks (Photo: M. Cohen).

nails. Chemical analysis of three nail remains using X-ray fluorescence, confirmed that it was iron (Fe 94.4 wt%). The nail remains could be seen as holes in the timbers—indicating the past presence of a nail; or as concretions containing black paste (iron sulphide corrosion products). Corrosion of underwater archaeological iron objects is common, and is caused by biological and electrochemical processes (North *et al.*, 1976: 192; Ashkenazi *et al.*, 2016: 228).

The upper timber of the eastern endpost has three square nail holes on its southern face, with an average cross-section of 10mm. On its eastern face (towards the inside of the hull), a 250mm-long iron nail concretion

was visible. On the lower timber eastern face was another 150mm-long iron nail concretion (Fig. 3a).

The eastern apron was fastened to the endpost by an iron bolt with a square cross-section of 25 × 25mm. Considering the moulded dimensions of the apron (230mm) and the endpost (220mm), this bolt would have been about 350mm long (Fig. 4a). The western apron was apparently fastened to the western endpost by a similar bolt, as suggested by a 200mm-long iron concretion that was found on its eastern face (Fig. 4b).

The hull planks were connected to the frames using square cross-section iron nails—the round imprint of their heads can be seen on the wood (Fig. 6a). The nail heads have an average diameter of 15.6mm (maximum 16mm), and the average inner cross-section is 4.3mm



Figure 8. Stringer HL-12: a) incised Greek letters Pi and Mu; and b) unidentified markings (Photos: A. Yurman).

(maximum 9mm). The average distance, measured centre-to-centre, between the nails is 220mm; however, no clear nailing pattern was discerned. The nails are driven from the outside and into the outer worked face of the frames. These nails would have had a maximum length of 95mm, based on the average thickness of the hull planks (32mm) and the average moulded dimension of the frames (123mm). So far, no evidence of edge-fasteners has been detected.

The stringers were fastened to the frames from the inside, using iron nails of 10.5×12 mm cross-section, with a typical head diameter of 32.5mm. These nails would have been about 160mm long on average, based on the average thickness of the stringers (100mm) and the average moulded dimension of the frames (123mm).

Rigging elements and ropes

Two wooden rigging elements, apparently turning blocks, similar in size and shape, were found amidships (Fig. 9a–c, Table 1). Both have a rectangular cross-section with chamfered edges and show evidence of tool marks. A similar block was found on the Yenikapı 35 shipwreck (Kızıltan, 2013: 189, object 207). Traces of rope friction and abrasion appear in the transverse holes in the blocks. The remains of a 161mm-long rope were found in block 238 adjacent to the sheave. The rope is 34.9mm in diameter, Z-twisted, and composed of three strands (12.3mm average diameter). Theoretically, based on an 18th-century equation, it is too thick to be used with a 26mm-thick sheave (Marquardt, 2003: 248); however, the rope is waterlogged, causing it to swell. No rope remains were found in block 237. Considering the area in which the blocks were found, it is possible that they were part of the rigging of the mainmast.

In addition to the rope remains in one of the blocks, five well-preserved ropes of various lengths were found in the shipwreck. Two ropes were found near the rigging elements, and it is suggested they were part of the running rigging. All but one of the ropes were three

Z-twisted strands with an average diameter of 33mm, the other was made of two strands (Fig. 9d). The fibres of the ropes were identified as hemp, coir, and bast (unidentifiable species) (Rast-Eicher, 2016; 2018). The earliest use of the hemp plant seems to have been for fibre, as it is strong and well suited for cordage and cloth used on ships. During the Roman period it was imported from Asia Minor, present-day Iraq, and Georgia (Kirby, 1963: 47; Clarke, 2013: 135, 160–161). Coir is known for its flexibility and lightness, and a rope made from this material floats when wet (Nash, 2002: 49). A rope from the Dor 2006 shipwreck was also made of tree bast, most probably of a coniferous species (Navri *et al.*, 2013: 315).

The finds

A variety of items was found during the excavations, comprising wooden, organic, ceramic, metal objects, and stones. The finds were documented on site, retrieved, registered, and are being studied.

Wooden artefacts

The wooden artefacts included some pieces of charcoal found near the eastern bulkhead and identified as *Juglans regia*, a roundel, and an unidentified worked object (Fig. 10a–b). The roundel was found between framing timbers F118 and F119. It is 104mm in diameter, and average 38mm thick. A single 1.5mm recess is carved 17mm from its outer perimeter. Three concentric circles are incised into one of its flat sides. At the centre of this side is a small notch, 4mm in diameter, and 1.5mm deep. On the other flat side are tool marks, possibly of a saw. In addition, there are three small holes, 1.3mm in diameter and 0.7mm deep, placed in a triangle. These holes indicate the use of a lathe (Fig. 10a). Parallels to this roundel were found in the Dor 2006 shipwreck (Navri *et al.*, 2013: 314).

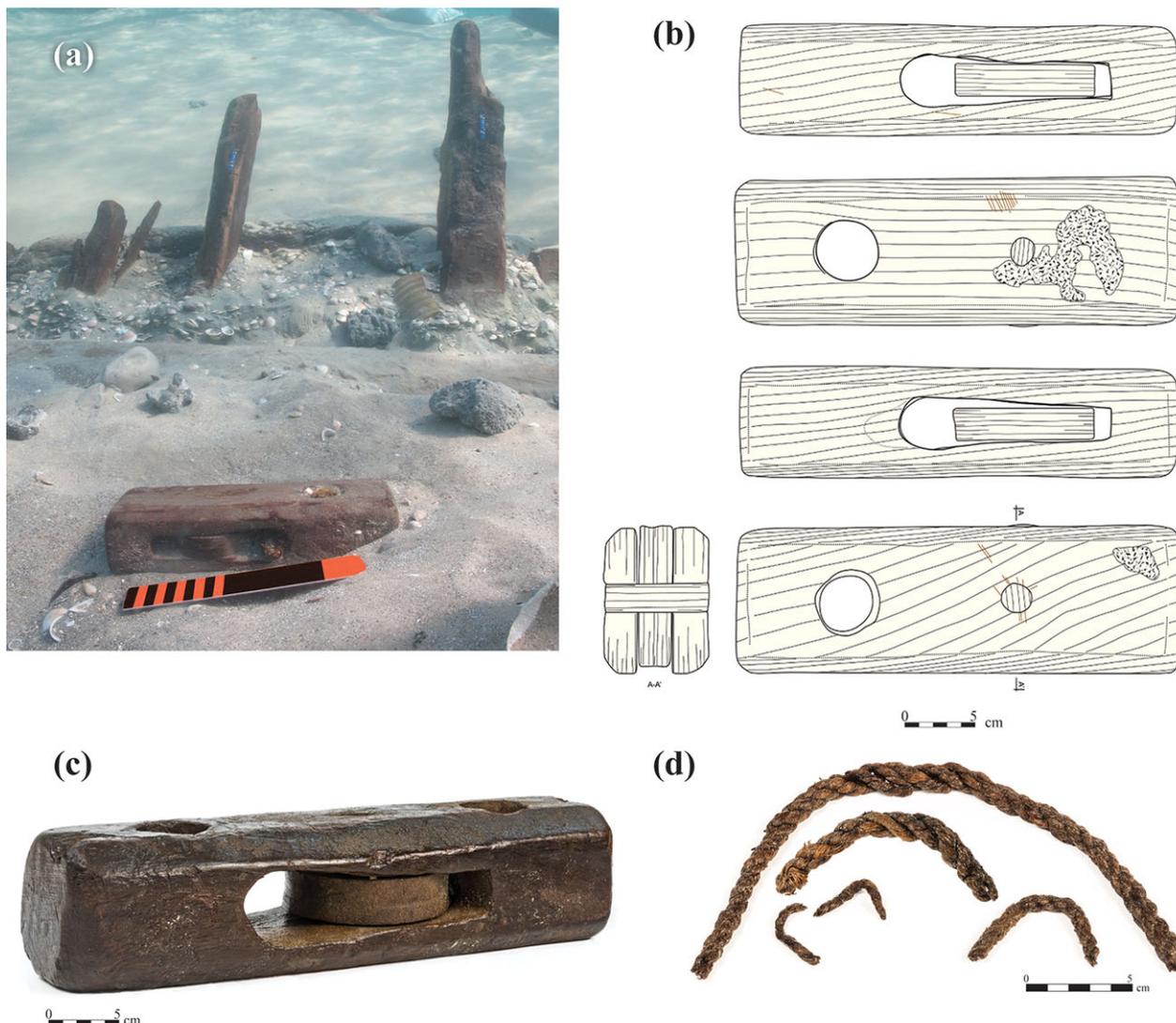


Figure 9. Rigging elements: a) Block 238 with rope remains as found *in situ* (Photo: A. Yurman); b) Block 237 (Drawing: S. Haad); c) Block 238 in the conservation laboratory, after the removal of the rope (Photo: A. Efremov); and d) assortment of ropes (Photo: A. Efremov).

Table 1. Rigging elements (dimensions in mm)

Artefact no.	Total length	Average width	Average thickness	Hole, average diameter	2nd hole, average diameter	Pin, average diameter	Sheave, diameter	Sheave, average thickness
237	360	102	84.98	44.52	42.39	21.03	~100	28.53
238	310	105	80.26	43.22	–	21.11	~100	26.09

The worked object was found at the western extremity of the hull, next to the apron. Its length is 200mm, and its maximum width 37mm, tapering to 15mm. Its maximum thickness is 31mm, tapering to 14mm. One side has a 121mm-long rabbet that contains two semi-circular holes: their diameter is 9.5×11 mm on average (Fig. 10b). The use of this wooden object is still undetermined.

Organic finds

Organic finds are typically divided into two groups: food remains and artefacts. The food remains, which may hint at various aspects of daily life aboard a ship of this period, consisted of well-preserved olive pits, walnuts, grape seeds, peach stones, carob pods, and pine cones (Fig. 11a–b). These were found in large quantities, some inside or near the amphoras. The olives

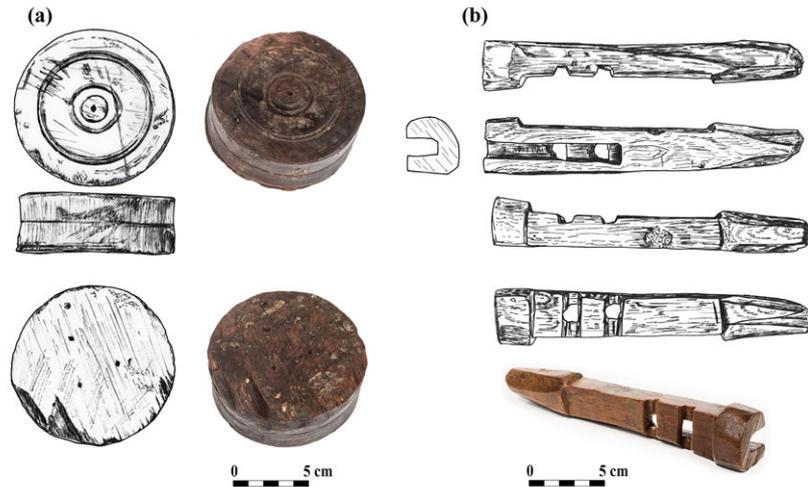


Figure 10. a) Wooden roundel; and b) worked wooden object (Photos: A. Efremov, drawings: R. Pollak).



Figure 11. Food remains: a) olive pits, walnuts, grape seeds, peach stones and carob pods (Photo: A. Efremov); and b) pine cones as found *in situ* (Photo: A. Yurman).

were identified as *Nabali* (Kislev and Simchoni, 2017), which were common in the central mountains of Israel, and mostly known pickled.

Nuts are commonly collected in autumn, and remain edible up to a year if kept dry and cool. Nuts are rich in fats, protein, carbohydrate, and minerals, especially iron and calcium. Both nuts and olives are sources of oil (Renfrew, 1973: 194–196). It cannot be ruled out that they were part of the crew's diet.

The grapes were identified as *Vitis vinifera*, which is a species of European origin. A few grape skins were found along with the seeds suggesting that these were either fresh grapes or raisins, but less likely wine. Depending on the region, grapes are harvested generally between August and mid-November in the Mediterranean (Thurmond, 2006: 117).

Peaches can be eaten fresh or dried. Dried fruits were hand-processed, and some pits may remain with the fruit; however, dried fruits were usually pitted so the stones most probably came from fresh fruit (Ward, 2004: 501; Sánchez-Mata and Morales, 2016:

27). Peaches are generally ripe in summer–autumn in the area of study (pers. comm. Simchoni, 2018).

The carob matures in July and August, and the fruits are picked from September to November; however, the carob can be preserved for a long time. Based on the size of carobs found in the shipwreck, they were from cultured trees (pers. comm. Kislev and Simchoni, 2017). Carobs and olive pits were also found in Tantura F shipwreck, which dates to the mid-7th–end of 8th century AD (Barkai and Kahanov, 2016: 23).

The pine cones were identified as *Pinus pinea*, the stone or umbrella pine (Kislev and Simchoni, 2017; Wicha, 2017). They are known for their edible nuts and use at temple altars, notably in the Roman period (Meiggs, 1982: 44; Kislev, 1988: 73, 75). Since the pine cones were found arranged among the amphoras inside the hull, it is suggested that they were used as dunnage, as seen on the 1st-century-BC Madrague de Giens shipwreck (Frost, 2011: 196).

The artefacts included matting, a leather sack, and animal bones (Fig. 12a–c). Several pieces of matting

were used for padding the amphoras. Ten samples were collected and identified as *Arundo donax*, *Juncus acutus* and *Desmostachya bipinnata* (Wicha, 2017; Rast-Eicher, 2018). Fragments of matting were also found in the Dor 2001/1 (Kahanov and Mor, 2014: 60) and the Dor 2006 (Navri *et al.*, 2013: 313) shipwrecks, but the species of the fibres were unidentifiable. The matting seems to have been plaited. The plaits could be made separately, and then sewn into the required shape (Crowfoot, 1954: 417). The leather sack is about 700mm long and 450mm wide at its base. From the pore pattern it appears to have been made of a goat skin. The hair on the hide is typical of a water skin (pers. comm. Volken, 2017).

The animal bone remains were found in different areas of the ship, but mostly concentrated amidships. Among the bones were a tibia, a femur, and the pelvis of a caprine; two mandibles and a maxilla belonging



Figure 12. Organic artefacts: *a*) fragment of matting (Photo: A. Efremov); *b*) leather sack as found *in situ* (Photo: A. Yurman); and *c*) an assemblage of animal bones (Photo: A. Efremov).

to a pigeon; a maxilla of a chicken; a sea turtle shell and girdle fragments; and a tortoise shell. The birds and caprine bones most probably represent food refuse; the upper hind quarter elements are thought to have been consumed on board as a complete portion. The sea turtle and tortoise remains may also indicate food consumption (Marom, 2018).

Ceramic ware, bricks, and stones

An assemblage of 38 complete amphoras was uncovered, and many sherds were recovered. The majority of the ceramics were located amidships, while some were found in the easternmost and westernmost areas of the ship separated by the bulkheads. The amphoras were laid on matting, and many pieces of dunnage (*Quercus ilex*) were packed between them. The dunnage consisted of sticks and twigs of various sizes—up to 0.50m long and the pine cones discussed above. Typological studies of the amphoras have identified at least five types of maritime transport jars, including Late Roman Amphora Types 1, 2, 4, and 5 (Fig. 13a–b). Some had *dipinto* decoration, Greek, Arabic, and Christian symbols.

Six of the complete amphoras, a cooking-pot lid, and a few bowls of Cypriot Red Slip type, along with the ceramic sherds, were retrieved for further study, and are undergoing treatment at the conservation laboratory of the Leon Recanati Institute for Maritime Studies at the University of Haifa. Petrographic analysis of thin section samples from the ceramics suggest origins of the clay in Cyprus, Turkey or the northern Levant, and Egypt (pers. comm. Goren, 2018).

Two clay bricks, reddish brown and red coloured (Munsell 5YR 4/4 and 2.5YR 5/6), were discovered near the eastern bulkhead (Fig. 14a). Both have charring marks, suggesting that they were part of the ship's cooking stove. One brick is elliptical, 140mm long and

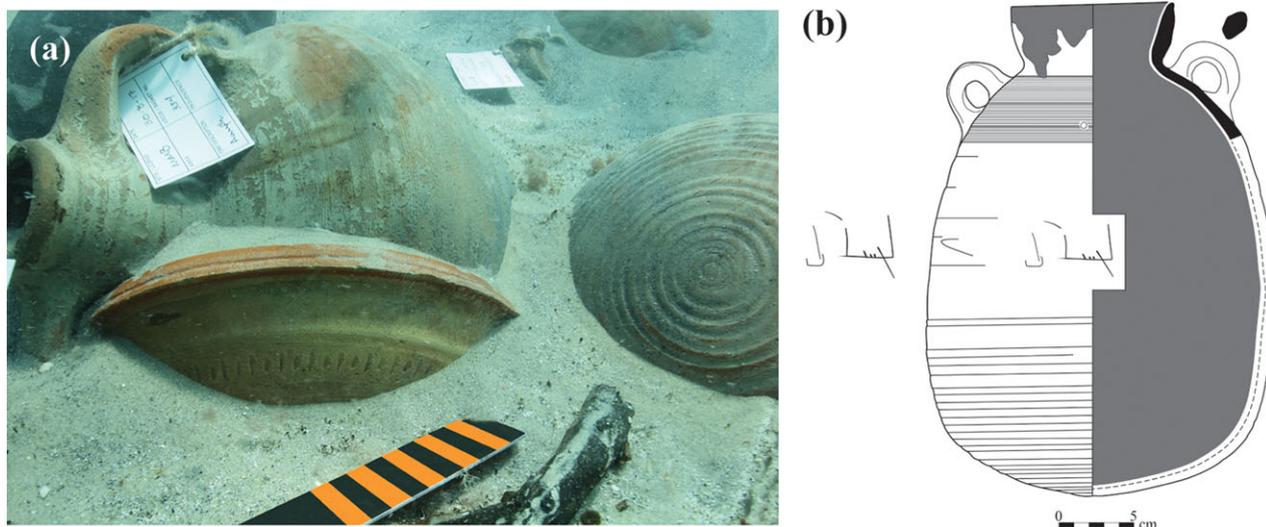


Figure 13. *a*) A Late Roman 1 amphora and a Cypriot Red Slip bowl (Photo: A. Yurman); and *b*) Late Roman 5 with an Arabic inscription (Drawing: S. Haad).

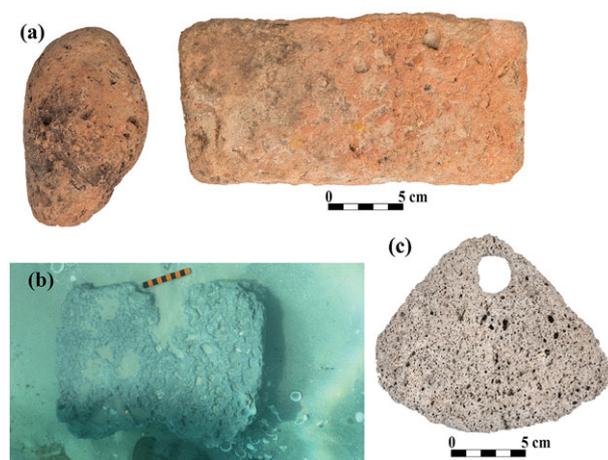


Figure 14. a) The clay bricks (Photo: A. Efremov); b) the hewn stone as found *in situ* (Photo: A. Yurman); and c) triangular perforated stone (Photo: A. Efremov).

90mm wide, and the other is rectangular, 230mm long, 110mm wide, and 53mm thick. Similar burnt bricks, often associated with cooking installations, have been found in other shipwrecks of the period: Dor 2006 (Barkan *et al.*, 2013: 130), Cefalù (Parker, 1992: 137), and Tantara E (Israeli and Kahanov, 2014: 380–381). Petrography of the rectangular brick revealed the origin of the clay to have been in Cyprus or the northern Levant (pers. comm. Goren, 2018).

The stones in the shipwreck were concentrated in its eastern extremity (Fig. 2). They varied in size and weight, and most probably were used as ballast. Preliminary evaluation suggests the stones were not of local origin, but this needs to be studied further. Among the stones, two were specifically noted: a hewn stone approximately 250 × 400mm, which was located near the eastern endpost (Fig. 14b), and a piece of limestone, which stood out due to its white colour (Munsell 2.5Y 8/1). Petrography of the two stones revealed their origin to have been in Cyprus or the northern Levant (pers. comm. Goren, 2018). A triangular perforated stone was found at the western extremity of the shipwreck. It weighs 492g, and is 135mm long, 160mm wide, and 31mm thick on average, with a hole 23 × 27mm (Fig. 14c). Although it is relatively small, it could have been used as a stone fishing sinker (Galili *et al.*, 2002: 183, 191–192), or perhaps as a weight in the rope production process, as suggested by Bohr and Olsen (2011: 1).

Glass and coins

Several glass fragments of unidentified use were found concentrated west of the eastern bulkhead. Among these finds, the 160mm-long neck of a glass bottle was discovered next to the leather sack. The bottle is made of bluish-green glass with a simple rounded rim. Based on its shape, it was part of a small bottle, perhaps containing a precious liquid (Fig. 15a). It is suggested

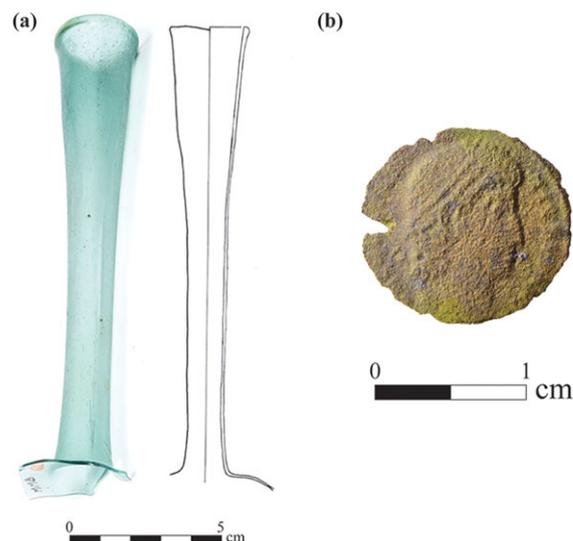


Figure 15. a) long neck of a glass bottle (Photo: A. Efremov, Drawing: R. Pollak); and b) a copper-lead alloy coin with the portrait of Constantine I (Photo: J. J. Gottlieb).

that the shape and quality of the bottle point to local production in the region during the late Byzantine and Early Umayyad period (pers. comm. Gorin-Rosen, 2018).

Seven copper-lead alloy coins were discovered in the north-western section of the shipwreck and retrieved for study. The average diameter of the coins was 14.4mm, their average thickness was 1.6mm, and their average weight was 1.07g. Four were identifiable, while the rest were completely corroded. Based on the portraits of Constantine I (Fig. 15b), the coins were dated to the mid-4th century AD (Late Roman period). These coins constituted small change in circulation during the 4th, 5th, and even 6th centuries AD. In some cases, they can also be found in contexts of the 7th century AD (Cohen *et al.*, 2018).

Tree species

More than a 100 wood samples were taken from various hull components for analysis, and five tree species were identified (Table 2). *Juglans regia* (82%) and *Abies* sp. (15%) are the dominant species used in building the hull. The framing timbers were made of hardwood, mainly *Juglans regia*, with a single frame timber made of *Quercus ilex*, and one of softwood *Abies* sp. These two timbers may be repairs, but this requires further investigation. The possible geographical distributions of the different tree species are given in Table 3.

Most of the tree species grow in the Levant and Turkey, and it is possible that the Ma'agan Mikhael B was built in a shipyard located in the eastern part of the Mediterranean. However, it is also possible that the wood was imported, which was a common practice in Antiquity (Meiggs, 1982: 335–336; Ward, 2009).

Table 2. Tree species used in the Ma'agan Mikhael B shipwreck

	Tree species	Eastern endpost	Western endpost	Aprons	Framing timbers	Hull planks	Stringers	Total	Total (%)	
Hardwood	<i>Juglans regia</i>	1	1	2	101	–	–	105	82.7	83.5
	<i>Quercus ilex</i>	–	–	–	1	–	–	1	0.8	
Softwood	<i>Pinus halepensis</i>	1	–	–	–	–	–	1	0.8	16.5
	<i>Pinus brutia</i>	1	–	–	–	–	–	1	0.8	
	<i>Abies</i>	–	–	–	1	14	4	19	14.9	
Total		3	1	2	103	14	4	127	100	100

Table 3. Geographical distribution of the tree species used in the hull (Data based on Renfrew, 1973; Steffy, 1994; Davis, 2008)

	Pinus halepensis	Pinus brutia	Juglans regia	Abies	Quercus ilex
Balkans	–	–	+	–	+
Caucasus	–	+	+	+	–
Eastern Aegean islands	+	+	+	–	+
Greece (mainland)	+	–	–	+	+
Levant (Syria, Lebanon, and Israel)	+	+	+	+	–
Mediterranean Europe	+	+	–	–	+
Turkey	+	+	+	+	+
Other	+	+	+	–	+

Dating

Eleven wood and organic samples, including short-lived materials such as food remains, ropes, and matting, were sent to the Institute of Particle Physics in Zurich (ETH) for ^{14}C analysis. The unmodelled results span the years 652–860 cal AD (Hajdas, 2016, 2017), which corresponds to the late Byzantine–early Islamic period in the region. Using the Charcoal Plus Outlier Plus model in OxCal 4.3 to build a preliminary single-phase chronological model (which models the ^{14}C dates as an exponential distribution and allows for some inbuilt age bias from older wooden elements) (Ramsey, 2009), the time frame can be narrowed down to 648–740 (95.4% probability) (Fig. 16) (pers. comm. Lorentzen and Manning, 2018). Further work will be undertaken using Bayesian modelling of dendrochronological and ^{14}C dates to refine the dates of both the ship's construction and period of use.

The dates of the various ceramics and amphoras correspond to the earlier part of the ^{14}C date range, specifically to the second half of the 7th century AD. The copper-lead alloy coins were dated to AD 364–375. The considerably earlier dating of the coins, combined with the results of the ^{14}C and ceramics, may imply that the coins were still valued (as small change or for the metal itself) centuries after their minting, and were still in circulation (Kahanov *et al.*, 2015: 321–322; Cohen *et al.*, 2018). Hence, they can be disregarded in terms of dating the ship. It is suggested that the Ma'agan Mikhael B shipwreck dates to the mid-7th to mid-8th century AD.

Discussion

The timbers of the Ma'agan Mikhael B shipwreck were discovered in a good state of preservation. The lack of *Teredo navalis* may indicate that it sank in a sudden event that would have resulted in its rapid burial under the protective sediment. This is highlighted by the presence, variety, and good degree of preservation of the *in situ* finds.

The dimensions of the ship's components can be compared to other shipwrecks of the period. In order to do so, short descriptions of 11 relevant shipwrecks and their characteristics are given below and in Table 4, in chronological order. However, at this stage of research there is insufficient information as to the geometry of the cross-section of the hull, and therefore it is too early to suggest the construction tradition of the ship (Pomey *et al.*, 2012).

Dor D

(Kahanov and Royal, 2001; Royal and Kahanov, 2005; Kahanov, 2011b: 169–178; Pomey *et al.*, 2012: 287 table 1)

The Dor D shipwreck site consisted of about 30 fragments of hull planks within a matrix of sand, shells, ceramic sherds, and stones, and is dated by ^{14}C analysis to 350–621 AD. Since frames did not survive, their measurements were based on staining patterns and scoring marks of trenails or nails in the hull planks: the frames were 100–110mm sided and 230mm average spacing. The hull planks were 70–240mm wide and 30mm thick, except for two planks, which were

Table 4. Comparative study

Shipwreck	Date (century, AD)	Estimated original length (m)	Planks: width, thickness (mm)	Frames: sided, moulded, room & space (mm)	Stringers: number, width, thickness (mm)	Concept and construction method (based on Pomey <i>et al.</i> , 2012)
Dor D	350–621	15–19	200, 30	100–110, —, 230	—	Concept: shell-first; construction: mixed shell and frame first
Tantura A	End 5th–beginning of 6th	12	38–260, 25	90, 95, 324	—	Frame first
Dor 2001/1	First third of 6th	16.9	50–206, 20–33	75–90, 85–120, 240	125, 82.5	Frame first
Dor 2006	Mid-6th–beginning of 7th	25	75–227, 20–40	65–250, 64–480, 240	Four, 227, 89	Mixed shell and frame first (Navri <i>et al.</i> , 2013: 323)
Yassiada 1	625	20.5	130–250, 35–42	140, 140, 300–350	—, 80, —	Mixed shell and frame first
Pantano	Early 7th	31.5	140–540, 50	180–250, 180–250, 350	Dimensions unknown	Mixed shell and frame first
Longarini						
St. Gervais 2	Second half of 7th	15–18	70–260, 25–30	110–175, 160–335, 250	—	Frame first
Tantura F	Mid-7th–end 8th	15.7	80–200, 25	80, 110, 310	Six, 150, 60	Frame first
Ma'agan	7th–8th	25	120–230, 30–34	120, 120, 440	182.7, 100.5	To be determined
Mikhael B						
Tantura E	7th–9th	12.5	100–210, 22–28	100, 120, 260	Eight, 102.1, 45.3	Frame first
Tantura B	Beginning of 9th	18–23	40–360, 30	92, 94, 260	Two, 125, 82.5	Frame first
Bozburun	874	14.3	30–40, 40	120–170, 140–220, 300–400	Yes	Concept: frame first; construction: mixed shell and frame first

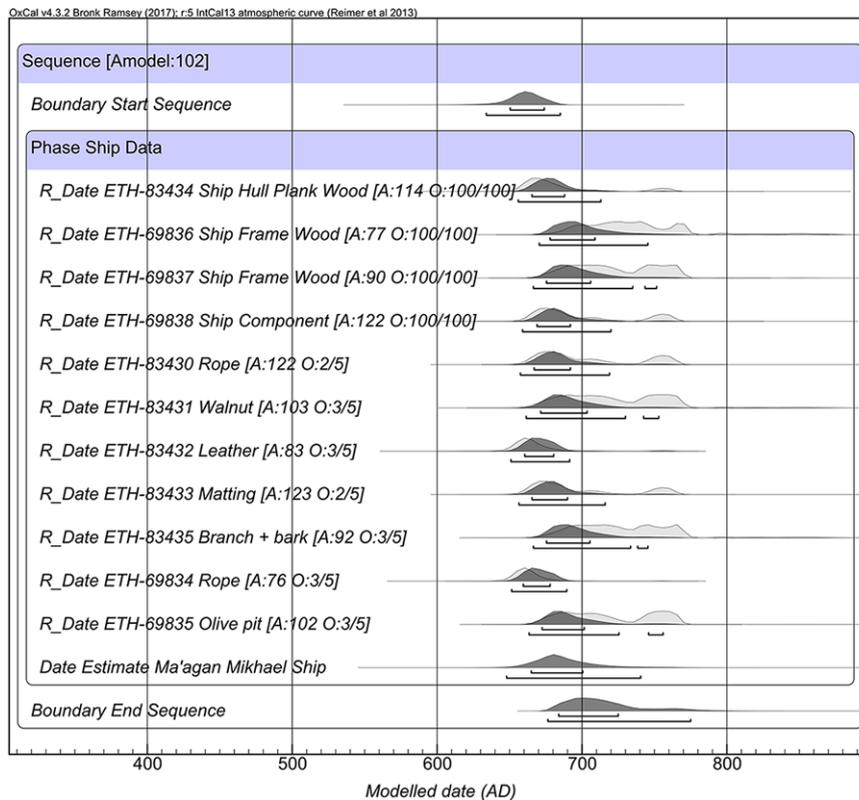


Figure 16. ^{14}C analysis results using the Charcoal Plus Outlier Model.

20mm thick. The hull concept was shell-first, and the construction was mixed shell and frames first. It is suggested that it was a medium-sized vessel, originally 15–20m in length.

Tantura A

(Kahanov, 2001; Kahanov *et al.*, 2004: 113–118; Kahanov, 2011a: 139–143; Kahanov, 2011b: 169–178; Pomey *et al.*, 2012: 286 table 1)

The Tantura A shipwreck was dated to the end of the 5th–beginning of the 6th century AD. Frames were on average 90mm sided and 95mm moulded, with an average room and space of 324mm. The planks were 38–260mm wide and 25mm thick. They were fastened to the frames by 6mm square cross-section iron nails. Butt-joints within strakes were located at frame-stations. The hull concept and construction were both frames first. The ship was apparently a 12m-long coaster.

Dor 200111

(Mor and Kahanov, 2006; Kahanov, 2011b: 169–178; Pomey *et al.*, 2012: 287 table 1; Kahanov and Mor, 2014)

The shipwreck was dated to the beginning of the 6th century AD. Seventy-nine framing timbers were documented (floor-timbers, half-frames, futtocks and top timbers), composing 44 frame-stations. The floor-timbers were 90mm sided and 120mm moulded; half-

frames were 85mm sided and 104mm moulded; and the futtocks were 75mm sided and 85mm moulded, with an average room and space of 240mm. Hull planks were 50–206mm wide and 20–33mm thick and were fastened to the frames by 7mm square cross-section iron nails. The hull planks were butt-jointed at frame-stations. The hull concept and construction were both frames first. The original ship is believed to have been a coaster, 17m long and about 5m across the beam, with an estimated displacement of 50 tons.

Dor 2006

(Barkan *et al.*, 2013; Navri *et al.*, 2013; Kahanov *et al.*, 2015)

The shipwreck was dated to between the second half of the 6th and the first quarter of the 7th centuries AD. Seventy-one extant framing timbers were found in the hull remains, 69 of which comprised 43 frame-stations. The staining pattern and nail remains indicated an additional 11 frame-stations; 54 frame-stations altogether. Frames were 65–250mm sided and 64–480mm moulded. On the outer surface of the frames, iron nails of 4–10mm cross-section were identified; evidence of plank–frame attachments. Hull planks were 75–227mm wide with an average of 155mm, and 20–40mm thick with an average of 32mm. The four half-logs stringers were 195–266mm wide (227mm average) and 65–111mm thick (89mm average). They

were attached to the upper surfaces of most framing timbers by square iron nails 8–10mm in cross-section. The hull concept and construction were both mixed frame and shell. The original ship was a 25m-long merchantman, with a beam of about 7.5m and a draught of about 3.5m, capable of carrying 170–200 tons of cargo.

Yassiada 1

(Steffy, 1982: 65–86; van Doorninck, 1982: 32–64; Pomey *et al.*, 2012: 287 table 1)

The Yassiada 1 shipwreck was dated to 625 AD, and comprised poorly preserved hull remains. The frames were on average 140mm sided and moulded, with room and space of 300–350mm. The planks were 130–250mm wide, and 35–42mm thick. The stringers were made of cypress half-logs, 80mm wide. The hull concept and construction were both mixed frames and shell. The shipwreck is the remains of a Byzantine wine-carrier about 20.5m long and a beam of about 5m, with a displacement of 73 tons.

Pantano Longarini

(Throckmorton and Kapitän, 1968; Throckmorton and Throckmorton, 1973; Kampbell, 2007; Pomey *et al.*, 2012: 287 table 1)

The Pantano Longarini shipwreck was dated to the 7th century AD. The frames were made of oak, 180mm sided and 250mm moulded, with room and space of 350mm. Hull planks were made of cypress and were 140–540mm wide and 50mm thick. The stringers were made of half-logs; one stringer was found to be crenellated. The hull concept and construction were both mixed frame and shell. The vessel was estimated to have been about 31.5m long and a 10.5m beam, with a cargo capacity of about 300 tons, and was used as a large barge to transfer heavy cargo.

St Gervais 2

(Jézégou, 1985; Jézégou, 1989; Pomey *et al.*, 2012: 287 table 1)

The shipwreck was dated to the second half of the 7th century AD. The floor-timbers were 120–200mm sided and 220–400mm moulded. The half-frames were 100–150mm sided and 100–270mm moulded, with an average room and space of 250mm. The planks were 70–260mm wide and 25–30mm thick. Stringers were used to reinforce the hull longitudinally and were nailed to the frames. The hull concept and construction were both frame first. Its reconstructed length is 15–18m.

Tantura F

(Barkai and Kahanov, 2007; Kahanov, 2011a: 143–144; Kahanov, 2011b: 169–178; Pomey *et al.*, 2012: 287 table 1; Barkai and Kahanov, 2016)

The Tantura F shipwreck was dated to between the mid-7th and the end of the 8th centuries AD. Thirty-six frame-stations were found, comprising floor-timbers, pairs of half-frames, futtocks, and long/short-armed

frames. The frames were on average 80mm sided and 110mm moulded, with an average room and space of 310mm. The pine hull planks were 80–200mm wide and 25mm thick on average, and were fastened to the frames by 5mm square cross-section iron nails. Six half-log stringers were 150mm wide by 60mm thick. The hull concept and construction were both frame first. The original ship was apparently a small merchantman or fishing vessel about 16m long with a beam of about 5m.

Tantura E

(Wachsmann and Kahanov, 1997; Royal and Kahanov, 2000; Kahanov, 2011a: 145–146; Kahanov, 2011c; Pomey *et al.*, 2012: 287 table 1; Israeli and Kahanov, 2014)

The shipwreck, which was found in a poor state of preservation, was dated to between the 7th and 9th centuries AD. Remains of 44 framing timbers were recorded in 24 frame-stations, comprising floor-timbers, pairs of half-frames, and futtocks. The frames were on average 100mm sided and 120mm moulded, with an average room and space of 260mm. Sections of 23 strakes survived, 13 on the western side and 10 on the eastern side of the keel. The planks, up to 210mm wide, and 22–28mm thick, were butt-jointed at frame-stations. The planks were exceptionally short; the longest being only 3.1m and showed many repairs. The hull concept and construction were both frame first. Its estimated length was 12.5m with a 4m beam.

Tantura B

(Wachsmann *et al.*, 1997; Kahanov, 2000; Kahanov *et al.*, 2004; Kahanov, 2011a: 146–150; Pomey *et al.*, 2012: 287 table 1).

Tantura B shipwreck was dated to the beginning of the 9th century AD. Thirty frames were preserved with evidence of nine more. Floor-timbers were 96mm sided and 97mm moulded; and half-frames were 87mm sided and 91mm moulded, with an average room and space of 260mm. Twelve strakes survived, 40–360mm wide, with an average thickness of 30mm. The planks had butt scarfs and L-shaped joints at frame-stations, and no edge-joints were found. The hull concept and construction were both frame first. The original ship is believed to have been 18–23m long and about 5m across the beam.

Bozburun

(Harpster, 2002; Harpster, 2005; Pomey *et al.*, 2012: 287 table 1)

The Bozburun shipwreck was dated to the 9th century AD. Its frames consisted of floor-timbers, half-frames, and futtocks. Floor-timbers were 120–170mm sided, 140–220mm moulded, with room and space of 300–400mm. The planks were 30–40mm wide and 40mm thick. Remains of ceiling planks, a stringer, and possibly a keelson, were also identified. The hull concept was frame, and the construction was mixed frame and shell.

The original vessel was estimated to have been 14.3m long and a beam of about 5m.

The surviving length of the Ma'agan Mikhael B shipwreck is 19.6m. This is larger than the estimated original length of Dor D, Tantura A, Dor 2001/1, St Gervais 2, Tantura F, Tantura E, Tantura B, and Bozburun. Similar dimensions of planks occur in all the shipwrecks, except for Pantano, in which some of the planks are much wider, up to 540mm, and thicker, 50mm. At the current stage it is difficult to deduce much from the frame dimensions. It is notable that the sided and moulded dimensions vary between the shipwrecks presented. In Dor D, Yassiada 1 and Tantura E the dimensions of the frames (sided and moulded) are generally similar to those of Ma'agan Mikhael B. In Tantura A, Dor 2001/1 and Tantura B the sided and moulded dimensions of the frames are smaller than in Ma'agan Mikhael B. The sided dimension of the frames in Tantura F is also smaller. In St Gervais 2, the sided and moulded dimensions are generally larger. The room and space in all 11 shipwrecks is smaller than in Ma'agan Mikhael B. Information on the stringers is available from Dor 2001/1, Dor 2006, Yassiada 1, Tantura F, Tantura E, and Tantura B. The stringers in Dor 2006 are wider but thinner than those in Ma'agan Mikhael B. In Dor 2001/1, Yassiada 1, Tantura F, Tantura E, and Tantura B the stringers are narrower and thinner.

Considering the archaeological evidence, it may be concluded that Ma'agan Mikhael B was smaller than Pantano Longarini (31.5m), but larger than Yassiada 1 (20.5m). The ship was perhaps closer in dimensions to those of Dor 2006 (25m). The length to beam ratio of Yassiada 1 was 3.9 (Steffy, 1982: 86); while that of Pantano Longarini was 2.86 according to Throckmorton and Throckmorton (1973: 260), and 3.07 according to Kampbell (2007: 67). Thus, the length to beam ratio of Ma'agan Mikhael B could have been about 3.5. Therefore, it is suggested that the original ship was approximately 25m long, with a beam of about 7m and draught about 3.5m; therefore, capable of carrying about 150 tons of cargo.

The 37 shipwrecks dated to between the 5th and 11th centuries AD, discovered in the ancient Theodosian Harbour of Istanbul, are an exceptional source for the study of ship construction. They seem to present a different, parallel technological development, which demonstrates the complexity of the transition process (Kocabaş, 2015; Pulak *et al.*, 2015: 45–68). The Ma'agan Mikhael B shipwreck is longer than the largest merchantmen of the Yenikapı shipwrecks (YK 22) (Kocabaş, 2015: 23, 29 fig. 24). YK 35 is the only one with a beam (5.20m) (Kocabaş, 2015: 23) similar to that of Ma'agan Mikhael B. The Yenikapı shipwrecks support the appearance of a typical Byzantine Empire merchantmen; rather small vessels with curving stems and sternposts giving a round look to the hull (Pryor, 2004: 43; Kocabaş, 2015: 11). The Ma'agan Mikhael B's endposts do not seem to curve enough to create a

similar round form to the hull. Regardless of the complexity that the transition process presents, perhaps this is a further indication of the existence of another method of construction in the Mediterranean region.

The two sets of well-preserved bulkheads were found *in situ* inside the shipwreck. These planks are about 36mm thick; thicker than the planks of bulkheads in YK 11 (18–21mm) (Ingram, 2018: 127–129). Bulkhead timbers were also found in YK 3, YK 12, YK 14, YK 20, YK 21, YK 29, YK 30 and YK 31: some of these shipwrecks have been thoroughly studied, while others are still being investigated (Kocabaş, 2015: 19, 21; Güler, 2017; Jones, 2017: 265; Özsait-Kocabaş, 2018: 13). Moreover, part of the bulkhead base was found in Tantura E (Israeli and Kahanov, 2014: 377–378). Since the bulkhead base has not yet been reached in Ma'agan Mikhael B, it is unknown how the planks were supported and connected to the hull.

The choice of wood used in shipbuilding depends on its characteristics and availability. The wood used for the construction of the Ma'agan Mikhael B seems to have been of good quality. Even though the processing of *Juglans regia* is easy and the quality of the results is excellent (Giachi *et al.*, 2003: 279), there is little archaeological evidence for its use in shipbuilding. Four other shipwrecks (not of the same period) were found to have used it for the frames: the 1st-century-BC Planier III (Gianfrotta and Pomey, 1981) and Madrague de Giens (Steffy, 1994: 65; Pomey, 1998), the 2nd-century-AD Ship F from the ancient harbour of Pisa (Giachi *et al.*, 2003: 272), and the 10th–12th-century AD shipwreck of Marsala (Ferroni and Meucci, 1995–1996). In the Yenikapı shipwrecks, *Juglans regia* was rarely used in construction; therefore, it has been suggested that when used, it was most probably for repairs (Akkemik and Kocabaş, 2014: 324).

Abies grows tall and straight, but was considered lightweight, and not nearly as resistant to decay as the pine found in shipwrecks of most ancient merchant vessels. However, fir planking has been found in some shipwrecks, for example: the exterior planking of the Madrague de Giens (Gianfrotta and Pomey, 1981: 268–270; Steffy, 1994: 65, 257), and in the Giglio Porto shipwreck part of the planking was made of *Abies* (Abbate Edlmann *et al.*, 1989: 113–119). Both Pliny (N.H., XVI, 18) and Theophrastus (H pl. V, 8) mentioned that *Abies* was a wood suitable for ship construction; and, because of its tall straight trunks, it was used for masts and yards (N.H., XVI, 76; H pl. V, 2). In addition, it was a good source of resin and pitch (Meiggs, 1982: 469), which has the advantage of imparting some resistance to decay in sea water.

The wooden components of the Ma'agan Mikhael B shipwreck were fastened by iron nails. The nails and bolts used in the construction of the ship are of 4.3mm, 100mm, and 10.5 × 12mm average square cross-section, depending on function. From the 3rd to the beginning of the 5th centuries AD, iron nails

gradually replaced copper nails, as is attested by shipwrecks from this period. This change parallels the transition process from 'shell-first' to 'frame-based' (Pomey *et al.*, 2012: 288–289, table 2, 297). For example, in the Dor 2006 shipwreck rectangular 4–10mm cross-section iron nails were used; and a 17 × 19mm bolt was recorded (Kahanov *et al.*, 2015: 322). In the Dor 2001/1 shipwreck, 7–12mm square cross-section iron nails and 49mm bolts were used (Kahanov and Mor, 2014: 45, 55, 57–58).

The assembly of planks into strakes using butt-joints is usually considered evidence of a 'frame-based' hull. Although only one butt-joint was observed in Ma'agan Mikhael B, it could perhaps suggest a 'frame-based' construction; however, it might also have been a repair. Butt-joints also appear in the Dor shipwrecks: Tantura A, Dor 2001/1, Tantura F, Tantura E, and Tantura B (Wachsmann *et al.*, 1997: 6; Steffy, 1999: 403; Kahanov *et al.*, 2004: 118; Kahanov and Mor, 2014: 49, 51).

The varied food remains found on board the shipwreck could be cargo or part of the crew's diet. Whichever is the case, they are characterized by ingredients found in Mediterranean cuisine; olives, walnuts, grapes, peach, and carob. These foods supply fats, vegetable oil, protein, carbohydrate, and minerals. It is very probable that fishing during the ship's voyage, especially while waiting for favourable winds, provided additional nutritious sustenance (Galili *et al.*, 2002: 193). Therefore, it is suggested that if these provisions, or part of them, were the crew's diet, then some consideration and thought were put into building a

healthy diet for the period at sea. Based on the fruit-picking season, a cautious assumption can be made regarding the sailing season of the ship. Generally, the fruits and nuts that were found during the excavation were gathered in autumn and remained edible for several months (Thurmond, 2006: 117). Thus, the ship most probably sailed in early autumn; as sailing was reduced to a minimum during late autumn and winter (Casson, 1971: 270).

Conclusions

The Ma'agan Mikhael B shipwreck promises to be an exceptional source of information regarding various aspects of ship construction, seamanship, and seafaring in the Mediterranean during Late Antiquity. Based on the archaeological remains, it is suggested that the ship was originally about 25m long. Preliminary dating, based on ¹⁴C analysis and the typology of the amphoras and ceramics, places the shipwreck in the 7th–8th centuries AD. Apparently, the vessel was a merchantman plying the Levant coast with a cargo carried in amphoras originating from various places, including Egypt and Turkey. The significance of this shipwreck goes beyond the 'shell-first' to 'frame-based' transition in Mediterranean ship construction and could improve our knowledge of ceramic typologies of the period, as well as other aspects of economic activity and daily life in the Umayyad and Byzantine Empires. The ship's sequence of construction, construction tradition, as well as the circumstances of the wrecking event, are yet to be determined.

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