The Jewel of Muscat

RECONSTRUCTING A NINTH-CENTURY SEWN-PLANK BOAT

Tom Vosmer

A unique ninth-century shipwreck discovered in the late 1990s provided a rare opportunity for an exceptional project: the recreation and sailing of the ship along the Maritime Silk Route from Oman to Singapore. The government of Oman, through its Ministry of Foreign Affairs, generously provided the funding to enable the construction of a vessel based on the remains of the Belitung wreck, while the government of Singapore supported the voyage.

Never before had such a ship been discovered, a sewn-plank vessel from the western Indian Ocean. Prior knowledge of the ships that carried the rich goods of the Maritime Silk Route between the Near East and Far East was limited to obscure textual allusions, a few iconographic images, and very sparse archaeological evidence.

By referencing more recent ethnographic evidence, certain characteristics that might have appeared in ancient ships could be inferred, but without the ships themselves there was no definitive way of knowing. Surprisingly, the Belitung wreck revealed construction techniques and design features extant in recent Omani traditional vessels. Some reliance could undoubtedly be placed on the use of ethnographic evidence.

On the wreck site, parts of the stem, keel, keelson, floors, frames, beams, beam shelf, and nearly all of the planking of one side from the middle of the ship forward were present. Clearly, this wreck would be invaluable and was to provide new and definitive information. But the archaeological evidence could not supply all the information that was required to design and build the reconstruction. Other sources had to be considered, such as historical texts, iconography, and ethnographic information, as well as even more indirect evidence.

The discovery and excavation of the wreck site is described in detail elsewhere, but what could be learned from reconstructing and sailing the ship on a long-distance passage from Oman to Singapore? What questions could be answered about the time required to build such a ship, as well as the construction procedure, processing of materials, organization of the workforce, and design and performance of the final product?

Design

As the search for materials expanded, a design for the reconstructed ship was being created. Excavator Michael Flecker, Nick Burningham, a colleague experienced in ancient ship reconstruction, and I met for several days to review the archaeological evidence and to consider what other sources might add to the picture. The result was a potpourri of information, direct and indirect, with elements of naval architecture and common sense stirred in. From this emerged a design.

The remains of the bow showed it had been narrow and relatively straight, but the distribution of the cargo indicated fullness just aft of the ship's midpoint, similar to the form of the *batil*-type vessel in recent Omani nautical history. The volume of the cargo—the sheer number of ceramics and other artifacts—indicated the ship had been capacious, and this was confirmed by the extant planking. From the intact hull planking amidships it was clear that the ship had had a large girth and, therefore, a broad beam. From the angle of the stem, the half-girth amidship, the shape of a possible floor timber, the twist of the garboard (the first plank, adjacent to the keel), and the angle of the rebates for the planking in the through-beams, much could be determined about the shape of the forward portion of the hull.

The original ship's stern, trapped in a coral concretion, was never excavated, so much of the design of the reconstructed stern was speculation based on scattered clues. A section of planking loose on the site near and apparently from the stern did indicate that the sternpost was vertical. The angle of the sternpost and distribution of the cargo indicated that the hull could well have been shaped like a *batil*. The *batil* form is characterized by an angled straight stem, with a long straight keel curving upward at the stern, the main beam occurring just aft of amidship (fig. 89). The design therefore evolved as a *batil*-like hull, featuring a very broad beam (6.5 meters) and extending about 18 meters overall in length.

All ship design and construction is compromise, and although the aim was to make a faithful reconstruction based on the original shipwreck, there was a condition that could compromise that. An edict from the sponsoring ministry declared, "There is no room for failure—this ship must get to Singapore." With that in mind, all decisions during the design and construction phases were colored and heavily canted toward safety as a primary concern.

PAGE 120

Fig. 88 View of the forefoot, showing the stitching holes plugged with putty.

Design Testing

The reconstruction project was fortunate to be funded well enough to enable the design to be tested. A 1:9 scale model of the hull shape was built and tested in the towing tank at Southampton University to see what might be revealed about its efficacy. The most profound discovery was that there was a vortex of swirling water forming near the stern, thought to be caused by a too-abrupt change of hull shape near the sternpost. The vortex was generating considerable drag. This could be easily eliminated or reduced by fairing (smoothing) the hull a little more gradually in this region while still remaining true to the archaeological evidence. When the full-size ship was built, the adjustment to the hull shape was made. In reality, the nature of the material—the hull timber itself—would not have allowed such an abrupt change in form.

These tank tests also showed that the hull probably needed a good breeze to get it moving but would cruise happily at around 6 knots with a top theoretical speed of around 10 knots. The full-size reconstruction demonstrated that in a very light breeze the vessel could make half the wind speed, in a moderate breeze (12–18 knots) it sailed at about one-third the wind speed, and in very heavy weather (under one storm sail) it reached speeds in excess of 11 knots.

In addition to the hull form, the shape, size, trimming, and spacing of the sails were tested in the wind tunnel at Southampton. Observing these tests, the most fundamental discovery was that the masts, as designed, were too close together. Accordingly, the design was adjusted and the masts moved farther apart.

Model

Based on this design, Burningham built a model (figs. 90–91), intended as a learning device as well as a representation for display. The process of building the model revealed procedures and structural problems that could then be resolved on a small, relatively inexpensive scale. The model would also be a handy reference tool for the Indian and Omani shipwrights, who were not accustomed to using plans in ship construction. Indeed, a gathering of the shipwrights and ropeworkers around the model in the early days of the project provided a lively discussion about design features and shipbuilding procedures. During the construction of the full-size ship, the model was frequently reviewed to see what could be learned for planning structures or procedures.

Materials

Wherever possible, the team employed the same wood that was used on the original ship. The Belitung wreck had been constructed primarily of African timber (*Afzelia africana*) and teak (*Tectona grandis*), along with others such as rosewood (*Dalbergia sissoo*), juniper, and palm wood. Timber trade was flourishing in the western Indian Ocean at the time the Belitung ship was built, but both the Indian subcontinent and Africa had plenty of excellent shipbuilding timbers, while the Arabian Peninsula would have had to import teak, rosewood, and *Afzelia africana*. India or Sri Lanka would have had no need to import *Afzelia* or rosewood, nor would Africa have needed the large pieces of teak that were part of the wreck. The provenance of these timbers—the Indian subcontinent, Arabia, and Africa—therefore indicate that the ship was most likely built in Arabia.

Afzelia africana is a heavy, dense hardwood that a thousand years ago grew all across sub-Saharan Africa. Today, most of the commercial stands are in West Africa, and so the team went to Ghana to source the timbers. These massive trees inspired awe of the people who felled, transported, and processed such timber a thousand years ago. The terrain was difficult, the environment hot and humid. How did they cut the timber? How did they transport it? Based on the archaeological record, the *Afzelia* planks and frames for the Belitung ship were sawn, and all by hand, probably with pit saws operated by pairs of workers. Our team had an old dilapidated tractor to haul the logs from the forest, but the felled trees were so heavy it was unclear how the ancients had done this job. Surely, they must have sawn the timber *in situ* where it was felled, making planks and frame blanks on the spot. The labor intensity was staggering.

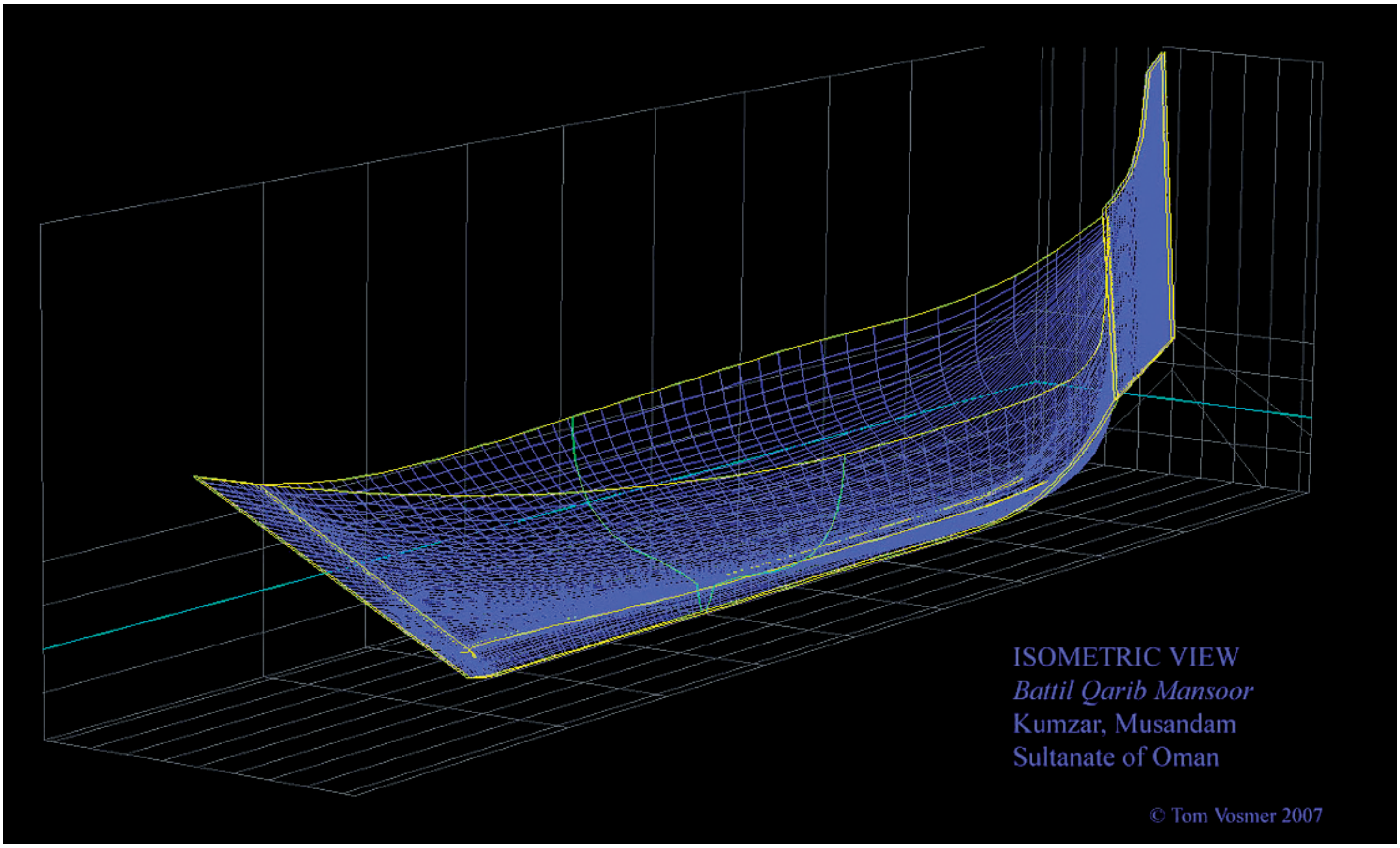
Construction

It was clear that the actual construction would be affected by the natural behavior, characteristics, and properties of the materials as well as the procedures used to handle and shape them. The centerline structure—the keel, stem, and sternpost—was fairly straightforward. The lugs observed on the top surface of the keel near the bow in the Belitung ship were apparently intended to act as a partial rebate, preventing the garboard strakes (those planks adjacent to the keel) from moving laterally toward the center of the keel. The team decided to use the same devices throughout the length of the keel.

The curving portion of the keel in the stern was securely fastened to the forward portion by a complex scarf (sloping) joint (fig. 92), and then the stem and sternposts were erected. The heel of the stempost had a tenon projecting from its underside. This was fitted into a slot cut in the top of the forward end of the keel. A similar arrangement was made for the sternpost. The stem and sternpost were then sewn to the keel.

As opposed to the centerline structure, the planking was not at all straightforward. Unlike most Western shipbuilding practice, where the hull planking is formed around a skeleton of frames, our reconstruction had to follow a different procedure. When a sewn-plank vessel is constructed, the shell of the hull is assembled first, and the framing fitted afterward. This procedure is necessary because it is impossible to sew planks where frames are already in the way.

Because the planks could not be bent or twisted around preerected frames, the planks had to be preshaped—twisted or curved to the correct shape—before they were attached to the ship. It is uncertain how this was done in the past, but there were several possibilities. The first was



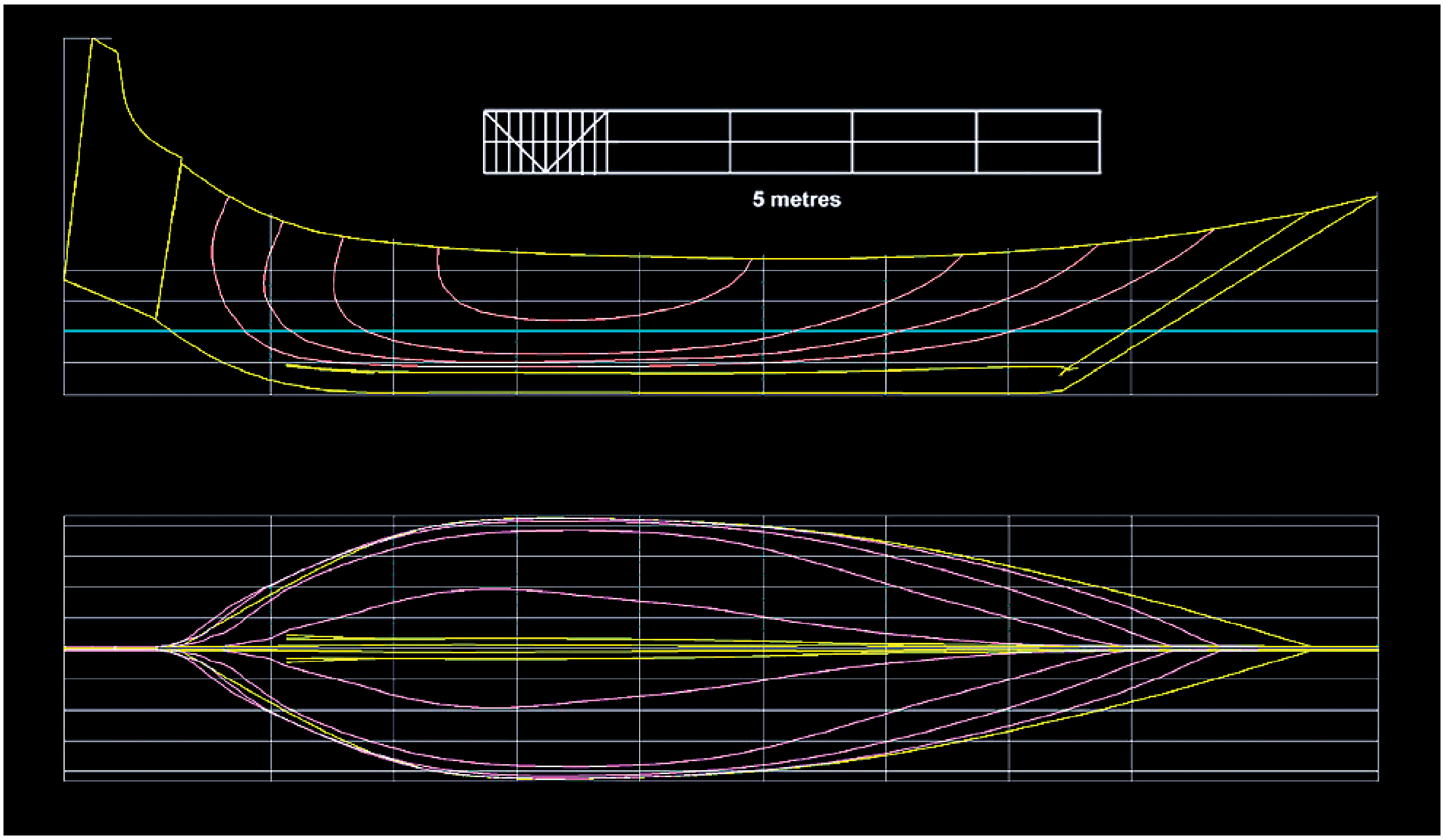
ISOMETRIC VIEW

Battil Qarib Mansoor

Kumzar, Musandam

Sultanate of Oman

© Tom Vosmer 2007



OPPOSITE

Fig. 89 Drawings of a typical *batil* hull form.

RIGHT

Fig. 90 Model of the Jewel of Muscat, built by Nick Burningham. Cat. 1.

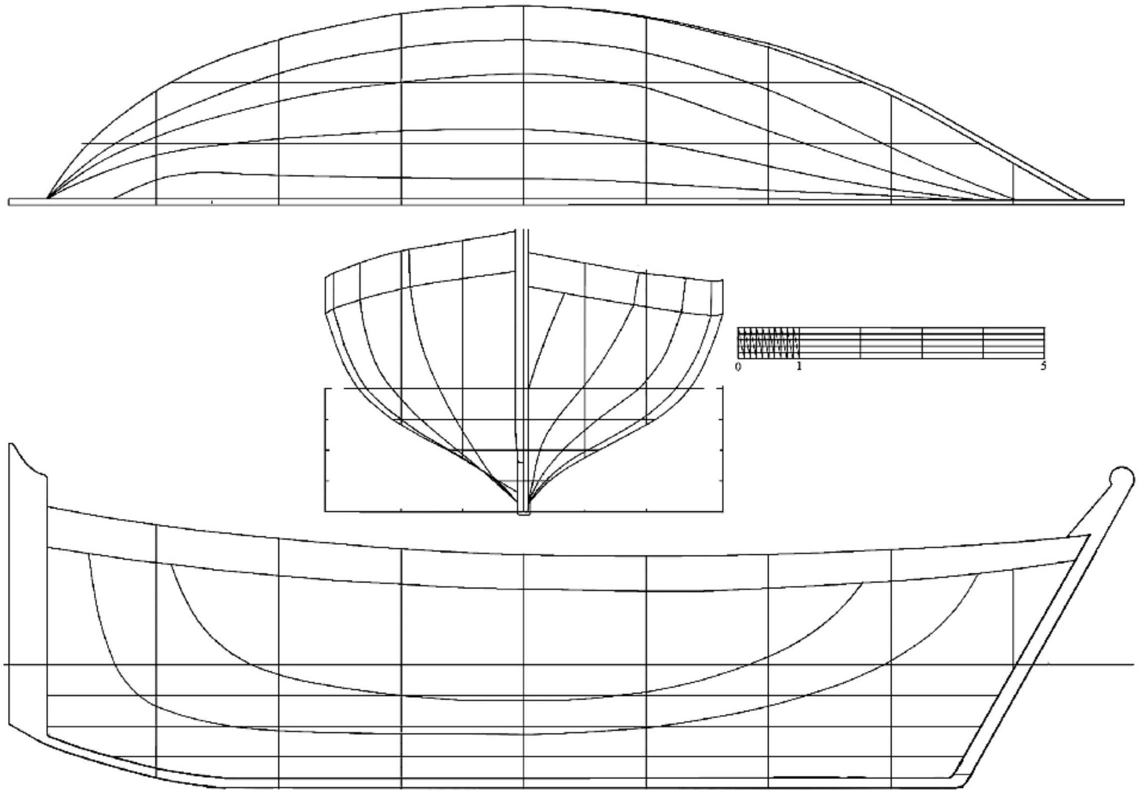


Fig. 91 Plan for the Jewel of Muscat.

to soak the planks in the sea to make them more pliable, then place them in “torture racks” to be forced into the desired shapes and allowed to dry (fig. 93). This method, however, was found not to be completely effective. Another method was fire-bending, where the plank, soaked in water or oil, was heated over a fire and simultaneously forced into the desired shape. Application of heat on one side of the plank tended to make that side concave. Heat also made twisting a plank easier. When the plank cooled, it essentially would stay in the forced shape.

The most successful method, however, was the use of a steam box. The team constructed a long sealable wooden box, 7 meters by 40 by 50 centimeters. One end had a removable lid that could be fitted to keep in the steam, which was supplied by two metal boilers that were connected by short pipes to the box. Roaring fires under the boilers delivered a vigorous supply of steam. The boilers were fired, and when steam was produced, one to three planks could be placed inside the box. The planks were given an intense steam bath for about two hours. When they were removed they had the consistency of hard rubber and could be molded, bent, and twisted to shape. This flexible condition lasted, however, only for a very brief time. If the planks were not forced into the desired form within two minutes, they began to cool and harden and were impossible to manipulate. Shipwrights had to work with great speed to get each plank to its desired shape. In some cases, the wood could not be made to obey, and we had to accept the fact that some of the forms designed into the vessel were not achievable.

The stern, with its swept-up keel and lower planking, was especially challenging. To achieve the desired shape required some complex joinery near the stern. In fact, the plank adjacent to the keel in the stern had to be fitted to four surfaces simultaneously, one of which twisted throughout its length. All had to fit perfectly. The difficulty was compounded by the fact that no one on the team had ever faced such a problem. It became so difficult that we began to wonder if the builders of the original Belitung ship had actually done it that way.

Sewn boats cannot be caulked in the traditional sense, so after an initial rough fitting, each plank needs to be mated perfectly to the previous plank on the boat. This is done by using a spiling gauge (a pair of wooden dividers) to transfer the shape of the edge of the previous plank to the next plank, then cutting to that line. After that, the edge needs to be repeatedly shaved, skimmed, relief-sawn, and checked until the surfaces mate perfectly.

STITCHING PROCEDURE

The sewing of the planks together is a skill that takes a very long time to master. The tension of the stitching has to be just right. If too much, the cordage might break; if too little, the planks will not hold together tightly.

After the next plank had been fitted perfectly, and pairs of matching holes had been drilled in the planks to be sewn together, the wadding was prepared. The wadding, which was placed on the inside and outside of the plank seams, was made in two layers: The first was a long "python" of coconut fiber, about 5 centimeters in diameter. Over this about 40 lengths of coconut cordage were stretched along the seam. When sewing was complete, this wadding would provide a cushion for the stitching cordage. When immersed in the sea, the wadding would expand, further tightening the stitching. The system produces a structure of remarkable strength, with some flexibility.

Workers formed pairs to sew the boat, one inside the boat and one outside (fig. 94). Each had an identical tool kit—a marlin spike (a tapered wooden lever about 50 centimeters long), a heavy mallet or hammer, and small tapered wooden plugs to lock stitches temporarily in the holes as they progressed. A piece of wire was twisted around the end of the stitching cord so that it could be easily pushed through the holes. The sewing cordage, a doubled length of coconut rope 3 millimeters in diameter, was first passed through a hole, over the wadding on the plank to the person on the opposite side, who drew the cordage up tight, using the marlin spike as a tightening lever. To further tighten the stitch, the cordage was hammered over the wadding while the lever was tightened. The sewing proceeded in a zigzag pattern, and when the end of a section was reached, the sewing direction was reversed, returning to the beginning. The end result was a series of X-shaped stitches alternating with vertical stitches (fig. 95).

The archaeological evidence suggested that the seams between the planks had been lined with a lime-based putty to act as a sealant. There are several indigenous putties that use lime as a base, with other ingredients such as fish oil or resin. Prior to construction, the team conducted a series of experiments to test the effectiveness of various systems and materials. One involved comparing the sealing effectiveness of a lime-based luting compound with a resin-based compound. A standard procedure in regional traditional boatbuilding is to seal a plank seam with a luting compound composed of fish oil and a resin called *khundrus*. This amber-colored resin is from India and believed to be either dammar or the Indian frankincense resin (*Boswellia serrata*). The chunks of resin are melted and combined with fish oil, producing a sticky dark substance the consistency of heavy molasses. The edge (called the faying surface) of one plank is painted with the glutinous luting, and a strip of cotton cloth laid on the edge of the plank over the luting. More luting is painted on the cotton, and on the bottom edge of the next plank, which is then fitted to the previous plank.

The testing procedure for the plank seams involved sewing together two planks about 1 meter long, using either the lime-based or the resin-based luting between them. These sets of planks then formed the bottom of a box, with the meter-high sides built of epoxy-sealed plywood to make them watertight. The boxes were filled with water and the rate of leakage through the seams monitored. Interestingly, the lime-based luting proved more successful at first, but the performance of the two substances reversed over time, the seam with the lime-based luting showing increased leaking and the resin-based luting showing a decrease. Following the ministerial caveat that "The ship must get to Singapore," the resin-based system was chosen.

LEFT

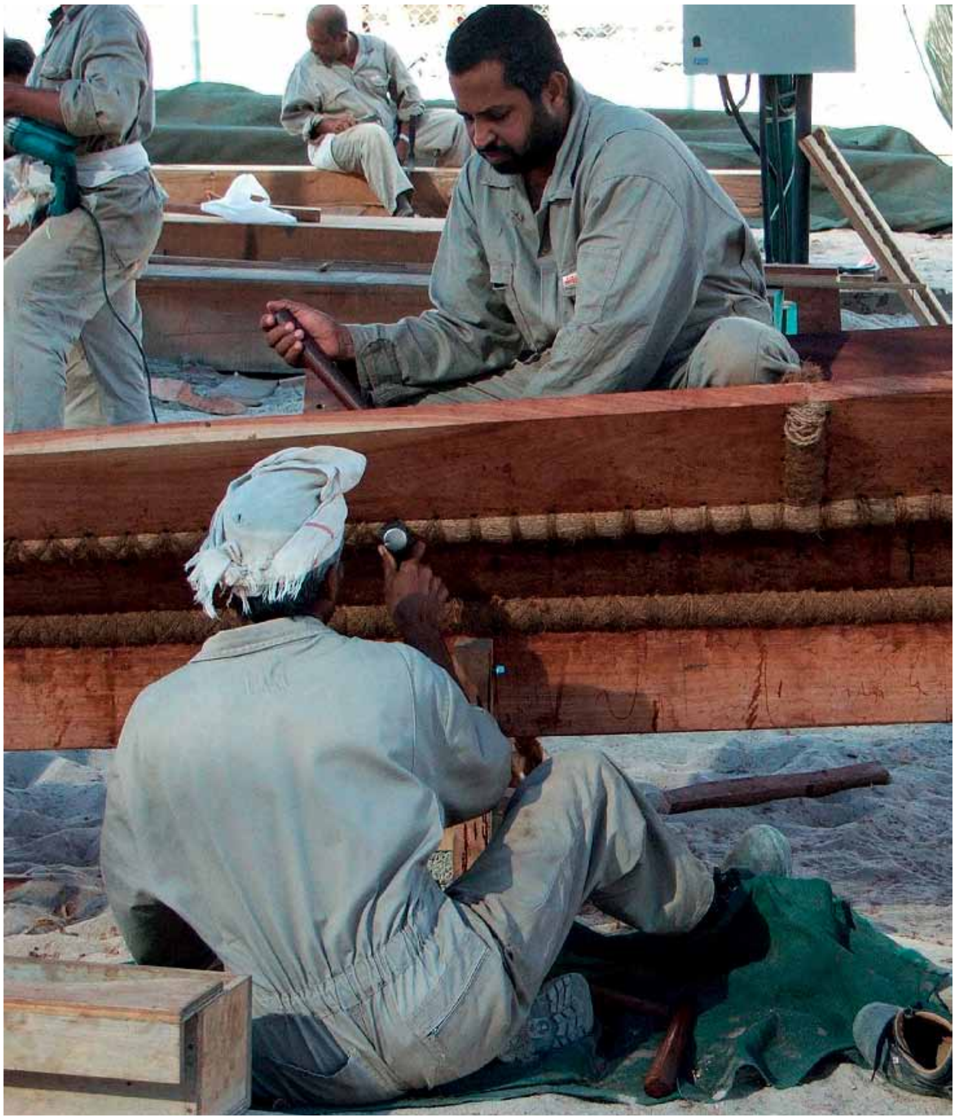
Fig. 92 To create the scarf joint, a tenon projecting from the stempost is fitted into a slot cut in the keel. The same is done with the sternpost. Then both posts are sewn to the keel.

RIGHT, CLOCKWISE FROM TOP

Fig. 93 Placing sea-soaked planks in "torture racks" was found to be a less-than-ideal way to curve them into shape.

Fig. 94 Two men working on either side stitched the planks together.

Fig. 95 The finished stitching pattern.



The team struggled with decisions on the spacing of the holes in the planking. Archaeological evidence suggested the holes were slightly more than 5 centimeters apart and about 17 millimeters from the edge of the planks. The disadvantage of this was that the more holes that were drilled, the more chance there was of the plank splitting along the “dotted line.” Other disadvantages would be the extra time required to drill more holes and the additional cordage needed to stitch the holes. In the end, we compromised at about 5.5 centimeters spacing. The advantages of close spacing were more holes and more stitches sharing the burden, therefore putting less strain on any one stitch. To stitch the entire boat together and to lash the frames in place required drilling more than 37,000 holes in the vessel and consumed more than 120 kilometers of coconut cordage, much of it handmade. Mindful of a tight building schedule, most of those holes were made with an electric drill, but the team did experiment with the traditional bow drill to determine how long the ancient method may have taken. The modern electric drill was about six to ten times faster than the bow drill.

Of course, having 37,000 holes in a boat is not a very good idea, so each hole had to be plugged after the stitching was complete. Plugging the holes is an art in itself—too tight, and the stitching may be damaged or the plank cracked; too loose, and the seams might leak. Large coils of processed coconut fiber had been used as wadding under the stitching; it seemed logical that this would be suitable for plugging the holes as well. But the ropeworkers asserted that the only suitable coconut fiber had to be fresh from the husks—and that they thus would need 1,000 coconut husks.

The husks were shipped from southern Oman to the building yard in Qantab, near the capital Muscat. Indeed, the fiber from the husk was significantly different from the processed fiber. It was spongier, softer, and could be compressed. The fiber was formed into small twisted plugs about 1 centimeter in diameter and 4 centimeters long. These were hammered into the holes from inside and outside, leaving a shallow recess in each stitching hole.

The plugging, however, was not complete. The fiber plugs had to be further sealed with putty. This putty comprised chalk powder (calcium carbonate) mixed with melted *khundrus* resin and fish oil, a traditional putty used in the region. The result was a dull grayish substance that resembled used chewing gum. In fact, when all the holes were plugged, the boat looked as though it had been attacked by a mob of chewing-gum addicts (fig. 88). This type of putty stays pliable. Another local type, made from a mixture of calcium hydroxide and fish oil or rendered animal fat combined and pounded for hours, yields a good sealant or putty, but it hardens after many days.

FRAMING

The size and spacing of the frames could generally be determined from the original wreck site, although both size and spacing were rather irregular. Much of the timber used in the original ship had been a matter of what was at hand, so frame sizes were not uniform. Their spacing, on average about 300-millimeter centers, was in practice much more irregular, often determined by such things as the location of butt joints in the hull planking, the shapes of available frame timbers, and the position of through-beams. When comparing the reconstruction to the original, this element of irregularity gave the reconstruction a feeling of authenticity.

Since so little of the original keel was exposed in the excavation, it was unclear how many floor timbers—those frames that span the keel and keelson and connect the two sides of the ship together—had been present. The model used very few, but in our full-size vessel were eighteen floor timbers, which proved imperative. They helped to distribute the weight of the keelson (a heavy timber running nearly the length of the vessel over the floor timbers) and the compression forces of the masts to the hull.

THROUGH-BEAMS

One hallmark of early ships in the Indian Ocean was the use of through-beams. They frequently appear in iconography and were in evidence on the Belitung wreck. As well as providing the foundation for any possible deck (see below), through-beams helped to lock the sides of the ship together. They were fitted with a locking joint between the planking and the beam and sewn to the hull, producing an immensely strong structure.

BEAM SHELVES

The beam shelves—those longitudinal timbers that fasten to the inside of the hull planking and help support the through-beams—were fitted on the original ship after the through-beams had been installed. This was something the team had not noticed during the original interpretation of the archaeological evidence. The clue was revealed after struggles to understand the pattern of the stitching around the beam, which held the beams to the hull planking. That stitching completely penetrated the hull, but the extant beam shelf of the Belitung ship showed no stitching holes, thereby indicating that the beam shelf was fitted after the through-beams were in place.

DECK

Historical sources indicate that Arab ships of this time usually did not have decks.[1] The archaeological evidence of the Belitung wreck appeared to confirm this. It does seem, however, that there would need to be a small deck aft for the helmsman and one forward to facilitate handling ground tackle. There is ethnographic evidence suggesting the same. The team therefore decided to fit the ship with small fore and aft decks, intending to cover the remainder of the open hold with *barasti*, the mid-ribs of the date palm leaf.

FINISHING

In accordance with tradition, the bottom of the ship below the waterline was coated with a substance called *chunam*, a mixture of hydrated lime and rendered goat fat. To prepare the *chunam*, the goat fat was heated over a fire until it melted, then the lime was mixed in. The team had done a number of experiments to determine the correct proportion of lime to goat fat, and the most effective application method. Wooden panels coated with various mixtures were suspended in seawater for a number of weeks to determine which lasted the longest and which discouraged the attachment of marine organisms. Interestingly, the most effective coating for keeping the wood free of marine organisms was plain fish oil. This, however, was not an option, and we settled for a 60/40 mixture of goat fat to powdered lime. In ancient times this lime probably would have been derived by heating calcium-bearing seashells or coral, but we used ordinary builders' lime.

This coating was intended to give some protection to the hull from marine borers, such as the teredo worm (*Teredo navalis*), but it will not discourage marine crustacea, such as barnacles, from attaching. In that sense it is not an antifouling compound. *Chunam* does, however, make removing barnacles easier.

En route to Singapore from Oman the vessel was put into dry dock in India, where the barnacles and other marine growth were removed, leaving much of the *chunam* intact. Another coating of *chunam* was applied by local workers, who allegedly knew this traditional method. But this time little attention was paid to the proportions of the concoction or even the ingredients. Their *chunam* comprised hydrated lime, calcium carbonate (chalk), calcium sulphate (gypsum), animal fat, and fish oil—everything, it seemed, but the kitchen sink. They combined these ingredients in a haphazard manner, displaying a totally cavalier attitude to the process. Within days of leaving India, most of the new *chunam* had fallen off.

The hull was painted, inside and outside, with fish oil. Although the substance's odor is enough to gag a maggot, its effectiveness as a wood preservative is superb. After some days, the odor decreases.

POST-LAUNCH CHANGES

After launching the vessel, the team noted that the vertical distance between the underside of the through-beams and the top of the keelson had increased by nearly 5 centimeters. The flexibility of a sewn-plank vessel was evident. While alarming at first, this flexibility turned out to be quite normal. Some of the increase in distance may have been due to the weight of the ballast (10 tons of lead and 15 tons of gravel in bags) centered over the keelson. Some might be due to the weight of the masts, which added at least another 2 tons of compression on the keelson. Not all of the movement, however, could be attributed to the flexibility of the hull—a portion was due to the expansion of the immersed planks. In fact, this was quite plain when one studied the spatial relationship of the frames to the planks. All the frames had been notched where they spanned the wadding of the plank seams. As the widths of the immersed planks expanded after launching, the relative positions of the notches and the seams changed. In any future build, this problem could be anticipated and addressed.

MASTING AND RIGGING

The wreck site did not make clear how many masts the ship originally had, but the team decided to fit two, for a number of reasons. First, two masts would split the compression forces of one mast into two, thereby distributing force in the sewn hull more evenly. Second, more sail area could be spread on two masts than on one, and the masts could be shorter, a benefit to stability. Third, fewer people might be required to handle the smaller rig on each mast. Fourth, two masts would provide more flexibility in possible sail combinations, according to wind strength and direction.

No trace of masts or other spars was found on the wreck site, but the first choice for spars in the Indian Ocean is *poona* wood (*Calophyllum inophyllum*). Luca Belfioretti, in charge of construction on the site, went to India to scout sources of *poona*. Unfortunately, it proved very difficult to find straight trees of suitable length. After many trips, Belfioretti had assembled a stack of about twenty-seven logs of various lengths and diameters, but it took so long to work through the delicate but crushing bureaucracy of export and import permits, shipping arrangements, customs clearances, road passes, etc., that in the end the timber had remained on the ground in India for nearly six months. By the time it arrived in Oman, half of it was infected with dry rot. The team selected the usable timber and burned the remainder.

Substitute timber had to be found. The second choice in the region for masts is teak (*Tectona grandis*), which, through the contacts developed during Belfioretti's previous trips, could be sourced in India. Now there were three problems—finding logs long enough (about 17 meters), obtaining permission to export unprocessed teak, and then getting them shipped to Oman. Logs of desired length were not available (the longest found was 14.5 meters); even if they could have been found, they would not have fit in a 12-meter container and therefore would have commanded exorbitant fees to ship. The team had to settle for two 11-meter lengths that could be scarfed together—both glued along a sloping joint—to form each mast.

The process of obtaining permission to export unworked teak proved to be complex and convoluted but eventually was resolved. The logs arrived and were trimmed, and pairs of them were scarfed together with a long (4 meters) scarf joint glued with epoxy. Unfortunately, the timber had a lot of sapwood, which is weak. Months later, when caught in a sudden squall of 40-plus knots between India and Sri Lanka, the sapwood of both masts cracked, and they had to be replaced at the next opportunity.

After a very lengthy search in Sri Lanka, two teak trees were found, felled, and shaped into masts. This time, with no containers involved in shipping, the team was able to obtain logs of sufficient length to make each mast from one piece. Obviously, having just been felled, the timber was very green, but there was no other choice. One day the birds had been singing in the treetops; a few days later the timber had been fitted as masts on the ship.

Sails

SAIL SHAPE

Contrary to popular belief, neither the triangular Arab lateen sail nor the settee (a lateen with the forward corner cut off) was used in the ancient western Indian Ocean. In the ninth century, square sails held sway, and that remained so until around 1500. There is a persistent and widespread myth that lateen or settee sails existed in the western Indian Ocean since antiquity, but a great deal of evidence refutes this. The ship illustrations from the *Suwar al-Kawakib* (Book of Fixed Stars), dating from 1134–35, consistently show square sails. One fifteenth-century Arab navigator, Ibn Majid, states that the constellation Pegasus reflects the shape of a typical Indian Ocean sail.[2] The main body of the constellation is square. Sixteenth-century iconographic evidence from the region shows no hint of lateen or settee sails on Arab ships before 1530 at the earliest.[3] The famous "Miller Atlas," a map of the Indian Ocean by the sixteenth-century Portuguese cartographer Lopo Homem, shows what are clearly Arab ships with square sails. Seventeenth-century illustrations by artist Franz Hogenberg show ships with dhow-like hulls fitted with vertical masts and square sails. Two ship images crudely produced on the walls of the eighteenth-century Hazm Castle in Oman show square sails on Indian Ocean ships. It is clear from all of this that the sails of the Belitung ship would have been square as well.

SAIL MATERIAL

By the ninth century, cotton had been known in India for millennia, so it could be expected that cotton canvas may have been used for the sails aboard the Belitung ship. But historical sources prove that woven palm-mat sails were also used in the Indian Ocean. Which to choose? Rather than a problem, the team recognized an opportunity to try both types of sail.

Bolts of canvas were purchased, and panels were sewn by hand. Two working sails were sewn with vertical panels, and two with horizontal panels. In addition, a storm sail of much smaller dimensions was sewn with horizontal panels. No traces of sails were found on the wreck site, but iconographic evidence indicated vertical panels to be the norm. Again, however, the team decided to take the opportunity to try both. The horizontal-panel sails set better, but that could be a result of the vertical sails having been made with the seams too tight.

A palm-mat sail is featured on the reconstruction of an East African *mtepe* in the House of Wonders Museum in Zanzibar. The people responsible for the sail were contacted, and a contract was drawn up to have two palm-mat sails made on the island of Pemba. The material would be *duom* palm (*Hyphaene thebaica*), traditionally used for sails and woven baskets. The team's documentation manager, Eric Staples, made three trips to Pemba to check on the sails' progress, as the artisans seemed to be struggling a bit with the task. In the end, the mat sails were delivered but not before the craftsmen admitted they were in fact basketmakers, not sailmakers.

The size of the sails was determined by calculations involving the displacement of the vessel, its wetted (underwater) surface, and stability considerations. There are naval architecture formulae to calculate the sail area required to drive a vessel based on its weight and the drag on the underwater surface created by water rushing along the hull. There are also stability calculations that take into account the position of the vertical center of gravity and the shape of the hull. The total working sail area decided upon was 160 square meters, divided almost equally between the main and mizzen (aft) masts, the main sail being just slightly larger. This sail area was slightly on the small side, but stability considerations had led the team to err on the safe side. More sail area would have meant less stability. As it turned out, the ship had plenty of stability, and a greater sail area would have been possible. It is doubtful that the ancient sails would have had a reefing capability, that is, the ability to reduce the sail area by wrapping up and securing parts of the sail. Indian Ocean sailing rigs of recent history merely change sails rather than reef, and this may well be a lingering holdover from ancient times.

RIGGING

Historically, it has been reported that coconut rope was commonly used for rigging on Arab and Indian sailing craft. The Belitung wreck, however, revealed something else. A thick piece of rope from the wreck had survived more than a thousand years under the sea. Scanning electron microscopy (SEM) done at the University of Massachusetts showed that rope to be composed of fibers of manila, cotton, and human hair. Manila normally rots quickly in seawater, and the fact that one piece of rigging composed primarily of manila survived is remarkable. (Whether the hair was an integral part of the rope or that of a hapless victim of the wreck who perhaps got his hair caught in the rigging is not known.)

Given this evidence, the team decided to use manila for most of the rigging. Coconut cordage was also used, primarily serving as seizing or whipping cordage. Since manila, as mentioned above, degrades in seawater, one crucial piece of rigging—the partially immersed line that holds the median rudder in its slot—was made of coconut fiber, which is known to last in seawater.

Fig. 96 Drawing of the rudder-control system.

Steering Systems

During the era the Belitung ship sailed, a significant technological change was underway: The system used for steering was changing from quarter rudders—that is, two rudders mounted on the sides of the vessel near the stern—to a single median rudder mounted on the sternpost. This transition was occurring in Europe at about the same time and took some three centuries to complete. There is iconographic evidence from Europe of both systems in use simultaneously on a vessel. A search of Arab sources revealed a similar situation. Several depictions, such as those from al-Hariri's *Maqamat* and the *Suwar al-Kawakib*, show vessels with both systems fitted. The team saw this as another opportunity to test both systems. Therefore, it was decided to fit both steering systems on the reconstruction. It turned out to be a wise decision, as the two systems sometimes needed to be used in tandem.

THE QUARTER RUDDERS

There are twin quarter rudders, one on each side near the stern. They are mounted between two heavy through-beams and, at their upper ends, in a “gallows” above the deck. They can be raised when not in use. Normally, only the leeward rudder would be deployed, with the windward quarter rudder raised.

THE MEDIAN RUDDER

The single median rudder is not easily raised, so when not in use it needs to be locked in a neutral position. This rudder is the most familiar type, attached to the sternpost, but the method of control is unique to the western Indian Ocean. Like most rudders, it is controled by a tiller, but a tiller that points aft rather than forward. To the outboard end of this, tiller ropes are attached that lead to either side of the ship. There, each rope attaches to the outboard end of a large wooden toggle that is suspended in its middle so that it can pivot. The inboard ends of the toggles are attached to another rope or sometimes to separate ropes on their ends. By pulling one way or the other on these ropes, the helmsman can pivot the toggles, causing the rudder to turn (fig. 96). Geographer Muhammad al-Muqaddsi in 985 CE wrote, “The captain from the crow's nest carefully observes the sea. When a rock is espied, he shouts ‘Starboard!’ or ‘Port!’ Two youths, posted there, repeat the cry. The helmsman, with two ropes in his hand, when he hears the calls tugs one or the other to the right or the left.”[4] This statement proves that this median rudder system was in use before the late tenth century.

Conclusion

A ship reconstruction based on incomplete evidence is always a fascinating challenge. The process involves much speculation, discussion, and a decision-making path that is complex. Inevitably, some decisions made early in the project have an impact on the construction plan that emerges.

Throughout the construction of the full-size ship, lively discussions ensued concerning the interpretation of the archaeological evidence, how it should be applied, and what the implications were for the developing trajectory of the building process, as well as the safety and performance of the ship.

Much remains to be analyzed about the structure and the performance of the ship. Digesting and making sense of all the data will take years. But already enormous amounts of information have been gleaned from the construction and sailing of the vessel (fig. 5)—information that could have been learned no other way. Certainly, the maritime archaeologist Sean McGrail was correct when he declared, ". . . the construction and operation of a full scale replica of a boat may often be the only way that the archaeologist can become aware of the full array of factors involved, and of possible solutions to the problems encountered."[5]

SHIPWRECKED

TANG TREASURES AND MONSOON WINDS

HOW TO ORDER

Cloth edition

328 pages | 9"x 12" | $65.00 US / $74.00 Can
220 color and 235 B&W illustrations
ISBN 978-1-58834-305-5
Distributed worldwide by Smithsonian Books via Random House
Available from Amazon.com, Barnes & Noble.com, and fine bookstores everywhere.

Paperback edition

328 pages | 9"x 12" | $40.00 US/$52.00 Sing
220 color and 235 B&W illustrations
ISBN 978-0-934686-18-1
Available in Singapore from:
ArtScience Museum, Marina Bay Sands
Asian Civilisations Museum and other National Heritage Board museum shops:
www.museumshop.com.sg

ABOUT THIS BOOK

Twelve centuries ago, a merchant ship—an Arab dhow—foundered on a reef just off the coast of Belitung, a small island in the Java Sea. The cargo was a remarkable assemblage of lead ingots, bronze mirrors, spice-filled jars, intricately worked vessels of silver and gold, and more than 60,000 glazed bowls, ewers, and other ceramics. The ship remained buried at sea for more than a millennium, its contents protected from erosion by their packing and the conditions of the silty sea floor. *Shipwrecked: Tang Treasures and Monsoon Winds* explores the story of both the sailors and the ship's precious cargo through more than 400 gorgeous photographs and essays by international experts in Arab ship-building methods, pan-Asian maritime trade, ceramics, precious metalwork, and more.

Edited by

Regina Krahl, John Guy, J. Keith Wilson, and Julian Raby

With contributions from

Alison Effeny | Michael Flecker | John Guy | Jessica Hallett | Hsieh Ming-liang | Regina Krahl
Li Baoping with Chen Yuh-shiow and Nigel Wood | Liu Yang | François Louis | Qi Dongfang
Tom Vosmer | Wang Gungwu | J. Keith Wilson

Published by

Arthur M. Sackler Gallery, Smithsonian Institution, Washington, DC
National Heritage Board, Singapore | Singapore Tourism Board