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Building Hatshepsut's Punt Ship: Science and Ship Reconstruction

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Introduction

Since the first substantial publication, in 1877,[1] of reliefs featuring sailing ships from c.1482 BCE at Queen Hatshepsut's funerary monument at Deir el Bahari, Egyptologists, archaeologists, naval architects and many others have speculated about the ships' destination, size, characteristics, and the accuracy of the relief representations[2]. Five ships, pictured in each of two registers, are shown arriving and departing from a location called Punt – "God's Land". Produce including frankincense, myrrh, leopard skins, ivory, gold, baboons, dancing dwarves, giraffe tails and other exotica is shown being loaded onboard the vessels.

Most Egyptologists agree that Punt was found on the African coast of the southern Red Sea, where these species are accessible and historically attested as trade items in images and writing on Egyptian royal monuments from at least the Fifth Dynasty (King Sahure), c.2480 BCE to Islamic and even modern times. Until recently, despite the enticing realism of the low-relief images (Fig. 1), the lack of any direct physical evidence from seagoing vessels made it difficult to test hypotheses about size, technology, capacity and capability in a rigorous way.

Fig. 1
Detail from one of the Egyptian ships arriving at Punt.

Today, with new data from excavations conducted at Wadi Gawasis by the University of Naples/Boston University team under the direction of Rodolfo Fattovich and Kathryn Bard,[3] it is possible to base a reconstruction of a Punt ship on scientific foundations.

The role of experimental archaeology, ship replicas and ship reconstructions within the field of maritime archaeology is both widely recognized and widely debated. Even for relatively recent vessels, where substantial hull remains may exist, as in the case of the Kyrenia ship[4] dating from c.290 BCE, significant interpretation and interpolation are required to reconstruct upper hull works, rigging, number of crew and other critical components of a working vessel. With funding arranged by Sombrero and Co., a French documentary production company, we have designed a 20 m-long ship to be sailed on the Red Sea. Unlike many of the ships discussed at the conference, its construction is not directly sponsored by a museum, but the vessel will find a home in a museum and will be exhibited in a number of museum displays after completing its sailing trials.

When we must rely on documentary and iconographic evidence without direct physical evidence, it is important to recognize which questions may and may not be specifically addressed by the reconstruction. Following Mc Grail,[5] our efforts are to:

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[1] *Mariette, 1877, pp. 229-232.*

[2] *For example: Faulkner, 1940, pp. 7-9; Landström, 1970, pp. 122-127; Wachsmann, 1998, pp. 18-29.*

[3] *Bard and Fattovich, 2007.*

[4] *Steffy, 1994, pp. 42-59.*

[5] *McGrail, 2001, pp. 6-7.*

1. Keep clear aims. In other words, be sure to understand how data used to create a design are related to the hypotheses or questions asked of the experiment and to the observed data. Circular arguments appear frequently, but rarely meet with success in the scientific community.
2. Maintain a rigorous approach. There are literally thousands of decisions to be made, and knowing why and how each choice is made is crucial to being able to assess the outcome of replica and reconstruction experiments.
3. Use methods that are both authentic and logical. That is, select technologies that reflect the seafaring times and economies that we seek to replicate rather than what 'seems natural', a phrase that almost always suggests a modern approach to an ancient problem.
4. Test decisions and models using modern techniques, for example: computer modelling of the hull and its characteristics. This enabled us to examine a number of slightly different hull forms in a short space of time, something that would have been achieved by the ancients through hull form refinement over a number of years.

Physical evidence and design background

In the case of *Min of the Desert*, our primary aim is to create a full-sized reconstruction of a pharaonic Punt ship in order to test its sailing abilities and to evaluate hull technologies with respect to fastenings, water tightness and disassembly.[6] The design is based on details from 22 ancient Egyptian full-sized craft,[7] seagoing ship timbers, ship models, and images of seagoing ships, especially those from Hatshepsut's mortuary temple at Deir el Bahari. Ancient Egyptian boats built for use on the Nile date from c.3000 to c.500 BCE,[8] but it is only recently that the remains of seafaring ships have been identified at Gawasis and further north at Ayn Soukhna on the Red Sea.[9]

Because construction techniques used to build river vessels differ significantly from those of later Mediterranean seagoing craft, many scholars assumed that Egyptian seafaring ships would more closely reflect Mediterranean-type construction techniques,[10] specifically mortise-and-tenon fastenings locked with pegs. Instead, discoveries at Gawasis prove that Egyptian design and construction techniques, relying on thick planks, frameless hulls and paired, unpegged, deep mortise-and-tenon joints were successful both on the Nile and at sea.[11] Our intention is to test the performance of a full-sized craft built to these specifications.

Because most of the timbers seem to be in contexts dated to the very late Middle Kingdom (MK), Second Intermediate Period or early New Kingdom (NK), we feel confident that they provide information pertinent to the design of a ship no later than Hatshepsut's time. Similarities in fastening patterns, timber shape, construction styles and tool kits are identifiable between Gawasis finds and the MK cedar ceremonial boats from Dashur (c.1850 BCE) and the disassembled MK working boat timbers at Lisht (c.1950 BCE). We drew heavily on these finds in establishing the hull form, selecting construction technology and identifying appropriate materials for the reconstruction.

Basis for the hull form

Min, like the reconstructed trireme Olympias,[12] will be a floating hypothesis, rather than a replica, because there are no ancient Red Sea shipwrecks available to study. Neither are there surviving river-craft from the New Kingdom to compare to earlier vessels nor precise dates available for individual ship components from Gawasis. Like Olympias, Min's design relied on a range of evidence from a broad chronological period, in our case, covering about 350 years. For the design of the rigging and information on construction practices, iconic and model evidence was used to supplement physical data from excavations.

From our review of these details and existing archaeological evidence, we then approached the Punt relief of Hatshepsut from a metrological perspective. We were able to do this because the Gawasis finds included a number of identifiable ship components that are directly and indirectly represented in the relief images, enabling, for the first time, comparisons between physical remains and artistic representation of similar components.

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[6] *line five requires a space between "pieces" and "145 km"*

[7] *Ward, 2004, pp. 12-24.*

[8] *Ward, 2000.*

[9] *Ward, 2006, pp. 118-129.*
M. abd el-Raziq, G. Castel, P. Tallet 2006, Ayn Sokhna et la Mer Rouge, Égypte, Afrique et Oriente 41:3-6.
At Ayn Soukhna near Suez, French archaeologists discovered ship timbers 10 cm thick and up to 23 cm wide with mortise-and-tenon fastenings and lashing channels re-used in architectural contexts in "galleries" that may date to the time of Sahure.

[10] *Hocker, 1998, pp. 245-246; Pulak, 1999.*

[11] *The authors are grateful to Kathryn Bard and Rodolfo Fattovich for permission to study this material; and would also like to thank Chiara Zazzaro, Rainer Gerisch, Mohamed abd el-Maguid and other members of the excavation team at Mersa/Wadi Gawasis for sharing their expertise and knowledge.*

[12] *Morrison, Coates, Rankov, 2000.*

Using the dimensions of Gawasis steering oar blades, planks, stanchion, and beam ends as tests of the Punt relief, we confirmed the reliability of human figure scaling. Comparing the spacing of the ends of the cross-beams, illustrated on one of the five ships arriving at Punt, with dimensions for Gawasis deck planks led us to decide on an overall length for the ship of 20.3 m, with a hull length of 18.3 m and a maximum beam of 4.9 m at the sheer. Length on deck will be about 17.8 m, with a DWL length of 13.4 m. As reconstructed, Min will displace about 30 tonnes.

The maximum beam and underwater hull form, not visible in the Punt relief's, are predominantly based on the MK Dashur boats from c.1850 BCE (Fig. 2) as recorded by Ward.[13] The Dashur boats reflect proportions visible in many models and images of watercraft in ancient Egypt. In addition, individual components such as deck planks, beams and hull planks demonstrate a continuity of practice and proportion across time and between river- and sea-going vessels.

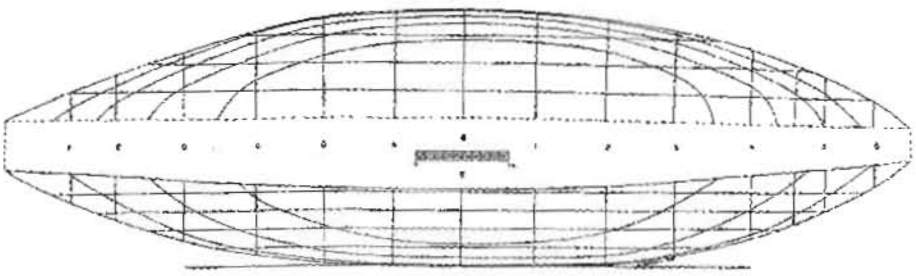

Fig. 2
Profile and plan for the Dashur boat in the Field Museum, Chicago
(C. Ward drawing)

A major difference between the Dashur boats and the NK Hatshepsut Punt relief ships is the presence of a significant keel plank in the latter. Although Egyptian river-boats were built around a central strake that protruded slightly below the hull planking, it was not substantially thicker than hull planks.

By the time of Hatshepsut, there are multiple strands of evidence, including a group of three models each about 2 m long from the tomb of Amenemhet II (c.1425 BCE), pointing to the existence of a true keel plank of substantial dimensions that, unlike later craft, protruded within rather than without the vessel below the waterline. In this case, we looked to three-dimensional ancient ship models and to the construction of the c.1300 BCE Uluburun ship, probably of Canaanite origin, to supplement two-dimensional information from the Punt relief's.

Naval Architecture

Min of the Desert was designed and analysed using the Maxsurf Naval Architecture design suite from Formation Design Systems (http://www.formsys.com) (Fig. 3). Analysis included tests of static stability as well as estimates of the seakeeping performance and calm-water resistance of the vessel.

Using the Dashur boat, modified for the profile views shown in the relief drawings, as a basis hull form, some adjustments were made so as to improve the vessel's stability. The Dashur boat was a river-going vessel, requiring less stability than a vessel operating in open water on the Red Sea.

We calculated stability curves for the parent and two modified hull forms for the same displacement and estimated vertical centre of gravity (Fig. 4 & 5).

The differences are subtle but significant. With the vessels ballasted to their design waterlines, the effect of lowering the centre of gravity is clearly shown with the angle of vanishing stability increasing from about 82 to 94 degrees.

The effect of reducing the beam/draught ratio is to reduce the initial stability slightly (but this is not necessarily a bad thing).

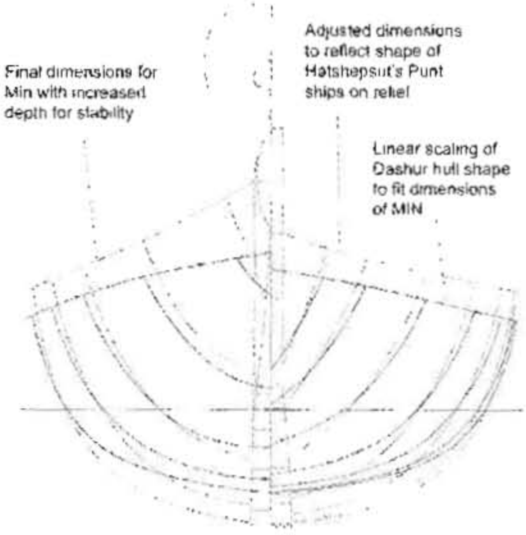

Fig. 3
Body lines for *Min of the Desert* with Dashur hull and two versions with increased depth of 10% and with an additional 10 cm
(P. Couser).

[13] *Ward, 2000.*

The deeper vessel has less initial GM (slope at zero heel) than the parent which will make the vessel feel less stable. This is actually beneficial because it means that the crew will probably be inclined to push the vessel less hard. Even with this reduced initial stability, the vessel is well within acceptable limits (except for angle of deck edge immersion). Where the deeper vessel has significantly better stability is at large angles of heel. It is hoped that the vessel will never reach this level of heel, but if it were to do so, it is likely that the deeper vessel would fair better than the parent because the effective angle of vanishing stability is extended from 68 to 78 degrees.

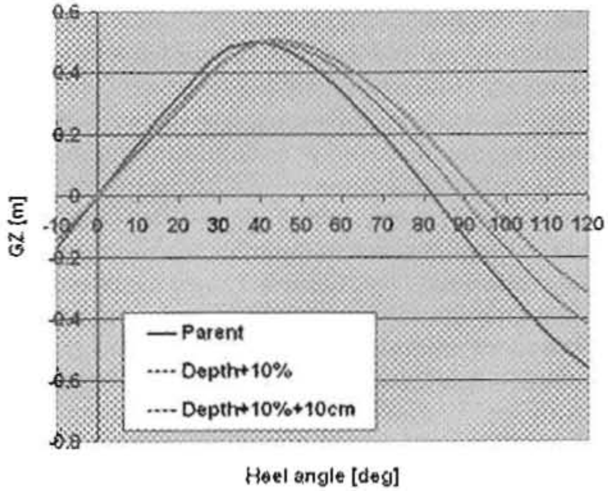

Fig. 4
Stability (GZ) curves for three versions of *Min of the Desert*. The deepest option was selected for safety and stability

Criteria	Units	Required value	Parent actual value	D+10% actual value	D+10%+10cm actual value
Effective angle of vanishing stability	deg	90.0	**62.0**	**68.9**	94.0
Angle of vanishing stability	deg	90.0	**82.0**	**85.0**	94.0
Angle of deck edge immersion	deg	40.0	**26.7**	**28.9**	**28.6**
Area 0 to 30	m.rad	0.056	0.128	0.114	0.110
Area 0 to 40	m.rad	0.090	0.213	0.196	0.192
Area 30 to 40	m.rad	0.030	0.085	0.082	0.081
Max GZ at 30 or greater	M	0.200	0.500	0.501	0.509
Angle of maximum GZ	deg	25.0	39.0	43.0	44.0
Initial GMt	M	0.150	0.965	0.839	0.793
Equilibrium - derived wind heeling arm	deg	15.0	**14.2**	16.8	16.3

Fig. 5
Stability criteria summary

The angle of deck edge immersion remains rather low for both vessels but there is no way of overcoming this except by increasing the freeboard. The vessel's stability is significantly affected by its vertical centre of gravity. A change of as little as a few centimetres can have a dramatic effect. The heeling moment of the sail under different sailing conditions must also be considered. Fortunately these effects on static stability are easy to evaluate and may be used to assess different interpretations of archaeological data, such as placement of cargo and/or ballast.

Other effects such as the loss of stability due to water in the bilges and dynamic stability in waves can also be assed using computer-based models. Such calculations lay a baseline for dealing with stability questions, but raise other questions immediately.

1. What value did the ancients place on their sailors, vessels and cargo – were losses at sea acceptable?
2. What kind of ballast might have been used, if any?
3. How much water did the ancients consider acceptable in the hold?
4. If a certain level of water is in the hold unrestrained by framing, how does that affect cargo lading?
5. How was excess water excluded from the hull?

The last question is extremely important to our project as there is no evidence for caulking or waterproofing agents such as pitch or luting on plank seams of large Egyptian craft. Rivercraft had battens over the plank seams, held in place by lashings, but there are no lashing channels on the shipworm-damaged timbers and no traces of foreign materials on their edges. A full-size model of part of the hull structure will be used to test the water tightness and structural integrity of the plank seams to help answer some of these questions; this is another vital component of the reconstruction.

Construction Technology

Others have outlined the difficulty in building ancient craft in today's world. Insufficient supplies of appropriate timber, loss of craftsmanship skills, and unfamiliarity with ancient methods create difficulties for those seeking to maintain the logistical and historical authenticity required for testing hypotheses in a scientifically rigorous manner. What reliability of scientific observation and interpretation can exist when so much must be inferred from the archaeological record?

In the case of Egyptian watercraft, we have a relative abundance of vessels from the past to examine, and because they range from the late fourth to the mid-first millennium BCE, it is possible to make some reasonable statements about developments in ship building technologies. The earliest watercraft preserved in Egypt, flat-bottomed canoes, relied on lashing through channels from inner faces to plank edges to unite the hull.[14] By c. 2550 BCE and the construction of the 43m-long Khufu ships, small, unlocked mortise-and-tenon fastenings between plank edges had supplemented these lashings.

By c.1950 BCE, lashing occurred only at plank ends and deep, paired mortise-and-tenon fastenings are to be found in joined planks at Lisht; originally from watercraft, these planks had subsequently been recycled as building materials. Paired mortise-and-tenon joints occur again at Gawasis, but not at Dashur, suggesting that heavy freight vessels and seagoing hulls made use of this unusual combination of thick planks (14–22cm thick) and deep joints. The only exception recorded is in the ancient reuse of planks with paired mortises as deck beams in the Dashur boat displayed as EM 4925 in the Cairo Museum and the Carnegie boat.

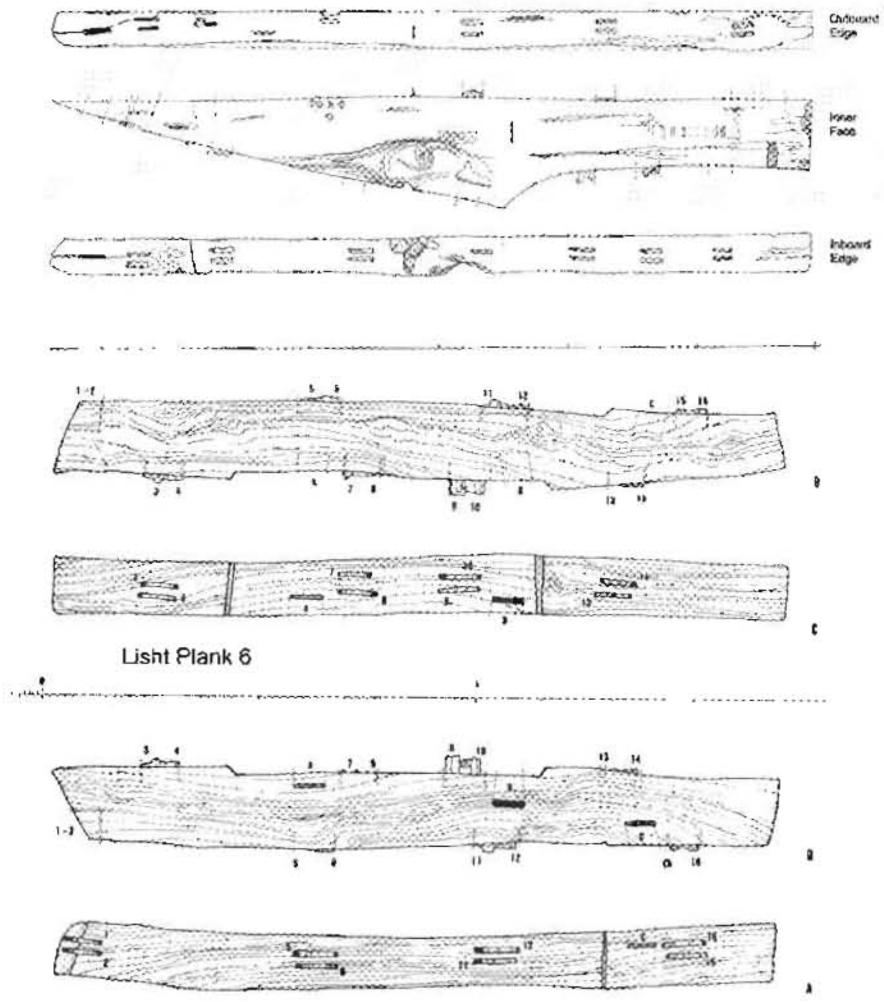

Fig. 6
Ship plank T34, 2.93 m long, from Gawasis (upper) and Lisht plank 6, 1.66 m long (lower)
(by C. Ward)

Like other ancient ships, Min depends upon wood-to-wood fastenings along plank edges. A single ligature channel on Gawasis plank T34 retained narrow copper straps to assist in in securing its narrow end to the keel plank, but on the whole, the fastening patterns closely resemble those of some Lisht timbers (Fig. 6).[15] By the repeated discovery of similar patterns, we infer ancient success in solving a problem even if our modern experience does not easily replicate the identical solution.

Analyses of the structural integrity of the main hull and the fastenings are always difficult but also very important in experimental construction, since if the fastenings are not sufficiently strong, it is possible that the vessel could break up. Full-scale test pieces can assess the strength of the joints. Cemal Pulak has shown that tests of mortise-and-tenon fastening patterns, in his case, those of the Hellenistic Kyrenia and Late Bronze Age Uluburun ships, provide useful data. [16] He notes that shear tests result in planks giving way long before the joints, informing us not only about the reliability of certain fastening patterns and methods, but also about the proficiency of ancient shipwrights in overbuilding for safety. For the sake of comparison, hull planks on the Uluburun ship are less than half the thickness of Gawasis planks although tenons are the same length. The major difference is the use of pegs to lock the tenons on either side of the plank seam in Uluburun planks and the use of paired joints in the Egyptian planks from Gawasis.

Tests of the strength and water tightness of plank fastenings will provide information regarding some of the major aspects of the hull but there are still significant questions relating to many other details, such as:

[14] *Ward, 2006, pp. 19-23.*

[15] *Haldane [Ward], 1992, pp. 102-12 and pl. 115-32.*

[16] *Pulak, 2003.*

- whether or not framing was present,
- how the hogging truss was fastened to the hull and its exact purpose,
- how the mast was linked to the hull (there are four different options presented on the Punt relief), etc.

With every decision, we step closer or farther from the original ancient solution according to our interpretations, a problem illustrated in the selection of building materials.

Materials and Methods

As noted earlier, the forestry resources available today do not provide the selection of timber available to shipwrights of the past. Typically, experimental craft attempt to balance availability and cost, resulting in choices that lead to laminated frames, non-authentic methods of fastening or reinforcement, and even the addition of modern safety equipment such as motors. Materials science is critically important to reconstruction and replica efforts both in the identification of original materials and in the identification of material properties such as density and Young's modulus.

Archaeological evidence unquestionably points to Lebanon cedar (*Cedrus libani*) as the primary wood for *Min*'s submerged hull. It is not available for commercial harvesting today in the quantities required: 100 cubic meters of planks 15–30 cm thick and up to 50 cm wide in lengths of 3 m or so with heartwood running through the center of the plank. Consultation with foresters suggested that Douglas fir (*Pseudotsuga menziesii*) is the wood with most comparable qualities of grain, Young's modulus and density, and we located a wood supplier who can provide the volume of wood with our requested dimensions and characteristics. We can duplicate the ancient choice of tenon wood – *Acacia nilotica* (Nile acacia) with no difficulty. Although we have no archaeological information for masts or spars, ancient texts suggest cedar was the wood of choice here as well, so again we have elected to use Douglas fir as a substitute.

The other major decisions relate to the rigging of the ship with a single square sail that reflects the Punt relief's directly. Its size (about 14m x 6m) produces a sail area of about 80 square meters, controlled by running rigging illustrated in models, the reliefs drawings and perhaps represented more directly by coils of rope found at Gawasis (5cm, 3.5cm, and 1cm in diameter). Textile fragments at Gawasis are linen, and one at least may represent a torn bit of sailcloth, so we will commission a linen sail for the voyage that corresponds to characteristics of looms, weave, and weight from archaeological evidence in Egypt. Rope identification has not been completed, but we are attempting to use halfa grass hand-laid in Oman on the basis of its overwhelming use in construction projects elsewhere in ancient Egypt and the gross morphological similarities between the Gawasis ropes and identified halfa grass samples. If we are not able to obtain a supply of halfa grass, we will use hemp cordage as its physical properties are most similar. Physical properties therefore are our guides in maintaining rigour of approach to materials selection and to the way in which the materials will be used.

With respect to construction methods, there are projects that attempt to replicate the ancient process with ancient tools.

Even the best of these, as at Roskilde where extensive hull remains, archaeological observation and experience, and scientific testing have produced some of the world's finest replicas, rely on *inferential* reproduction of ancient tools wielded by modern shipbuilders who have developed their own rhythms and practices that may or may not be similar to those of the tenth-century Vikings. Elsewhere, such as on the Kyrenia replica, builders began with hand tools and "traditional" methods, but quickly shifted to replicating the results with power tools, a process that certainly speeds up cutting mortises by people without the years and decades of experience the ancient shipbuilders would have acquired.

MIN will be built in Oman under the direction of Tom Vosmer by shipbuilders who have extensive experience in using hand-hefted adzes, drills, chisels and pull saws similar to ancient Egyptian examples as well as modern band saws and cranes.

The documentation of the process by a maritime archaeologist and stress testing of different methods is also a part of our project.

Again, we turn to rigorous documentation and scientific testing to ensure that our data are relevant to understanding how these ancient vessels were built and sailed.

Our particular situation is even more complicated because we must build the ship as if it were to be disassembled and reassembled after a 145km hike across the Eastern Desert of Egypt.

Conclusion

Our experimental craft is exactly that—an experiment in the design, construction and operation of an ancient type of ship that successfully made voyages of over 1800 miles some 3500 to 5000 years ago. We intend to test its performance, its maneuverability and response to different sailing conditions and especially the water tightness and strength of its hull. We also intend to examine the effects of submersing the hull in the warm waters of the Red Sea on a 425 km voyage from near Mersa Gawasis to Port Sudan, scheduled for the season of steady winds from the northwest. Our expectation is that scientific study of archaeological evidence will have brought us to a position of reasonable security of interpretation, but the reality we all must face is that we must document our insecurities and tenuous assumptions as well.

Bibliography:

Abd el-Raziq, M., Castel, G., Tallet, P., 2006, Ayn Sokhna et la Mer Rouge, in: *Egypte, Afrique et Oriente* **41**, pp. 3-6.

Bard, K.A., Fattovich, R., 2007, Seaport of the Pharaohs to the Land of Punt, in: *Archaeological Investigations at Mersa/Wadi Gawasis, Egypt, 2001-2005.* Naples.

Faulkner, F.O., 1940, Egyptian Sea-going Ships, in: *Journal of Egyptian Archaeology* **26**, pp. 7-9.

Haldane, C., [Ward] 1992, The Lisht timbers, in: D. Arnold et al., *Publications of the Metropolitan Museum of Art Egyptian Expedition XXV. The South Cemeteries at Lisht III. The Pyramid Complex of Senwosret I at Lisht*, pp. 102-12 and pl. 115-32. New York.

Hocker, F., 1998, Did Hatshepsut's Punt Ships Have Keels? in: S. Wachsmann, *Seagoing Ships and Seamanship in the Bronze Age Levant*, pp. 245-246, Texas.

Landström, B., 1970, *Ships of the Pharaohs*. New York.

Mariette, A., 1877, *The Monuments of Upper Egypt*. London.

McGrail, S., 2001, *Boats of the World*, Oxford.

Morrison, J.S., Coates, J.F., Rankov, N.B., 2000, *The Athenian Trireme: The History and Reconstruction of an Ancient Greek Warship* (2nd ed.). Cambridge.

Pulak, C., 1999, The Late Bronze Age Ship at Uluburun, in: W. Phelps, Y. Lolos, and Y. Vichos, *The Point Iria Wreck: Interconnections in the Mediterranean ca. 1200 BC Proceedings of the International Conference. Island of Spetses, 19th of September 1998*. Athens.

Pulak, C., 2003, Paired Mortise-and-Tenon Joints of Bronze Age Seagoing Hulls, in: C. Beltrame, *Ship Archaeology of the Ancient and Medieval World*, pp. 28-34. Oxford.

Steffy, J.R., 1994, *Wooden Ship Building and the Interpretation of Shipwrecks*, Texas.

Wachsmann, S., 1998, *Seagoing Ships and Seamanship in the Bronze Age Levant*. Texas.

Ward, C., 2000, *Sacred and Secular: Ancient Egyptian Ships and Boats*, in: New Monographs Series, Archaeological Institute of America, No. 5., Boston.

Ward, C., 2003, World's oldest planked boats: Abydos hull construction, in: C. Beltrame, *Ship Archaeology of the Ancient and Medieval World*, pp. 19-23. Oxford.

Ward, C., 2004, Ancient Egyptian ships and boats, in: F. Hocker and C. Ward, *Towards a Philosophy of Ancient Shipbuilding*, pp. 12-24. Texas.

Ward, C., 2006, Boat-building and its social context in early Egypt: interpretations from the First Dynasty boat-grave cemetery at Abydos, in: *Antiquity* **80**, pp. 118- 129. York.