LADING OF THE LATE BRONZE AGE SHIP AT ULUBURUN

A Thesis

by

SHIH-HAN SAMUEL LIN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

May 2003

Major Subject: Anthropology

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Approved as to style and content by:

Cemal Pulak (Chair of Committee)	Shelley Wachsmann (Member)
Christoph F. Konrad (Member)	David L. Carlson (Head of Department)

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ABSTRACT

Lading of the Late Bronze Age Ship at Uluburun. (May 2003)

Shih-Han Samuel Lin, B.A., Rutgers University

Chair of Advisory Committee: Dr. Cemal Pulak

The Uluburun shipwreck was discovered in 1982 when a Turkish sponge diver informed the Institute of Nautical Archaeology (INA) of his discovery of "metal biscuits with ears." INA archaeologists recognized this as a description of "oxhide" ingots, a clear indication of a Late Bronze Age site. This find was of considerable interest as very little is known about seafaring, long distance trade, and ship construction during the Late Bronze Age, except for a glimpse provided by the Cape Gelidonya shipwreck excavated in 1960 by George Bass. The site at Uluburun revealed only a handful of disarticulated ship fragments; nevertheless, a meticulous study of these timbers and the distribution of the cargo and shipboard items on the seabed resulted in a hypothetical, but carefully guided, reconstruction of the ship and the lading of its cargo.

The artifacts recovered from the Uluburun shipwreck are unlike those discovered on land in quality of preservation as well as the quantity found. Items pertinent to this study include 354 copper oxhide ingots (approximately 10 tons), 152 copper bun ingots (nearly 1 ton), 110 tin ingot fragments (approximately 1 ton), 175 glass ingots (approximately 0.3 tons), 150 Canaanite jars (approximately 2 tons if filled with water), 10 large storage jars (*pithoi*) (approximately 3.5 tons if filled with water), approximately

51 Canaanite pilgrim flasks, 24 stone anchors (3.3 tons), nearly 1 ton of ballast stones, and the hull remains itself.

Two computer programs, Rhinoceros and PHASER, were used to visually model the artifacts and ship in three-dimensions and to systematically test various hull shapes and lading arrangements in a range of hydrostatic conditions. Tests showed that a hull measuring 15 x 5 x 2 m would be capable of carrying the estimated 20 tons of cargo and shipboard items recovered from the wreck at a draft of 1 m, with sufficient freeboard to allow six passengers to stand on one side of the vessel without compromising the stability of the ship.

To Cemal,
for giving me the privilege of working on this project.

ACKNOWLEDGEMENTS

A project that encompassed such a great number of artifacts, experimented with different methods, and that sometimes seemed to have no end, would not have been possible without the help and encouragement of an equally great number of people. First, I must say "Xie Xie" to my parents, Paul and Olive, my siblings Shirley and Andy, and other family members and friends who consistently prayed for me as I worked on this project. I probably would have given up were it not for their support and encouragement.

I would like to remember and thank my lab partner, the late Erkut Arçak, who playfully taunted me at the beginning of the project, but also motivated me to get cracking through his example of devotion and enthusiasm to his own work. "We all miss you, man."

Many thanks to Wendy van Duivenvoorde for providing the lines drawing of the Uluburun ship, which was a crucial element of this project, and one I am glad I did not have to do. She was also a great encouragement and very insistent on helping to proofread the completed text despite her own busy schedule. Glenn Grieco very generously took the time to turn the model Canaanite jars on the lathe while finishing the model of the ship *La Belle*. Comic relief from my work was also provided by my good friend and labmate Dante Bartoli, who excelled at telling amusing stories with his funny Italian accent.

Much appreciation is also due to Bruce Hays of Proteus Engineering who very kindly donated a copy of PHASER for this study and provided truly excellent support. I would also like to thank Larry Liebermann from Proteus for his technical assistance with setting up the program on my computer.

Without a doubt, this project would not have been possible without the diligence of Kathy Hall, Tuba Ekmekci, Gulser Kazancioglu, Sukran Senyüz, and the rest of the Bodrum Conservation staff in Turkey who mended broken pottery, hunted down missing sherds, and provided measurements of artifacts and other vital information by email. I am also indebted to Mr. Steffy for his wisdom and guidance on ship construction and providing unpublished information about *Kyrenia II* to use as a model for the many unknown aspects of the Uluburun ship's hull and rigging. The text of this thesis was greatly improved by Erika Laanela, who took time out of her busy semester to edit the final draft.

Lastly and most importantly, there should be a line on the cover of the thesis saying: POWERED BY CEMAL PULAK. His guidance has been invaluable for the genesis and evolution of this project. I thank him for his trust, criticism, insightfulness, patience, and most importantly, the meticulous excavation of the Uluburun shipwreck that made this study possible.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

A Ship's Lading

The study of a ship's lading is integral to a comprehensive understanding of a specific ship or a particular vessel type because the cargo, whether people or goods, is the primary reason for the ship's existence. Despite the symbolism that has developed regarding ships, the fundamental purpose of ships is transportation, or as Steffy simply states, "something or someone had to be moved from here to there."[1] Often, the type of cargo a ship carries determines its general shape and structural features. On the most basic level, merchant ships and warships may differ drastically in design because of their different purposes; this was true of the giant grain ships and oared *liburni* of Roman times and remains true of the oil tankers and aircraft carriers of the present. A ship can also be modified to accommodate cargo it was not specifically designed to carry, such as the use of triremes as horse transports by the Greeks during the Peloponnesian war.[2] It is clear that the ship cannot be disassociated from its cargo.

Because the form of a ship is closely tied to its intended cargo, a careful study of the distribution of artifacts on a wreck site can yield valuable information about a ship that has been incompletely preserved in the archaeological context. Innovative computer technology has simplified the study of the hydrostatic characteristics of a ship based on its displacement and weight distribution, which is a function of how the cargo is

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This thesis conforms in style and format to the *American Journal of Archaeology.*

[1] Steffy 1994, 8.

[2] Morrison and Williams (1968, 248) note that the number of rowers was reduced from 170 to 60 and modifications probably included some additional structures to help stabilize the horses.

positioned in the hold. As a case study, this project will focus on the Uluburun shipwreck to demonstrate the ability to retrieve significant information through carefully documented archaeological excavations of shipwreck sites despite minimal hull preservation. The Uluburun shipwreck presents an interesting but challenging example because the largest contiguous section of preserved hull measures only 1.8 x 1.0 m. Although only small portions of the hull were preserved, a detailed examination and reconstruction of the cargo placement provides the approximate dimensions and tonnage capacity of the ship. Locations of structural features that were not preserved, such as the mast step, can be determined once all of the artifacts are restored to their "original" positions on the ship. Based on the disposition of approximately 20 tons of cargo documented on detailed site plans, a reconstruction of the ship's lading and estimates of its original size and general shape are proposed. Hydrostatic data was generated from this reconstruction to test the validity of the hypothetical model.

Background and Excavation of the Uluburun Shipwreck

A Late Bronze Age shipwreck (ca. 1200 B.C.) was excavated at Cape Gelidonya off the southern coast of Turkey in 1960, marking the advent of nautical archaeology as a specialized field within the discipline of archaeology. G.F. Bass headed the project and was the first diving archaeologist to coordinate the excavation of an ancient shipwreck. This excavation shed a small but significant light on Late Bronze Age trade and the conclusions reached overturned the existing theory that Bronze Age Greeks, or Mycenaeans, dominated overseas trade in the eastern Mediterranean. Bass argued that the nationality of the ship was in fact, Syro-Palestinian or Cypriot, not Mycenaean, and that the Syro-Palestinians played a much greater role in Late Bronze Age trade than previously recognized.[3]

In order to test this hypothesis, the Institute of Nautical Archaeology (INA, later formed by Bass as a non-profit research organization) conducted annual surveys of the Turkish coast, partly in search of another Bronze Age shipwreck, but also to record shipwrecks from other periods. As a complement to these surveys, INA team members interviewed Turkish sponge divers and taught them to identify ancient shipwrecks while diving for sponges. In the summer of 1982, a local sponge diver named Mehmet Çakır informed INA staff in Bodrum of his discovery of “metal biscuits with ears.” This was recognized as a description of “oxhide” ingots and was a sure sign of a Late Bronze Age site. The site, near the southern Turkish town of Kaş, was located 400 m from the terminus of Uluburun, Turkish for “Grand Promontory,” and about 60-70 m from its eastern face (fig. 1.1). Cape Gelidonya was situated just to the east (fig. 1.2). Archaeologists from INA and the Bodrum Museum of Underwater Archaeology investigated the site in 1982 to verify the discovery. They returned in 1983 to conduct a 10-day formal inspection, and raised representative artifacts including a copper bun ingot, a Canaanite jar, a wall bracket, and a pilgrim flask. All three pottery vessels seemed to be of Syro-Palestinian origin, although the wall bracket appeared to be

[3] Bass 1967, 164-7 and Bass 1973, 36-7.

Fig. 1.1 Uluburun, the “Grand Promontory.”
(Courtesy of Institute of Nautical Archaeology).

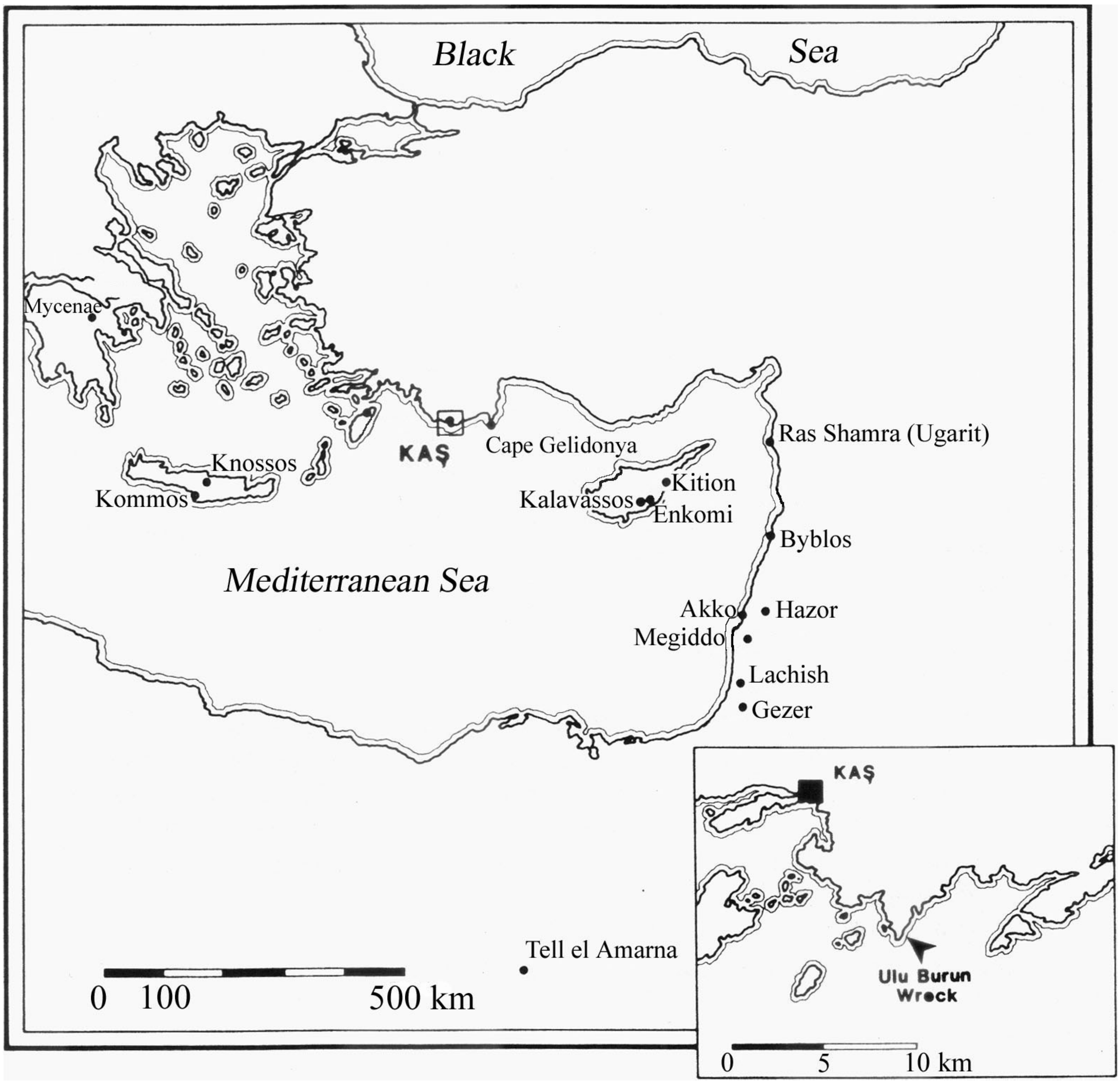

Fig. 1.2 Location of the wreck site in the eastern Mediterranean. (After Pulak 1997, 234, fig. 1).

Cypriot. A study of the artifacts suggested a date between the 15th and the first half of the 14th century B.C. for the wreck.[4]

The excavation campaign began in 1984 and for 11 consecutive summers, the Uluburun wreck was carefully excavated, first under the direction of Bass in 1984 and 1985, then under C. Pulak through to its completion in 1994. Visible artifacts were strewn down a steep, rocky slope from 44-52 m below the surface. Four distinct rows of copper oxhide ingots were arranged athwartships, suggesting that the ship came to rest with an approximate east-west orientation. Three stone anchors found in the deeper part of the site indicated that this area likely corresponded to the bow of the ship. The ship probably came to rest on the sea floor with a list to starboard, spilling its cargo around a large boulder-like rock outcrop just south of the second and third row of copper oxhide ingots and down the narrow gully that opened into an open sandy area at a depth of 52 m (fig. 1.3). All of the dispersed large pithoi, or storage jars, had their mouths pointing downslope as did many of the Canaanite jars found throughout the site, confirming the direction of the ship's list as it settled on the seabed.

The bulk of the cargo carried on the Uluburun ship consisted of raw materials, although some finished goods were also present. Approximately 10 tons of copper ingots and 1 ton of tin ingots were present, sufficient to yield 11 tons of bronze when alloyed. Other raw materials included discoid glass ingots, hippopotamus teeth, an elephant tusk, terebinth resin in Canaanite jars, ebony logs, and ostrich eggshells. Cypriot fine ware packed in large pithoi, faience drinking cups, copper and tin vessels,

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[4] Bass 1986, 270.

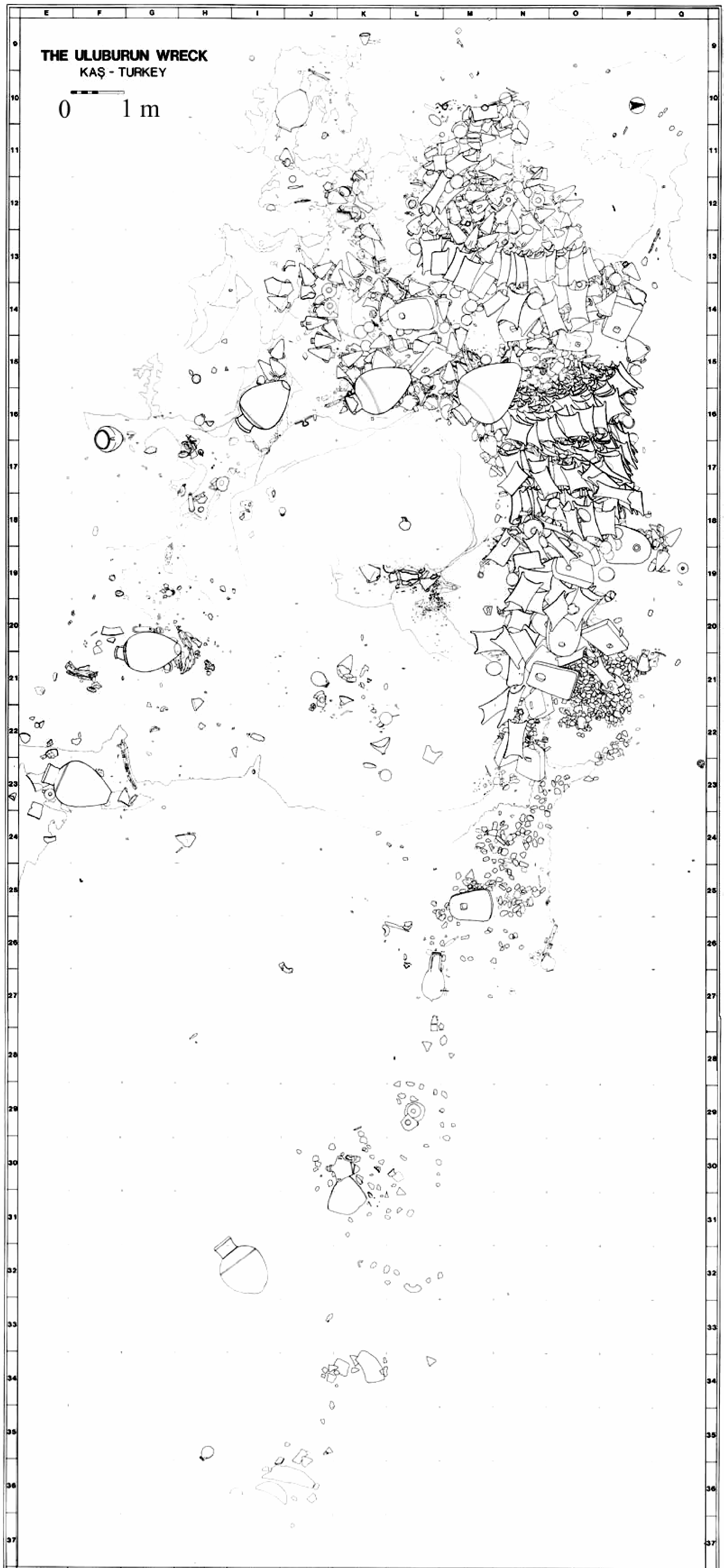

Fig. 1.3 Site plan following the 1992 excavation season.
(After Pulak 1998, 192, fig. 4).

ivory cosmetic containers, wooden containers, glass and faience beads and seashell rings were among the finished goods.[5]

Much of this cargo is associated with Syro-Palestinian traders as depicted iconographically on contemporary Egyptian tomb paintings and, textually with the trade items listed in the Amarna Letters.[6] In addition, many of the personal articles found in the wreck suggest that the cultural origin of the vessel was Syro-Palestinian; among them are a pair of bronze cymbals, a gilded bronze Canaanite female figurine, an ivory trumpet, two wooden writing boards, 150 pan balance weights in Near Eastern mass standards, 24 stone anchors of Syro-Palestinian form, and used oil lamps of the Syro-Palestinian type.[7] However, not all of the personal effects were of Syro-Palestinian origin: evidence for a Mycenaean presence, possibly in the form of officials or mercenaries, includes weapons, pottery, jewelry, and seals.[8] The majority of the evidence points to a Syro-Palestinian home port for the ship and corroborates the conclusions drawn from the Cape Gelidonya wreck, that people along the Levantine coast played a much greater part in Late Bronze Age maritime trade than previously realized.

The Uluburun excavation campaign was concluded in 1994. A total of 22,267 dives were logged during 11 years of excavation for an equivalent of 303.7 days spent

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[5] Pulak 2001, 13.
[6] Pulak 2001, 13-4; see also Pulak 1997, 239-41; Pulak 1988, 34-5; Bass 1986, 293-4. The Amarna Letters are a corpus of nearly 400 cuneiform tablets dating to the mid-14th century B.C. containing correspondence of the Egyptian court with rulers of neighboring states. These tablets give a rare glimpse into the royal social, economic and military transactions of the ruling and dependent states of the Levant. An updated English translation can be found at Moran, W.L., ed. and trans. 1992. *The Amarna Letters*. Baltimore: The Johns Hopkins University Press.
[7] Pulak 2001, 14; see also Bass 1986, 288-90 ill. 28; Pulak 1997, 244-5, 246, 252-3.
[8] Pulak 2001, 14; see also Pulak 1988, 37; and Pulak 1997, 253.

underwater.[9] Individual artifacts recovered number more than 5,000 items but three times that amount of material is now undergoing conservation in the conservation laboratory of the Bodrum Museum of Underwater Archaeology. The Uluburun shipwreck has produced the single largest assemblage of Late Bronze Age artifacts ever discovered and has brought to life the dry lists of the Amarna Letters and the still paintings of Egyptian tombs. Dendrochronological dating of a freshly-cut piece of firewood or dunnage carried on the ship provides a date of 1305 B.C., making the Uluburun ship the world's oldest known shipwreck.[10]

Evidence for Reconstruction of Hull

Hull preservation is limited to three main sections. The largest piece, section 1, measures 1.8 x 1.0 m, and includes a portion of the keel, starboard garboard, port garboard and two port strakes (fig. 1.4).[11] It was found on the site's only relatively flat and sandy area, located between the uppermost and the second rows of copper oxhide ingots (fig. 1.5). The weight of the stone anchors and the displaced copper oxhide ingots pushed this section into the sand that had collected on this flat portion of the cliff face. Section 2 consisted of four poorly preserved starboard strakes measuring 1.1 x 0.85 m. A drop strake was found in this section, indicating that the planking was narrowing towards the bow and that some of the strakes would eventually come to an end, or

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[9] A recalculation of the total number of dives has been conducted since the number of 22,413 published by Pulak (1997, 235). The difference is due to the inclusion of the survey dives at the conclusion of the excavation season in the original count.
[10] Pulak 1998, 214. For further discussion, see Pulak 2001.
[11] For a more detailed discussion of the hull remains and ship construction, see Pulak 1999 and 2003.

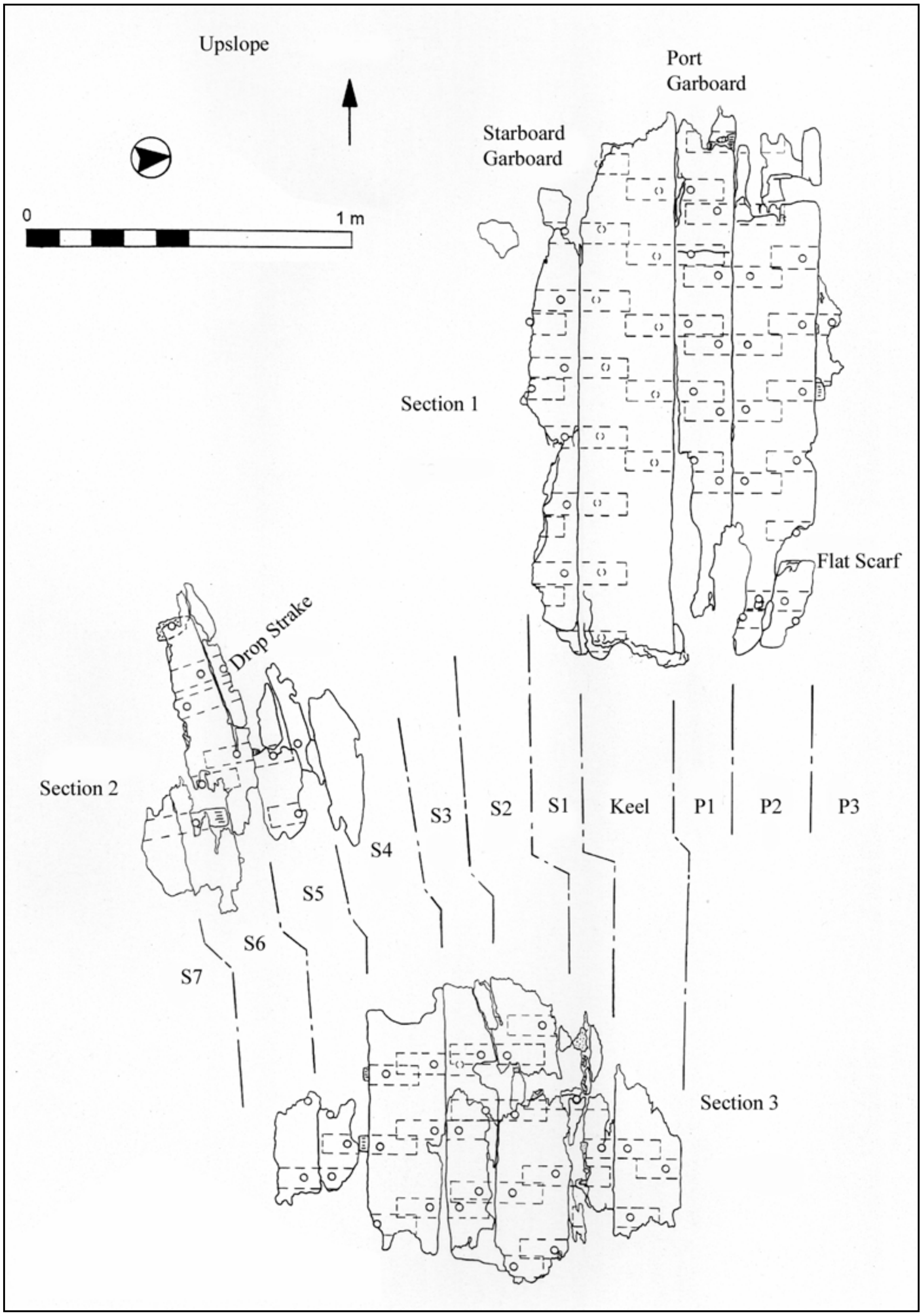

Fig. 1.4 Preserved fragments of the Uluburun hull.
(After Pulak [forthcoming]).

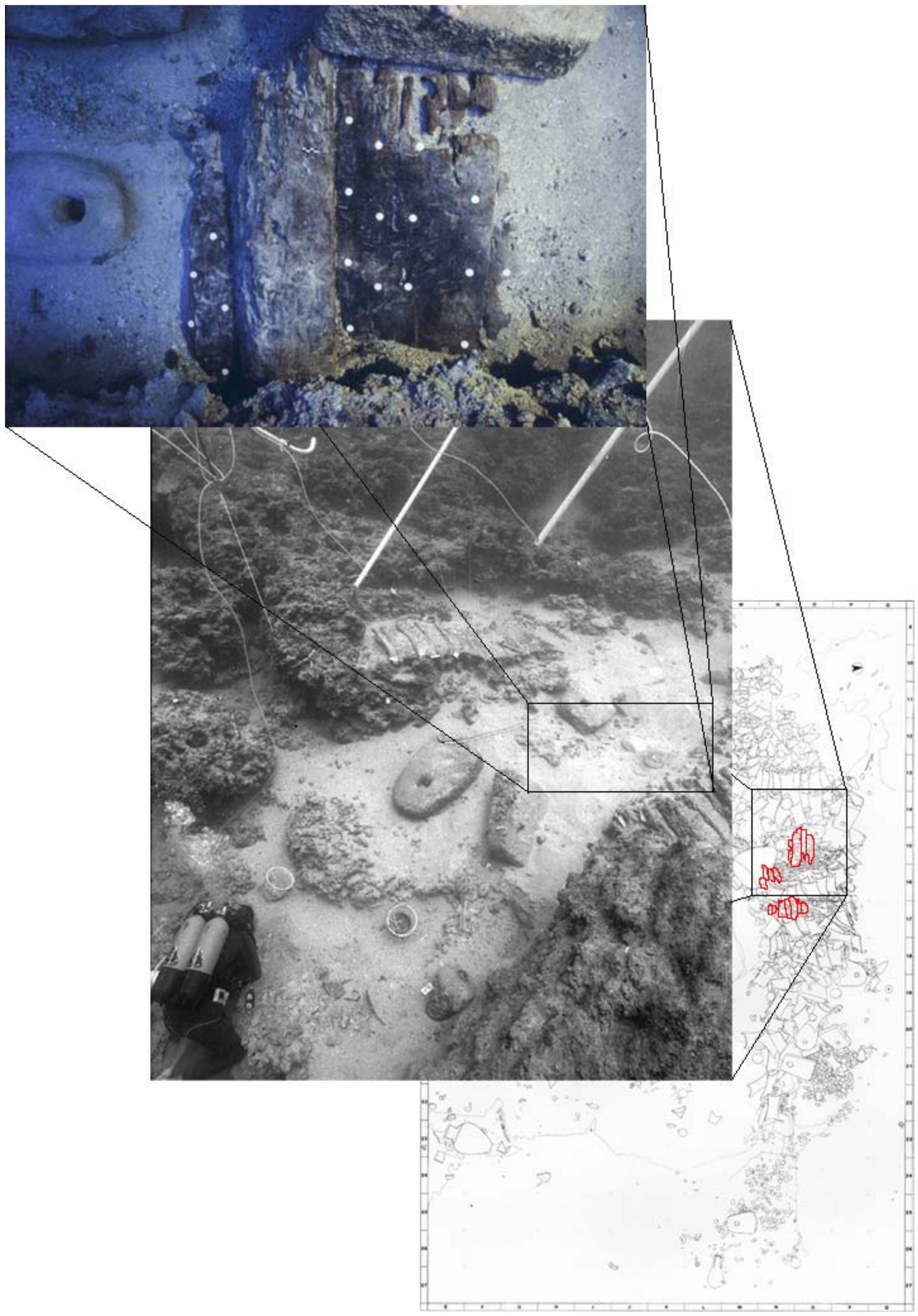

Fig. 1.5 Location of hull fragments on wreck site. (Compiled from photographs courtesy of Institute of Nautical Archaeology).

"dropped." The keel also appears to narrow towards the bow, and presumably in the stern as well, as the preserved portion in section 3 indicates. In this area, the keel measures only 22 cm sided as opposed to 28 cm in section 1, a reduction of about a quarter of its maximum width. The amount by which the keel would have eventually narrowed toward the extremities cannot be determined at present from the extant remains. Six starboard strakes accompany the keel in section 3 and seem to parallel the alternation of strake widths as seen in section 1. Sections 2 and 3 were found underneath the second and third rows of copper oxhide ingots, respectively. The slowly disintegrating copper ingots created a toxic environment that deterred marine borers from destroying the fragments of hull in direct contact with the rows of ingots. There is a fourth section of preserved hull, but these fragments are damaged and completely disarticulated, rendering them less meaningful.

Although it is regrettable that so little of the hull was preserved, some important aspects of the ship's construction were nevertheless revealed by the scanty remains. Sections 1 and 3, which include sections of the keel, has revealed that instead of protruding into the water beyond the planking as in most wooden hulls, the keel of the Uluburun ship extends upward into the hold. The top of the keel is 10 cm higher than the inboard surface of the garboards. Originally, the garboards were thought to have been displaced by the weight of the cargo, since they are usually at the same level as the interior surface of the keel on ancient Mediterranean hulls. After closer inspection, no evidence was found that suggested they were originally fastened to the upper portions of the keel. Since the garboards are 10 cm thick on their keel face and taper to 6.0-6.5 cm at their outboard edge, only an estimated 2 cm of the keel protrudes beyond the planking on the exterior of the hull. This robust proto-keel provided longitudinal strength for the vessel and protected the lower planks when beaching or hauling the vessel ashore. Unlike a true keel, however, it would not have helped the ship to hold course or to point nearer the wind when sailing against contrary winds.[12]

The keel fragment in section 3, shows another transition in the ship's form, in addition to the narrowing width of the keel. The distance from the inboard surface of the keel to the garboard diminishes to 3 cm. While the keel and garboard have not been preserved to the full extent of their outboard surface in this section, this diminishing gap seems to suggest that the keel protrudes below the garboard at the extremities of the ship. This is reminiscent of Queen Hatshepsut's Punt ships (ca. 1460 B.C.) painted on the temple walls of Deir el Bahari, where the keel is believed to taper to a thin sliver amidships (although this is not shown in depiction), but gradually extends well beyond the planking and terminates in the large end posts at the bow and stern.[13] A Late Bronze Age boat model from Byblos corroborates the assumption that the keels of ancient Egyptian ships projected inwards, with only a small protrusion below the planking amidships (fig. 1.6).[14]

[12] Pulak 1999, 216; see also Wachsmann 1998, 241-3 and Hocker 1998, 245-6.
[13] Pulak 1999, 223. Other boat models with similar keel features come from the tombs of Amenhotep II (ca. 1400 B.C.) and Tutankhamun (ca. 1330 B.C.).
[14] Both Pulak (1999, 224) and Wachsmann (1998, 53) agree that even though this model was found in Byblos, it is actually a representation of an Egyptian vessel.

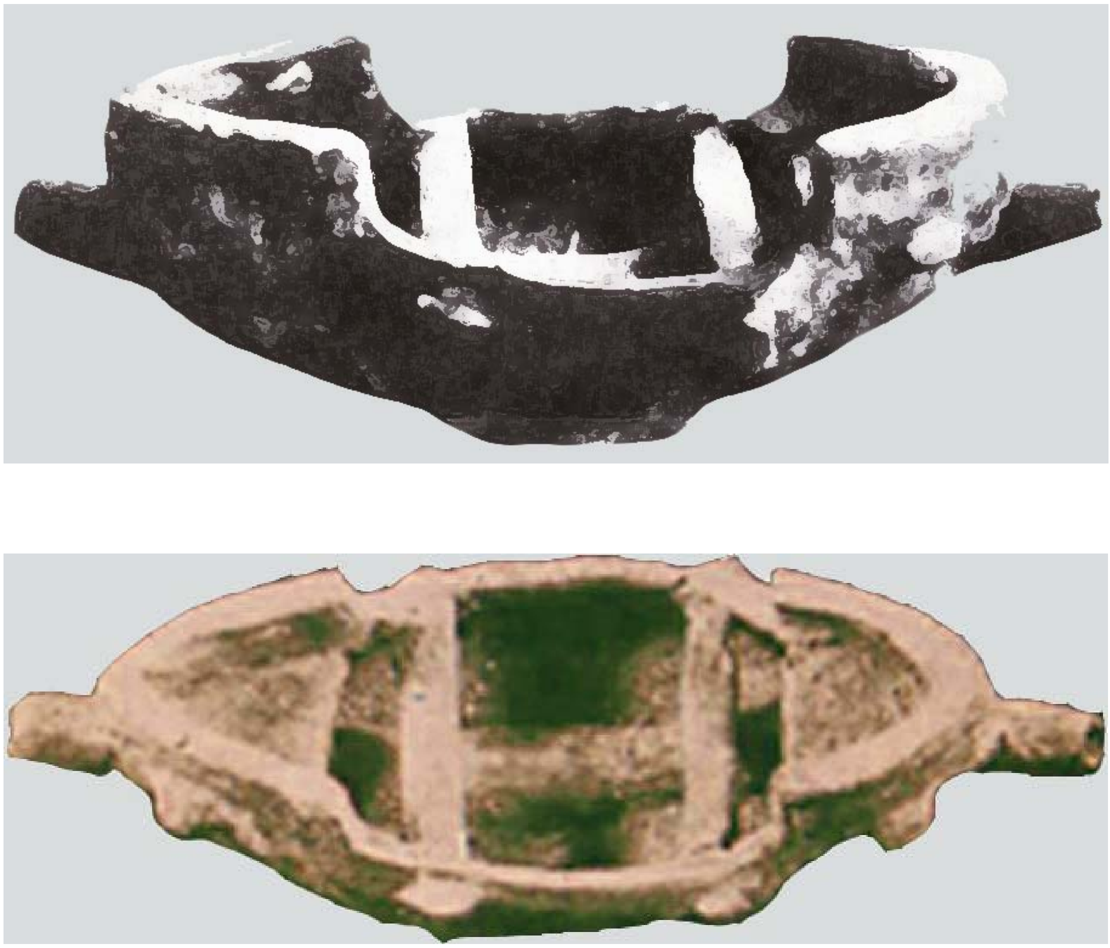

Fig. 1.6 Late Bronze Age boat model from Byblos showing internal keel projection. (After Basch 1987, 67, fig. 122).

Project Tools

The most essential tool in this reconstruction project was the site plan. During excavation, each of the more than 5,000 artifacts was carefully measured from at least three fixed datum points using trilateration to record its position on the seabed before being removed. These data were then graphically recorded on a site plan, drawn at 1:10 scale. The site was divided into 1 x 1 m grids and labeled alphabetically along the transverse axis and numerically on the longitudinal axis on the site plan. Each grid was subdivided into four 0.5 x 0.5 m squares, designated upper left (UL), upper right (UR), lower left (LL), and lower right (LR). A final division of each subset into four quadrants (1, 2, 3, 4) allowed an alphanumeric coordinate to be assigned to each artifact to indicate its general location in the grid system, in addition to the precise measurements from trilateration (fig. 1.7). The importance of an exceedingly accurate visual record of the site and the positions of the recovered artifacts should not be understated. Not only did the site plan facilitate an overall understanding of the general layout of the site, it was also critical in the creation of distribution maps of various artifacts group, in order to reconstruct the hypothetical original placements of the displaced cargo.

A preliminary set of lines for the vessel (fig. 1.8) were drafted at 1:20 scale based on the recovered hull remains, the distribution of the cargo, and Egyptian iconography showing Canaanite ships.[15] The lines represent a vessel with an estimated capacity of 20 tons to accommodate all of the cargo and shipboard items such as anchors and ballast stones. Estimates of the weight of the ship itself and possible perishable cargo is

[15] I thank Wendy van Duivenvoorde for sharing her drawings with me for use on this project.

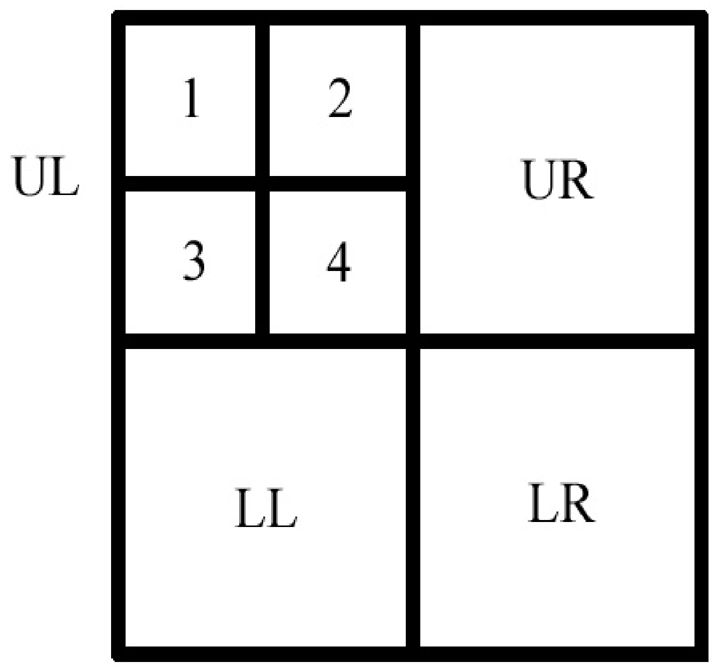

Fig. 1.7 Example of a 1 x 1 m grid square.

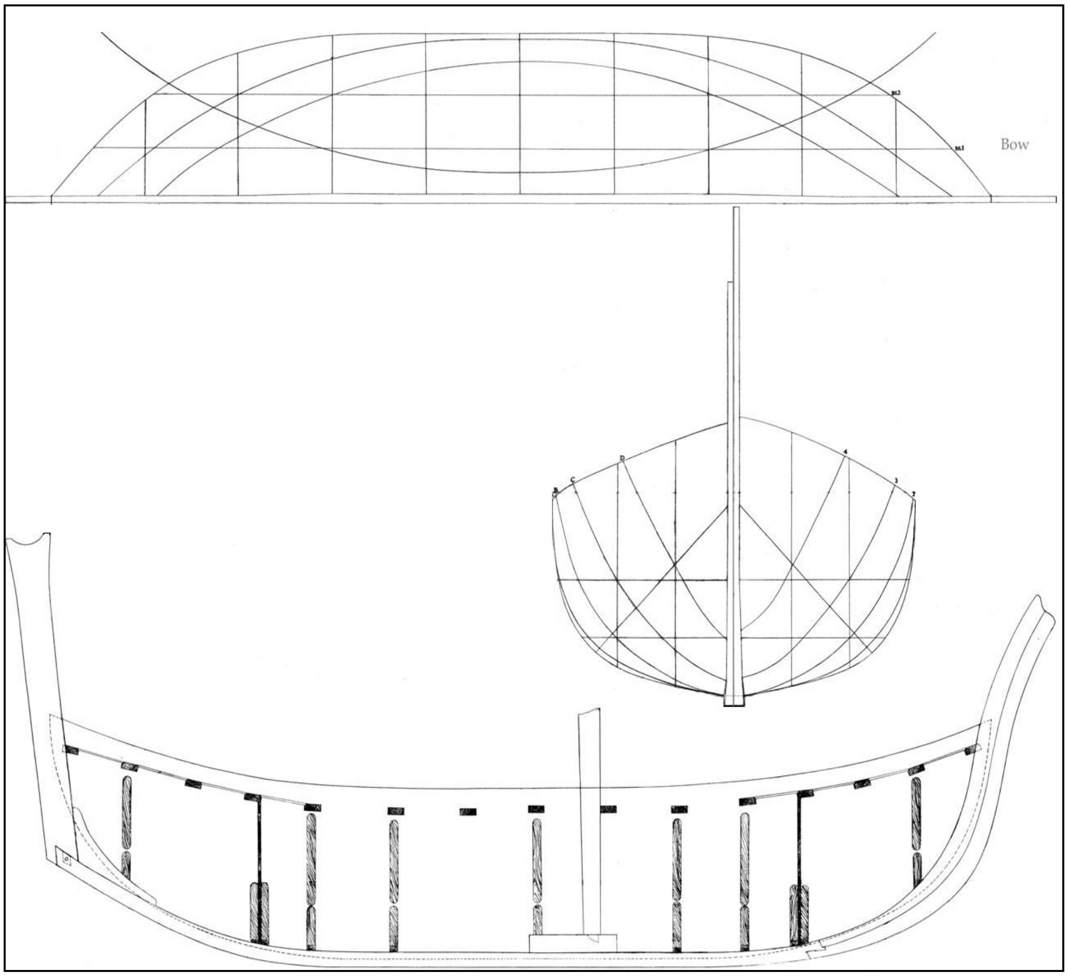

Fig. 1.8 Hypothetical lines and construction drawing of the Uluburun ship. Length between perpendiculars is 15 m. (W. van Duivenvoorde).

discussed in chapter VII. Although the lines for the Uluburun ship were based on only two to three percent of the actual hull, it provides a hypothetical hull shape in which different cargo arrangements can be tested.

From these lines, a 1:10 scale model of the ship (1.5 m long) was built to visually test the various lading configurations for the cargo (fig. 1.9). The lines drawing was enlarged to the proper scale and the station lines for the hull were cut and pasted onto plywood. The portion of the lines representing the interior of the hull was then cut, leaving a roughly U-shaped section of plywood corresponding to the different station lines. Because the lines drawing represented the inner surface of the planking, the sections were cut an extra 2 mm beyond the lines to accommodate the strips of balsa wood used to form the hull. The keel and end posts were fashioned from solid pine, scaled and cut to the correct size and glued together at locations representing hypothetical scarves used on ships of similar construction.[16] The plywood hull sections were cut to accommodate the keel and were lined up in their respective positions following the lines drawing. Since only the interior volume of the ship was needed for configuring its lading, no effort was made to represent the planking accurately or to assemble it with mortise-and-tenon joinery as observed in the surviving hull timbers. Strips of balsa wood, 2.5 cm wide and 0.2 cm, thick were laid across the plywood sections to represent the interior surface of the planking. The resulting working model was simple, light, easy to manipulate, and sturdy due to the cradle-like external structure.

[16] The scarves were modeled after the forward scarf on the Kyrenia ship. (Steffy 1994, 45, fig. 3.24).

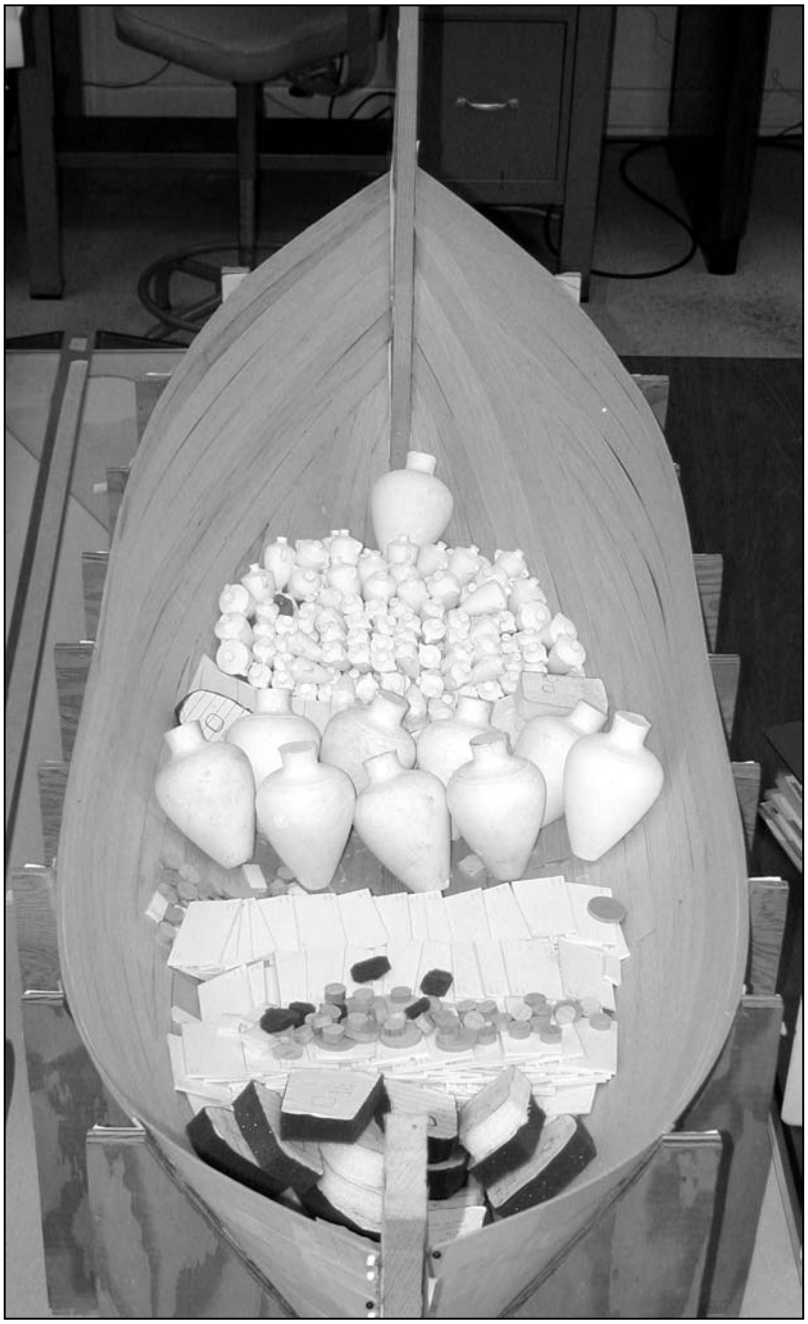

Fig. 1.9 1:10 scale model of the interior of the hypothetical hull no. 1 with keel and end posts.

Scale models of the artifacts were made and positioned in the hull to quickly evaluate different stowage arrangements. Items pertinent to the study include 354 copper oxhide ingots (approximately 10 tons), 152 complete and fragmentary copper bun ingots (nearly 1 ton), 110 tin ingot fragments (approximately 1 ton), 175 glass ingots (approximately 0.3 tons), 150 Canaanite jars (approximately 2 tons if filled with water), more than 51 pilgrim flasks in various sizes, 10 large storage jars or *pithoi* (approximately 3.5 tons if filled with water), nearly 1 ton of ballast stones and 24 stone anchors (3.3 tons).[17] Because the weight distribution and trim was calculated with a computer program, the model artifacts were constructed using a variety of materials regardless of their density. These physical models proved very useful as a tangible way to load and shift the cargo, and develop an overall impression of the ship. To assist in making general estimates about the trim of the vessel, a single plywood board with the same length as the scale model and roughly 8 cm in width was placed on a pivot at the ship's center of buoyancy (approximately amidships). To simulate the center of gravity of each artifact group, pennies, each representing 200 kg of cargo, were stacked along the length of this board at the longitudinal center of gravity (LCG) of each pile of cargo, for example, the four rows of copper oxhide ingots, pithoi, and Canaanite jars (fig. 1.10). Using this rough working model, it quickly became evident which lading arrangement resulted in a gross imbalance in the ship's trim. Once a reasonable arrangement was achieved, computer aids were used for more precise numerical results, as discussed below.

[17] Pulak 2001, 13.

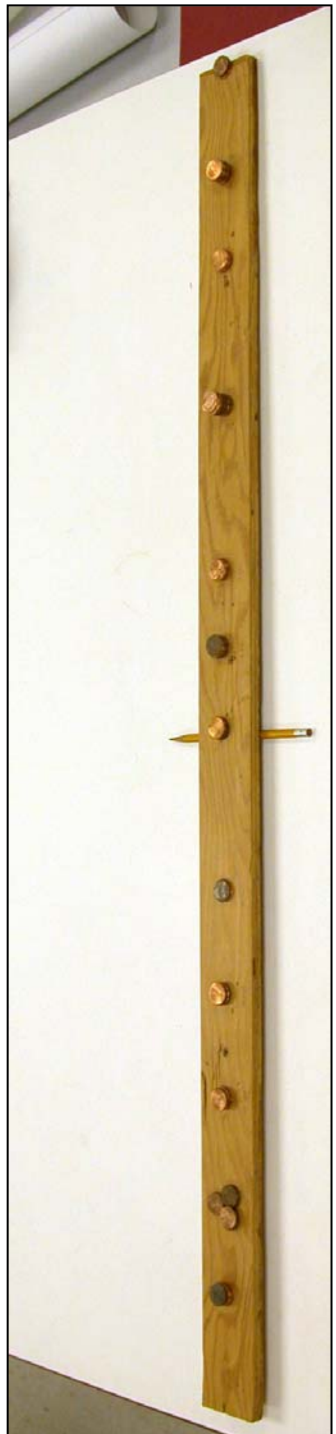

Fig. 1.10 See-saw arrangement used to estimate the trim of the vessel.

To aid in the presentation of the ship and the different lading configurations of the cargo, three-dimensional models of the hull and all relevant artifacts were constructed in Rhinoceros, a non-uniform rational b-splines (NURBS) modeler for Microsoft Windows-based systems.[18] It is not feasible to create physical models for all the artifacts, but three-dimensional computer models can be made quickly, and can be reproduced to give a better representation of the ship and its cargo. More importantly, Rhinoceros is able to calculate both the volume and area centroid for any object or group of objects created with the program. These data are important, as shall be shown, in calculating the flotation and stability characteristics of the ship. Overall, Rhinoceros was a good choice as a three-dimensional modeling program because the learning curve was relatively low compared to other programs. Many tutorials are available on the Internet to help familiarize the user with the program, and it is a relatively inexpensive solution considering its modeling capabilities.

The greatest advantage of using Rhinoceros was a plug-in called Proteus Hydrostatics & Stability Engine for Rhinoceros (PHASER), created by Proteus Engineering, a company that develops custom software specifically designed for naval architecture applications.[19] This program provided Rhinoceros with the ability to perform the computations necessary for this study. PHASER is designed to calculate the intact hydrostatics and righting moment curves for a hull surface generated in Rhinoceros. Flotation can be entered as a range of waterline heights, a waterline height

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[18] For more information about Rhinoceros, visit their website at www.rhino3d.com. A free demonstration version of this program can be downloaded from their website. It is fully functional and allows 25 saves.
[19] For more information about PHASER and Proteus Engineering, visit their Web site at www.proteusengineering.com.

and trim angle, or displacement and center of gravity. The data can be put out in tables and graphic charts as a HTML file or a Microsoft Excel spreadsheet. It is also possible to have Rhinoceros move the modeled ship to the resultant flotation plane to graphically represent the results of the entered data.

Lastly, a spreadsheet program like Excel is needed to compile all the data produced by Rhinoceros for input into PHASER. Currently, PHASER is unable to deal with more than one center of gravity (*cg*) value at a time, so that value must be established independently within Rhinoceros for objects of different weights and averaged out by hand or using a spreadsheet program such as Excel to find the cumulative *cg* for the ship with the loaded cargo. It is this final value that is entered into PHASER, in order to calculate the new flotation plane.

Discussion

With the proper tools, a well-documented shipwreck, and a working knowledge of the principles behind ship reconstruction, even a very poorly preserved hull can contribute to a better understanding of construction techniques, seafaring practices, and shipbuilding traditions. Despite the increasing dependence on sophisticated computer technology to accomplish these goals, the tools would be useless without a solid foundation of archaeological methods and theory. While the use of Rhinoceros and PHASER significantly simplified the hydrostatic and stability calculations and reduced the turn-around time between entering new information and calculating the results for the Uluburun ship project, the data used were generated through many years of meticulous excavation and measuring followed by years of conserving, restoring, and studying the recovered artifacts. This study would not have been possible, or at least greatly degraded in validity, without a great investment of time and resources devoted to carefully recording the artifacts while on the seabed and piecing together sometimes hundreds of sherds to reconstruct even the smallest of the pottery carried on the ship. Computer technology can enhance, but not replace, the archaeologist's adherence to principles of common sense, detailed recordkeeping, and comprehensive documentation. This study is a tribute to those whose diligence made it possible.

CHAPTER II

METHODOLOGY

Identifying the Obstacles

The greatest handicap in trying to reconstruct the Uluburun ship is the glaring poverty of physical hull remains. As discussed in chapter I, only three small sections of the ship survived. Based on the estimated size of the vessel (explored in detail later in this chapter), the preserved portions consist of only two to three percent of the entire ship.[1] These data are not sufficient for a reliable reconstruction by any means and relegate all results to being hypothetical. By comparison, other reconstructed shipwrecks were better preserved: for example the fourth-century B.C. Kyrenia ship had an estimated 60 percent of its original hull preserved;[2] the seventh-century Yassıada wreck 10 percent;[3] the 11th-century Serçe Limanı wreck 20 percent;[4] and the 11th-century Skuldelev ships in Denmark 20 to 85 percent.[5]

Not only is there little physical evidence for the general aspects of the Uluburun ship, such as overall length and beam, but specific features of the ship's structures, with the exception of the short portions of keel and few adjoining strakes, are also absent. The ship is assumed to have had a mast and rigging for propulsion but no evidence of these was found. No trace of the mast step was found, nor was there any indication

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[1] Rhinoceros calculates the proposed hull planking as having a volume of 5.198 m^3, the keel and end posts as 1.782 m^3, and the preserved portion of hull as 0.207 m^3. Thus, 0.207 divided by 6.980 is approximately three percent.
[2] Steffy 1994, 43.
[3] Steffy 1994, 215; see also Bass and van Doornick 1982, 32-86.
[4] Steffy 1988, 3.
[5] Crumlin-Pedersen and Olsen 2002, 136 (Skuldelev I 70 percent), 176 (Skuldelev II 20 percent), 240 (Skuldelev III 85 percent), 301 (Skuldelev VI 75 percent).

among the surviving hull fragments of a mast step attached to the keel. This makes identification of the midships area difficult. Not knowing where midships is located increases the difficulty of efforts to trim the vessel, since the center of gravity, roughly located amidships, acts as the pivot for the weight of the cargos. Depending on where the pivot is located, the leverage exerted by the cargo at the extremities will vary greatly.

Other aspects of the ship's interior that affect cargo stowage are also unknown. Whether or not the ship was fitted with a full deck or only partial decks at the bow and stern can only be surmised. No frame timbers were found, and it is uncertain if any bulkheads were used to separate the hold to carry certain types of cargo or equipment. Even where fragments of the hull survive, the sections do not line up with one another, obscuring the longitudinal axis of the ship as it settled on the seabed. This may be related to the next major problem—the violent stages of breaking up of the ship throughout the wreck-formation process.

Had the ship come to rest on a level sea floor, reconstructing the lading of the vessel would be vastly simplified. Unfortunately, the steep angle of the seabed caused much of the cargo to be displaced, often without leaving a trace of its original position on the ship. The problem is compounded by the fact that the wreck experienced at least three separate episodes of violent deterioration after it landed on the seabed, with the cargo drastically shifting each time.[6] Although the details of each of these episodes cannot be systematically outlined, they are hypothetically reconstructed as follows: 1) when the ship first came to rest with a list to starboard, spilling some artifacts directly

[6] According to Pulak (personal communication), a Canaanite jar found on the site revealed three separate and distinct layers of concretion, indicating at least three major shifts of the cargo.

down the slope due to the angle of the seabed, while others tumbled over the starboard side;[7] 2) because only portions of the hull, primarily the extremities, were supported by the cliffs and ledges of the sea floor, the vessel experienced sagging, as if suspended between two wave crests (fig. 2.1). As the pressure of the cargo weakened the hull, a "catapulting" effect may have thrust some of the artifacts carried in the stern towards the deeper end of the site when the keel eventually snapped;[8] 3) once the hull disintegrated through marine borer activity and other factors, the objects spilled beyond the hull. This is most evident in the bow. If the bow had not disintegrated completely, the original disposition of the anchors and ballast stones would be much better understood. Cumulatively, these three events require an assessment of whether certain types of cargo and specific objects were originally stored in the forward section of the ship or simply settled there as a consequence of the site formation process. For artifacts believed to have been originally stored in the stern, questions remain as to their precise location in the after section of the ship.

Lastly, while some 20 tons of artifacts were recovered during the excavation, an unknown quantity of cargo undoubtedly vanished. Evidence of organic items carried on the ship, including foodstuffs, ebony logs, terebinth resin, orpiment, murex opercula, spices and condiments, have survived only through fortuitous circumstances.[9] The quantity of these items originally transported on the ship will never be known. Other

[7] While the list has been measured at 15 degrees based on the excavation of the keel (Pulak 1999, 209), the after portion of the ship probably experienced a much greater amount of listing to allow the cargo to spill outward the way it did.
[8] Pulak, personal communication.
[9] For a detailed list of the spices and condiments found, see Pulak 2001, 36-7.

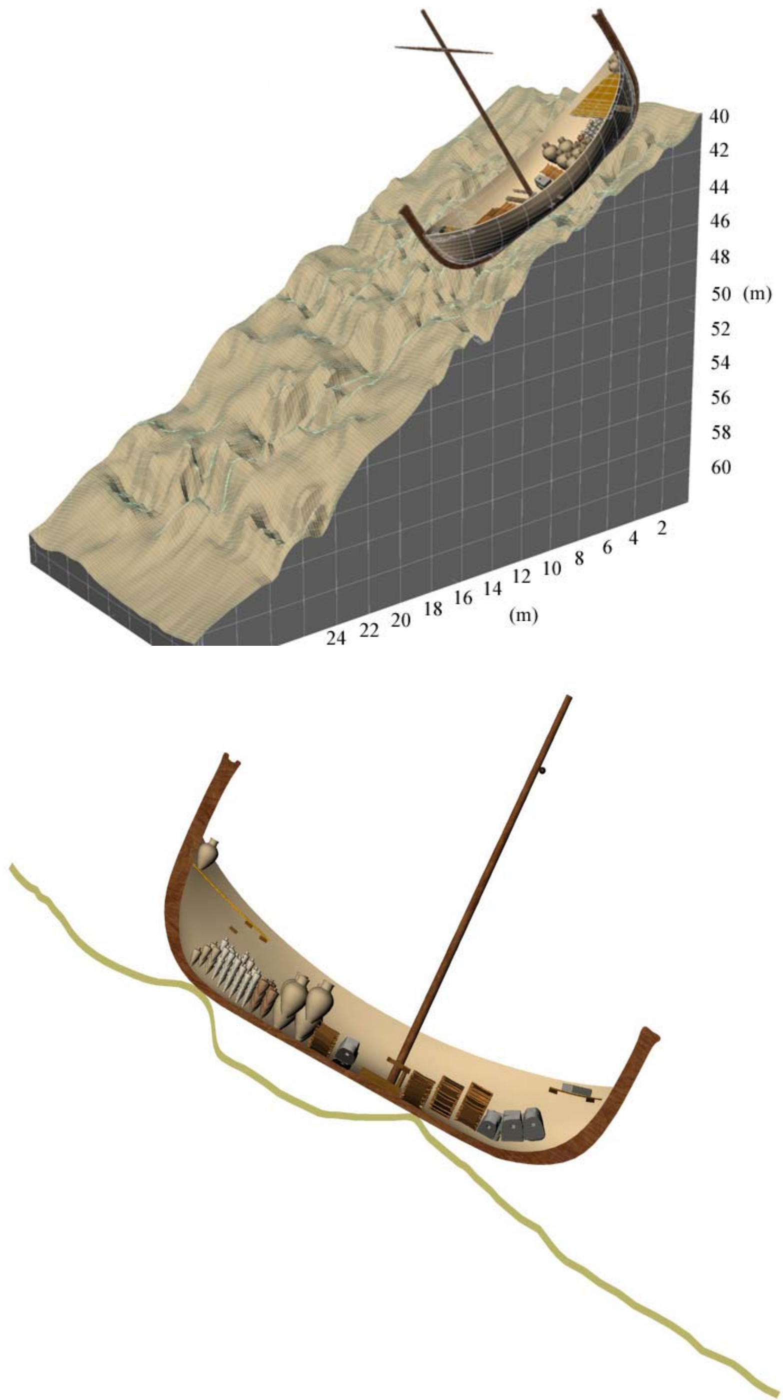


Fig. 2.1 Views of the hypothetical ship on the seabed.

items whose presence has been inferred include wine, olive oil, textiles, and grains.[10] Even metal artifacts that survived largely intact, such as the copper ingots, lost an unknown amount of metal due to corrosion.[11] Assuming that an estimated 5-18 percent of metal was lost per ingot,[12] any trim calculations performed will be questionable.

The reduction of ingot weights due to corrosion only exacerbates the foremost problem regarding the trim of the vessel—it is clear that three of the four rows of copper oxhide ingots were located in the forward section of ship. As found, there is not enough cargo in the stern of the shipwreck to balance the tremendous load of copper ingots, stone anchors, and ballast stones carried in the bow. This study will explore the problems discussed hitherto that have produced this seemingly unbalanced disposition of the cargo and attempt to reconstruct the original position of these artifacts.

Identifying the Parameters

Despite the apparent lack of evidence for a reconstruction of the Uluburun ship and the lading of its cargo, the meticulous methods employed during the excavation yielded enough clues for a reasonable conjecture on certain key characteristics of the hull and the placement of cargo. Also, the assumed cultural origin of the ship as a Near

[10] Pulak 2001, 35-7, 44.
[11] Pulak 2000b, 141.
[12] Following Pulak's assumption (2000b, 140) that these ingots originally weighed about one talent (28-29 kg), and using the mean weight of the measured 165 ingots, the difference in weight is about 18%. Since some of the ingots were clearly less than the projected weight of one talent, an arbitrary figure of 25 kg is used as the lower range of this calculation, yielding roughly 5% metal loss.

Eastern, possibly Syro-Canaanite or Cypriot merchantman,[13] helps to identify appropriate representations of similar hull types.

Near-contemporaneous depictions of Near Eastern merchant ships include Egyptian wall paintings (fig. 2.2 and 2.3) and various clay models (fig. 2.4) from the Late Bronze Age and later periods. From these examples, several common features are observed. These ships are double-ended vessels with a mast carrying a square sail located near midships and steered by two quarter rudders. Through-beams are spaced uniformly along the length of the hull and weather fencing runs along the full length of the sheer strake. The keel protrudes inside the hull rather than outside towards midships, and narrows towards the extremities.

The wall paintings and models, however, do not depict reliably the sizes of such ships. This crucial information was deduced from the distribution of artifacts on the site. Much of the approximately one ton of ballast, consisting of roughly fist-sized cobbles, was found at the deeper end of the wreck, clustering in grid squares O to P20-22. The trail of displaced copper oxhide ingots also ends at the same depth in grid square N22, and all artifacts downslope from this point were clearly spilled beyond the confines of the original vessel. Therefore, it is assumed that the bow of the ship was located somewhere near grid square 21, or possibly slightly higher in grid square 20 (assuming that all objects slid downhill at least 1 m).

The position of the stern of the ship is more difficult to define. The bulk of the cargo ends upslope of grid square M10 but the ship must have extended farther upslope

[13] Pulak 2001, 13-7; see also Bass 1986, 293-6; Pulak 1988, 34-7; 1997, 252-6; 1999, 223-5.

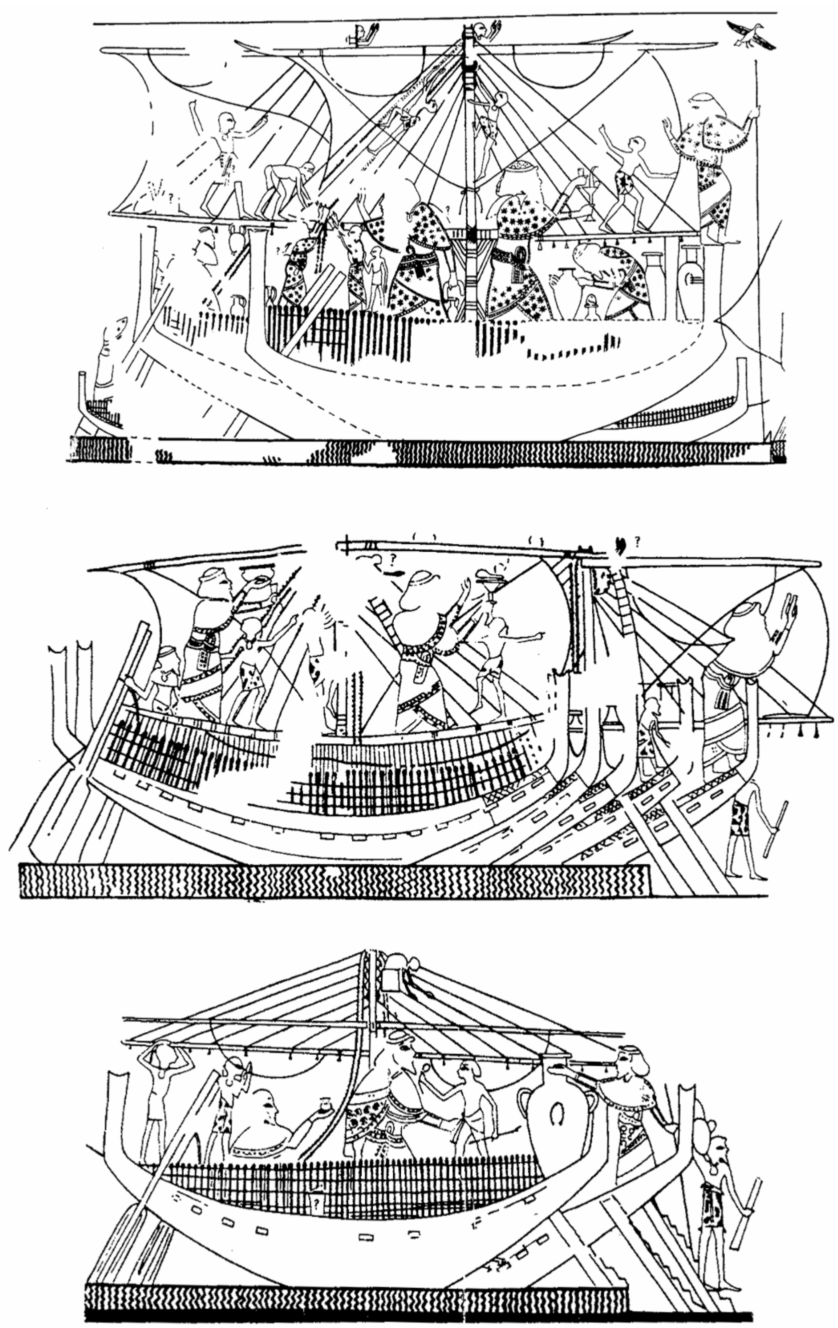


Fig. 2.2 Egyptian wall painting from the 18th-dynasty tomb of Kenamun showing Syro-Canaanite ships. (From Wachsmann 1998, 43-4, fig. 3.4, 3.5, and 3.6).

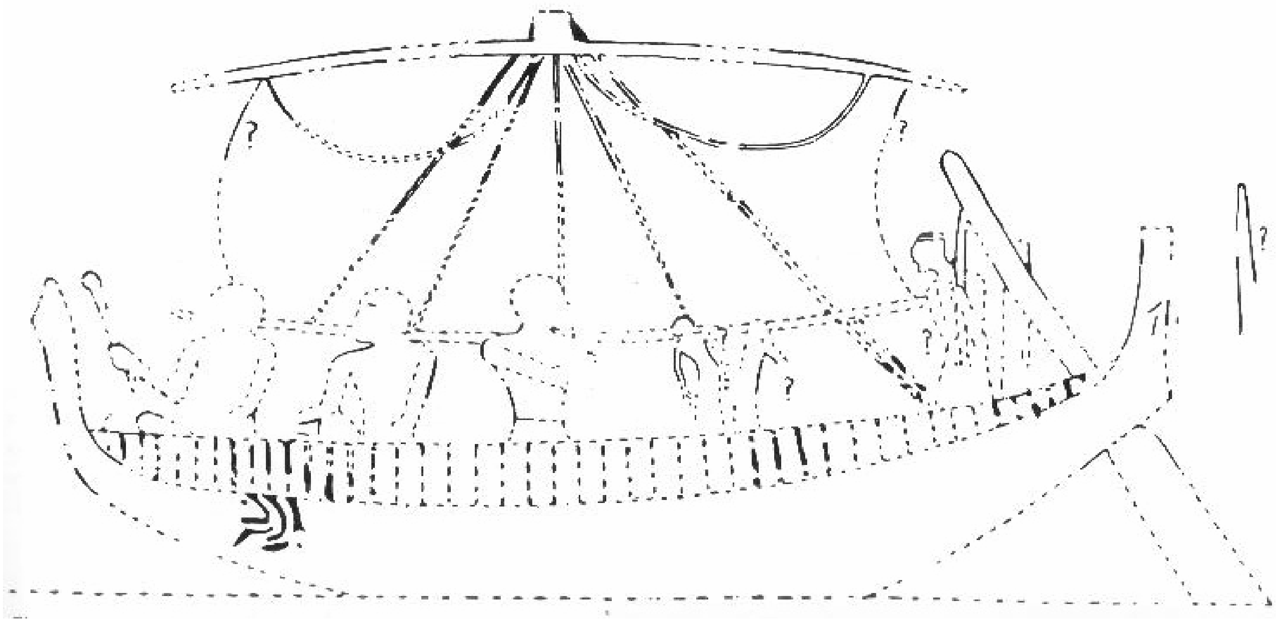
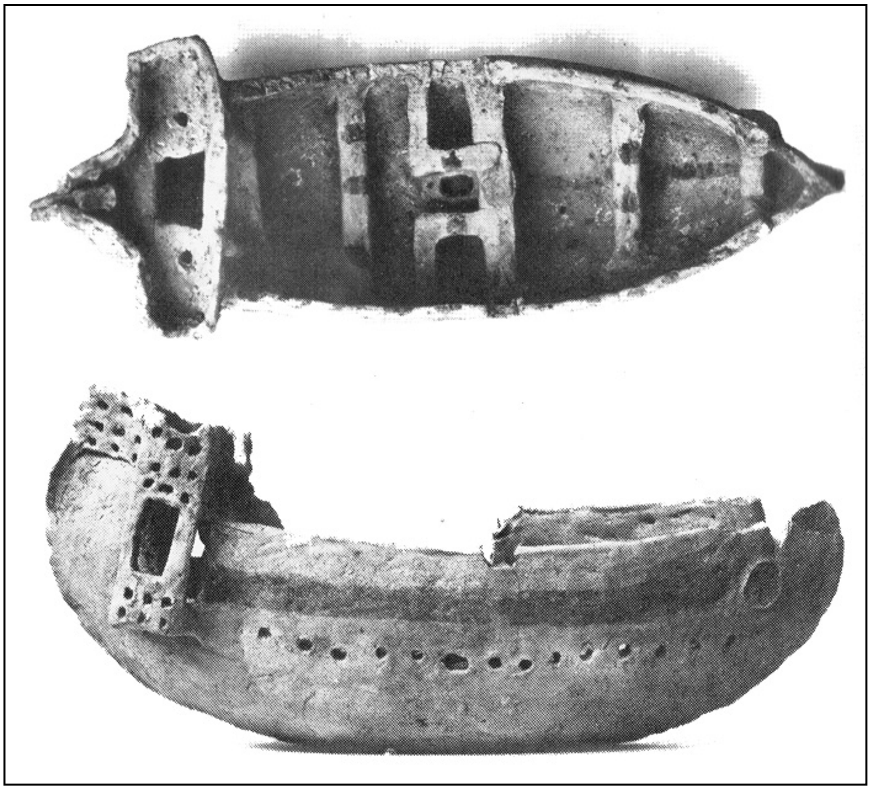


Fig. 2.3 Egyptian wall painting from the 18th-dynasty tomb of Nebamun showing a Syro-Canaanite ship. (From Wachsmann 1998, 47, fig. 3.9).



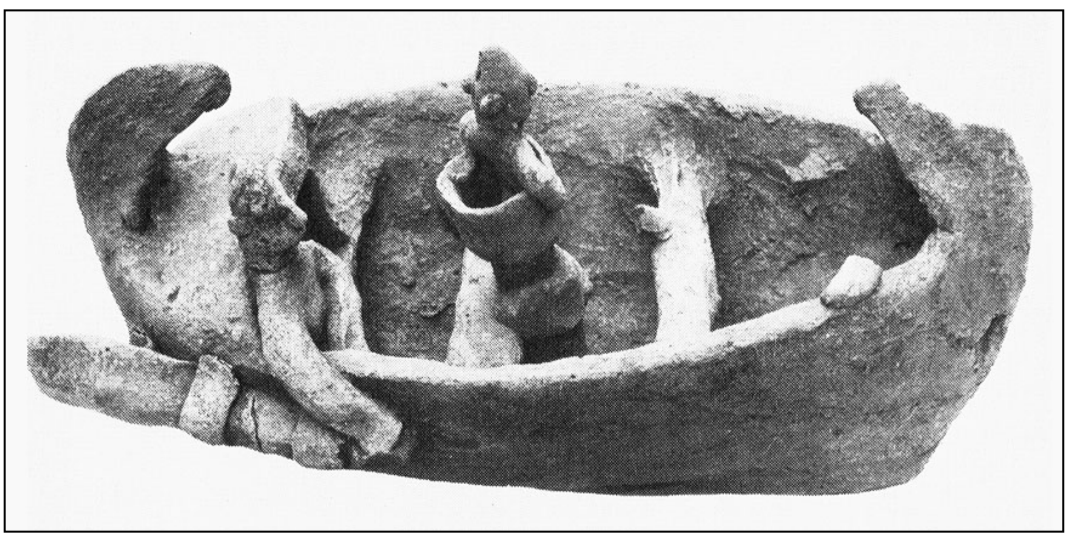


Fig. 2.4 Clay models from Cyprus possibly similar to the Uluburun ship in historical period and general hull form. The upper model measures L. 31 cm, W. 9 cm, H. 7 cm (After Westerberg, 1983, 28, 102, Fig. 32). Lower model measures L. 30 cm, W. 14 cm, H. 10 cm (From Westerberg, 1983, 22, 95, fig. 23).

to explain the position of the artifacts found in grid squares I10 and J10. Because the ship landed on a steep slope with a gradient varying between 30 and 45 degrees, artifacts could not spill out horizontally as the ship listed to starboard. Rather, the objects tumbled out diagonally down slope as demonstrated by the trajectory of the Canaanite jars and, more convincingly, a pair of finger cymbals that would have been stored together but were found apart in grid squares M10LL2 and K12UL4 (fig. 2.5).[14] Following this path, the various objects found in squares I10 and J10 were probably originally located in square M9 or higher. A sword, trident, and blade found in square K9 may indicate that the terminus of the vessel extended even farther into squares M8 or M7. From this distribution, a length of approximately 15 m is estimated for the ship. Since merchant ship were rather beamy, an average length-to-beam ratio of 3:1 gives a beam of 5 m.[15] This figure is supported by the distance of approximately 5 m between the stone anchor in square P14 and the southern end of the first row of copper oxhide ingots in square L13.[16]

Assuming that this vessel had a mast and support structures including a mast step and mast partners, it is possible to determine the general area in which they would have been located. It has already been established that most of the anchors were stored towards the bow of the vessel, which means that the mast must have been situated aft of them, or somewhere farther upslope. Immediately aft of the anchors are three rows of

[14] Pulak, personal communication.
[15] A number of merchant vessels excavated display this length-to-beam ratio, e.g. the Kyrenia ship (13.86 x 4.2 m), the Serçe Limanı wreck (15.36 x 5.12 m), and Skuldelev Wreck I (16.5 x 4.5 m). Steffy 1994, 55, 87, 110.
[16] The port end of row 1 is not used in this estimate because, as will be discussed in depth in chapter IV, the ingots on that side shifted towards the center of the ship, slightly compressing the row.

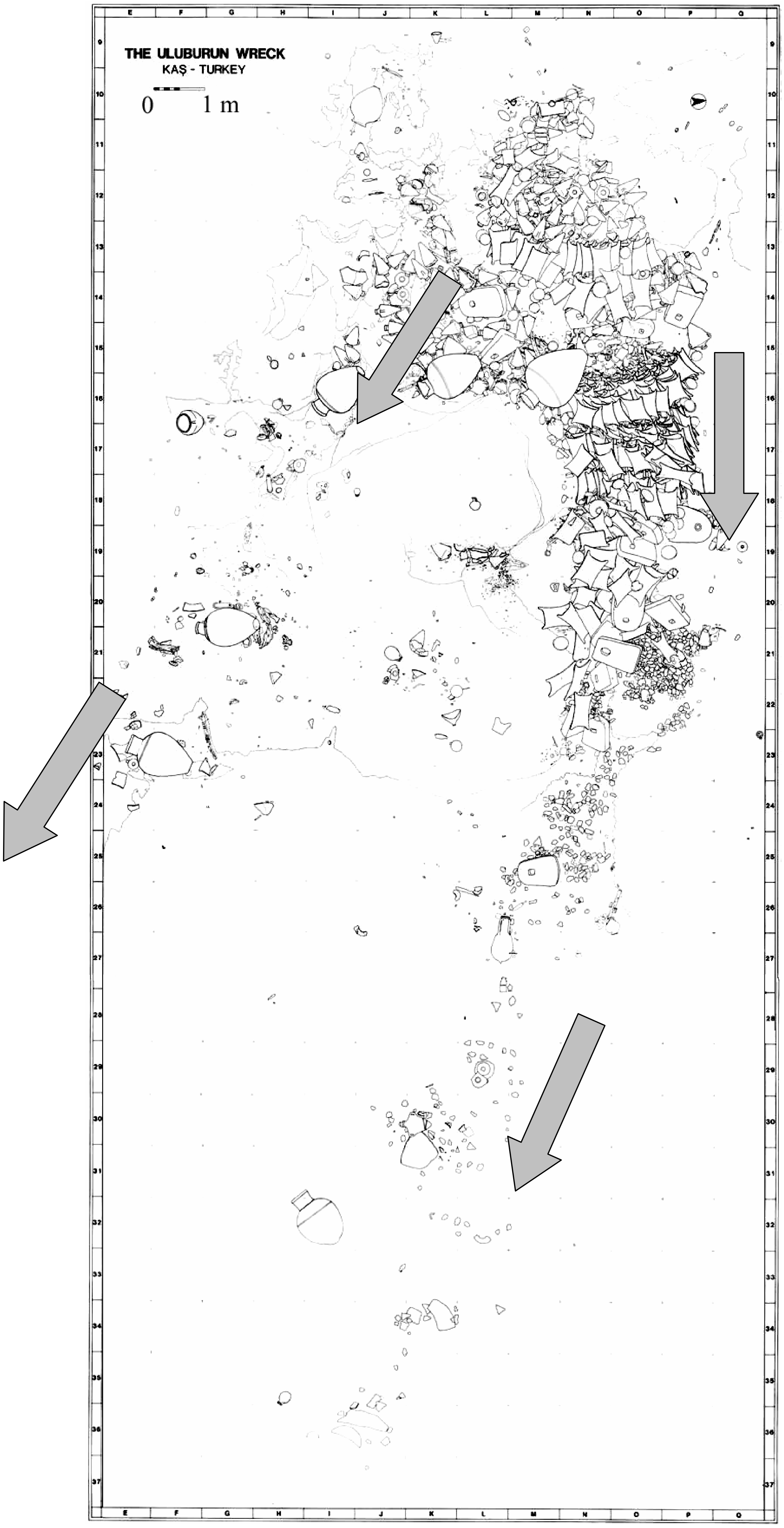


Fig. 2.5 Trajectory of the spilled artifacts from the stern. (After Pulak 1998, 192, fig. 4).

copper oxhide ingots. While the upper layers of these rows suffered some shifting, ingots in the lower layers appeared to remain in their original locations. However, very little space exists between these rows to accommodate a mast and mast step.[17] Consequently, the mast must have been located abaft the second row and forward of the first row of copper oxhide ingots if it is to be located at or near midships (figs. 2.6 and 2.7). Conveniently, there is a fairly open area in grid squares 14 and 15 that corresponds to section 1, measuring roughly 2.14 m in length. All of the artifacts uncovered in this area, other than a small group of ballast stones, seem to have been deposited during the wreck formation process, supporting the placement of the mast and associated structures in this area. Despite the lack of physical evidence for a mast step in section 1 of the hull, it is possible that the mast structures were located aft of the preserved sections of hull and still be forward of midships, as expected in this type of sailing merchant ships.

Another factor contributing to the design of the vessel in terms of both weight and volume is its cargo capacity. The ship is assumed to have a carrying capacity of at least 20 tons based on the cargo excavated as well as the 3.3 tons of stone anchors and 1 ton of cobble ballast. These data allow tests to be conducted on the proposed shape of the vessel. For example, if the waterline for the full-load displacement (weight of water displaced by the ship, equipment, and cargo) leaves too little freeboard,[18] the hull can be made fuller to increase its buoyancy or deeper to increase freeboard, while maintaining

[17] Measurements of the lowest layers of each row were taken from the site plan.
[18] The ratio of two-fifths of hold height for freeboard is assumed to be a safe freeboard for sailing merchantman in the Mediterranean. McGrail 1987, 13.

Fig. 2.6 Hypothetical placement of the mast behind row 2 of oxhide ingots. (Photograph courtesy of Institute of Nautical Archaeology, modified by author).

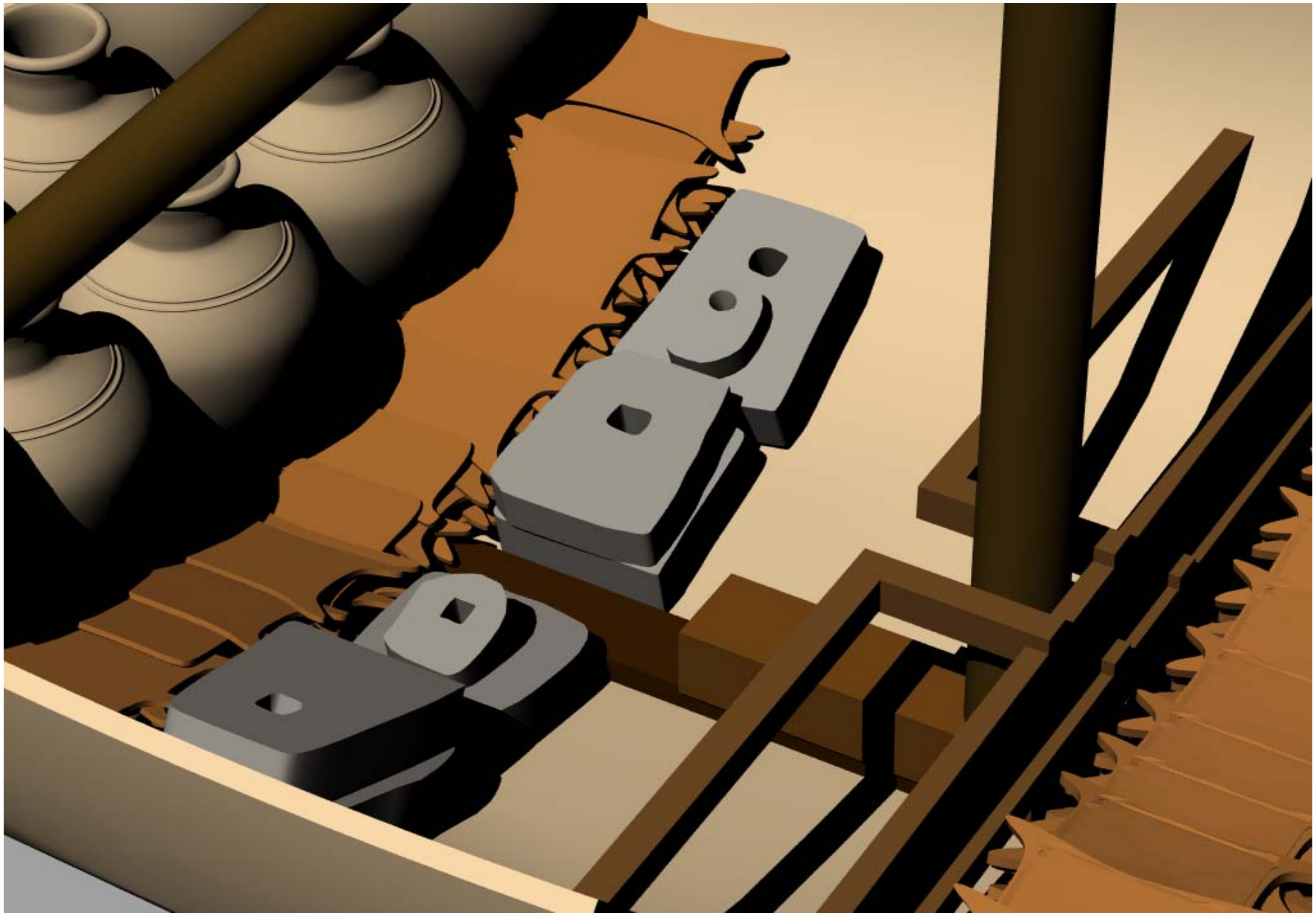


Fig. 2.7 Hypothetical placement of the mast and mast step.

the same overall length and width. The testing of such modifications is greatly simplified when using Rhinoceros and PHASER.

Not only is the cargo capacity a defining factor in terms of weight, but the density of the objects constituting that weight can have drastic effects on the hypothetical hull form. If the Uluburun ship had carried a low density cargo, such as grain, a larger ship capable of holding a greater volume would have been needed to accommodate the 20-tons of cargo. Since all of the Uluburun cargo was recovered and weighed, we are constrained in the limits of the volume of the ship. Also, because relatively little stone ballast was carried, the ship can be assumed to have been filled nearly to capacity and to have been sailing at or near the optimal waterline.[19] The hypothetical vessel, therefore, cannot sit too high in the water (hull too large) or have dangerously low freeboard (hull too small).

The artifacts also come in manifold shapes and sizes that must fit into the proposed hull. The artifacts cannot simply be inserted into the hold in the most convenient manner, because the locations of certain artifact groups are well-documented. Chapters III to VI will explore the locations of the heaviest artifacts in relation to each other on the ship. Therefore, the resultant hull is determined first by cargo weight and then further refined by the volume, density, and location of the cargo.

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[19] Pulak, personal communication.

Drawing the Lines

The general form of the vessel for the lines drawing comes from the 18th-dynasty Egyptian wall paintings in the tomb of two Theban officials, Kenamun and Nebamun (see figs. 2.2 and 2.3). Both show crescent-shaped vessels with upright end posts, a mast with a square rig stepped amidships, a wickerwork weather fencing running the full length of the sheer, and quarter rudders used to steer the vessel (two per ship in Kenamun and one in Nebamun). The possible presence of small decks at the bow and stern and gangways on either side of the mast joining the two platforms can also be assumed from these drawings. In particular, one of the ships from Kenamun's tomb depicts a merchant whose lower body is clearly below deck, implying open access to the hold, and passing an object, possibly a gift, to the another merchant who is perhaps standing on a gangway close to the level of the sheer strake (see fig. 2.2). The Byblos model of a contemporary Egyptian vessel also shows a ship with decks at the bow and stern and an open central area, but there is no indication of a gangway (see fig. 1.6). The ships in Kenamun's tomb have a crow's nest near the top of the mast large enough to accommodate at least one person. Seven of the ten ships depicted in this tomb also show a row of through-beams placed uniformly along the full length of the hull (ranging from 8 to 15), while the Byblos ship shows only four.

Although the ships from Kenamun's tomb contain considerably more detail, the stem of the reconstructed Uluburun ship drawing is modeled after the Nebamun representation. Moreover, the latter ship's sheer seemed to be more realistic and less exaggerated, possibly suggesting a more accurate overall representation. The authenticity of both drawings, however, is questioned by S. Wachsmann, who believes these vessels were copied by Egyptian artists from a common source, and the artists themselves had probably never seen Syro-Canaanite ships.[20] Nevertheless, it is generally agreed that these ships were beamy vessels with high end posts and that sailed with a square rig.

Based on the visual guides and dimensional parameters discussed above, the initial hull was designed with a length of 15 m, width of 5 m, and depth of 2.5 m. Applying the general principle of two-fifths of the hold depth as freeboard, the load waterline was designated at 1.5 m. Nine sets of floor timbers and futtocks were added as well as two bulkheads, one in the bow and one at the stern, and bow and stern decks, though none of these features were actually recovered from the wreck (see fig. 1.8). Because no frames were found on the main section of hull (section 1), which measured 1.8 m long, the frames were spaced 2 m apart amidships. The mast was stepped 1.15 m forward of midships and supported by one through-beam while 14 other through-beams were interspersed along the length of the hull at roughly 0.9-1.0 m intervals. The result is a hull with a volume of 48.4 m^3 and a displacement of 49.6 tons at the draft of 1.5 m.[21]

While the general shape of the vessel is reasonable, its optimal full-load displacement corresponds to twice the amount of cargo recovered from the wreck. Unless there was 20 tons of cargo that perished, this hull configuration is not reasonable. Loaded with only 20 tons of cargo and various shipboard items, the ship would not have been loaded to a safe sailing depth (see displacement chart 2.19). At the same time, little

[20] Wachsmann 1998, 44-5.
[21] Displacement in tons is calculated as volume multiplied by density of sea water 1025.9 kg/m^3, divided by 1000 kg.

stone ballast was found on the ship, so it is assumed to have been loaded close to the proper load waterline.[22] One way to improve the design is to lower the sheer to decrease the freeboard, thereby lowering the load waterline and subsequently, the displacement. While these changes would be troublesome to implement on paper, the advantage of using computer models is evident in such cases. The next section will discuss the process of converting two-dimensional drawings into three-dimensional models.

Converting Two Dimensions to Three Dimensions

To model the hull in Rhinoceros, it is necessary to first digitize or scan the lines of the ship and save them as an image file.[23] Before any images are imported into Rhinoceros, it is important to set the scale used within the program. This can be done by clicking the *Tools* > *Options* > *Document properties* > *Units*. It is also important to crop the image to the proper dimensions of the hull before importing it into Rhinoceros (the sheer view and half-breadth view should be cropped to the very edge of the end posts and the plan view to the edge of the planking).[24] This is necessary because these images lose their dimensional properties once they are imported since they can be stretched to any size within Rhinoceros. The sheer view should be placed in the "front"

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[22] Pulak, personal communication.
[23] A basic working knowledge of Rhinoceros will be helpful in understanding these procedures. M. Becker's *Rhino NURBS 3D Modeling* is a useful tool for getting acquainted with Rhinoceros. As Rhinoceros 2.0 was used for this project, users of version 1.0 or 3.0 might find some slight differences in the menu layout. Rhinoceros 2.0 supports the following types of image files: BMP, TGA, JPG, JPEG, PCX, PNG, TIF, and TIFF.
[24] It is not necessary to crop the width of the half-breadth view and the height of the plan and sheer view to the edge of the drawing because Rhino will keep the drawing in the proper proportions as long as the length of the sheer and half-breadth view and the width of the plan view correspond to the actual measurements.

window, the plan view in the "right" window, and the half-breadth view in the "top" window (fig. 2.8). The proper lengths and widths for the vessel can be marked in the construction plane with a line or a point to facilitate setting the images to the correct dimensions.

Once the images are properly placed and dimensions ascertained with the *Analyze* > *Distance* command, simply trace the section lines in the right window using *Curve* > *Free-Form* > *Interpolate points* (fig. 2.9). After all the sections have been traced, it is necessary to flip either the bow lines or the stern lines so that all the section lines are on the same side. Then each section is moved to its corresponding line in the sheer view (fig. 2.10). To complete the planking surface, the lines representing planking ends on the end posts in the sheer view must be traced. These lines need not meet the end of the closest section lines since some distance between them is desirable to allow Rhinoceros to smooth out the generated surface; if the two lines are too close, a kink might be generated in the resulting surface. It is also important that these end lines are properly aligned in the plan view on the same side of the keel as the section lines. To generate the surface, use the *Surface* > *Loft* command and at the prompt, select the two end curves and all the section lines (fig. 2.11). The resulting surface can then be mirrored (*Transform* > *Mirror*) to the opposite side of the keel to complete the hull surface.

The keel and end posts are traced in the sheer view as three separate pieces because the keel has a greater sided dimension than the end posts. The command *Solid* > *Extrude Planar Curves*, with the *Bothsides* option on, converts the line tracing into a

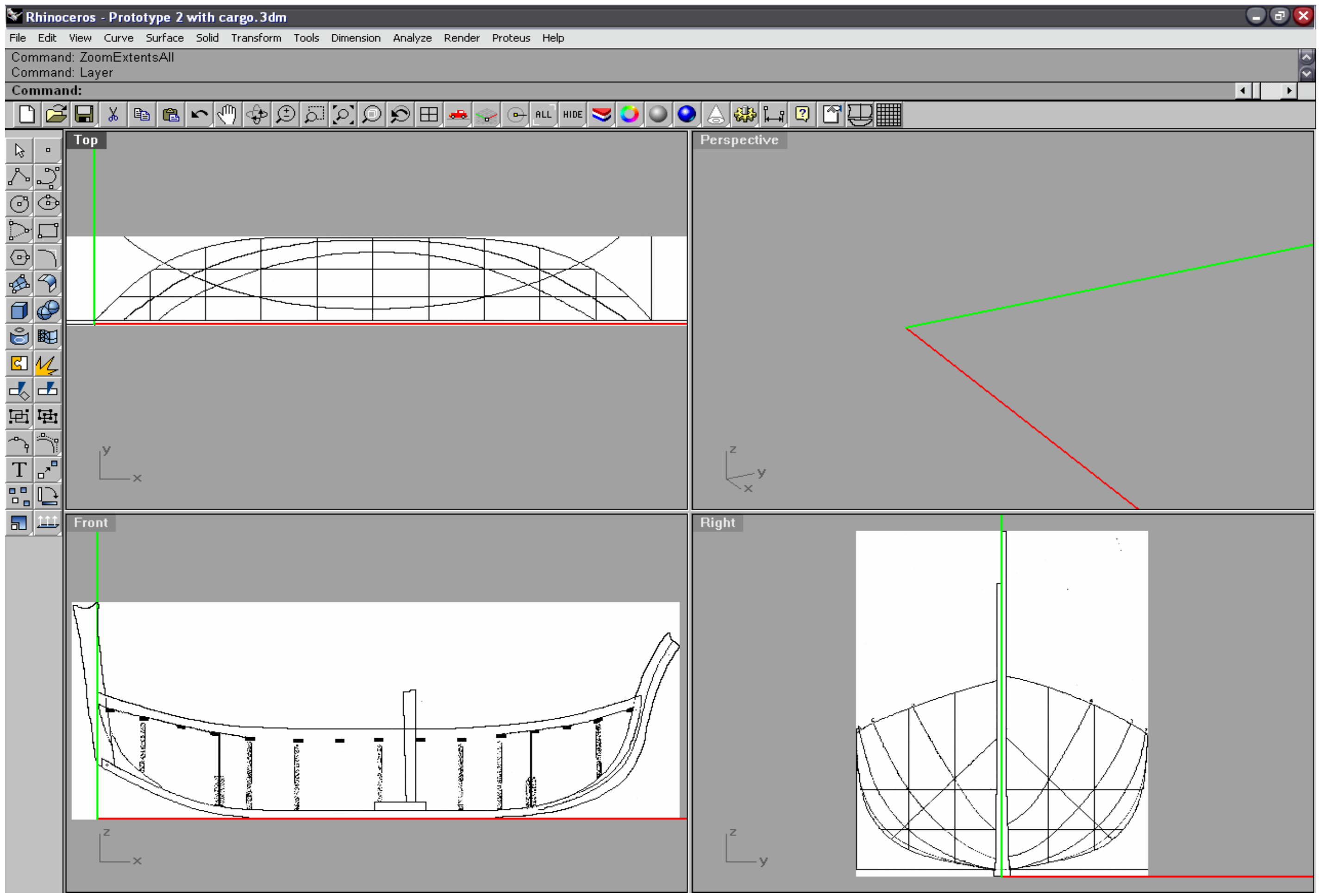

Fig. 2.8 Setting the hull drawings as the background bitmap in the Rhinoceros program.

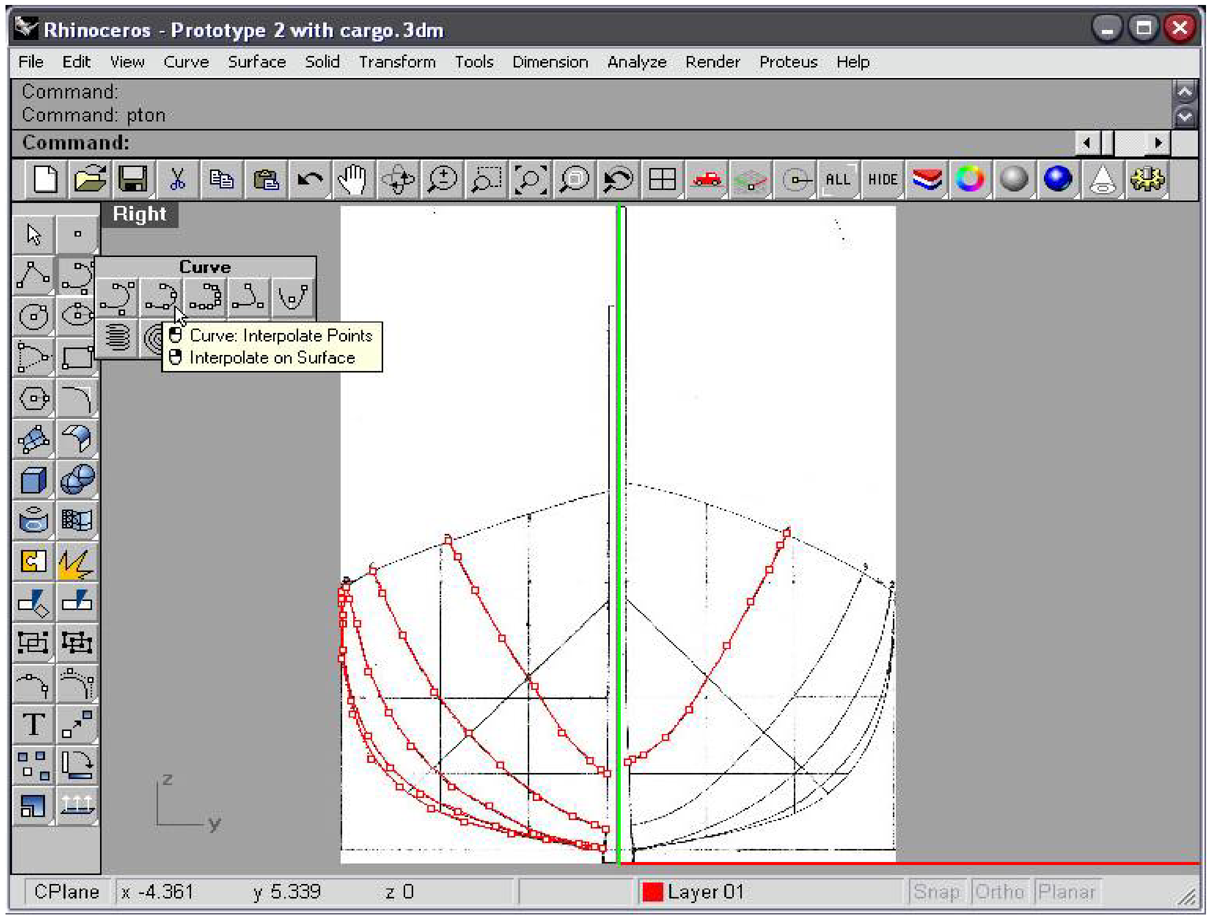

Fig. 2.9 Tracing section lines.

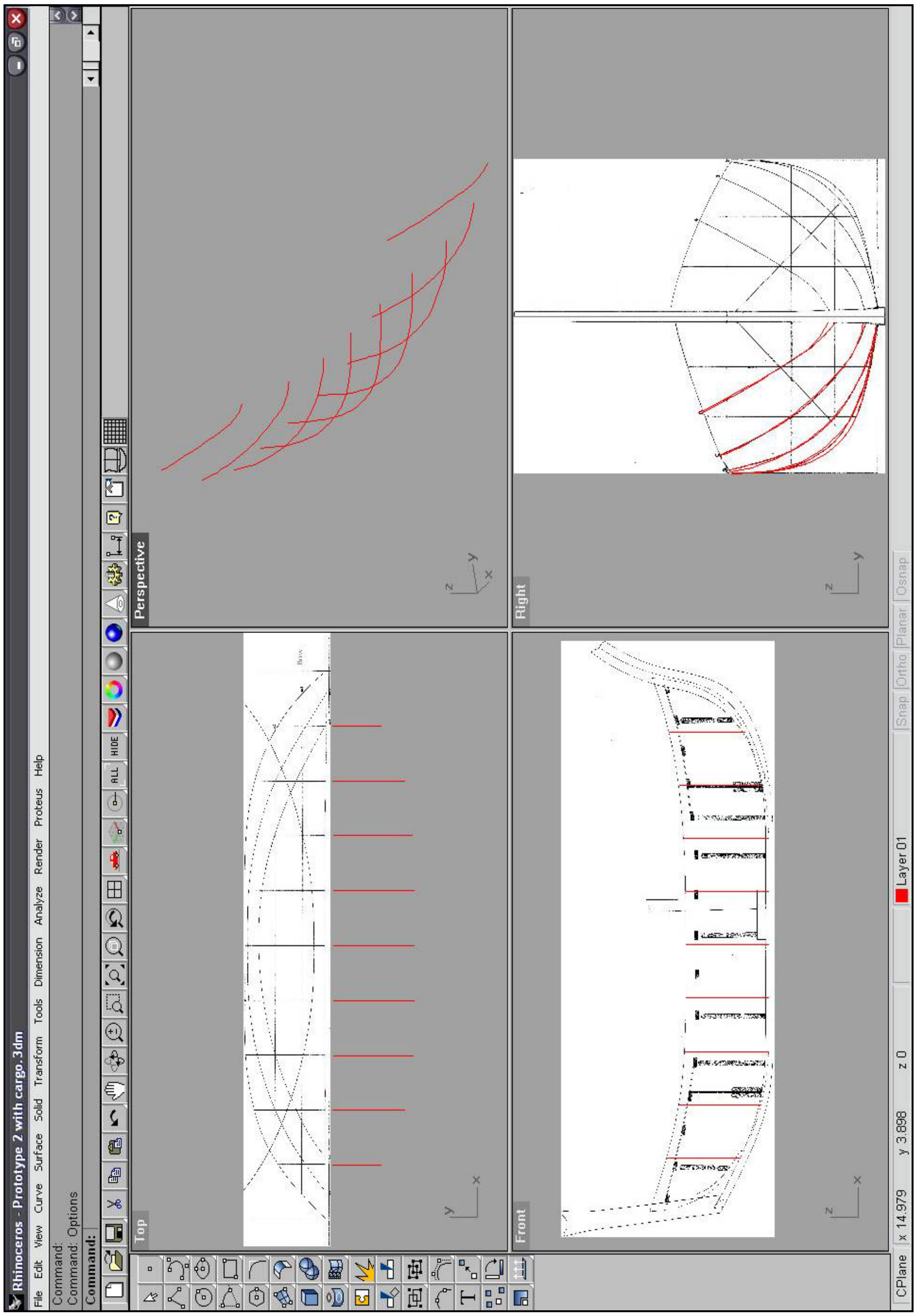

Fig. 2.10 Placing the section lines in their respective positions.

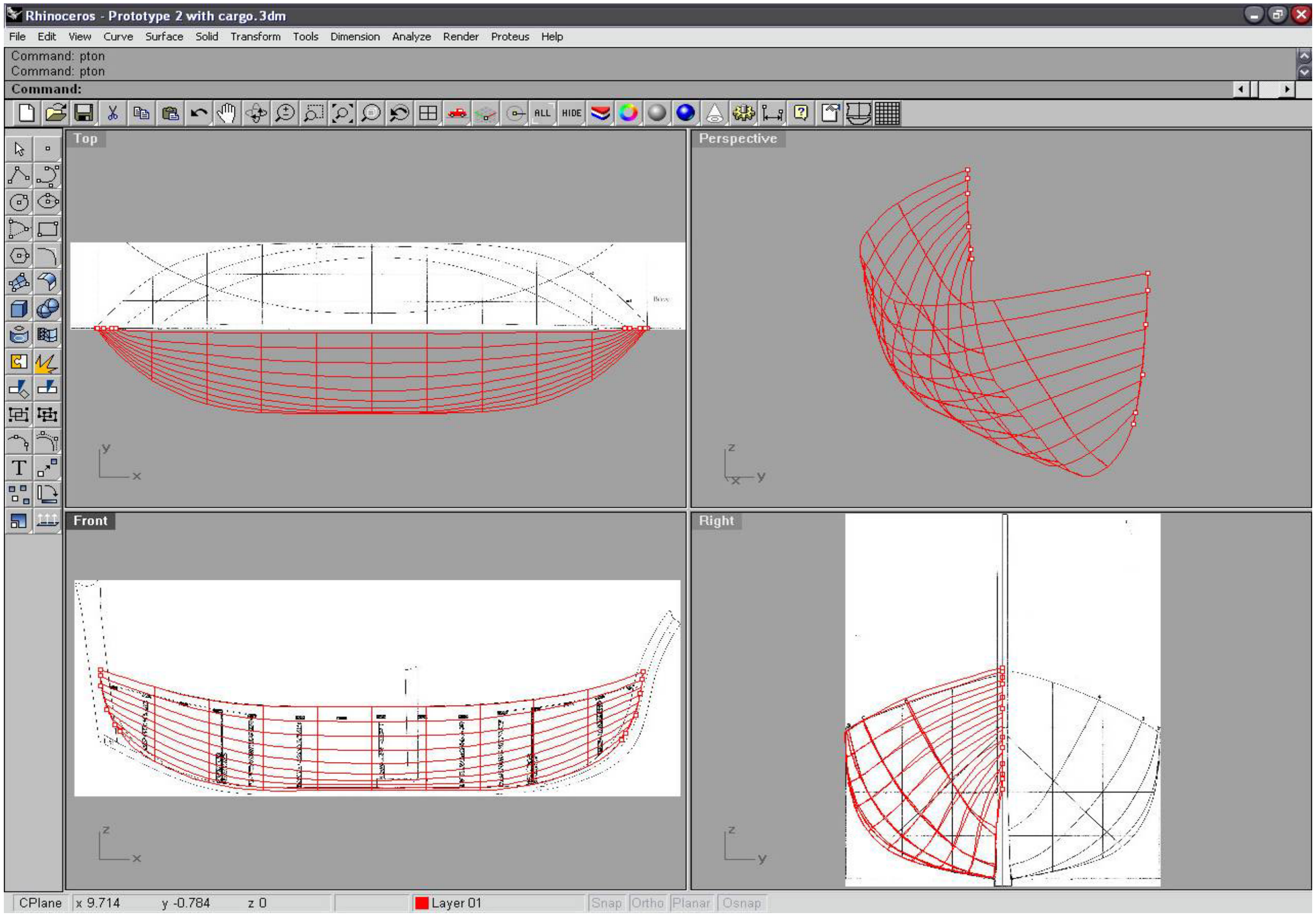

Fig. 2.11 Using *loft* command to create the hull surface.

solid, which should match the sided dimensions for keel and end posts in the plan and half-breadth views. To create the tapering from the keel to the stem and sternpost, a *Surface* > *Rectangle* > *Cutting Plane* is made in the half-breadth view to trim off the excess portions of the keel. In order to cut a solid, the cutting plane has to extend through the entire thickness of the keel. After the cutting plane is in place, the *Edit* > *Trim* command will remove the unwanted portions of the keel (fig. 2.12). Once the keel is trimmed, *Solid* > *Cap Planar Holes* will place a new surface on the open plane of the cut portion. If so desired, the three pieces of the keel can be grouped together using the *Edit* > *Group* command.

The mast and mast step are of simple design and are easily modeled within Rhinoceros. Since this program allows many different ways to model the same object, so the following should be taken only as a suggestion. The mast step is simply a rectangular box with a width slightly less than the sided dimension of the keel (length 1.4 m, width 29 cm, thickness 26 cm. Since nothing is known about Bronze Age mast steps, the exact dimensions are not critical, only a simple structure is needed to hold the mast. To model the mast itself, any of the *Curve* > *Circle* commands may be used to generate a circle 35 cm in diameter in the half-breadth view. A second circle, 27 cm in diameter, is made and then moved up along the z-axis to the desired height of the mast, which in this case is 12.5 m. Using the *Loft* command, the two circles are then transformed into a tapering cylinder. The yard and boom are created using the same

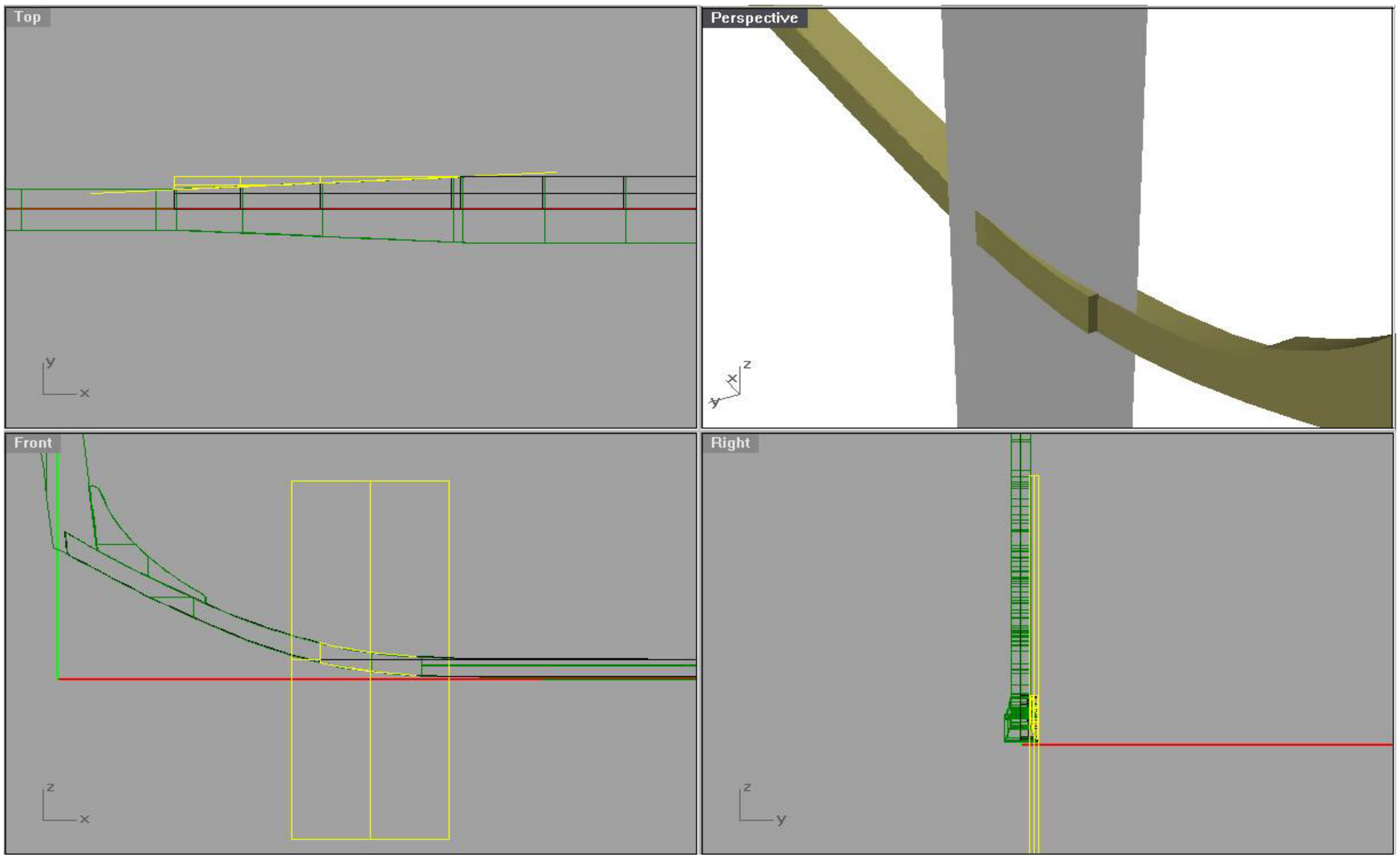

Fig. 2.12 Trimming the keel.

procedure but with the length of 12 m and diameter of 0.20 m and 0.08 m.[25] Three circles are used with the smaller diameter circles on the ends in order to develop the taper toward the extremities. The configuration for the mast partners was adopted from a much later seventh-century B.C. Cypriot boat model (see fig. 2.4). The mast is braced against a through-beam, which has the dimensions 4.50 x 0.26 x 0.10 m. A flat rectangle of that length and width is drawn in the sheer view and extruded (*Surface* > *Extrude* with *Bothsides* option on) beyond the surface of the hull planking. This way, the excess protrusions of the through-beam can be trimmed by the hull surface using *Edit* > *Trim*. The mast partners are modeled using the same procedure. The stanchions used for supporting these timbers can be made with the *Solid* > *Cylinder* command.

Five more through-beams are placed on the ship,[26] two at the bow to support the foredeck and three aft underneath the stern deck. A fourth beam in the stern is lower than the others in order to support the quarter rudders. The decks begin as a single line drawn from the sheer view for the entire length of the deck. This curve is then projected (*Curve* > *From Objects* > *Project*) onto the planking on both halves of the hull. These three lines are then selected and lofted to form a surface, which is then extruded to the proper thickness to complete the process (fig. 2.13). Figure 2.14 shows the completed hull model.

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[25] Since very little is known about Late Bronze Age rigging, dimensions were roughly based on the *Kyrenia II* ship which had a mast 10.6 m long and 0.35 m thick, and a 12.2 m-long yard. I would like to thank Mr. Richard Steffy for sharing this information as well as other helpful items regarding the Kyrenia ship and the *Kyrenia II*. Incidentally, calculations using a 17th-century shipbuilding treatise where the mainmast was two and a half times the length of the beam and the thickness of the mast is one inch per three feet the height of the mast yield a figure of 0.348 cm for the Uluburun ship's mast (Miller 1957, 2).

[26] The 15 through-beams in van Duivenvoorde's drawing would have made it nearly impossible to load the cargo, especially some of the larger items such as the pithoi. While it is likely that the Uluburun ship had some through-beams as shown in the later Cypriot models, such a great number of beams are a feature of Egyptian ships seen, for example, on Hatshepsut's Punt ships (see Wachsmann 1998, 20, Fig. 2.15).

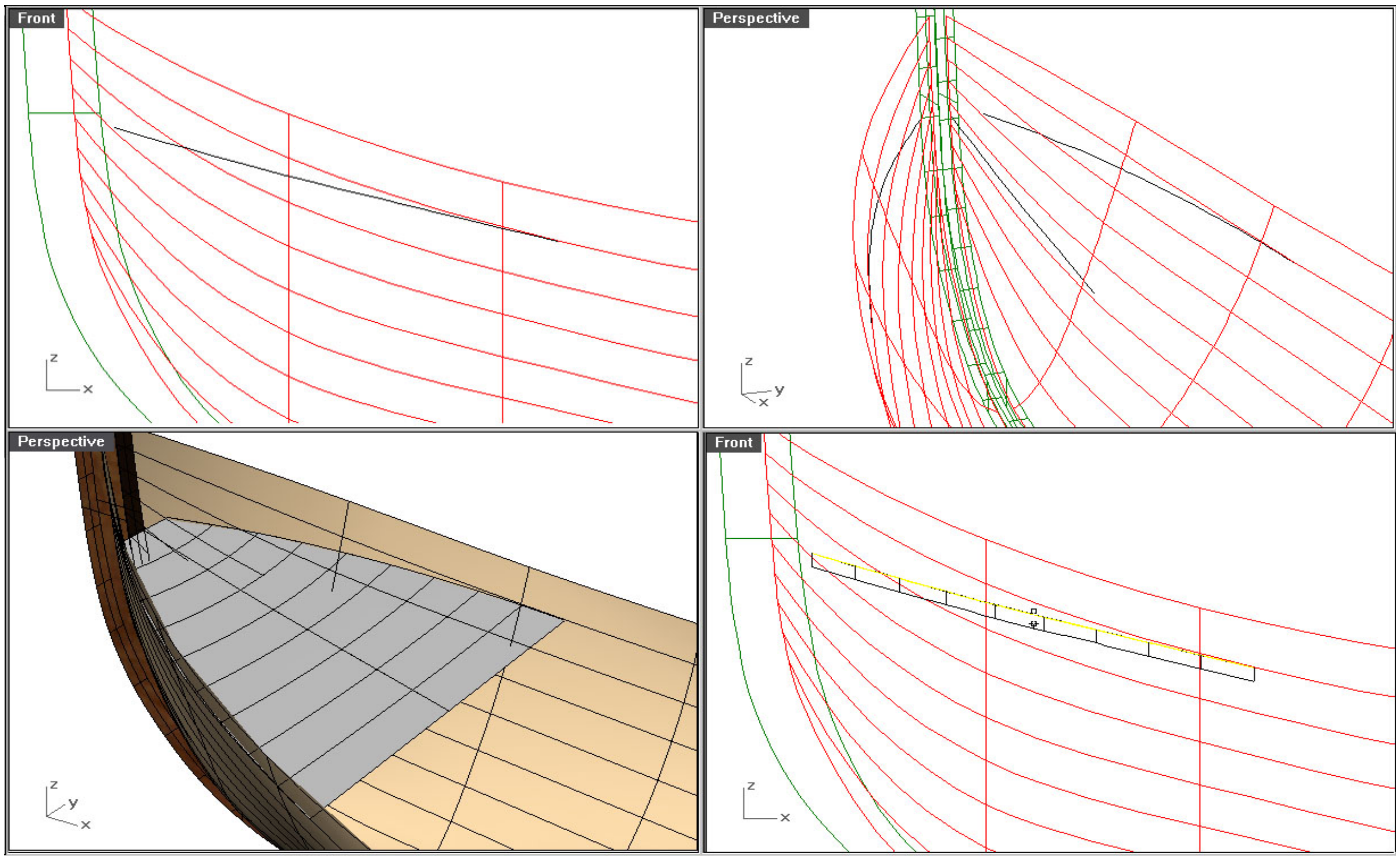

Fig. 2.13 Constructing the stern deck.

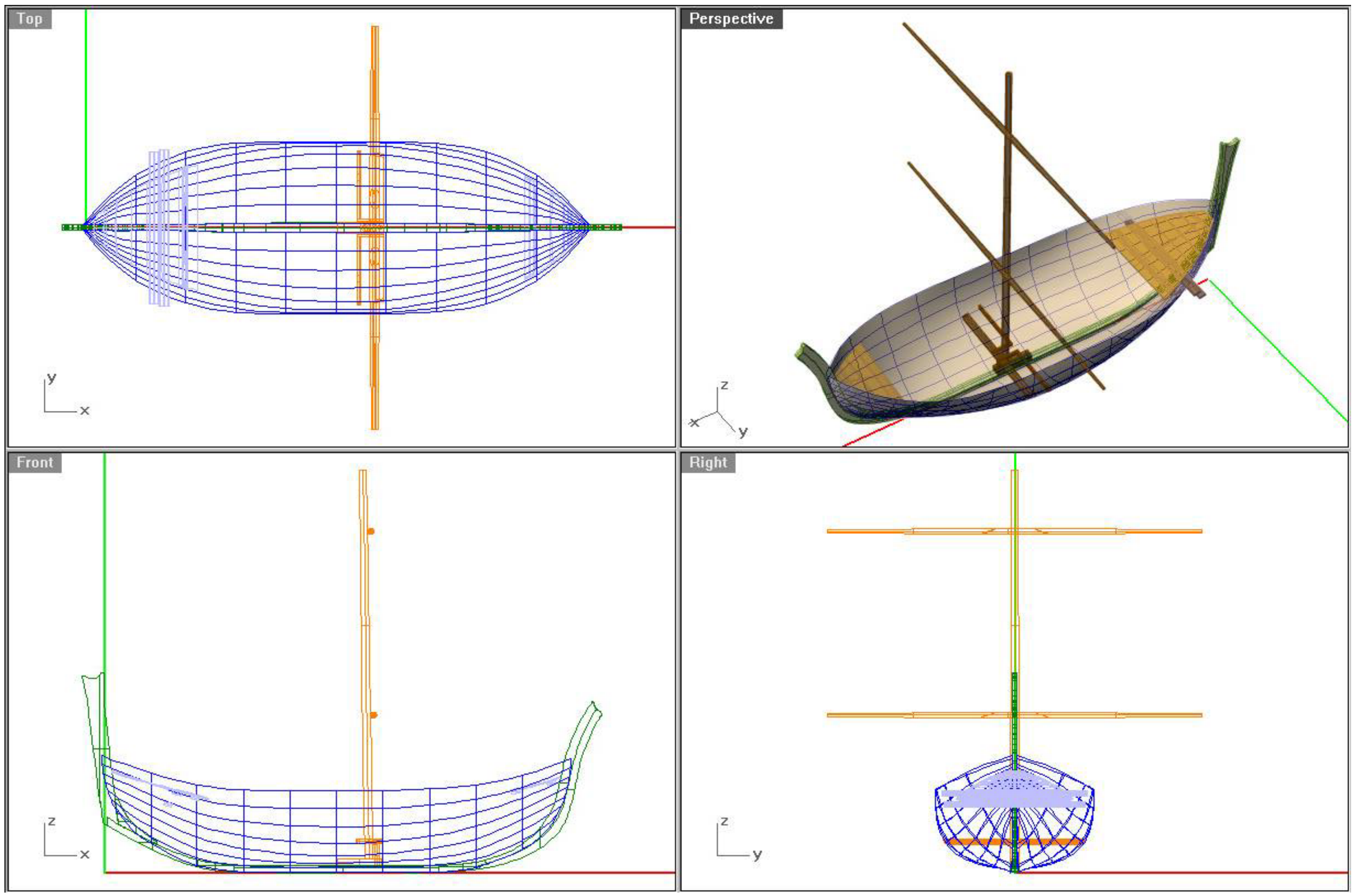

Fig. 2.14 Hypothetical hull no. 1.

Although these structures do not contribute greatly to the volume and weight of the ship and there is very little evidence to indicate their original configuration, they were conservatively and carefully designed. They serve as a boundary of sorts for the placement of the artifacts since cargo generally would not be stored too near the mast assembly and the decks limit the height to which the cargo can be stacked.

Computing Lightship Hydrostatics and Stability

The weight of the volume of liquid that is pushed aside by a floating body is called displacement. According to Archimedes' Principle, the weight of the floating body itself is equal to the weight of the volume of liquid displaced, and the volume of liquid displaced is equal to the immersed volume of the object. Determining the volume of the underwater portion of the hull is usually done by integration using Simpson's Rule or with the Trapezoidal Rule,[27] but PHASER can calculate displacement using a model of a ship created with Rhinoceros. One problem that arises using Rhinoceros, however, is that a ship's lines are usually drawn to the inside of the planking, therefore the results do not reflect the correct displacement if the model is created according to those lines. To rectify the problem, it is necessary to adjust the section lines to include the thickness of the planking by making a copy of the section line (*Curve* > *Offset*) and moving the copy so that it corresponds with the outside of the planking and then readjusting the end

[27] The Trapezoidal Rule is volume=d(1/2[D] + [C] + [B] + [A] + ¤ + [1] + [2] + [3] + ½[4]), where the numbers and letters represent the area of that station in the half-breadth view and d is the distance between each station line (Steffy 1994, 252).

points to coincide with the keel and sheer lines. A new surface is then lofted from these new section lines to give the correct displacement.

Once the vessel has been drawn and modeled, data regarding how the ship sits in water unburdened or fully laden, its displacement at different flotation planes, the hull coefficients, its center of buoyancy, the distance between the center of gravity and the metacenter, and the moment to trim the ship by one centimeter can all be calculated by plotting a chart of hydrostatic curves. While it is possible to calculate this by hand (fig. 2.15), the task is greatly simplified with the use of PHASER. The benefits were particularly appreciated on this project since modifications to the hull and cargo arrangement had to be made throughout the course of the study, and instead of having to recalculate new sets of results each time, the curves were quickly plotted with each change to hull and cargo, and the new data was entered into the program.

Once the PHASER program is initiated, it will prompt the user to select the surfaces to compute.[28] The first menu that appears will allow the user to adjust a number of settings such as input and output units for length and weight, fluid type and density, to specify whether the model represents one half or the entire vessel, and to adjust the polygon mesh density.[29] For the Uluburun ship, the model is the full ship floating in sea water (1025.9 kg/m^3) with outputs in meters and kilograms (fig. 2.16).

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[28] It is important that the normal direction of the analysis mesh is oriented in the right direction when selecting a surface for PHASER calculations. To do this, open the *Analyze* tab and the *Directions* option. White arrows will appear indicating the direction of the normal. If the arrows are pointing inward toward the hull, press “f” to flip the direction.

[29] It is necessary to increase the polygon mesh density because PHASER calculates displacement from these surface meshes rather than from sections. Therefore, the denser the surface mesh (more polygons), the more accurate the calculation. The PHASER help guide recommends adjusting it to at least 85% polygonal density.

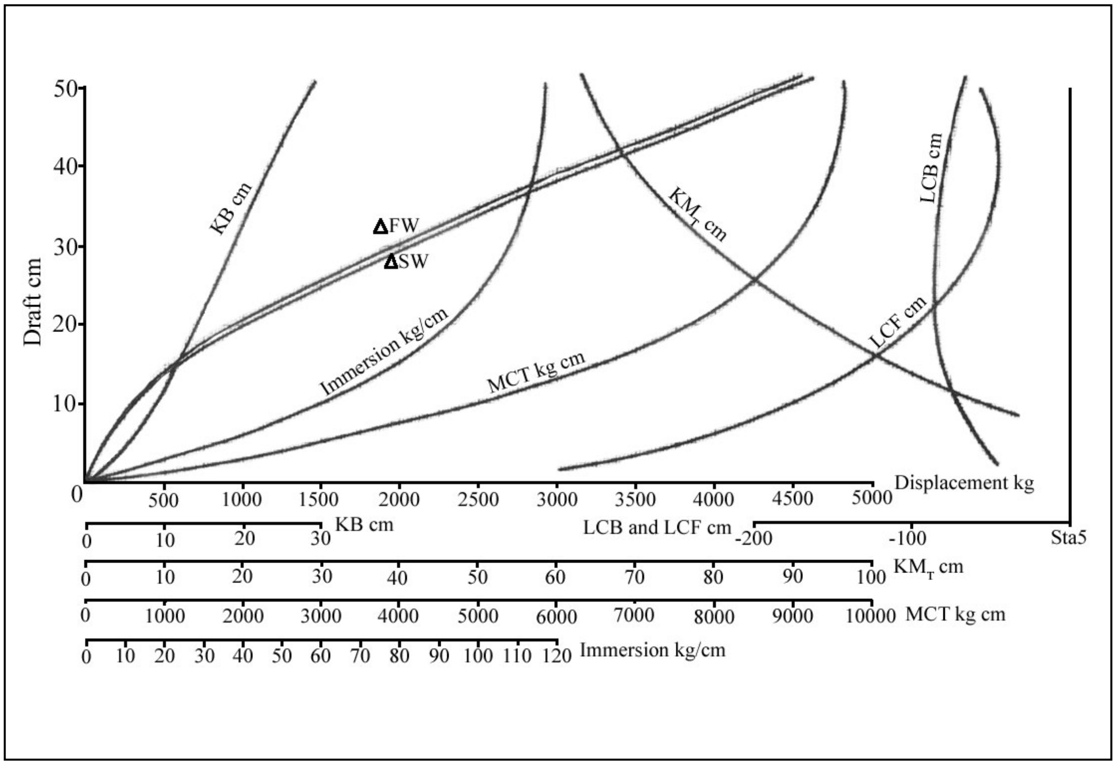

Fig. 2.15 Example of hydrostatic curves chart from the Poole logboat. (After McGrail 1987, 14, fig. 3.2).

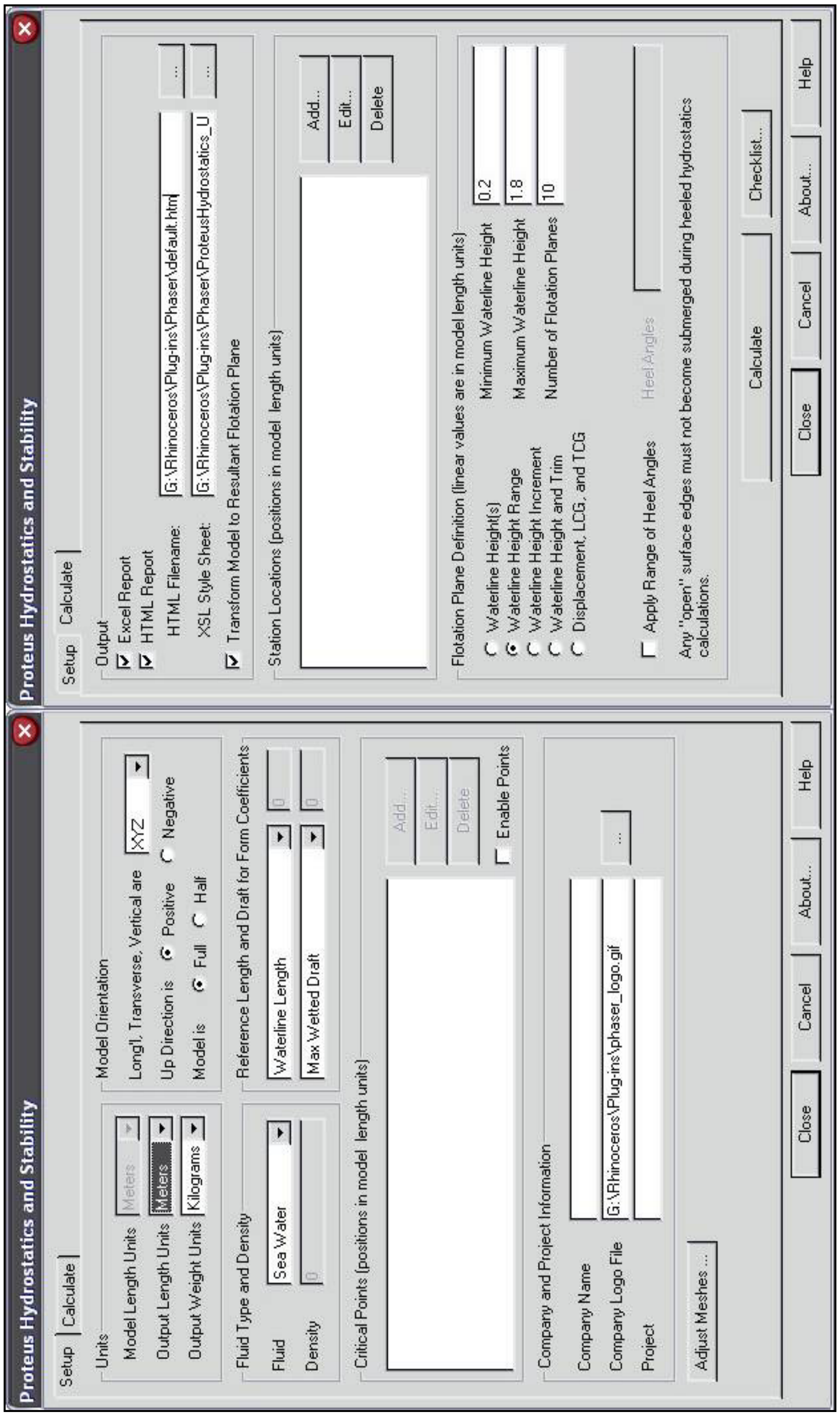

Fig. 2.16 PHASER's primary and secondary input menu.

The main menu is accessed by pressing the *Calculate* tab. Data output can be in the form of hydrostatic curves in an Excel file format or an HTML report, which lists the computed data in table form. To help visualize the calculated position of the vessel, there is an option to transform the model to the resultant flotation plane. The principal input for PHASER is in the *Flotation Plane Definition* selection box. The basic idea is to test the hull form at one or more flotation planes to compute characteristics of the ship such as volume of submerged hull, displacement, longitudinal center of buoyancy (LCB), freeboard, metacenter, and all coefficients. Hydrostatic curves for this reconstruction of the Uluburun hull were derived by setting the minimum waterline height at an arbitrary value of 0.2 m (just enough for the hull to touch the water) and a maximum height of 1.8 m (arbitrary)[30] with 10 flotation planes between these two values (figs. 2.17-2.20).

According to Steffy, "For the archaeologist, one of two goals [when reconstructing a ship] is possible—the determination of a flotation line by measuring displacement, or the determination of displacement from a given flotation line."[31] The derivation of the hydrostatic curves discussed above partially fulfills the second goal by providing an idea of the displacement of the ship at various flotation planes. However, since the displacement of the Uluburun ship and its cargo can be very closely estimated, the first goal discussed by Steffy can also be attempted using PHASER to see if the

[30] Two-fifths of hold depth as freeboard yields a waterline of 1.5 m, but 1.8 m was used to see the results if the optimal waterline was exceeded.
[31] Steffy 1994, 251.

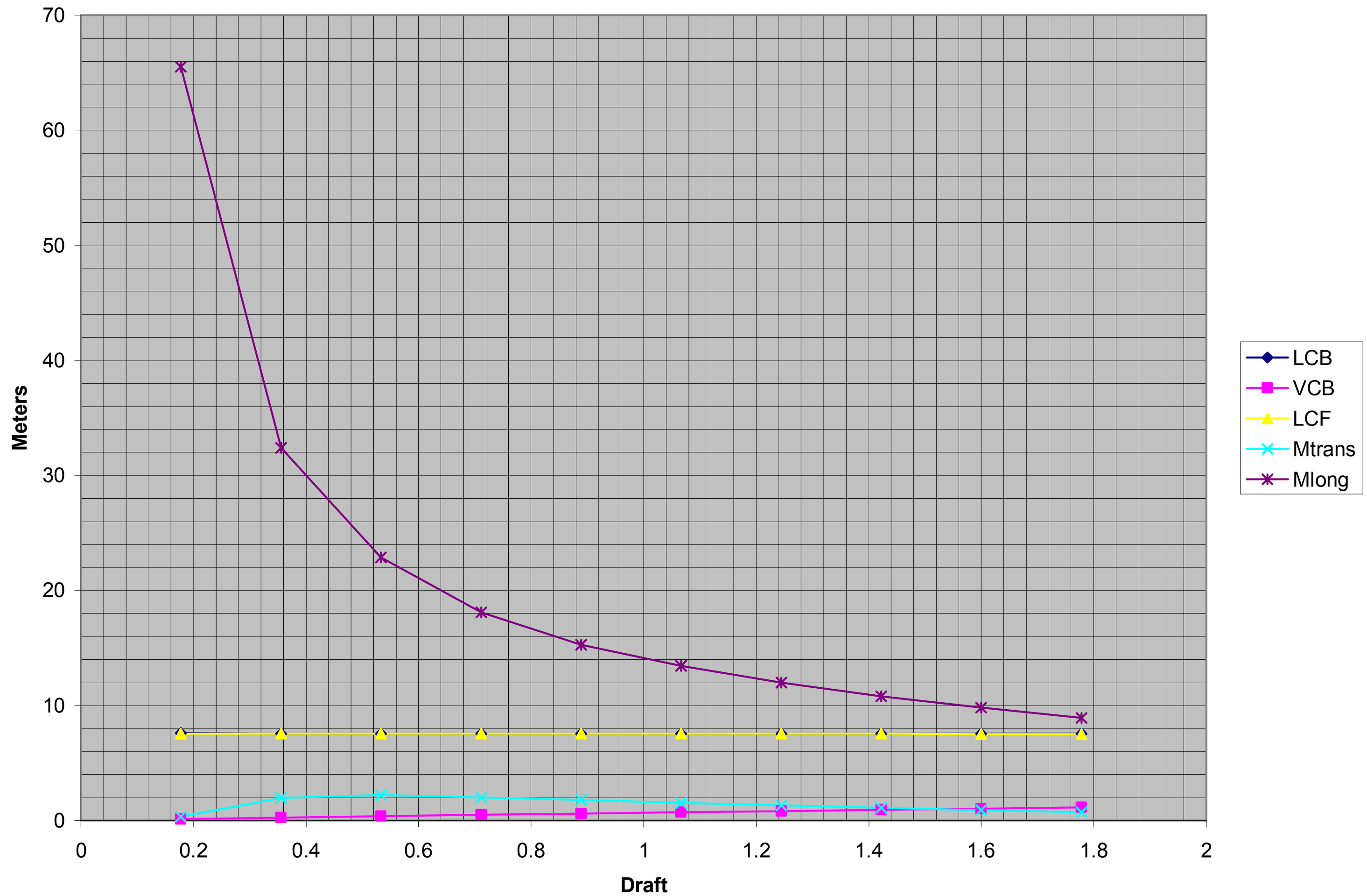

Fig. 2.17 Hydrostatic curve for hypothetical hull no. 1 (linear values).

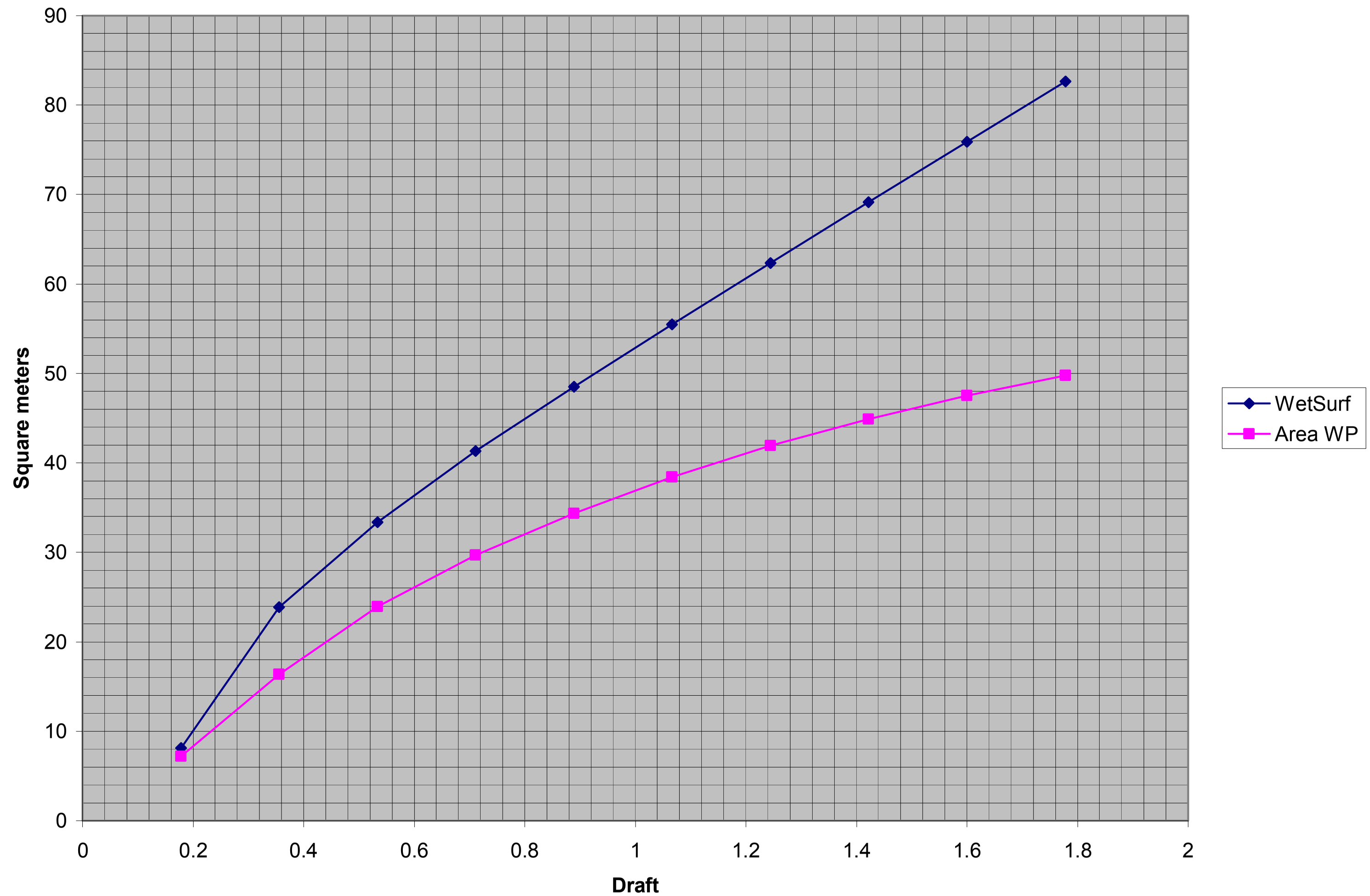

Fig. 2.18 Hydrostatic curve for hypothetical hull no. 1 (area values).

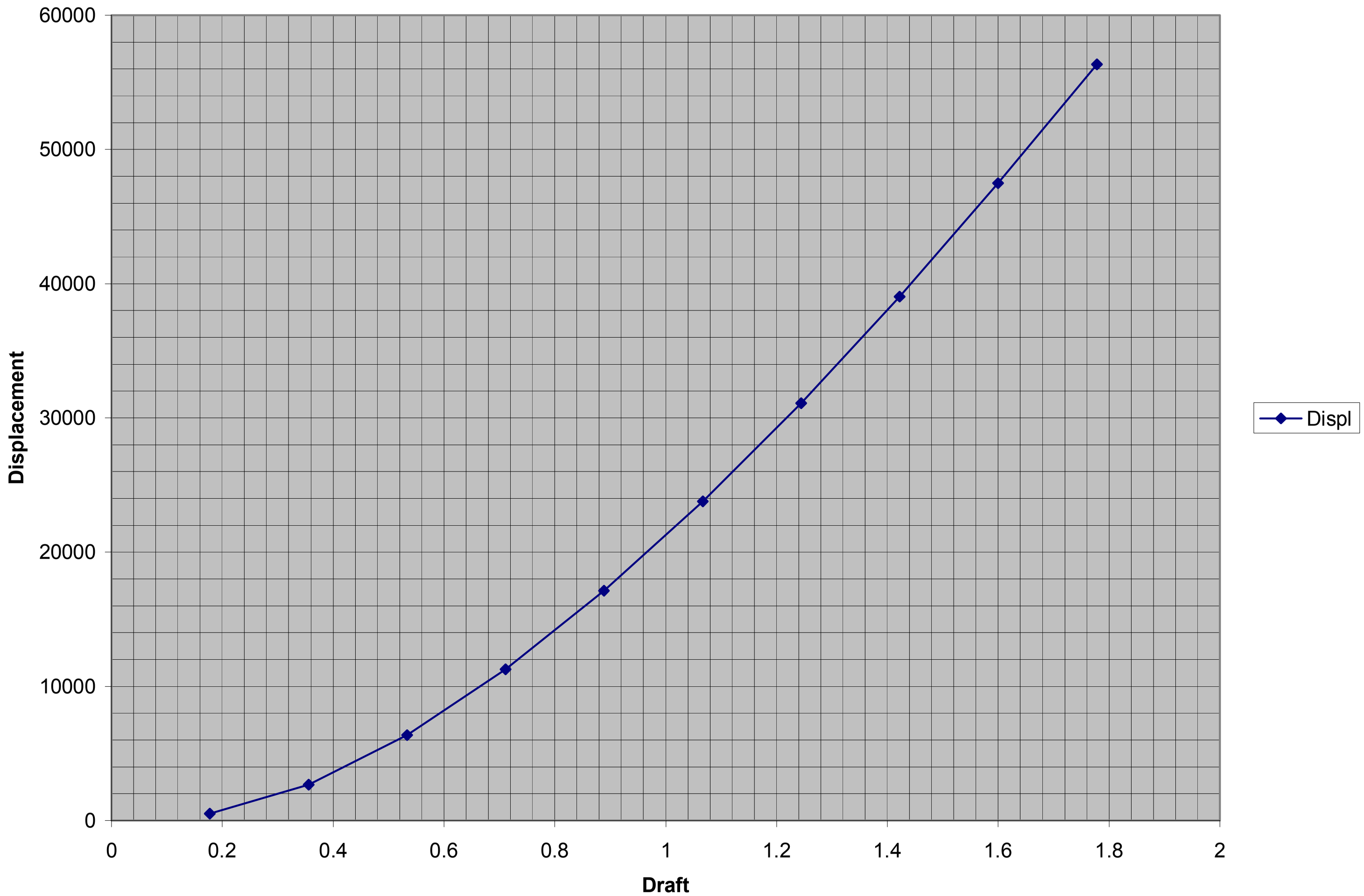

Fig. 2.19 Hydrostatic curve for hypothetical hull no. 1 (volume values).

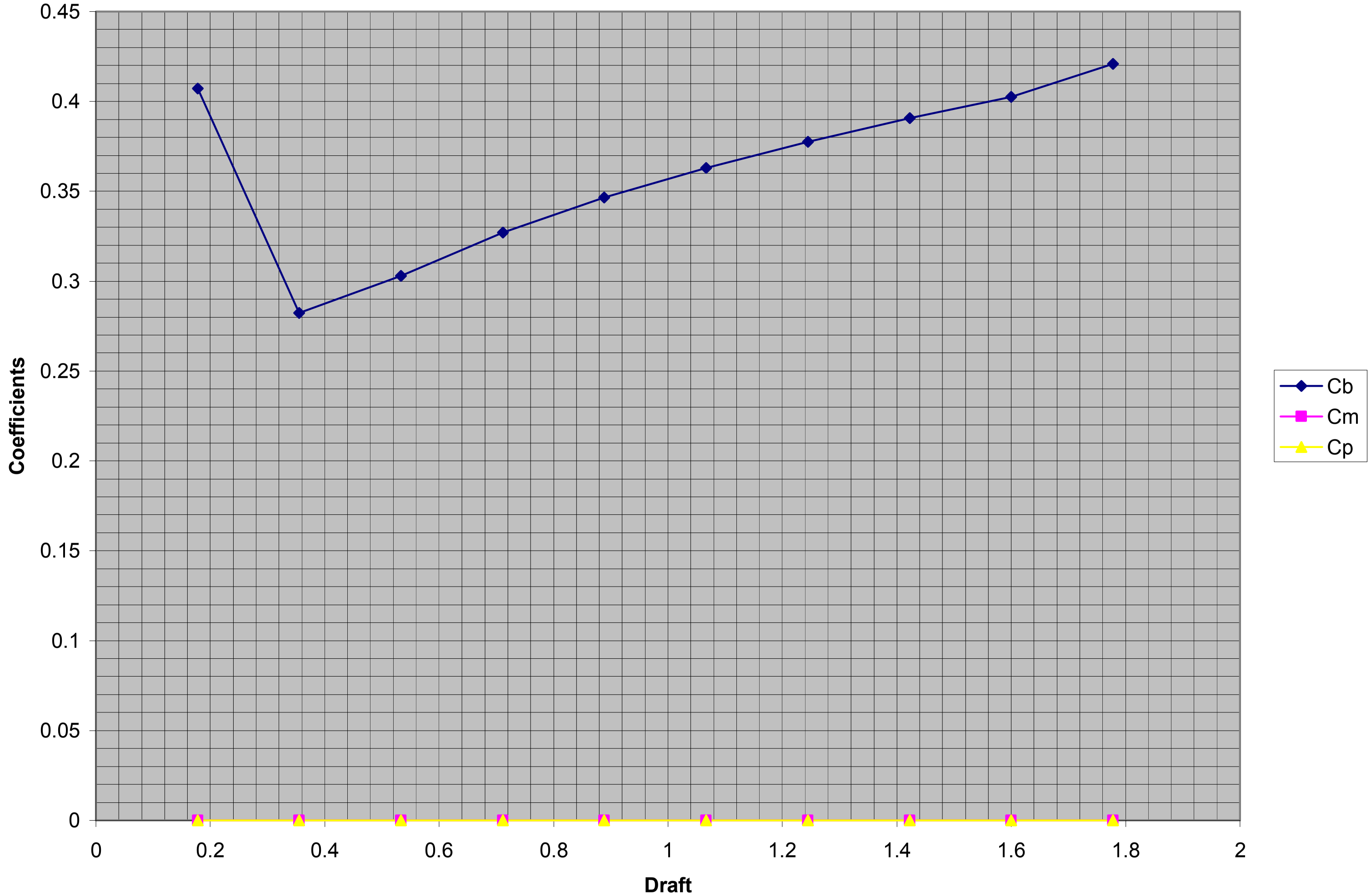

Fig. 2.20 Hydrostatic curve for hypothetical hull no. 1 (coefficients).

proposed hull is too light and sits too high in the water or is too heavy and has too little freeboard.

The most common input option used for this project was the displacement and center of gravity option. Displacement of the planking surface was calculated by multiplying the surface area of the planked portion of the vessel, 103.5 m^2, (determined within Rhinoceros—*Analyze > Mass Properties > Area*) by a density of 38.7 kg/m^2 (with an uniform plank thickness of 0.06 m), which was derived from the dimensions and weight of three planks of American southern yellow pine, substituted for the cedar used in the Uluburun ship.[32] The total weight for the planking is 4005.5 kg. The same density used for the planking cannot be applied to the remainder of the ship since that figure includes the denser live oak tenons and pegs. Therefore, it will be assumed that the other structures of the ship were also made from cedar, as was the planking, which has a density of 560 kg/m^3.[33] After modeling the keel and end posts, Rhinoceros calculated a volume of 1.7 m^3 which was then multiplied by 560 kg/m^3, yielding a weight of 952 kg. The planking and the keel together weigh 4957.5 kg. Cumulative volume for the mast assembly, including the mast, yard, boom, mast step, forward beam, partner beams, and after beams, is tentatively proposed as 1.66 m^3. The foredeck with two supporting through-beams is estimated at 0.24 m^3, and the stern deck with its two supporting beams along with the two through-beams for attaching the quarter rudder total 0.8 m^3. Therefore, the calculated weight of the mast assembly is 930 kg and the

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[32] The physical properities of southern yellow pine are similar to that of cedar (Pulak 2003, 30). The dimensions for the three planks are as follows: 1.17 x 0.67 x 0.06 m. Weight was 30.2 kg. For a more detailed discussion regarding the strength testing of these planks, see Pulak 2003.
[33] Steffy 1994, 256.

decks and beams 582.4 kg, which brings the total to 6469.9 kg.[34] This figure is entered into the box for displacement in PHASER.

Only one center of gravity (*cg*) value can be entered in PHASER, so each item indicated above must be calculated separately in order to account for their different densities. While the density for each part of the ship's structure is not drastically different since the same wood type is assumed to have been used, this step becomes critical when incorporating the centers of gravity of the cargo. The *cg* is readily calculated within Rhinoceros by selecting the target surfaces or solids and running the area or volume centroid command (*Analyze > Mass Properties > Area/Volume Centroid*).[35] The centroid for the planking surface is 7.5, 0, 1.4 m (x, y, z) from the origin point in Rhinoceros' world plane. The keel and end posts have a centroid of 7.2, 0, 1.9 m, the mast assembly 8.5, 0, 5.5 m, and the decks and through-beams 4.9, 0, 2.6 m. Because Rhinoceros cannot assign weight values to objects created within the program, their weights must be figured in at this time to derive the correct *cg*. The moment is equal to the weight of an object multiplied by its orthogonal distance from a fixed point, so a chart similar to table 2.1 can be set up in a spreadsheet program to compute the X, Y, and Z moments for each of the hull structures. For the planking, 4005.5 kg was multiplied by its centroid values of 7.5, 0, 1.4 m to derive its X, Y, and Z moments, and the same was done for the keel and end posts. To arrive at the final *cg* to

[34] This value does not include any interior hull structures such as frames or bulkheads for which we have no direct evidence, nor does it include all of the shipboard items still needed on a sailing ship such as sails, rigging and cables carried on board, quarter rudders, etc. In actuality, a ship of this type was probably closer to 8000 kg, as was the *Kyrenia II*, which is an even smaller ship.

[35] Rhinoceros can calculate the area or volume centroid of an object but cannot take into account different densities.

Table 2.1 Sample chart calculating the lightship weight and center of gravity (hypothetical hull no. 2).

Hull Section	Weight (kg)	X	Y	Z		X-Moment (kg-m)	Y-Moment (kg-m)	Z-Moment (kg-m)
Planking	4005.5	7.5	0	1.5		30041.25	0	6008.25
Sternpost	342.04	0.35	0	3.15		117.6	0	1058.4
Stem	301.68	14.59	0	2.54		4313.9712	0	751.0272
Keel	308.28	7.56	0	0.13		2277.6768	0	39.1664
Foredeck & Through-beams	134.4	13.67	0	2.73		1875.524	0	374.556
Aft deck & Through-beams	448	2.26	0	2.56		974.512	0	1103.872
Mast components	930	8.52	0	5.49		6679.68	0	4304.16
					Total	**46280.214**	**0**	**13639.432**
Lightship	**6469.90**	**7.36**	**0.00**	**2.17**				

enter in PHASER, each X, Y, and Z moment column is added up respectively and divided by the total weight, yielding: 7.37, 0, 2.24 m from the origin. Together with a total weight of 6469.9 kg and the cumulative center of gravity, PHASER determined that the proposed Uluburun ship had a draft of 0.48 m, a load waterline length (LWL) of 11.2 m, and a center of buoyancy at 7.35, 0.29 m (X, Z) (see table 2.2 for other output data).

Computing Hydrostatics for the Loaded Vessel

The same procedure is followed for calculating the trim of the vessel based on the cargo distribution. Once the actual models of the cargo were placed in their hypothetical positions on the 1:10 scale ship, this scenario was recreated in Rhinoceros. For distinctive groups of artifacts like the copper oxhide ingots stacked in orderly rows, the *cg* can be taken as a whole rather than for individual objects. The post-excavation weights of these artifacts are inserted into the weight column in Excel; when their *cg* calculated within Rhinoceros is entered in the X, Y, Z columns, Excel will calculate the moments. The different moments are then added up and divided by the total weight to derive the final cumulative *cg* of the ship and cargo. This information can then be entered into PHASER. It is important to remember to select only the hull when prompted by PHASER to choose the surface for the calculation of hydrostatics and not all the artifacts that have been placed in the hull. The final displacement and *cg* will account for all the items within the hold. A more detailed description of the reconstructed location of each artifact group will be discussed in chapters III to VI.

Table 2.2 Hydrostatic output of hypothetical hull no. 1 in table form.

Proteus Hydrostatics & Stability Report

Project: The Uluburun Ship - Hull Prototype 1

Free Float Hydrostatics

Date/Time:	March 04, 2003	**Version:**	Phaser 2.0.9
Input file:	D:\My Documents\Thesis Project\Models\Hull\Hull Prototype 1.3dm		
Output file:	E:\Rhinoceros\Plug-ins\Phaser\Phaser\default.htm		
Parts Mirrored:	No	**Fluid Type:**	Sea Water
Up-direction is:	Positive	**Fluid Density:**	1025.9 kg/m^3

Flotation Plane

PlnConst	NrmlX	NrmlY	NrmlZ
0.569	0.012	0.003	1.000

Overall Dimensions Units (meters)

Name	Value
Length OA	16.725
Length WL	11.218
Beam OA	5.125
Beam WL	3.313
Depth	6.380
Draft	0.480
Freeboard	5.899

Integrated Properties Units (meters, meters^2, meters^3, kilograms)

Name	Value
Volume	6.307
Displacement	6,469.908
LCB	7.353
LCB Percent LWL	52.807
VCB	0.291
TCB	0

Wetted Surface Area	33.168

Table 2.2 (cont'd.)

Waterplane Properties **Units (meters, $meters^2$, kilograms/cm, meters-kilograms/cm)**

Name	Value
Area WP	23.925
LCF	7.435
TCF	0
VCF	0.459
M Transverse	2.152
M Longitudinal	22.793
BM Transverse	2.320
BM Longitudinal	22.961
Weight to Immerse	245.44
Moment To Trim	118.538

Form Coefficients

Name	Value
Cb	0.353
Cwp	0.644

Stations **Units (meters, $meters^2$)**

Long'l Loc	WetGirth	WetArea

Stability Data **Units (meters, degrees, kilograms-meters)**

Name	Value
Heel	0.008
Trim	-0.503
GM Transverse	0.371
GM Longitudinal	21.013
Righting Mom1Deg	41.918

Modifying the Hull

When the same model is immersed to the optimum waterline of 1.5 m, however, it becomes apparent that changes to the shape of the hull are required. At the depth of 1.5 m, the ship would displace 46.9 tons. As discussed above when considering the lines of the ship, there are not enough preserved artifacts or sufficient evidence of perished cargo to suggest that the ship had this great a displacement.

Thus, modifications were made to the hull to decrease the displacement. The sheer line at midships was lowered by 0.45 m (*Edit* > *Point Editing* > *Control Points On*) and the rest of the sheer line was faired accordingly.[36] In the breadth view, the profile of the hull was also trimmed fore and aft of midships to make the hull slightly tighter while keeping the same beam amidships. For this rendition, the end posts were also slightly straightened, mostly for aesthetics, to closer represent the ships on the Kenamun wall painting. The depth of the vessel now becomes 2.15 m from 2.50 m, which is closer to the Kyrenia ship's 2.20 m, and the load waterline decreases from 1.50 m to 1.29 m. This small alteration alone was enough to decrease the volume of the ship to 37.6 m^3 with a full-load displacement of 38.6 tons, reduced by 8.3 tons from the 46.9 tons of the first iteration (fig. 2.21).

This chapter discussed the technological procedures for using the tools of Rhinoceros and PHASER to manipulate the hull structure based on archaeological data. The calculations themselves are standard procedures that can be found in any naval engineering book, and these computer programs merely facilitate the task. The difficulty

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[36] These modifications only need to be applied to half of the hull since this part can then be mirrored (*Transform* > *Mirror*) once the changes are finalized.

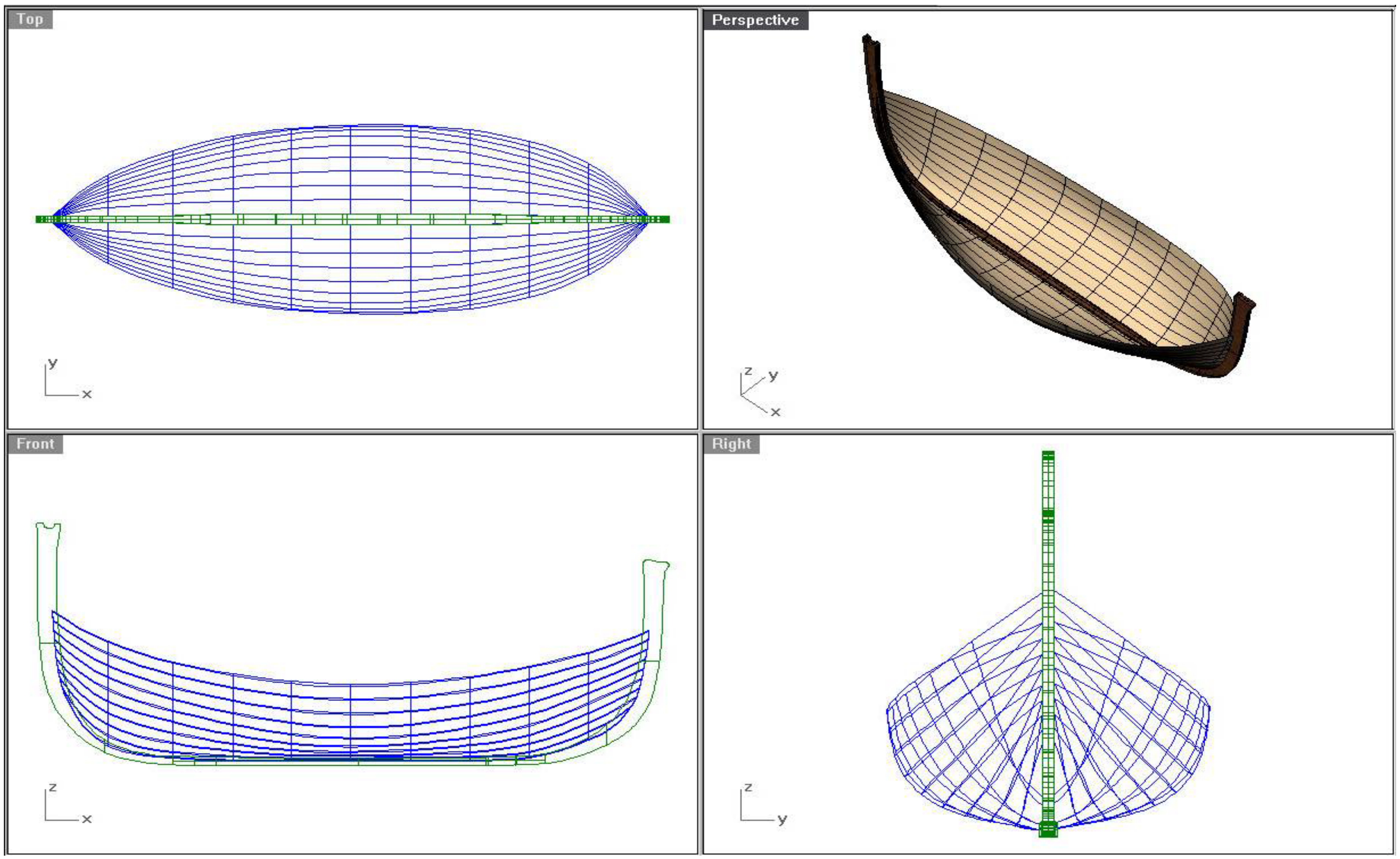

Fig. 2.21 Hypothetical hull no. 2.

comes in the interpretation of the archaeological data, which will ultimately decide how the ship was laden. The remainder of this study will focus on the reconstruction of the original locations of major artifact groups by examining the archaeological evidence. Final calculations of the trim of the vessel will be presented and evaluated in chapter VII.

CHAPTER III

ANCHORS AND BALLAST

Location on the Wreck

Twenty-four stone anchors were found on the wreck in two general locations (fig. 3.1). One transverse cluster of eight anchors (six large and two small) was located almost directly downslope of the first row of copper oxhide ingots. In fact, the displaced ingots from the first row covered three of these anchors (KW 2339, 3336, 4009).[1] Two of the anchors in this area (KW 1603, 3335) were found farther to starboard than the others, conforming to the direction of spillage of other artifacts due to the ship's starboard list. A longitudinal cluster of 15 anchors formed a trail from grid square O18 down to N22. These anchors began at the terminus of the displaced fourth row of copper ingots and paralleled the trail of spilled ingots all the way down to the narrowest point of the gully in square N23, before it widened to a sandy opening. Both ingots and anchors were prevented from rolling farther downslope by this constriction. One last anchor (KW 2917) was found separate from the others, having slid past the gully to grid square M25.

Approximately 78 percent of the stone ballast was located in the bow and about four-fifths of that was found in a concentrated area between anchors KW 2920 and KW 2916 in a 4 m quadrant (O21-P22) (see fig. 1.3). Approximately 572 stones were

[1] A KW ("Kaş Wreck") number was given to an artifact raised from the seabed if it was determined to be sufficiently diagnostic as a single individual object (e.g. a nearly or completely intact Canaanite jar, an anchor, an copper oxhide ingot, or an agate bead). Items that did not constitute an individual object such as a Cypriot pottery fragment, a ballast stone, or a small piece of fragmented metal, were given lot numbers which may include more than one item recovered from the same area.

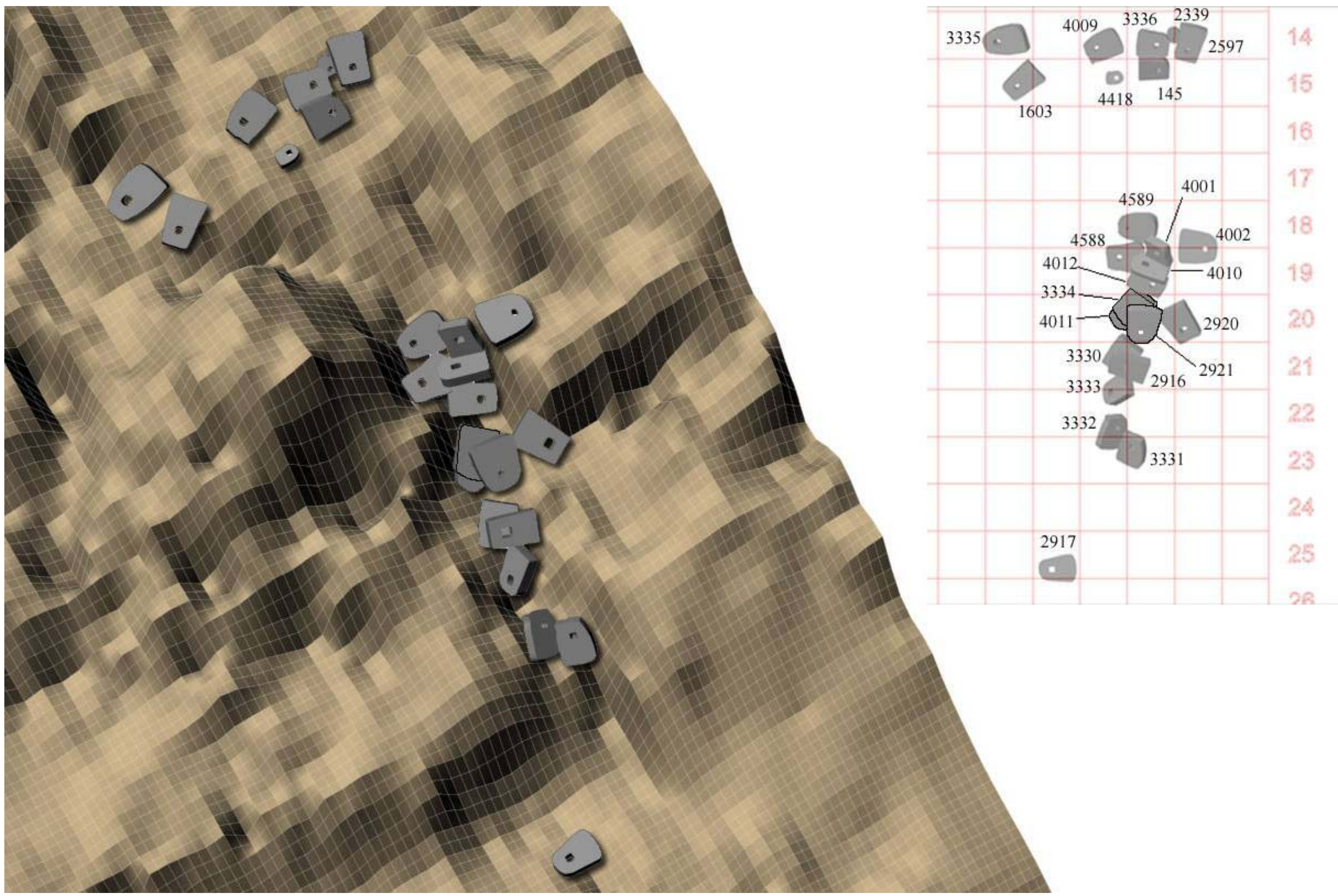

Fig. 3.1 Distribution of the Uluburun stone anchors.

counted among that assemblage.[2] A trail of ballast stones leading from anchor KW 3331 to KW 2917 most likely represents spillage from the main pile. Ballast continued to be found at the deepest part of the wreck among fragments of pithoi and Canaanite jars. These two groups totaled 153 stones. Farther upslope, less than a dozen ballast stones were found in the area of ingot rows 3 and 4. There was a small concentration of roughly 15 stones just east of pithos KW 251, but that area was a catch basin for many tumbling artifacts. It is safe to conclude that no ballast stones were intentionally placed underneath the oxhide ingots and that the few cobbles found around the ingot rows were due to post-wreck deposition.

The next largest pile of ballast stones was located upslope of the ingots on the west side of pithos KW 251 and anchor KW 1603. KW 1603 is a dislocated anchor so any ballast found under it is probably a result of the wrecking process and, as mentioned above, that entire area served as a catchment area for displaced artifacts. To the north was another small pile of ballast stones directly on top of the surviving main hull fragments. Since this part of the site was relatively flat and the ballast stones were lying on top of the hull in a neat pile, it is likely that this reflects their original position on the ship. In fact, it is likely that some ballast (perhaps left over from another excursion) was placed in the midships area around the mast where the hold is relatively free of cargo. The stones around anchor KW 1603 can also be considered part of this cluster of ballast placed amidships.

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[2] All counts of the ballast stones were taken from an unpublished preliminary study conducted by Patricia Sibella. Therefore, the exact numbers of the ballast stones are subject to change.

There was yet another small group of ballast stones immediately to the south of anchor KW 3336 but these most likely came from the larger group of ballast stones upslope of the anchors amidships in square N12. Some of the ballast stones from this large pile were actually found underneath the uppermost row of oxhide ingots, but the highest stone (lot 4435) only abuts ingot KW 1433, which has been displaced from the top layer of the first row. It seems, therefore, that only the displaced ingots were found overlying the ballast stones, and that ballast stones were not intentionally placed beneath the uppermost row of ingots. A total of 93 stones were recovered from the midships of the wreck.

Thirty-four pieces of ballast were found in the area of the main group of Canaanite jars aft of the uppermost row of ingots. Three of them were found under the copper oxhide ingots in this area. The evidence is so sparse that the conclusion that the copper ingots rested on the ballast cannot be drawn. The highest upslope ballast stone recorded is lot 10576 in grid square L8. Most likely this stone fell out of the ship as it was sinking along with some of the other artifacts found in the vicinity or, perhaps, an octopus carried it there. In all, 34 stones were found in the stern, aft of oxhide ingot row 1, 171 stones amidships, and 725 stones from the bow—a total of 930 ballast stones were recorded from the excavation.

General Description of the Stone Anchors

All but two of the anchors are within a height range of 0.59-0.96 m, with an average height of 0.79 m (table 3.1). These are large weight anchors used by Bronze

Table 3.1 Basic physical attributes of Uluburun stone anchors.

KW	Weight (kg)	Max Height (cm)	Stone	Apical hole	Markings
145	97	65.3	sandstone	square	marked
1603	154.3	82.3	sandstone	circle	
2339	21.9	36.9	limestone	circle	
2597	160	80.6	sandstone	square	
2916	141	80.4	sandstone	circle	
2917	134.5	78	sandstone	square	
2920	175.5	84.4	sandstone	square	
2921	196.4	87.5	sandstone	circle	
3330	148.3	75.4	sandstone	square	marked
3332	138	82.5	sandstone	circle	
3331	120	78.6	sandstone	square	
3333	149.1	78.2	sandstone	square	
3334	158.5	80.3	sandstone	square	marked
3335	201	96	sandstone	circle	
3336	107.3	69	sandstone	square	
4001	100.45	59.4	sandstone	square	
4002	180	83.5	sandstone	circle	
4009	138.2	79.8	sandstone	square	
4010	135	80	sandstone	circle	
4011	168.2	84.5	sandstone	square	marked
4012	153.5	79.7	sandstone	circle	
4418	25.93	38.3	limestone	?	
4588	122.2	81	sandstone	circle	
4589	171	81	sandstone	square	
Total weight	**3297.28**				

Age seafarers to immobilize a ship by the sheer mass of the material employed (fig. 3.2). Other types in use at this time, curiously absent from this ship, are defined by Frost as sand anchors and composite anchors. Sand anchors are simply slabs of rock that are considerably smaller than weight anchors, and have, in addition to a hawser hole, two holes to accommodate wooden spikes that dig into sandy sea floors. Composite anchors are similar in size to weight anchors but include the holes for the wooden spikes as found on sand anchors.[3] The two smaller anchors are both just under 0.40 m and would also be classified as weight anchors despite their unsubstantial size because they lack holes to accommodate wooden spikes. Their small size suggests they were probably used with the ship's boat.[4] Another possibility is that they were used as hawser weights to give some slack to the anchor cable. At present, it is impossible to determine what function the smaller anchors served. While it seems more likely that the ship would have carried two boat anchors instead of only two hawser weights, others might have been lost while in use, in an attempt to prevent the imminent wrecking.

Any classification of the shapes of the Uluburun anchors at this time is tentative since Late Bronze Age stone anchor typology is still in its formative stage. Isolated anchors found on the sea floor are practically useless for classification purposes since there is no datable archaeological context. Therefore, the existing typology, aside from a few anchors found in association with dated shipwrecks,[5] has been derived from land

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[3] Frost 1963, 7-10; see also Wachsmann 1998, 255-6.
[4] Pulak 1999, 210; see also Wachsmann 1998, 286-8.
[5] In addition to the 24 anchors from the Uluburun shipwreck, one large anchor weighing 219 kg was discovered at Cape Gelidonya in 1994 and 15 anchors from a presumed shipwreck in Newe-Yam were found in 1983. (Pulak and Rogers 1994, 20-1; Galili 1985, 143-53).

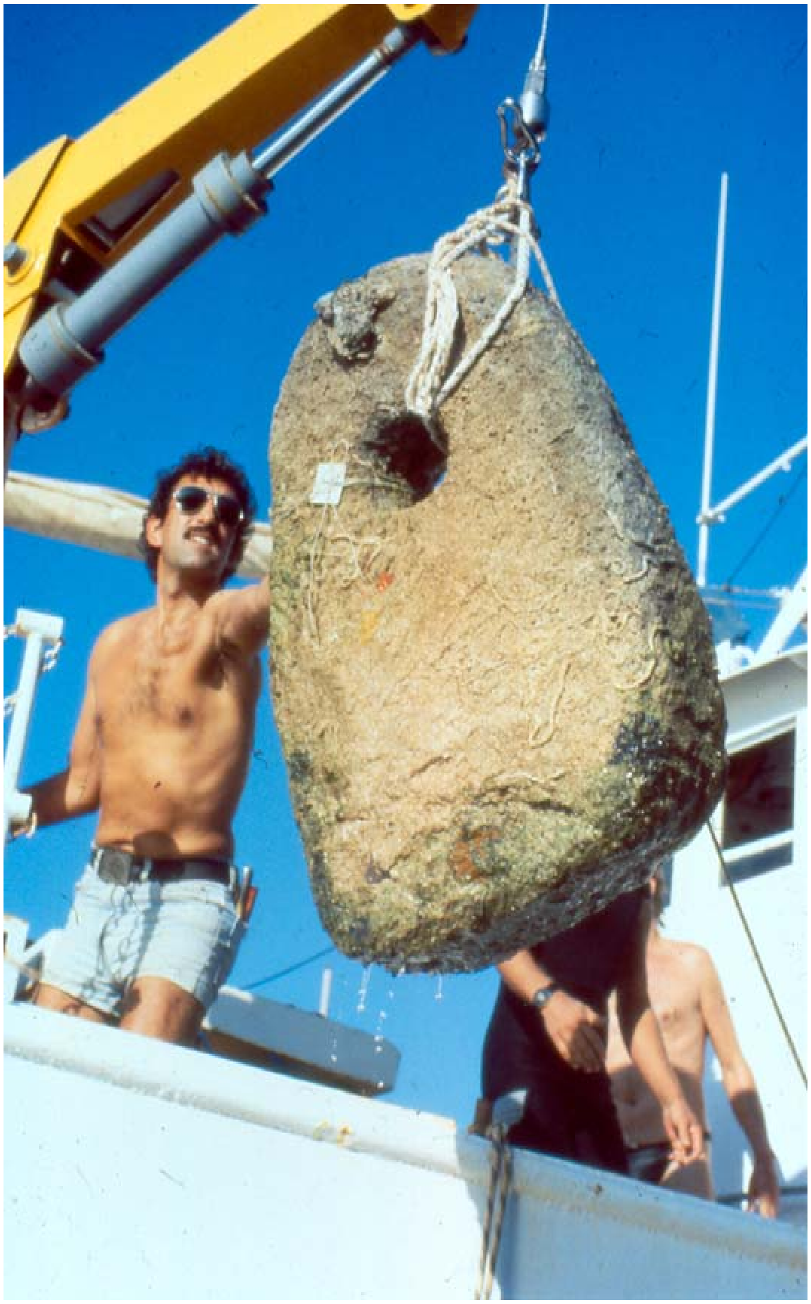

Fig. 3.2 Hoisting a stone anchor from Uluburun with a hydraulic crane. (Courtesy of Institute of Nautical Archaeology.).

finds.[6] Anchors are difficult to categorize by region because they were designed for shipboard use and were picked up from various ports and lost along the way on a journey.

Nevertheless, several regional types have been defined, although the typology is in need of further refinement.[7] Generally, Egyptian anchors are characterized by ovoid tops, asymmetrical profiles, round apical holes with a hawser groove at the top, and an L-shaped perforation near one corner of the base (fig. 3.3).[8] The Byblian type includes similar anchors with a triangular profile, a circular apical hole, and a well-defined rope groove (fig. 3.4).[9] Anchors discovered at Ugarit are not as uniform in their features and come in three distinct shapes: a short rectangle, an elongated rectangle, and a triangle (fig. 3.5). Seven of the 26 anchors from Ugarit have two basal holes for wooden stakes and one even has the Egyptian L-shaped hole at its basal corner.[10] The last of the major anchor types is the Kition anchor type known from Cyprus. These are usually squat and rectangular or triangular in shape with rounded corners (fig. 3.6).[11] The Uluburun anchors most closely approximate the Ugaritic and Cypriot anchors in shape and size. All the anchors are single-holed with no rope grooves or L-shaped perforations. Fourteen of the hawser holes were square cut and 10 were circular in shape. Almost all of the anchors are elongated trapezoids or rectangles with varying degrees of rounding on the corners. None of the anchors, however, could be considered triangular like the

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[6] Frost 1969a; Frost 1969b; Wachsmann 1998, 258-62, 271-4.
[7] For example, only six out of the 28 anchors excavated at Byblos have the features of a "Byblian" anchor (Wachsmann 1998, 272).
[8] Wachsmann 1998, 259-62, fig. 12.11.
[9] Wachsmann 1998, 271-2.
[10] Frost 1969a, 245.
[11] Wachsmann 1998, 274.

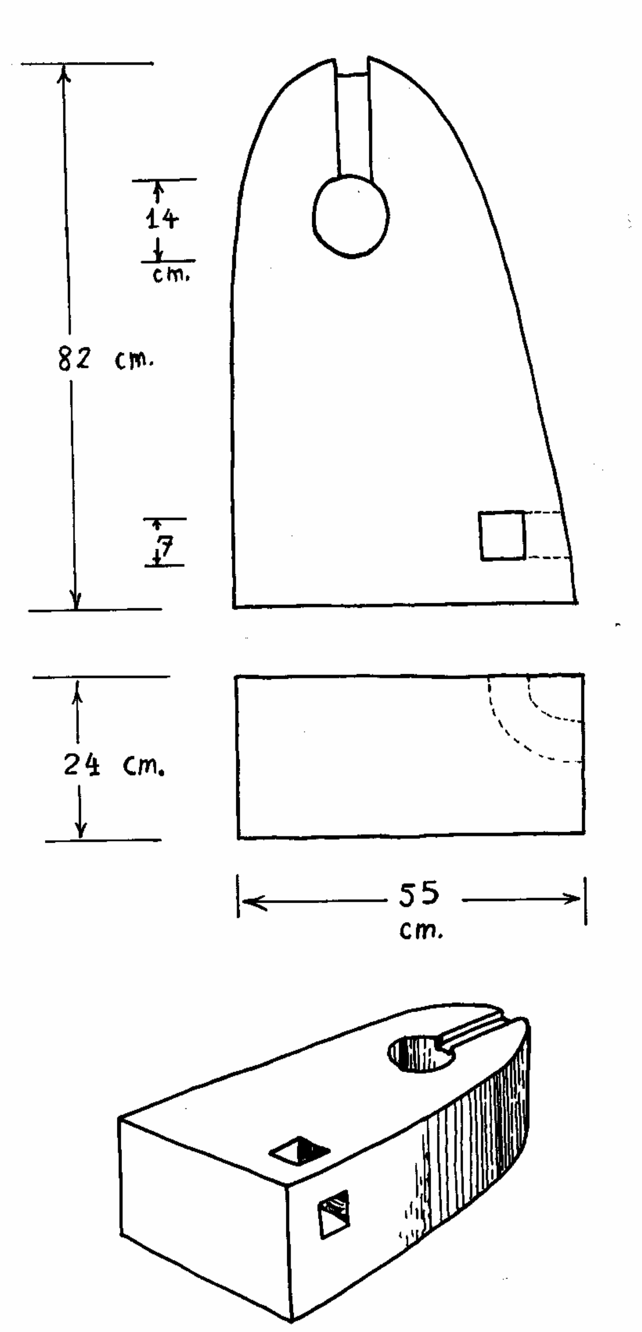

Fig. 3.3 Example of an Egyptian anchor.
(From Wachsmann 1998, 261, fig. 12.11).

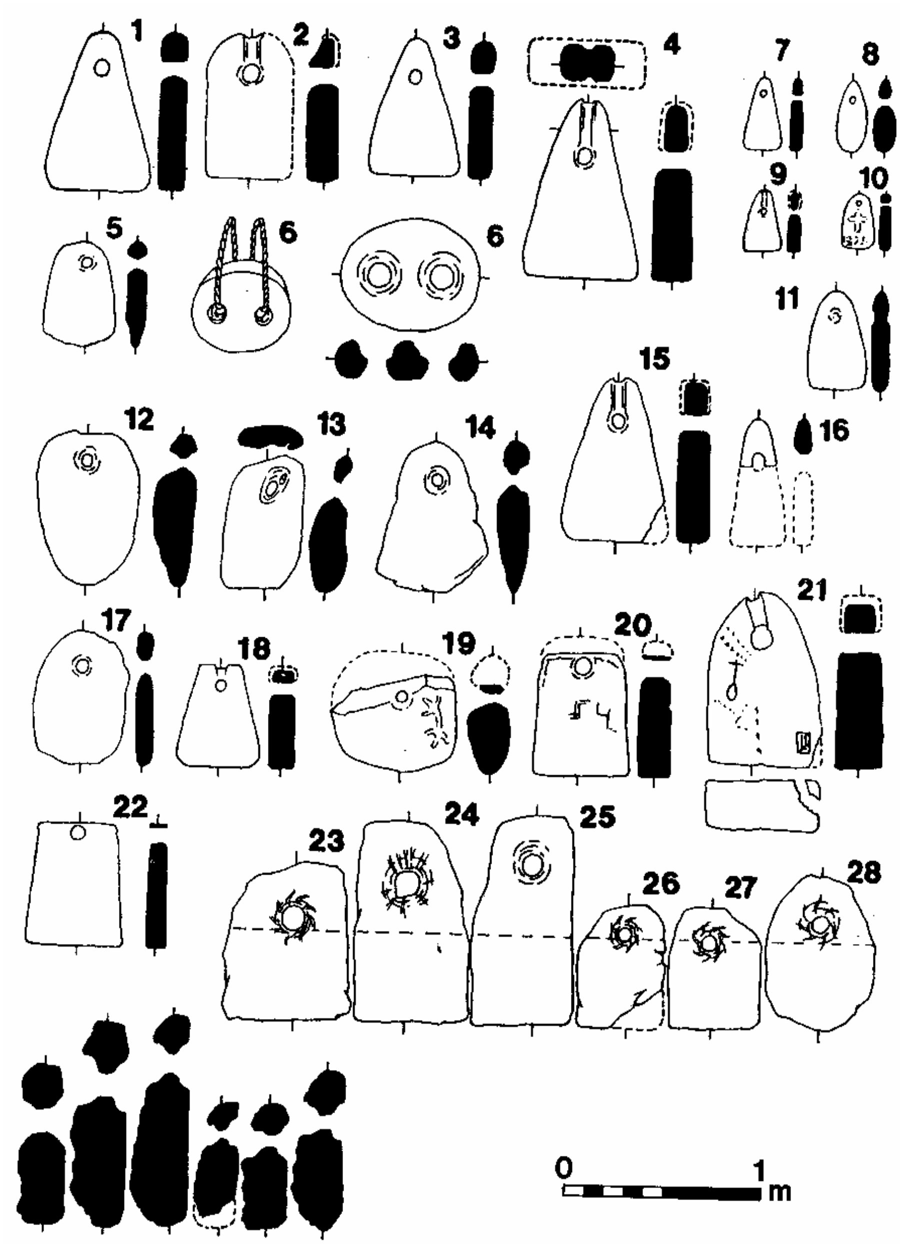

Fig. 3.4 Examples of Byblian anchors.
(From Wachsmann 1998, 271, fig. 12.28).

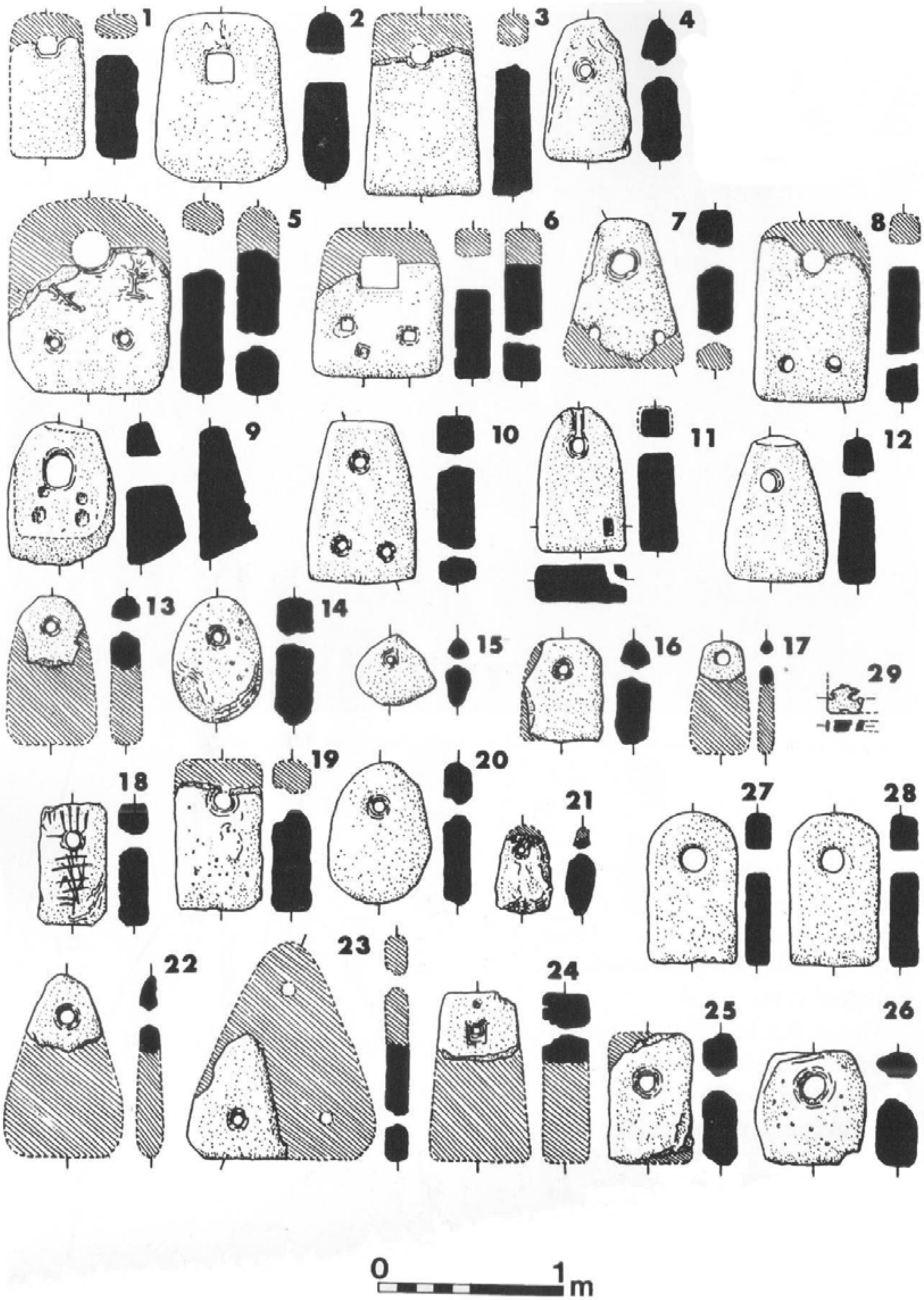

Fig. 3.5 Examples of Ugaritic anchors. (From Wachsmann 1998, 274, fig. 12.33).

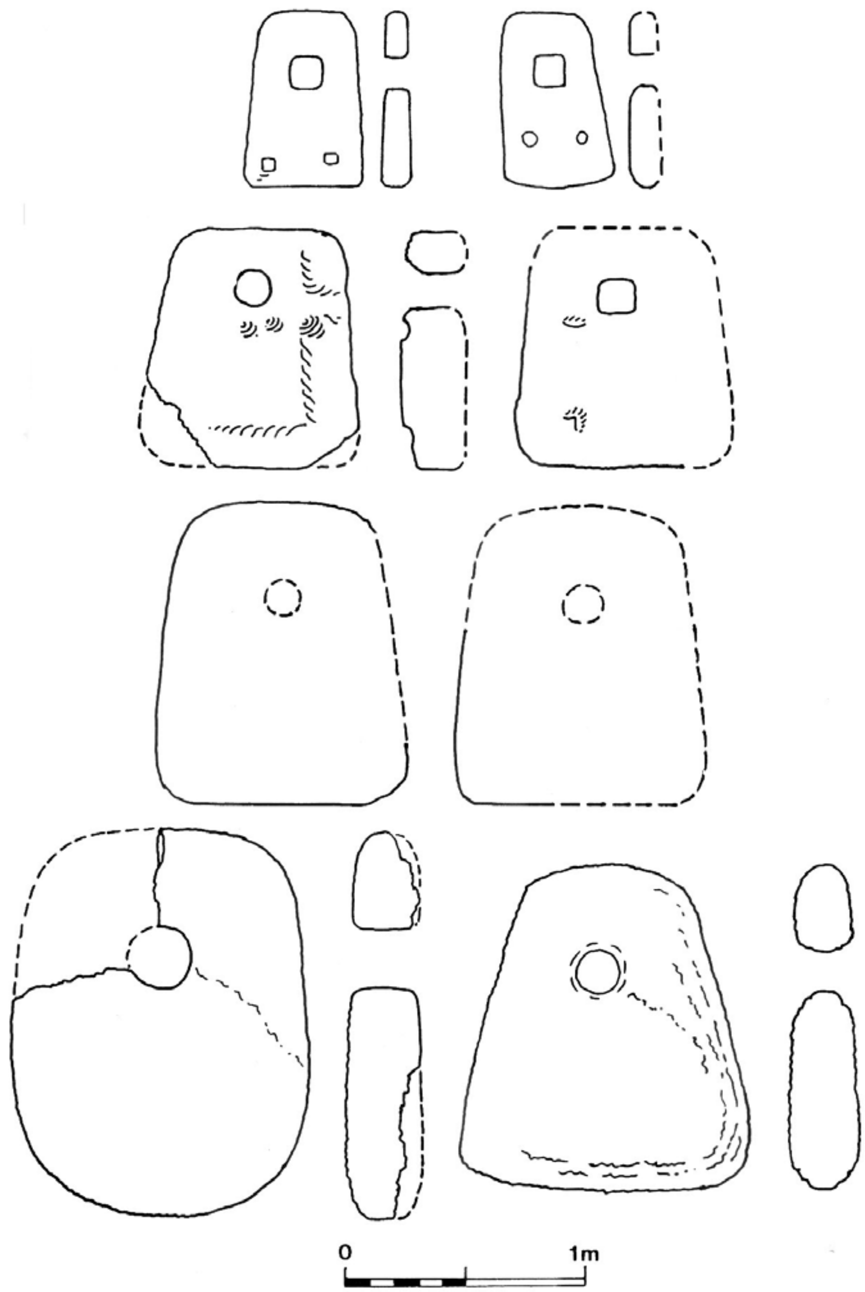

Fig. 3.6 Examples of Cypriot anchors.
(After Wachsmann 1998, 289, fig. 12.52).

Byblian examples. All of the large Uluburun anchors were cut from sandstone while the two smaller ones were from limestone. Most likely these anchors were loaded at the same place, given their general similarity in shape and material, and thus provide some indication of the ship's home port.

Stowage and Stacking

Six large anchors (KW 145, 1603, 2597, 3335, 3336, 4009) and two small anchors (KW 2339, 4418) were located near midships. These anchors were probably spares stored in the hold as ballast:

> Ships from ancient times used stone anchors and thus many of them were lost. For that reason it was necessary to prepare a stock of reserve anchors, to replace those that were lost. Logically, these reserves would be stocked in the belly of the ship as ballast stones; when needed, the spare anchors were taken out and ordinary stones were used to replace them.[12]

It is likely that the eight anchors found in this section of the wreck represent the entire original complement of reserve anchors, since there were an additional 16 anchors ready for deployment in the bow. From the positions of the anchors amidships, it is clear that they were stacked in groups of two. The best indicators for this are KW 145 and 3336, where the former was still partially overlapping the latter. This is not due to mere coincidence as KW 1603 and 4418 were found almost perfectly in line longitudinally with KW 3335 and 4009, respectively. The upper level of anchors most likely slipped downslope when the ship landed

[12] Galili 1985, 149.

on the steep slope. The configuration of the last two anchors, KW 2339 and 2597, is not as obvious. It is unlikely that the larger anchor was placed on top of the smaller one, as found. A possible clue to their original placement is the direction of the hawser holes on the three anchors at the lower level. KW 3335 and 4009 both have their holes oriented toward starboard while that of KW 3336 faced port. While this is not proof that KW 2597 should have also faced that direction, the possibility seems likely. An anchor would be easier to raise to an upright position and lift out of the hold if a rope or pole could be inserted into the hawse hole and raised with the opposite end of the anchor serving as the pivot. This is further facilitated if the raising arc was shorter due to the pivoting end being on the lower part of the hull rather than the upper part. It is significant that the keel runs between anchors KW 4009 and 3336, indicating that those anchors were indeed placed on the starboard and port sides of the ship, respectively. This means that these anchors were placed in an optimum position for raising when reserve anchors were needed (fig. 3.7).[13]

The direction of the upper level of anchors also concurs with the lower ones: KW 1603 was facing starboard and KW 145 faced port. Only anchor KW 4418 did not face the same direction as the anchor below, but since it is of

[13] Frost notes that these anchors probably were too heavy to lift in and out of the hold unless some mechanical device like a mast derrick was used (Frost 1995, 167-72). A possible depiction of this device can be seen on a seventh century B.C. Cypriot jug showing the raising of an anchor(?) (Wachsmann 1998, 183, fig. 8.41c).

Frost's suggestion that the Uluburun anchors were stacked in an upright position to facilitate their raising, however, cannot be reconciled with the manner in which these anchors were found. Had they been stored upright, then all of them should have had their hawser holes pointed to starboard when the ship listed in that direction. Since this group of anchors were held in reserve, for use after most of the bow anchors were depleted, it was not as critical to make them so readily accessible, especially when it would have been more unstable to store the anchors vertically than horizontally on a curved surface.

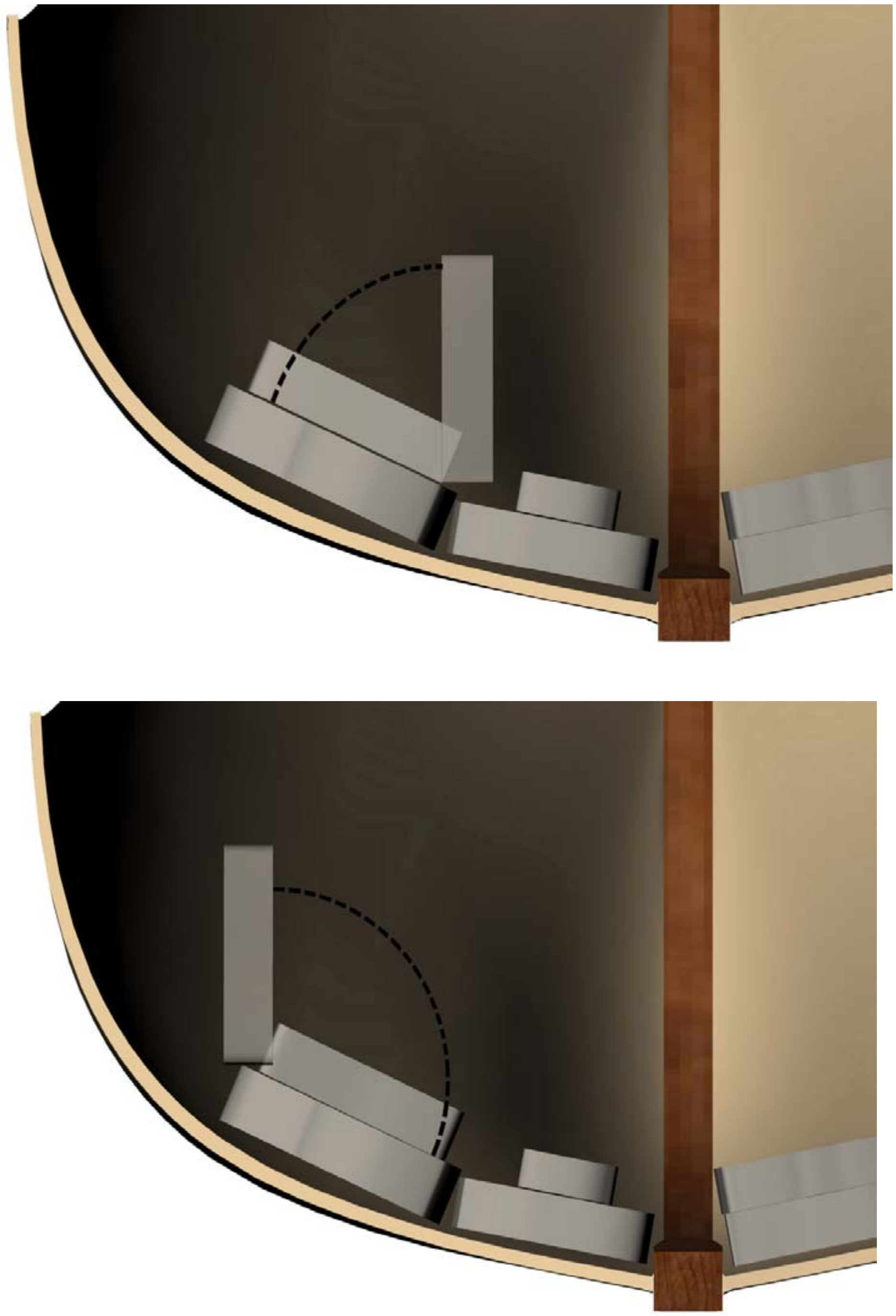

Fig. 3.7 Benefit of raising an anchor if hawse-hole is oriented away from the keel. In the upper illustration, the hawse hole faces away from the keel, while the lower illustration shows the arrangement with the hawse hole facing the keel.

considerably smaller size, it would not have been difficult to raise regardless of the direction in which it faced. This scenario suggests that anchors KW 2597 and 2339 have been significantly displaced from their original position, possibly even flipped over. While the smaller anchor (KW 2339) might have originally rested on the larger one, this was reversed during the wrecking of the ship. It would be disadvantageous to keep the pivot end of the anchor higher up along the side of the hull since the heavier end might scrape along the hull or swing outward and damage the cargo as it was lifted. Figure 3.8 shows the reconstructed arrangement of the midships anchors.

The deeper section of the wreck is believed to correspond with the bow of the ship, in part because of the great number of stone anchors found. Because anchors would be deployed whenever the ship came to port, moored for the night, or encountered a storm, the crew stowed 16 anchors in the bow for easy deployment. Although it cannot be ascertained, at least one or more of these anchors were probably stored on a small foredeck ready for use.

Only four of the 24 anchors carry incised marks: KW 2920, 3330, 3334, and 4011. All four marked anchors were found in the bow. Anchor KW 2920 has a complex arrow-like mark with one central incision and two radiating lines on either side. Anchor KW 3330 is incised with an upside down V (or ^ mark), while KW 3334 exhibits a similar mark but is closed off to form a triangle, and KW 4011 has a more complex, grid-like marking with two long parallel vertical lines and four parallel perpendicular

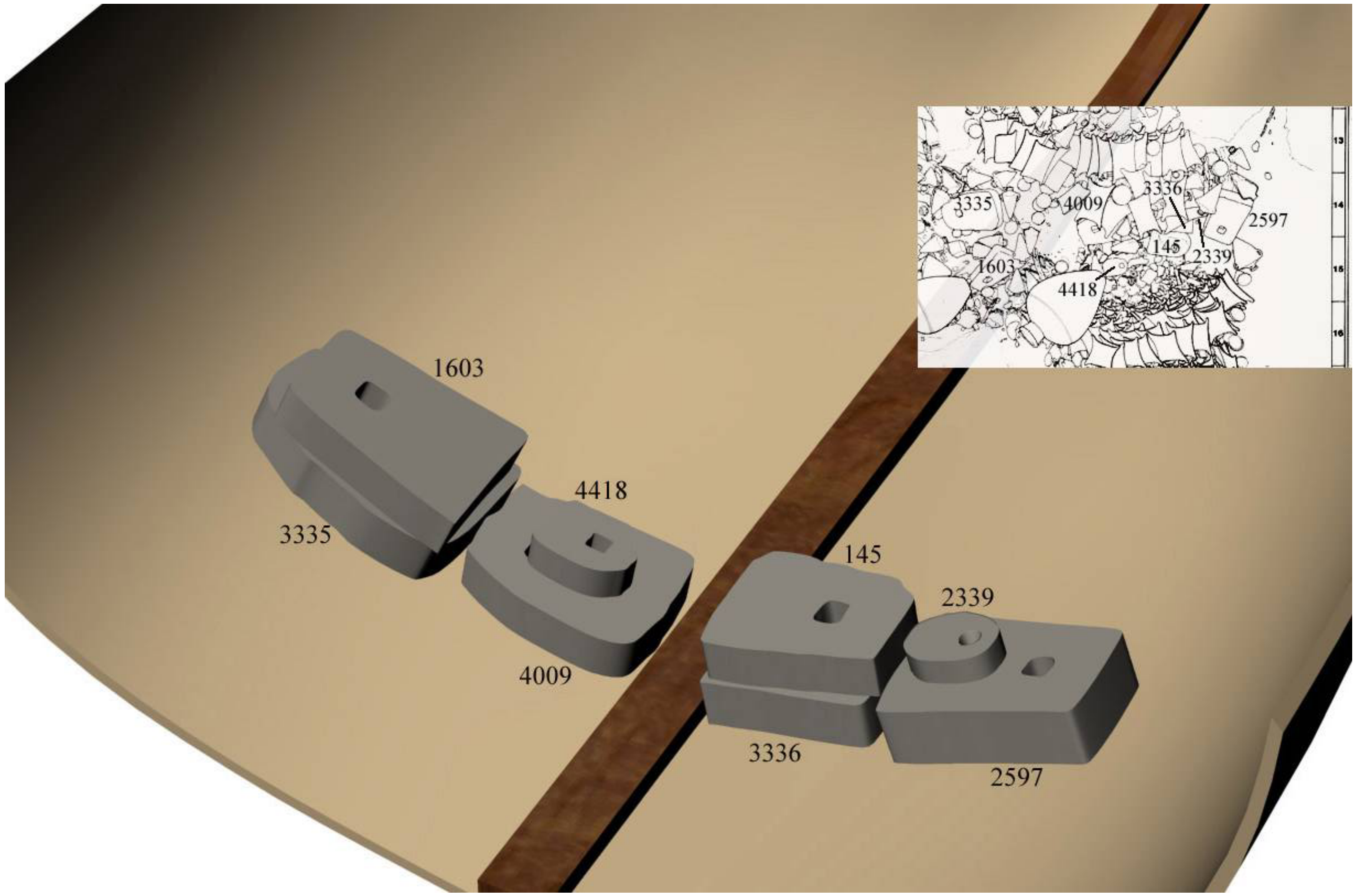

Fig. 3.8 Reconstructed arrangement of the anchors stored at midships.

lines intersecting the verticals (fig. 3.9). Anchor KW 3334 was found directly on top of KW 4011, while KW 3330 was just downslope of it. Had it not been for anchor KW 2921 that was found on top of KW 3334, the latter three marked anchors would have appeared to have been stacked on top of each other. It is noteworthy that the larger and heavier anchor KW 4011 (ht. 84.5 cm, wt. 168.2 kg) was on the bottom and the smaller anchor KW 3334 (ht. 80.3 cm, wt. 158.5 kg) on top. It is logical to place the largest anchors as low as possible to provide more space for the smaller anchors and to keep the center of gravity of the ship low, assuming they were placed horizontally amidships. This was also the case with anchors KW 3331 and 3332, the two anchors at the bottleneck of the gully. Anchor KW 3332 is larger and heavier, and is also positioned behind or underneath anchor KW 3331. Since these two anchors were highly mobile and slid a considerable distance from their original locations, it cannot be said with the same degree of certainty that they were originally stacked in the same fashion as the others. Without exception, all of the anchors amidships were found in a manner suggesting a similar configuration: anchor KW 3335 is larger than KW 1603, KW 4009 is larger than KW 4418, KW 3336 is larger than KW 145, and KW 2597 is larger than KW 2339. If this was the pattern that the crew followed in stowing the anchors, then it would be strange to place the largest anchor in the bow (KW 2921; ht. 87.5 cm, wt. 196.4 kg), on KW 3334 rather than KW 3330 (ht. 75.4 cm, wt. 148.3 kg), which is the smallest of the marked anchors. While it is tempting to suggest that all the marked anchors were stored together, the evidence is simply inconclusive.

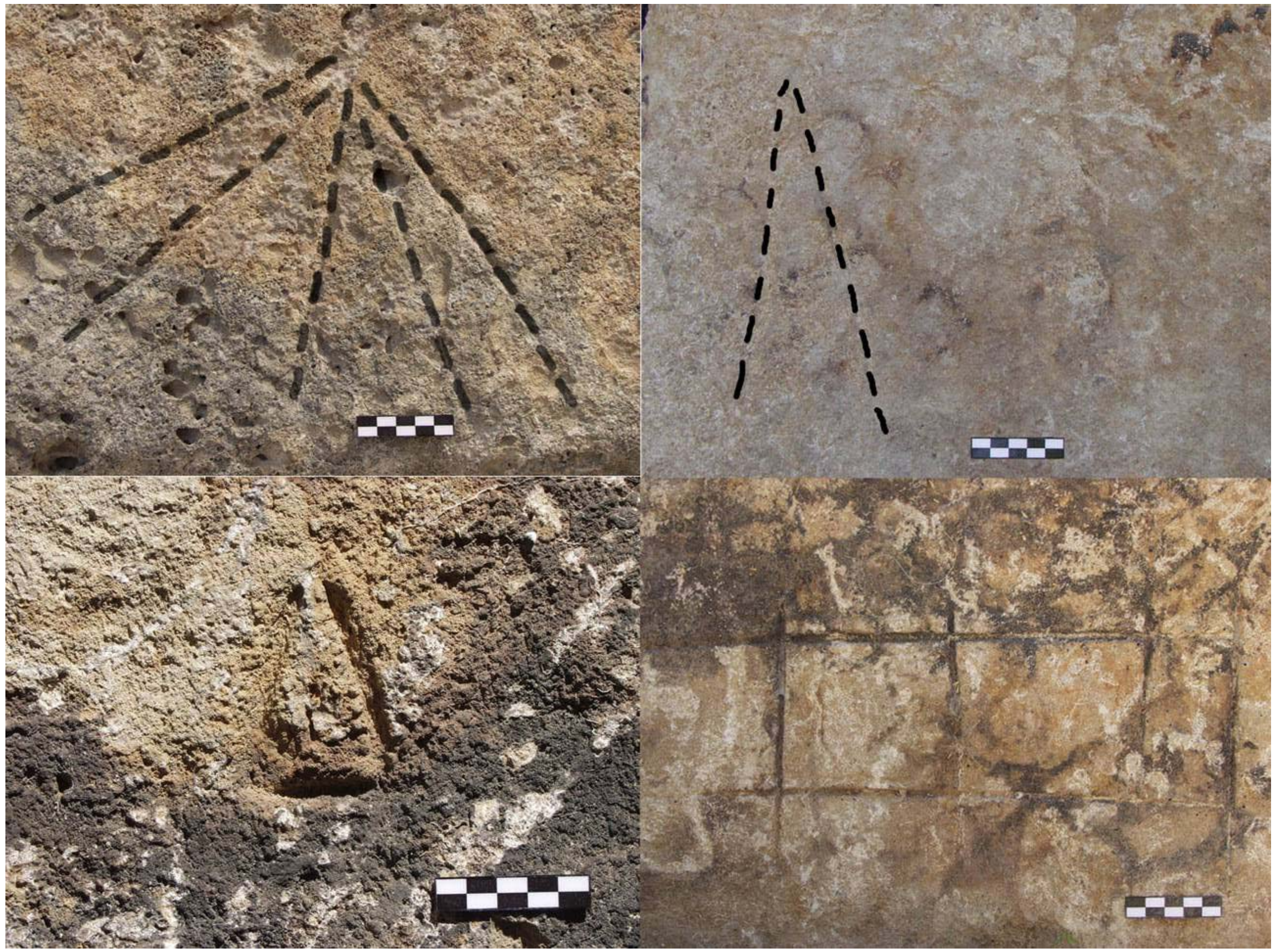

Fig. 3.9 Marks found on stone anchors. Upper left: KW 2920, upper right: KW 3330, lower left: KW 3334, lower right: KW 4011. (Courtesy of Institute of Nautical Archaeology.).

The general arrangement of the anchors at the bow is also ambiguous. Were they placed horizontally like the midship anchors or kept upright, possibly for easier access? It is likely that the anchors were more vertical than horizontal since the hull narrowed toward the bow. If they were leaning against the hull, then this also leads to the assumption that they were placed parallel to the keel, as with the midship anchors, but vertical. The orientation of the anchors on the seabed supports this assumption.

A diminishing progression can be seen in the bow anchors: closest to the copper ingot rows were six anchors (KW 4001, 4002, 4010, 4012, 4588, 4589); downslope of them four more (KW 2920, 2921, 3334, 4011); another three anchors were placed forward of that (KW 2916, 3330, 3333); followed by KW 3331 and 3332; and finally KW 2917. This may indicate that the anchors were stowed in four rows in decreasing numbers towards the bow of the ship. KW 2917 could, however, have been an anchor stowed on deck, which might explain its distance from the others. Anchor KW 4010 may have also been stowed on deck. Although not the most obvious candidate, since it was among the group of anchors closest to the oxhide ingot rows, its location makes it a suspect. Superficially, its removal would improve the diminishing transition of anchors to five and four, instead of six and four. Also, its orientation when found was propped up, nearly perpendicular to the sea floor, as if it had fallen from a greater height and inserted itself into the pile of artifacts. The direction of its hole is also perplexing since the anchor beneath it (KW 4012) has its hole facing the opposite direction. There are no other instances of this configuration among the other anchors. Anchors KW 3331 and 3332 may also have been on the foredeck, which would bring the complement of bow anchors to four, a number suggested by Pulak.[14] Only these two anchors and KW 4001 (located farther upslope) among the anchors in the bow have their hawser holes pointing upslope, perhaps an indication that the two anchors were positioned differently than the others. If there were four anchors on deck, then it is curious that they were not distributed in a more recognizable pattern on the site. A tenuous comparison can be made to the Old Kingdom depiction of two Egyptian seagoing ships carrying Syro-Canaanite passengers found on the causeway of Unas's burial temple. A single weight anchor is shown at the bow of one of the ships as if prepared for deployment (fig. 3.10). Although the relevance of this example to the Uluburun ship is highly debatable, it is nonetheless one of the few such clues from the Bronze Age. To have four anchors on deck might adversely affect the stability of the vessel, especially as the load lightened as food stores were consumed and anchors lost over board. Overall, the anchors were too displaced to arrive at a definitive conclusion regarding their original configuration, but two hypothetical configurations are proposed in figure 3.11.

Weight Distribution

The total weight of the stone anchors is 3297.3 kg. This figure is derived from measurements taken after the anchors were cleaned of marine growth and encrustation, and should be very close to the anchors' original weight. Of this total, 905.6 kg (27 percent) of the weight is located amidships and 2391.7 kg (73 percent) at the bow. The anchors in the bow have a weight factor similar to an

[14] Pulak 1999, 211.

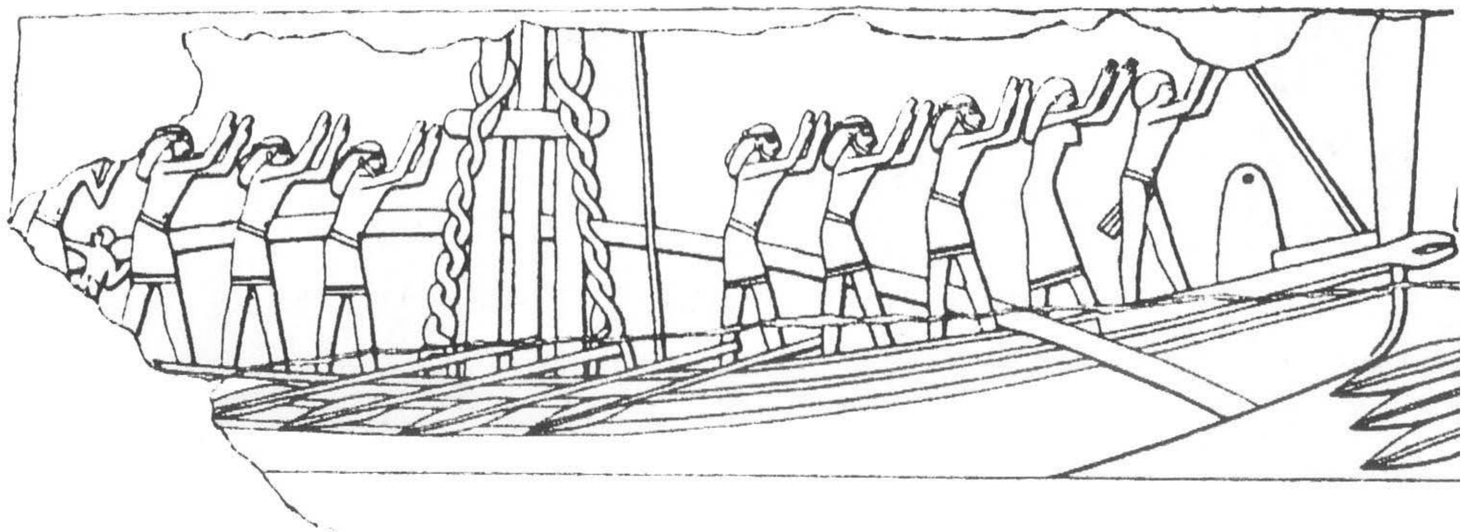

Fig. 3.10 Anchor on foredeck of seagoing ship from causeway of Unas at Saqqara. (From Wachsmann 1998, 14, fig. 2.5).

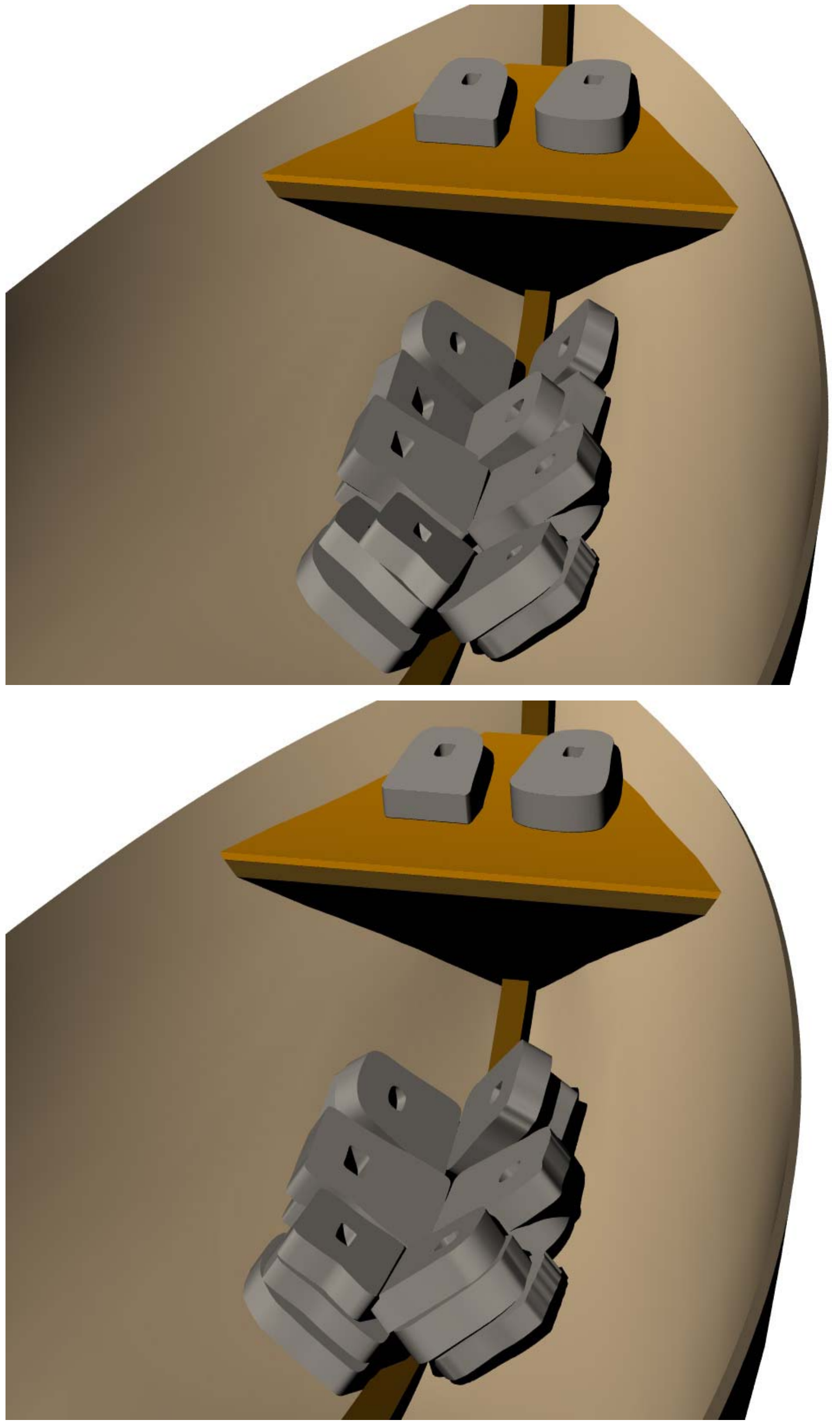

Fig. 3.11 Reconstructed arrangements of anchors at the bow. The upper illustration shows the 5-4-3-2 configuration, while the lower illustration depicts the 6-4-4 configuration.

entire row of copper oxhide ingots. The 930 ballast stones total 713.4 kg, with an average of 0.77 kg a piece. Approximately 558 kg (78 percent) of the total weight was from the deeper portion of the wreck and contamination from the midships and stern ballast piles seems minimal. That most of the stone ballast was in the bow while only minimal ballast was found amidships and in the stern implies that the stern was sufficiently loaded to counterbalance the copper oxhide ingots and anchors in the bow. This becomes an important factor when considering the placement of the cargo carried aboard the ship.

CHAPTER IV

THE INGOTS

Copper Oxhide Ingots[1]

Background

A total of 354 ingots of the "oxhide" shape were found in four distinct rows lying perpendicular to the axis of the keel, an estimated 10 tons of raw copper as cargo aboard the Uluburun ship (fig. 4.1). A fifth stash of copper ingots was located in the stern behind the first row and the Canaanite jar pile; all five of the smaller, pillow-shaped ingots (KW 117, 388, 389, 390, 517) were located here, as well as one two-handled ingot (KW 408) and seven four-handled ones (KW 404, 413, 624, 625, 626, 628, 636). It is unknown why these particular copper ingots were placed in this location and not with the others. Also found in this area were nine large copper bun ingots and at least 10 smaller ones, and more than 25 quarter-oxhide tin ingots and all four of the tin bun ingots found on the site. It could be that this cache of copper and tin ingots may have been the personal property of a passenger or crew member since almost all of the personal effects aboard were found in the stern area, or it may have had a different destination from the rest of the ingots.

The copper oxhide ingots in the four rows were stacked in layers with the handles overlapping one another in a herringbone pattern.[2] Generally, the direction of overlap alternated from layer to layer, although there are some exceptions to this rule,

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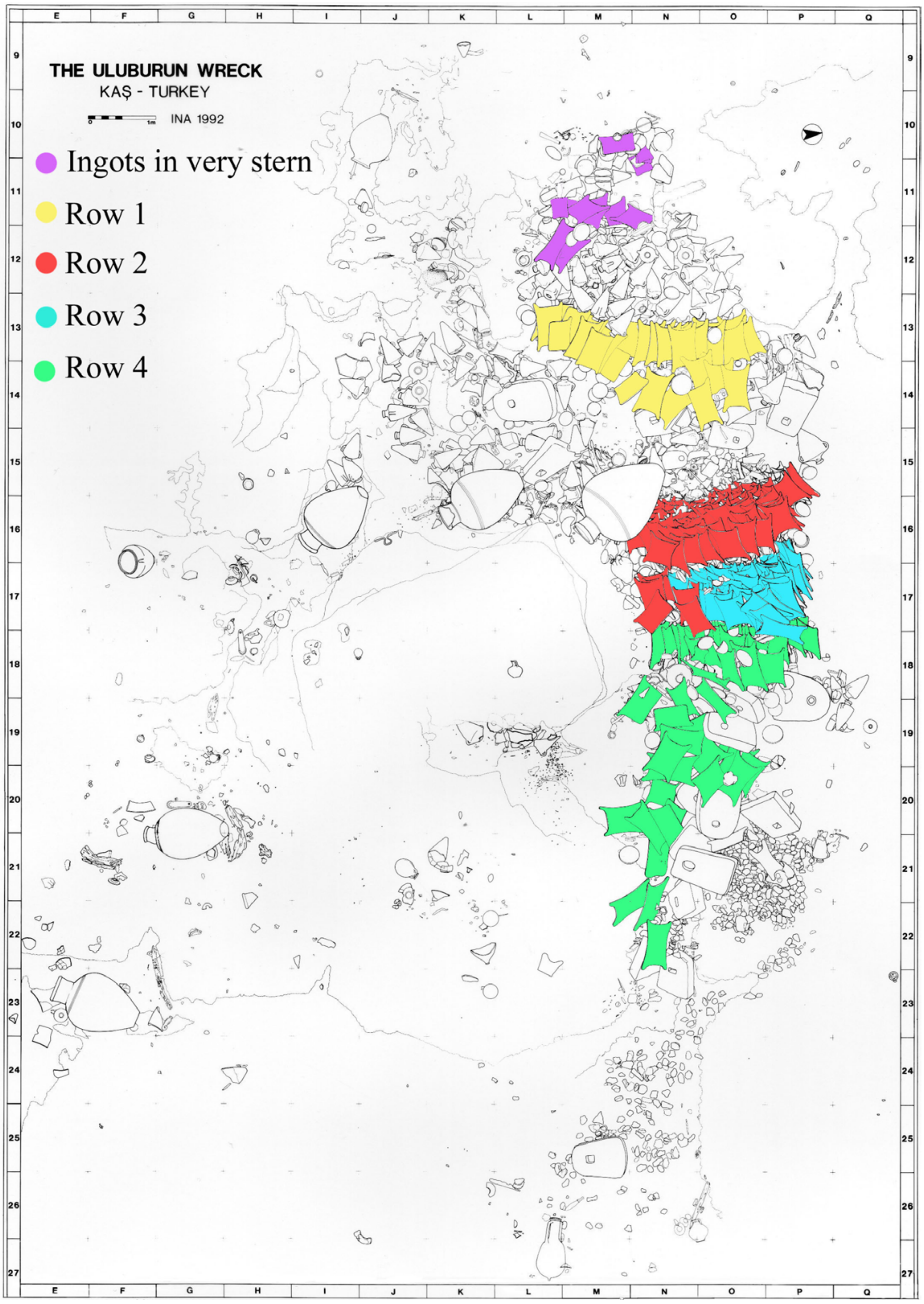
[1] For a more detailed discussion of copper and tin ingots in general, and the Uluburun ones in particular, see Pulak 2000b, 137-57.
[2] Pulak 2000b, 140; see also Pulak 1997, 237; 1998, 197.


THE ULUBURUN WRECK
KAŞ - TURKEY
INA 1992
Ingots in very stern
Row 1
Row 2
Row 3
Row 4

especially in the third and fourth rows. Apparently, this stacking pattern became increasingly difficult to follow as the curvature of the hull narrowed towards the bow and more ingots had to be placed in the middle of the row in order to keep them level with the steeper sides. The bottom-most layers of ingots were cushioned with dunnage, consisting of small branches with a layer of thorny brushwood (*Sacropoterium spinosum*) over them. The branches beneath the thorny burnet were laid athwartships to prevent the ingot from splitting the plank seams.[3] There was no evidence of ceiling planking in the hold. Each ingot was laid with its smooth, or mold, side facing down on the rough surface of the ingots below, which helped to deter the stacked ingots from sliding, especially the ones along the sloping walls of the hold. For additional grip, each ingot was placed so that the side resting on the lower layer made full contact with the body of the ingot below and not just with its handles. It was also probably easier to set down and lift up the ingots with the hands gripped around the beveled, smoother surface rather than the rough side.[4] An additional benefit was the ready visibility of the markings found on 58 percent of the ingots, which were always found on the rough surface near the handles.[5] Four-handled and two-handled oxhide ingots were mixed together in these four rows, and there does not appear to be a deliberate attempt to segregate the two types.

Almost all of the copper oxhide ingots were displaced from their original positions when the ship settled with a list to starboard. This is evident from the site plan, which shows the ingots, as well as many other artifacts, tilted to starboard. The ingots

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[3] Pulak 1999, 222.
[4] Pulak 2000b, 141.
[5] Pulak 2000b, 141.

later experienced further dislocation when the keel broke as the waterlogged and decayed hull gave way to the massive weight of the cargo, sending much of the cargo down the steep slope. The first row of oxhide ingots on the upper regions of the wreck and the fourth row on the deeper end experienced the greatest amount of disturbance. The second and third rows both had ingots in front of them that prevented them from sliding down slope.

All the ingots have been cleaned of their surface concretion and exhibit a weight range of 20.1-29.5 kg with a mean weight of 23.9 kg.[6] The degradation of the copper ingots due to corrosion, especially of the handle-like protrusions, indicates that the ingots were originally heavier and that, in their current condition, they cannot exceed their original weight. Nevertheless, the weight variation cannot be solely attributed to corrosion because the heaviest ingot (KW 3068) is missing one of its handles while one of the lightest ingots (KW 2801) is completely intact.[7] The difference in weight implies that these ingots were never meant to be used as an absolute form of currency but were cast to an approximate weight of 28-29 kg (weight of ancient unit of one talent) to facilitate a rough estimate of a store of copper before it was weighed.[8] The estimated 10 tons of copper and 1 ton of tin found aboard are in the ideal proportions to produce 11 tons of bronze.

[6] Pulak 2000b, 141, 143, fig. 7.
[7] Pulak 2000b, 142.
[8] Pulak 2000b, 140; see also Pulak 1998, 194.

<u>Row 1</u>[9]

Row 1 consists of five layers of ingots placed in alternating directions. Each layer is distinguished by ingots placed in the same direction. The next layer above begins with an ingot placed in the opposite direction. Ten ingots from the upper layers are considerably displaced and their exact placement is uncertain, although the rest form a cohesive pattern that aids in the reconstruction of the remaining shifted ingots. Two general shifts of the ingots are observed from the orientation of the displaced ingots. Ingots KW 72, 182, 60, 62, 64, and 1169 fell down the slope, not only as a result of a simple forward plunge, but the ship must have heeled to port at some point because the ingots are rotated clockwise between roughly 30 and 90 degrees from their original orientation (fig. 4.2). A number of Canaanite jars and copper oxhide ingots also seemed to have been tossed in the same direction. At some time later, probably when the ship landed on the seabed with a list to starboard, KW 61, 63, 71, and 65 fell on top of the first group of dislocated ingots in a downward thrust with a tilt to starboard. Due to the list, all the port side ingots that rested on the side of the hull slid onto each other towards the center, increasing the amount of overlap between each ingot. This is clear on the cross-section drawing made from measurements taken during the excavation (fig. 4.3).[10] Compare the presumably normal overlapping surface of ingots KW 1493, 1475, and 1452 with the compressed spacing of ingots KW 187, 869, and 877. Ingots in the middle of the pile (KW 184, 74, 73) also experienced the same effect and are clustered together.

[9] The designation of row numbers does not reflect the order in which the original crew may have placed them but rather the order in which these rows were excavated. Row 1 was uppermost on the site in squares M-P13, row 2 in M to P15-16, row 3 in N-P17, and the undisplaced ingots of row 4 in N-P18. These rows could have been laid singly or several simultaneously.

[10] The cross-section drawings were made looking at the ingots from the top of the cliff down the slope.

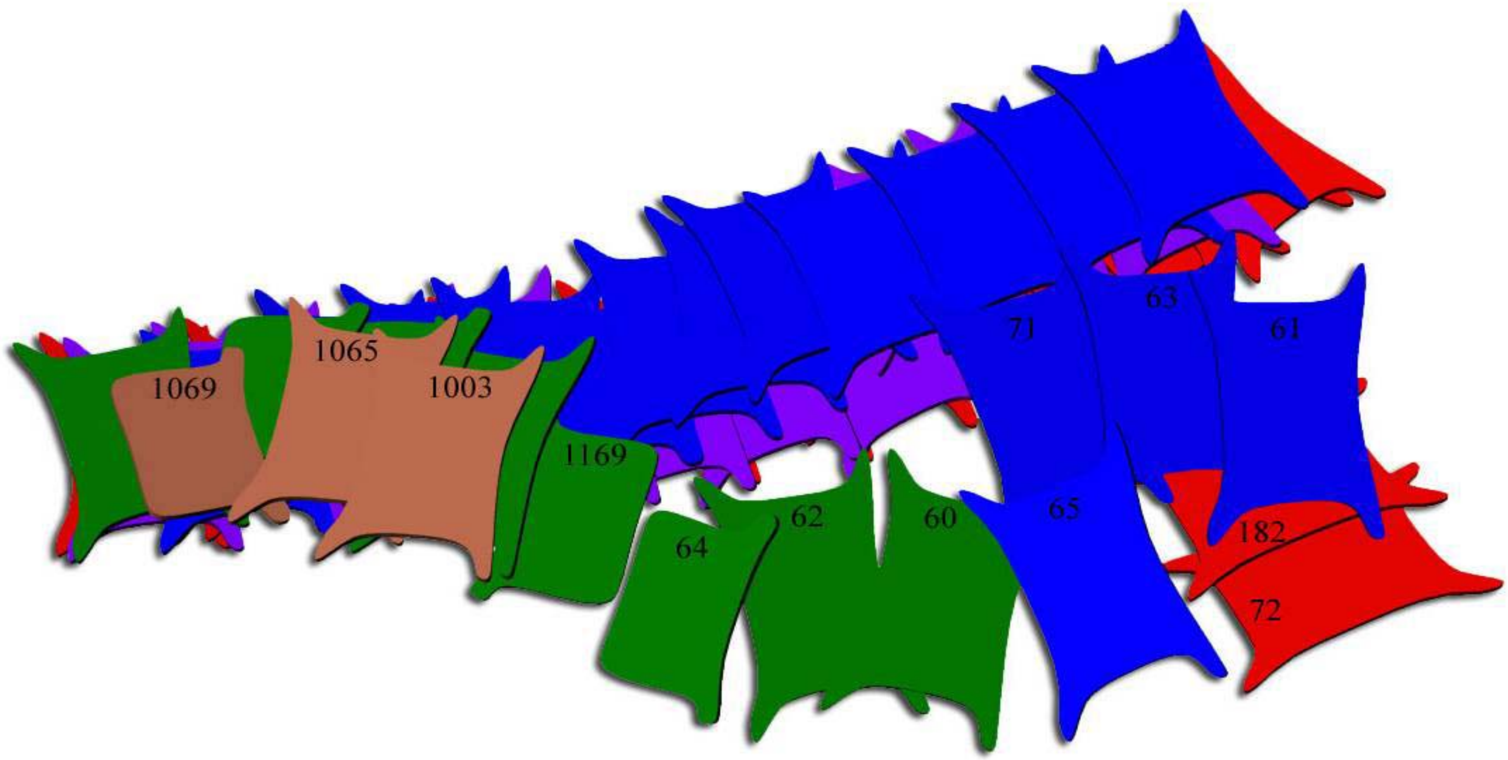

Fig. 4.2 Row 1 of copper oxhide ingots as found, color coded by layers.

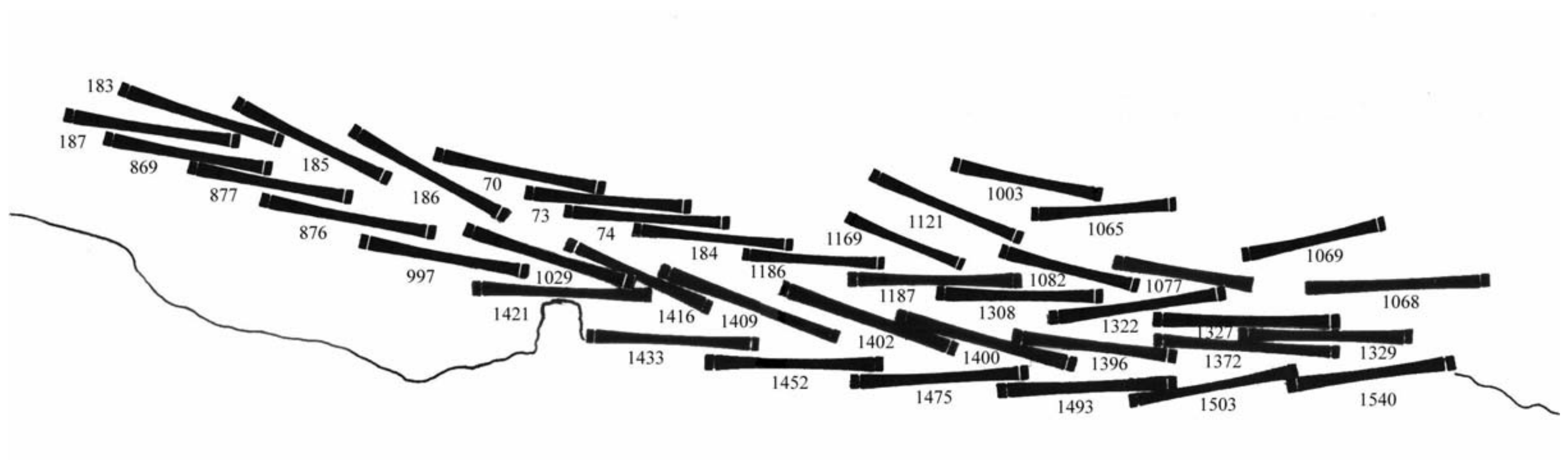

Fig. 4.3 Cross-section of the row 1 copper oxhide ingots as found. Drawings were made looking at the ingots from the top of the cliff down the slope. (Drawing courtesy of Cemal Pulak, ingots numbered by author).

Twelve ingots make up the first layer of row 1, which was first laid on the starboard side: KW 1540, 1503, 1493, 1475, 1452, 1433, 1421, 997, 876, 877, 869, 187. No portions of the keel and planking were preserved beneath this row of ingots, but if the keel of section 1 of the hull remains is extended toward the stern, ingots KW 1421 and 997 would have rested on the keel. Layer 2 begins on the port side with ingot KW 183 placed over half of KW 187 with its handles resting on KW 869 and continues with ingots KW 185, 186, 1029, 1416, 1409, 1402, 1400, 1396, 1372, and 1329; for a total of 11 ingots. The cross-section shows a break in the sequence where KW 186 is above KW 1029, which is probably a result of the shifting during the wreck formation. The former ingot has a broken handle, which allowed KW 1029 to fall beneath it, resulting in this anomaly.

Layer 3 consists of 13 ingots, also laid from starboard to port: KW 1327, 1322, 1308, 1187, 1186, 184, 74, 73, 70, 71, 63, 61, and 65. As found, KW 70 was the last ingot in its original position in this layer. KW 71, 63, 61, and 65 had fallen off the ingot row, with KW 65 laying farthest down slope of all the ingots in row 1. For the reconstruction, KW 71, 63, and 61 were simply replaced onto the stack but KW 65 was placed at the end of layer 3, on top of KW 61. KW 65 has the same orientation as KW 71, 63, and 61 so it can be assumed that it also came from the port side. It was placed at the end of the third layer because as the last ingot of that layer, it would have had the least amount of resistance to overcome as well as having the greatest potential energy since it was higher up in the hold than the other ingots, thus experiencing the greatest movement.

Layer 4 is reconstructed as follows, stacked from port to starboard: KW 72, 182, 60, 62, 64, 1169, 1121, 1082, 1077, 1068, and 627. The original arrangement of this layer is not as certain since six of the 11 ingots fell off the stack. Ingot KW 627 was probably the last ingot in this layer, resting on KW 1068, and fell over the ledge when the walls of the ship gave way. Ingots KW 60, 62, and 64 were found in the same stacking direction as the five ingots that were in place (KW 1169, 1121, 1082, 1077 and 1068) and their inclination is a progression of that seen in KW 1169 and 1121. Ingots KW 72 and 182 were the most problematic because they were buried under three ingots and did not seem to fit anywhere on the port side. Finally, it was reasoned that since they have a similar orientation and the same overlapping direction (from port to starboard) as those of ingots KW 60, 62, and 64, they were probably from the same layer and were jolted free from their positions by the same force.

Layer 5 has only three ingots stacked from starboard to port: KW 1069, 1065, 1003. It is not certain why this layer is so abbreviated or why all three ingots were stacked on the starboard side, however, it brings the total for row 1 to 50 ingots. Whether or not this number is significant is unknown at this time. The displaced ingots cannot have been part of layer 5 because the stacking direction is different, and if that were the case, it would mean that layer 4 started in the middle of the pile, which is unlikely. It is possible, however, that layer 5 did not exist and was actually a part of layer 4. When the ingot pile was jolted, KW 1003 and 1065 might have slid past KW 1069, which rested on top of KW 627, because of their greater height. The great disturbance of this area is also attested by the direction of the Canaanite jar mouths behind the ingots, which seems to suggest that many of the Canaanite jars spilled over the first row of ingots. If this were the case, then layer 4 would have had 14 ingots, more than any of the other layers. This is not entirely problematic since three two-handled ingots (KW 64, 1082, 1169) were found in layer 4 (four if counting KW 1069) and these tend to be smaller and sometimes narrower, which may explain why the ingots in this layer were placed closer together. Also, because of the flat shape of the hold at this location, it is easier to place more ingots per layer as the height of the row increases. As it stands, however, the existence of a fifth layer is not certain. Figure 4.4 shows the reconstructed stacking of the copper oxhide ingots in row 1.

The location of row 1 within the reconstructed hold is approximately 2.49 m (maximum value) from row 2.[11] The distance between the first and second ingot rows was measured as 2.15 m on the site plan, but because they rest on a slope that is roughly 30 to 45 degrees in some areas and this value corresponds to the projected distance between the ingot rows,[12] a 30/60 triangle was used to arrive at a horizontal distance of 2.49 m (fig. 4.5). This is based on the assumption that the lowest layers of copper ingots did not shift as much as the higher ones, and represent a close approximation of their original positions. This distance is reasonable and does not seem to be the result of significant sliding between the ingot rows because the mast, mast step, six large and two smaller stone anchors, and some ballast must fit in this area, as discussed in chapters II and III.

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[11] The minimum value for this distance is 2.25 m. No matter how carefully this value is measured, it is only an approximation since it is not known how far ingot row 2 moved from its original location since it was found nearly vertical on the slope.

[12] A value of 31.7 degrees for the overall slope as measured in Rhinoceros.

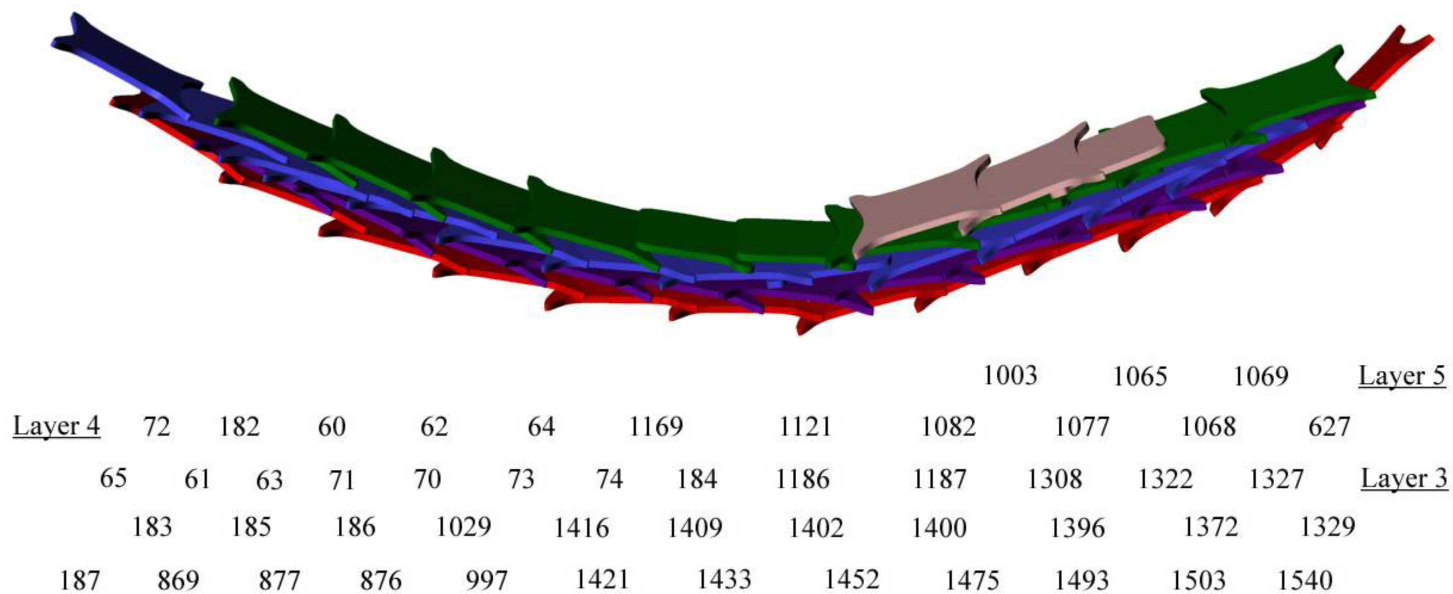

Fig. 4.4 Reconstruction of row 1 copper oxhide ingots, color coded by layers.

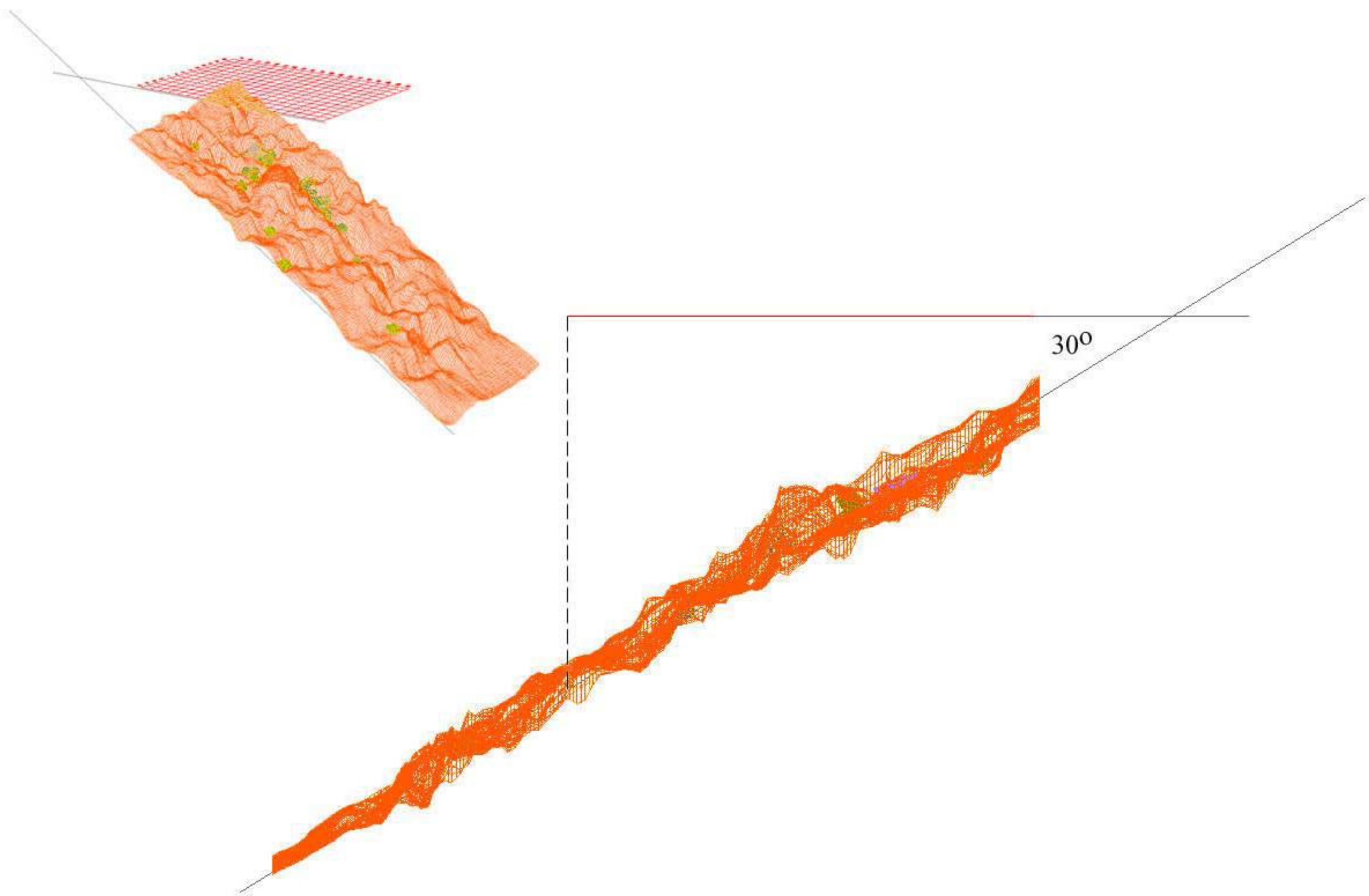

Fig. 4.5 Angle of seabed used to calculate distance between rows 1 and 2 of copper oxhide ingots.

The row of oxhide ingots closest to the stern is also the lightest of all four rows on the ship, which is unexpected considering that the bow of the ship seems disproportionately laden based on the artifacts that have been preserved. It would appear more logical for the aftermost row to have had the greatest number of ingots to help offset the three rows in the forward section of the ship, but this last row comprised only 50 ingots. If an average weight of 25 kg[13] is assigned to each ingot, then row 1 is approximately 1250 kg, or only 14 percent of the total ingot weight. This indicates two things: first, from a loading perspective, there was sufficient other cargo in the stern area to compensate for the small number of copper ingots carried here; second, perhaps there was a deliberate attempt to segregate these ingots for some unknown purpose. In this regard, it is noteworthy that of the 204 oxhide ingots with incised markings on their rough surface, none were found in the first row. The specific implications for this, if any, are as yet unknown.

Row 2

The first row of ingots just forward of midships and, presumably, the mast and mast step, was row 2. This row was composed of eight distinct layers that followed the alternating pattern seen in ingot row 1, although there was a stark exception to this rule, discussed below. This row of ingots was not as disheveled as the first, but almost all the layers had spilled downslope leaving a layered cascade of oxhide ingots. This portion of the wreck rested above a gully between two large rock outcrops to the north and south.

[13] Pulak 1997, 235.

The broken ends of the first section of preserved hull, resting on a nearly flat area of accumulated sand, nearly abut the undersides of ingot layer 1 because the ingots slid off the edge of the flat area and came to rest in an almost a vertical position. The keel was located between ingots KW 3166 and 3155. After the waterlogged keel broke under the weight of the cargo in the bow, the remnants of the vessel and the ingots inside dropped into the gully. The drop and the narrowness of the gully compressed the ingot stacking, resulting in a greater amount of overlap than was present originally, especially on the port side. In other instances, layers became discontinuous as overlapping ingots pulled apart (fig. 4.6).

The first layer consists of 12 ingots laid from starboard to port: KW 3342, 3188, 3184, 3174, 3179, 3168, 3166, 3155, 3140, 3138, 3135, and 3136. The first ingot, KW 3342, was rotated so that its upper ears were facing southwest instead of west as with the other ingots. Since it was found under ingot KW 3188, this is a good indication that it is part of the first layer and had shifted when the ingots slid down the side of the rock outcrop. The keel was found abutting ingots KW 3155 and 3166 but it may have originally been under ingots KW 3166 and 3168 before the ingots shifted. Such a reconstruction places six ingots on either side of the keel.

Layer 2 also has 12 ingots but the direction of overlapped in the opposite direction from port to starboard: KW 3137, 3139, 3124, 3125, 3120, 3118, 3122, 3115, 3117, 3114, 3112, 3110. Layer 3, again with 12 ingots, alternates from starboard to port: KW 3106, 3105, 3103, 3104, 3102, 3096, 3092, 3093, 3091, 3090, 3088, and 3080. Layer 4, with 11 ingots, is the last level laid from port to starboard until the last layer:

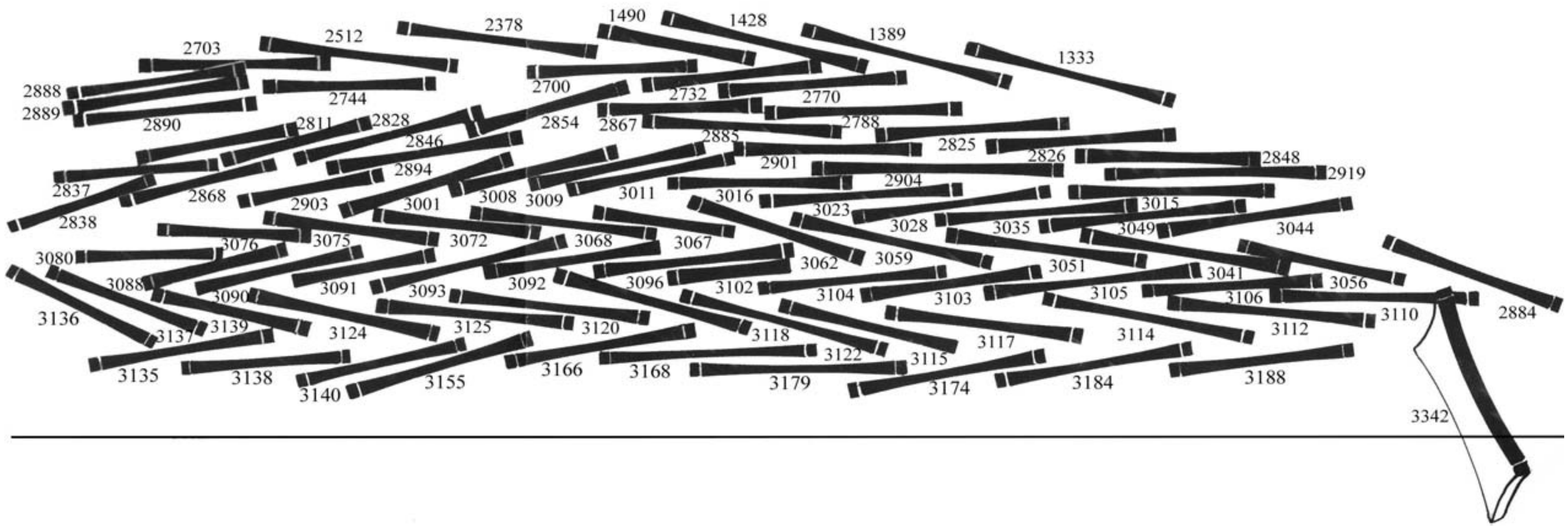

Fig. 4.6 Cross-section of the row 2 copper oxhide ingots as found. Drawings were made looking at the ingots from the top of the cliff down the slope. (After Pulak 1998, 197, fig. 12).

KW 3076, 3075, 3072, 3068, 3067, 3062, 3059, 3051, 3041, 3056, and 2884. Ingot KW 2884 was found displaced in a manner similar to ingot KW 3342, but was found above KW 3056 rather than under it, so its assignment to this layer is somewhat tenuous.

For an unknown reason, the next three layers are all stacked from starboard to port, breaking the alternating pattern used thus far. Layer 5 tentatively consists of 15 ingots: KW 3044, 3049, 3035, 3028, 3023, 3016, 3011, 3009, 3008, 3001, 2903, 2894, 2868, 2838, and 2837. The uncertainty lies with ingot KW 2894. This ingot is not directly associated with any particular layer but is sandwiched between layers 5 and 6. It is logical to assume that it was displaced rather than purposely laid where it was found since there is a high degree of uniformity in the stacking of the ingots in this row both below and above this ingot. No other examples exist of an ingot in row 2 stacked in this fashion. Most likely, KW 2894 was part of layer 5 since layer 6 cannot accommodate it in any meaningful arrangement. From the orientation of the ingots on the site plan, and the greater amount of overlapping observed in the cross-section, it is clear that the port section experienced greater shifting as the ingots piled toward the starboard side of the hull. Therefore, I hypothesize that ingot KW 2894 was originally laid after ingot KW 2903, but during the wrecking, slipped out from above ingot KW 2903 and came to rest in its present position. How ingot KW 2894 could have shifted with the weight of three additional layers of ingots above of it is difficult to imagine, but it is likely that when the ship was breaking apart, the falling ingots were temporarily suspended and the friction between them was reduced, allowing KW 2894 to slip out.

Layer 6 consists of 11 ingots stacked in the same direction as the layer directly below it: KW 3015, 2919, 2904, 2901, 2885, 2867, 2854, 2846, 2828, 2811, and 2890. What effect, if any, the different stacking pattern had is indeterminable. The uppermost layers in all four rows experienced the greatest amount of shifting regardless of the stacking pattern.

Layer 7 is composed of 10 ingots also laid from starboard to port: KW 2848, 2826, 2825, 2788, 2770, 2732, 2700, 2744, 2889, and 2888. There is a gap between ingots KW 2700 and 2744, the only break in an ingot layer in row 2. Although the distance between the two ingots is relatively substantial, there is no doubt that ingot KW 2744 is a continuation of the seventh layer that was left behind when the other ingots in that layer slid to starboard, as shown by the significant overlapping seen in ingots KW 2732, 2770 and 2788. There is also a much smaller gap between ingots KW 2744 and 2889, probably the result of the same starboard shift.

Layer 8 begins with ingot KW 2703 and continues with six more ingots: KW 2512, 2378, 1490, 1428, 1389, and 1333. However, several clues point to the likelihood that several ingots from this layer slipped down to row 3. First, layer 8 seems unnecessarily abbreviated, with ingots covering only a little more than two-thirds of the complete length of this row, and that with the starboard list. Second, the site plan suggests that ingots KW 1526, 1548, 2734, 2798, 2850, and 2851 might be an extension of this layer. This is supported by the large gap seen between these ingots and the ingot below them (KW 3251) on the cross-section of row 3. Usually these gaps in the cross-sections are due to an ingot that has partly fallen off the row so that the measured end is higher than the ingot below it due to the inclination of the ingots. Also, when ingots on the sides of the rows are caught on a ledge and retained in position while the ingots below them slip out and fall down, the same result is seen. In this case, however, neither of these two scenarios can explain the sand, three bun ingots (KW 3277, 3285, 3322), and other materials that were found trapped between ingots KW 2851 and 3251 and, likewise, between ingots KW 2734 and KW 3040. Most significant is a lower half of a Canaanite jar found between rows 2 and 3. It was suggested by the project director during the excavation that it seemed as if the near-vertical Canaanite jar had its top half cut off by an object that fell down slope.[14] This most likely was caused by the sliding oxhide ingots. Lastly, the ingots under discussion most likely did not shift sideways from the third row since they do not fit into any of the layers of that row. This will be further elaborated in the discussion of row 3. A reconstructed arrangement of row 2 is shown in figure 4.7.

The eight layers contain a total of 96 ingots for an estimated weight of 2350 kg if a uniform value of 25 kg is assigned to each ingot, which accounts for 26 percent of the total ingot weight on the ship. A total of 51 ingots (57 percent) have incised marks in this row: four in layer 8, five in layer 7, six in layer 6, three in layer 5, one in layer 4, twelve in layer 3, eleven in layer 2, and eight in layer 1. Of the 51, seven have two incised marks, one from layer 2, two from layer 3, two from layer 6,[15] and two from layer 7. Adjacent ingots KW 3110 from layer 2 and KW 3106 from layer 3 share similar

[14] Pulak, personal communication.
[15] KW 2828 actually has three marks, the third is found on the thin edge of the ingot, but this is not of the same type as those on the other ingots with incised marks on their sides in this row (KW 1333, 1428, 1490, 3155, 3166).

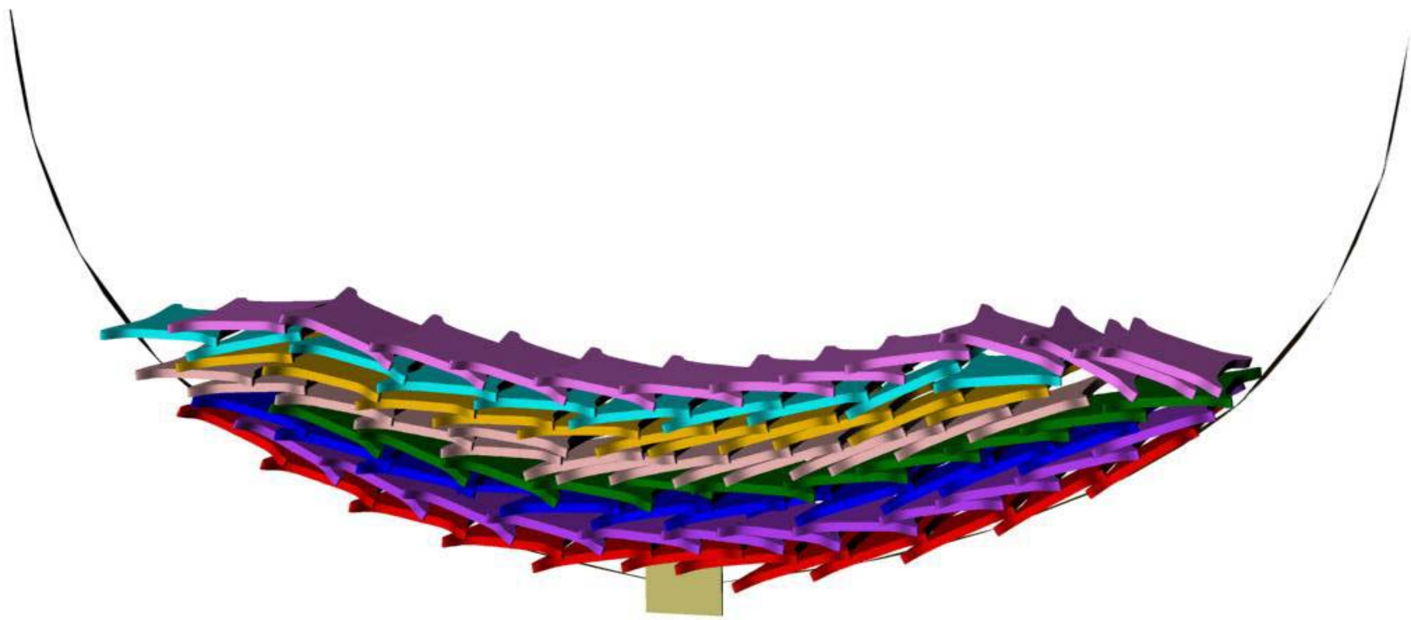

Fig. 4.7 Reconstruction of row 2 copper oxhide ingots, color coded by layers (hull line delineates interior surface).

marks, as do KW 2811 and 2828 in layer 6, and KW 2744 and 2889 in layer 7; only ingot KW 3102 in layer 3 is without a partner. The two marks on the same ingot are never the same, except in ingot KW 3102; neither do the partner ingots share the exact same two marks, at least one of the marks is slightly different from that on the partner ingot. At present, comments regarding the ingot marks and any relationship to the stacking must be tenuous as more work is needed to ensure that the marks are properly assigned to the correct ingot. However, there is an apparent tendency for ingots with similar marks to be located within the same layer and mostly stacked adjacently. In row 2, certain marks are almost exclusive to certain layers; if a mark is found in any particular layer, there will not be another ingot with the same mark in a different layer.[16]

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[16] Layer 1 has three ingots with nearly identical marks. Ingots KW 3135, 3136, and 3138 all share the mark with opposing crescents with a vertical line, with KW 3168 and 3179 sharing a similar motif. Ingots KW 3155, 3166 and 3184 share almost similar marks except the first two ingots have their marks scratched on the thin edge instead of the rough surface, as with all the other ingots.

Every ingot in layer 2 except for KW 3125 is incised with a mark, but the marks here show even greater diversity than in the previous layer. There are at least eight different types represented here, with only the marks on KW 3124/3117 and KW 3139/3114 displaying similarity. Marks on KW 3114 and 3139, however, draw closer comparison with those of KW 3103 and 3096, respectively, from the third layer. Other than this exception, there are no other ingots in this row bearing marks similar to those in layer 2.

Layer 3 shows the greatest consistency with seven of the 12 mark-bearing ingots displaying similar incised designs, with the last ingot (KW 3110) of the second and first ingot (KW 3076) of the fourth layers contributing with related marks for a total of nine in that area. There are two ingots in layer 6 that bear the U-shaped mark but each is accompanied by another mark that has no parallels in layer 3. Since KW 3076 bore the same mark as most of the ingots in layer 3, layer 4 is considered devoid of any incised ingots.

Three of the four incised ingots in layer 5 have marks that loosely resemble each other: KW 2837, 2838, and 3001. KW 3001, however, is more closely related to KW 2885 and 2904 of layer 6 than those of ingots in layer 5. Ingot KW 2894's mark is unique to this row but has parallels in ingots from row 3 as well as on the copper bun ingots.

In addition to the ingots mentioned above, layer 6 also has the only two ingots in this row with ship motifs placed on top of one another. KW 2919's mark is more detailed than that of KW 3015, with two lines for the hull and an additional line probably representing a fore- or backstay. Other examples are found in Row 3.

Layer 7 has four ingots with incised marks with KW 2744 and 2889 sharing like symbols, while the other two, KW 2732 and 2770, have very different markings. In layer 8, only KW 2888 and 2512 have marks on the usual rough surface, albeit different designs, but KW 1333, 1428, 1490 all have the same ││││ mark scratched onto their thinner edge surfaces.

Row 3

Row 3 consists of 93 copper ingots roughly reconstructed in nine layers. It is positioned a maximum of 20.1 cm forward of row 2. The presence of row 4 kept this row from spilling far forward, but there is still a significant amount of movement and displacement of the ingots in this row, especially in the upper layers. Once again, due to the starboard list, the ingots on the port side overlap significantly, as shown in the cross-section of the row (fig. 4.8). This row of ingots is also located deeper in the narrowing gully, which further compressed the ingot layers. Moreover, as the ingots dropped into the gully, many of the ingots on the port edge were pressed against the gully wall so that they remained nearly vertical when viewed in cross-section, while other ingots slipped down the ravine. The layers here are not as readily apparent as those in rows 1 and 2, and, noting the lack of stacking regularity in row 2, the reconstruction offered here is more hypothetical (fig. 4.9).

The first layer is different from those of the two previous rows because the ingots are laid in both directions. If the preserved keel were extended down to this row, ingot KW 3932 would rest on top of it. Ingots to port of the keel are KW 3702, 3705, 3692, and 3450. KW 4379 was probably placed adjacent to the keel and ingots KW 4373, 4378, and 4374 extended layer 1 in the starboard direction. It is not certain why the first layer was laid in this fashion since it is unique among the first layers of all four rows. Neither is there any apparent advantage to this configuration. It may simply be that the crew loading the ingots did not communicate fully or were simply so overwhelmed with the number of ingots being loaded that they could not coordinate their lading properly.

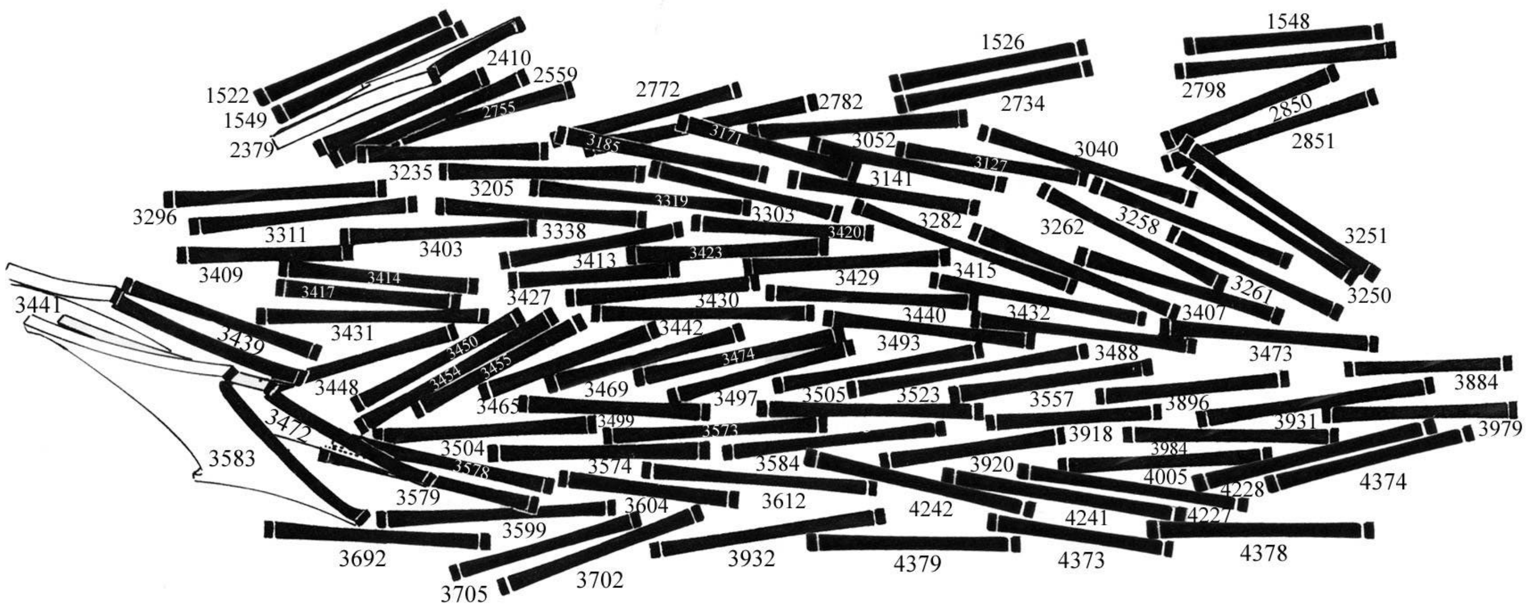

Fig. 4.8 Cross-section of the row 3 copper oxhide ingots as found. Drawings were made looking at the ingots from the top of the cliff down the slope. (Drawing courtesy of Cemal Pulak, ingots numbered by author).

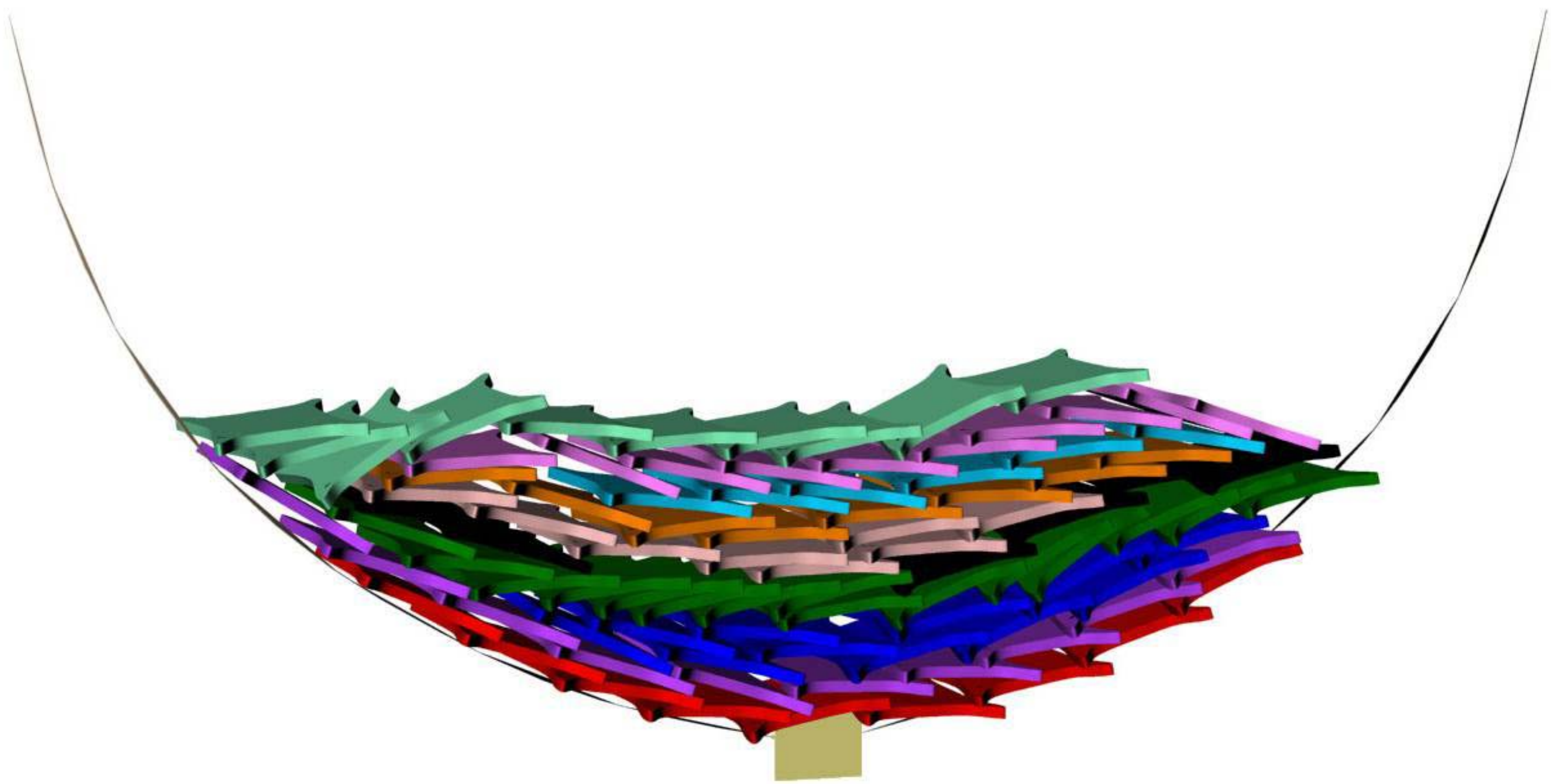

Fig. 4.9 Reconstruction of row 3 copper oxhide ingots, color coded by layers (hull line delineates interior surface).

Regardless, the distinction between each layer is not as well defined as in the two previous layers.

As best reconstructed, layer 2 is also laid in both directions but with only three ingots going in the port direction: KW 3579, 3472, and 3441. The majority of this layer was placed from port to starboard: KW 3599, 3604, 3612, 4242, 4241, 4227, and 4228. Again, the reason for this configuration is not known.

Layer 3 is considered a filler layer. Because this row is located in the forward portion of the ship where the walls are narrower than at midships, ingots placed on the sides built up higher and quicker than the ingots in the middle, creating a U-shape. Therefore, filler layers were needed to build up the middle of the pile to the level of the ingots on the sides. This theory was tested and validated with the 1:10 scale models of the oxhide ingots. Layer 3 starts from starboard with ingots KW 4005, 3920, and 3584. On the port side are also three ingots, KW 3578, 3574, and 3573 to balance out the starboard ingots. The filling continues with KW 3984, 3918, and 3565 from the port side and KW 3504 and 3499 from starboard.

With the middle area now bolstered and the row evened out, layer 4 is laid almost continuously from starboard to port: KW 3979, 3931, 3896, 3557, 3523, 3505, 3497, 3474, 3469, 3465, 3455, 3454, 3450, 3448, and 3439. The break in the uniformity is with KW 3493, which starts another partial layer back to starboard with ingots KW 3488, 3473 and 3884. Although ingots KW 3431 and 3417 do not readily fit into the port side of layer 4, it is possible that these two ingots were used to balance the four extra ingots on the starboard side.

KW 3442 initiates layer 5 at the lowest point of the row and is considered the second filling layer. Extending in both directions, ingots KW 3430, 3427, 3414, and 3409 span the port side and ingots KW 3440, 3432, and 3429 the starboard side. Ingot KW 3429 is not stacked on the starboard side of KW 3432 but on its port side and also partially rests on KW 3430; it seems out of place, but when reconstructed with the scale models, it nicely filled in a depression in that area.

Layer 6 is another filler layer starting exactly where layer 5 began. KW 3423 is the central ingot with ingots KW 3413, 3403, and 3311 placed on its port and ingots KW 3420, 3415, 3410, and 3407 on its starboard sides. Although not readily apparent in the cross-section view, the filler layers always seem to start at the lowest point in the row when replicated in the 1:10 scale models.

After the row was leveled with two filler layers, two layers followed it, stretching from port to starboard. Instead of starting on top of ingot KW 3311, KW 3338 also initiates the partial layer 7, again at the lowest point in the row and the layer continues with ingot KW 3319, 3303, 3282, 3262, and 3261. Layer 8 spans the entire length of the row starting with KW 3296, 3235, 3205, 3185, 3171, 3141, 3127, 3258, 3250, and 3251. The ninth and last layer for this row is a complete layer placed from starboard to port: KW 3040, 3052, 2782, 2772, 2755, 2559, 2410, 2379, 1549, and 1522.

The third row accounts for 27 percent of the entire copper oxhide ingot assemblage, weighing 2375 kg, if an average weight of 25 kg is applied to all 93 ingots in this row.

Row 4

The forward-most row of ingots is also the least complete because nearly one-third of the 102 ingots in the row spilled off the stack and was found strewn from the base of the row to 5 m downslope. Unlike rows 2 and 3, which had ingot rows forward of them to prevent them from spilling downslope, there was no obstacle to restrain the ingots in row 4 from spilling as far as their inertia would carry them when the ship landed on the seabed, and again as the hull disintegrated. Sixty-nine ingots, however, retain most of the overlapping layers despite also having cascaded part way down the gully. An examination of the cross-section view shows that the starboard portion of this row was split into two when the bottom of the hull gave way and the ingots were pulled apart as they plunged to the bottom of the gully (fig. 4.10). The restoration of the displaced 33 ingots to their original lading is nearly impossible, so it will be assumed that they continued the stacking pattern set by the ingots discussed thus far.

Unlike row 3, the first layer of row 4 was a complete layer laid from port to starboard: KW 3706, 4003, 4503, 4462, 4501, 4460, 4458, 3806, and 3775. An extension of the keel to this row shows that ingot KW 4503 straddled the keel; this, however, creates an imbalance with six of the nine ingots on the starboard side. It is possible that the keel originally lay under ingot KW 4462 or 4501, but the entire row shifted when the ship came to rest with a list to starboard.

A second complete layer placed in the opposite direction follows layer 1: KW 3747, 4004, 3917, 3862, 3778, 3776, 3637, 3676, and 3581. Although ingot KW 3581

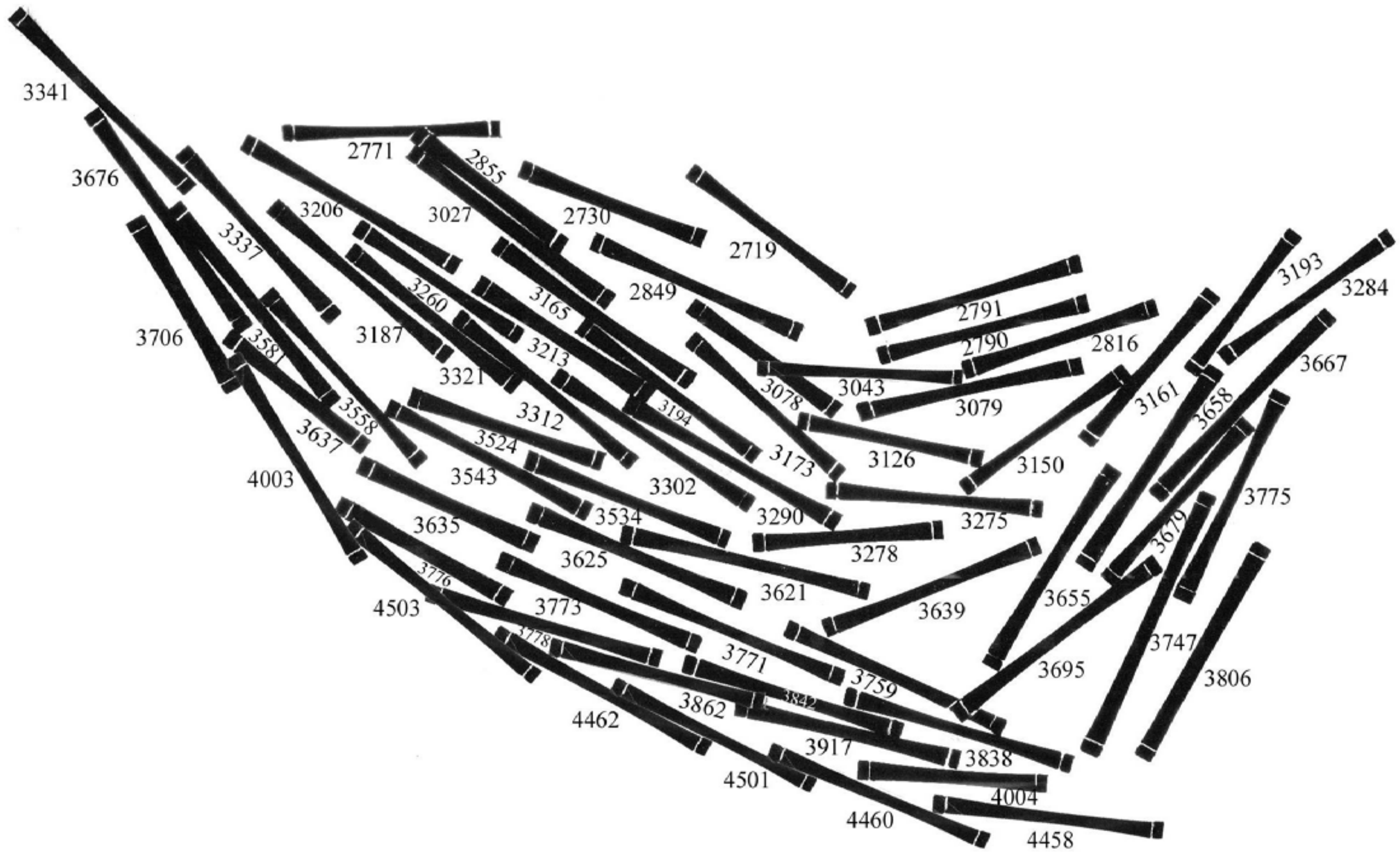

Fig. 4.10 Cross-section of the row 4 copper oxhide ingots as found. Drawings were made looking at the ingots from the top of the cliff down the slope. (Drawing courtesy of Cemal Pulak, ingots numbered by author).

does not follow the normal stacking pattern and, instead, rests between ingots KW 3676 and 3737, it is still considered part of layer 2 because it supports an ingot from layer 3.

Similar to the lading employed in row 3, filler layers were also used in this row—both the third and fourth layers level out the row by filling the middle of the ingot pile. Layer 3 consists of five ingots starting near the center of the row; to starboard are ingots KW 3842 and 3838, while to port are KW 3773, 3635, and 3558. Neither side reaches the ends of layer 2 because the intent of this row was to fill the middle of the pile and not raise its sides any further.

Ingot KW 3771 is the central ingot for layer 4 upon which four ingots are laid to starboard (KW 3759, 3695, 3679, and 3667) and two ingots were placed to port (KW 3625 and 3543). The four ingots on the starboard side serve to balance the port ingots from layers 2 and 3, both of which had more ingots on the port side.

True to the pattern observed thus far, layer 5 reverts to a uni-directional layer placed from starboard to port: KW 3658, 3655, 3639, 3621, 3534, and 3524. Layer 5 may also be a filler layer since it does not exceed the limits of layer 4.

Layer 6 is the last discernible layer under the uppermost ingots, which are so scattered that it is very difficult to determine how they were originally stacked. It begins on the port side, higher up on the side of the hull than layer 2, with ingots KW 3341, 3337, 3187, 3321, 3312, 3302, 3290, and 3278, most likely ending with ingot KW 3275, which does not reach the wall of the hold to starboard.

Twenty-four additional ingots were drawn on the cross section of row 4 but their reconstructed locations are highly tenuous (fig. 4.11). Generally, they were restored as

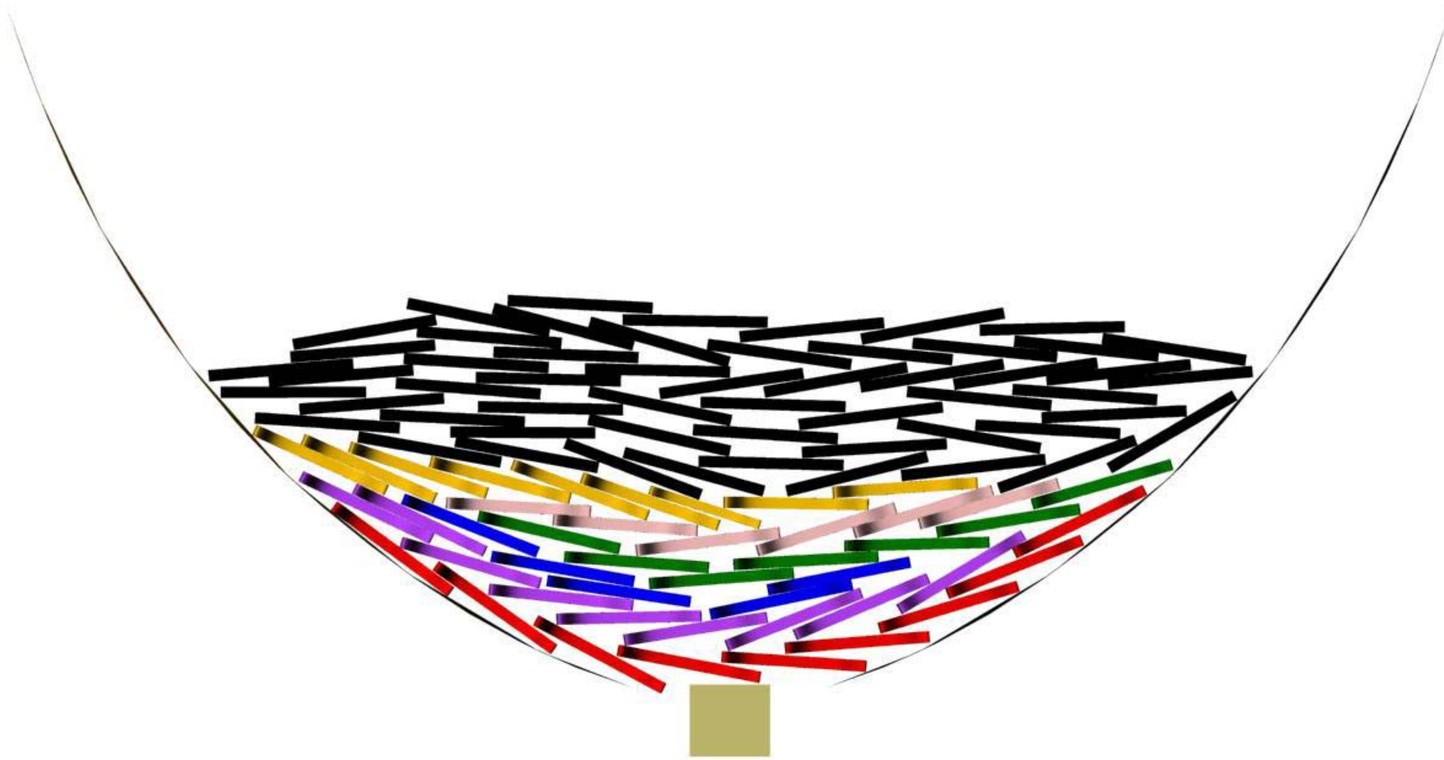

Fig. 4.11 Reconstruction of row 4 copper oxhide ingots, color coded by layers (hull line delineates interior surface). The position of ingots show in black is unknown.

two layers, both of which are filler layers, with ingots placed in the starboard and port directions simultaneously. Thirty-two oxhide ingots were not included in any of the cross section plans because they had spilled downslope in an incoherent trail. Whether or not all 32 were a part of row 4 is uncertain, but it is possible that a few of these ingots may have belonged to row 3. The fourth row accounts for 30 percent of all copper oxhide ingots if a weight of 25 kg is applied to each of the 101 ingots in the row.

<u>Weight distribution</u>

Collectively, the four rows, as found, consist of 308 ingots. An additional 13 ingots were found in the stern, stowed behind the first row of ingots, and 32 displaced ingots were found forward of row 4, bringing the total to 354 copper oxhide ingots.[17] The total weight is calculated at 8750 kg, if each of the full-sized ingots is assigned an average weight of 25 kg and the pillow ingots 10 kg. The copper oxhide ingots, therefore, account for an estimated 43 percent of the entire extant cargo carried aboard the Uluburun ship.

A mere 17 percent of this weight is located behind the mast step, which means additional cargo totaling at least 7250 kg is required in the stern to counterbalance the ingots in the bow, assuming an equal distance from the center of gravity for both loads. Some of this burden can be alleviated by the hull configuration and structures, which

[17] One ingot, KW 1983, has not been accounted for in the weight calculations of the four rows of oxhide ingots partially because the shape does not conform to that of a normal oxhide ingot, being substantially smaller in size, and also, it is not certain in which row, if any, it was stacked. So, in fact, only 353 ingots are used in the weight calculations.

may have been more substantial in the stern than at the bow. Nevertheless, the oxhide ingots are heavily concentrated in the forward portion of the ship.

Copper Bun Ingots

<u>Background</u>

Copper was also transported in an alternate form on the Uluburun ship as plano-convex, or bun-shaped, ingots. A total of 152 pieces of bun ingots were found, of which 115 were complete and intact. The remainder consists of 5 incomplete ingots, 9 half ingots, and 23 fragments. The bun ingots came in three general sizes, with the largest having a minimum diameter of 0.25 m and the medium-sized 0.22 m. The largest ingot measured 0.297 m in diameter while the smallest was 0.183 m. The weight of the ingots within each size group, however, was not always consistent since different amounts of metal were used for each pouring, resulting in varying thicknesses for each ingot. Thicknesses range from 0.012 m to 0.072 m. The weight of the heaviest bun ingot is 10.52 kg and the lightest complete ingot weighs only 2.62 kg; how much mass was lost due to metal corrosion is unknown. The average weights for the three sizes are: 3.83 kg, 5.71 kg, and 8.26 kg.

Included in this category of copper ingots, although not discoid in profile, are six oval ingots (five intact and one cut into two halves [KW 2715+2799]) that are nearly rectangular in shape, with a bulge in the middle of the ingot. Each oval ingot was also incised with four parallel lines. The ingot that was split in two in antiquity had this mark incised on both halves. These ingots were so similar in size and shape that they were undoubtedly cast in the same mold.[18] This led to an investigation of the other bun ingots that resulted in the identification of 28 distinct mold-sibling groups whereby each group exhibited sufficiently distinct surface features, and sometimes incised marks, to demonstrate that they were cast in specific molds unique to each mold sibling (table 4.1).[19] The finalization of these mold group assignments awaits further study but their existence is without doubt. The distribution of the copper bun ingots on the wreck site was examined in relation to the mold groups to see if any relationship could be established that would assist in determining their original placement on the ship.

Distribution according to mold groups

The oval ingots (KW 2731, 3004, 3005, 3006, 3421, 2715+2799) were designated as the first mold group since their similarities were most obvious. Intriguingly, all six ingots were found in the same area (square O17-18) on the wreck, mixed with the oxhide ingots of row 4 (fig. 4.12).[20] Oval ingots KW 3004, 3005, and 3006 were found concreted together as they must have been originally stacked, lodged between oxhide ingots KW 3206 and 2771 from the two uppermost preserved layers of row 4. This implies that all of the oval ingots were probably stored together, perhaps in a basket or sack, and became separated as the container that held them disintegrated or opened up. KW 3421 was actually found even lower down in row 3, trapped between layers 5 and 6. KW 2731 and the two halves (KW 2715, 2799) were found on top of the

[18] Pulak 2000b, 144.
[19] Originally 29 mold groups were identified but mold 9 has since been combined with mold 7, resulting in the present number of groups.
[20] Fragments are not represented on distribution map unless they were found outside of the M15-16 area, where 62 percent of the copper bun ingot fragments were recovered.

Table 4.1 Copper bun ingot mold groups.

Legend		Mold7A	
		xxx	KW 3073, (KW 3470 + 4259)
xxx	definitely of the same mold group	7B	KW 724, 3283 (4d)
xx	most likely of the same mold group	7C	KW 1535 (4d)
x	probably of the same mold group	7D	KW 781
1/2 x	maybe of the same mold sibling group		
"+"	denotes 2 fragments joined together	Mold 8	
		xxx	KW 1563 (3f), (KW 3020 + 3494 + 3656 + 4453 + L. 6882)
Mold Group	Ingots		
Mold 1		Mold 9	combined with Mold 7
xxx	KW 2731, 3004, 3005, 3006, 3421, (KW 2715 + 2799) (5e on all ingots)		
		Mold 10	
		xxx	KW 4264
Mold 2		1/2x	KW 1054
xxx	KW 66.2 (4b), 1554 (4b), 3675 (4b)		
xx	KW 3600 (4b)	Mold 11	
x	KW 1604 (4b)	unique	KW 4586 (4d)
1/2 x	KW 3107 (fragment), 4989 (fragment)		
		Mold 12	
Mold 3		xxx	KW 2756, 2758, 2836, 3097, 3466
xxx	KW 3000 (4f), 4277 (4d)		
		Mold 13	
Mold 4		xxx	KW 69, 191, 394, 649
unique	KW 3701		
		Mold 14	
Mold 5		xxx	KW 192 (3b), 509, 822 (3b), 875
unique	KW 3418	xx	KW 3287 (4d)
Mold 6		Mold 15	
xxx	KW 823, (KW 709 + L. 429)	xxx	KW 631 (3b), 1558, 1564, 2134 (3b), 2145 (3b), 3003, 3108,
			3277, 3285, 3304, 3645, 3810, 3998, 4381, 4756
		xx	KW 395 (3b), 397 (3b), 405 (3b), 799 (3b), 2178 (3b)
			(KW 1191 + 3804)
		x	KW 1572

Table 4.1 (cont'd).

Mold 16		Mold 22A	
xx	KW 630, 825, 2905	x	KW 96 (6d), 193 (6d), 195 (6d), 841 (6d), 3691
		1/2 x	845 (6d)
Mold 17A		22B	
xxx	KW 1122 (rough side, 2d), 2364 (4d), 2568 (4d)	x	KW 105 (6d), 107 (6d)
xx	KW 3698		
17B		Mold 23	
xx	KW 629 (rough side, 2d), 4409 (4d)	xx	KW 106 (6d), 809, 2852
17C		x	KW 4394
xx	KW 1536 (4d)	1/2 x	KW 780 + 999 + 3456
Mold 18		Mold 24	
xxx	KW 510, 512, 514, 635	xx	KW 826, 2906, 3758
		Mold 25	
xx	KW 406, 634	xx	KW 3178, 3322
		1/2 x	(L. 767 + L. 3251)
x	KW 194	Mold 26	
1/2 x	KW 402, 407	xx	KW 109, 824 (3b)
Mold 19A		Mold 27	
xxx	KW 2587 (4d), 2602 (4d)	unique	KW 3690
1/2 x	KW 963 (fragment), 1055 (fragment), 2569 (fragment)		
19B		Mold 28	
x	KW 66.1 (4b), KW 1573 (4f)	unique	KW 396 (3b)
		Mold 29	
Mold 20		xx	KW 1088 (rough side, 2d), 2792 (4d)
xxx	KW 131 (6d), 132 (6d)	x	KW 828 (3f)
x	KW 104 (6d)		
xxx	KW 108 (6d), 196 (6d)		
x	KW 411 (6d), 821, 842 (6d)		
x	KW 2757 (6d)		
1/2 x	KW 1045 (6d)		
Mold 21			
xxx	KW 623, 998		

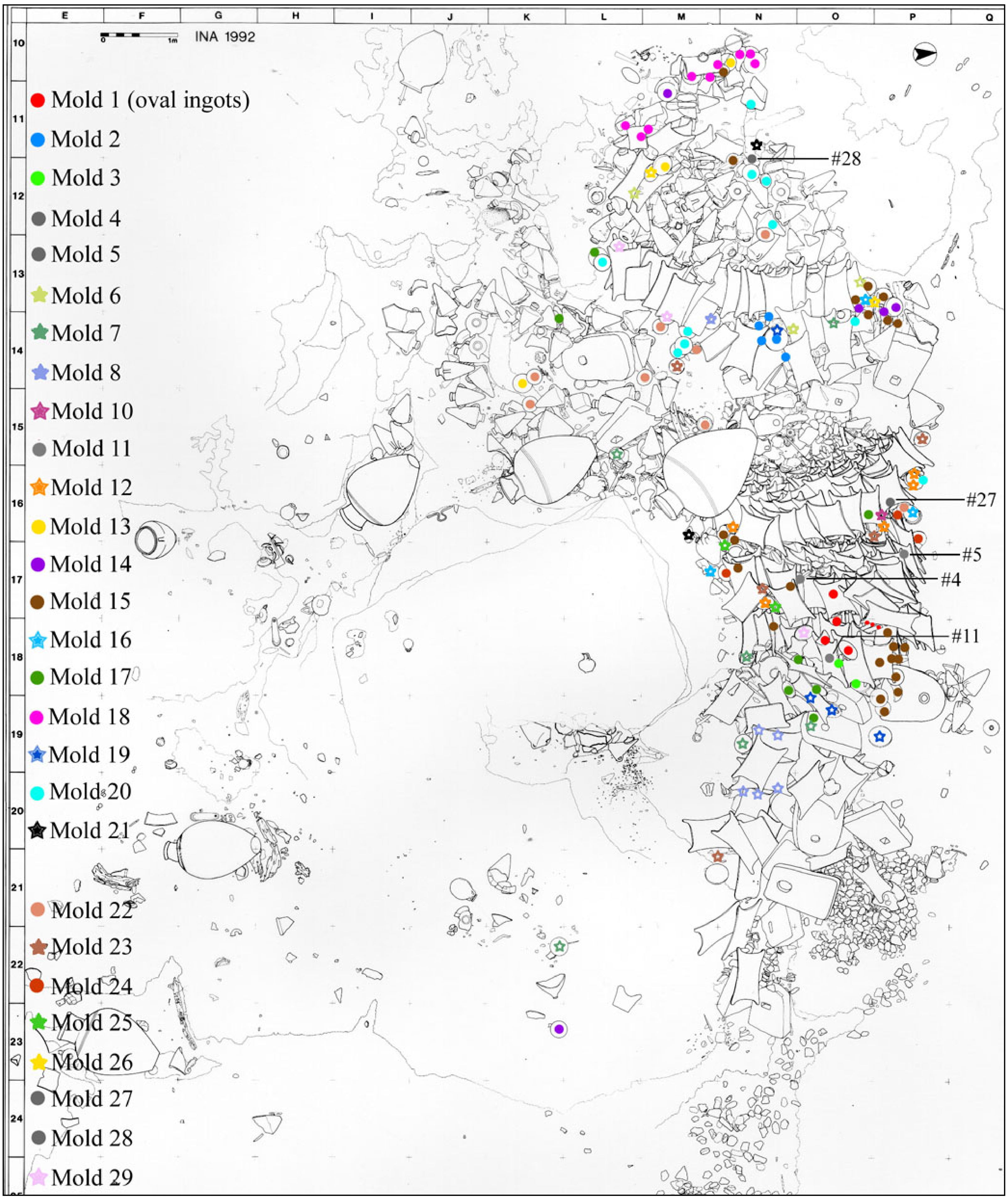

Fig. 4.12 Distribution of copper bun ingots according to mold groups.
Unique mold groups in gray (After Pulak 1998, 192, fig. 4).

last preserved layer of row 4. Because these ingots were found between the oxhide ingots, they were definitely not stored on top of row 4 and most likely were flung from somewhere aft of row 3, at the very least.

Mold group 2 shows a similar pattern with KW 66.2, 1554, 1604, 3600, and 3675 all congregated just forward of row 1, specifically oxhide ingot KW 70. Two other groupings of bun ingots were located to the immediate north and south of this group. Oxhide ingots that had spilled from row 1 covered these bun ingots, which may be an indication that they were placed on top of row 1. Two bun ingot fragments, KW 3107 and 4989, were also assigned to this mold group, but the fragments were apparently kept separately since 62 percent of the bun fragments were located in areas corresponding to grid squares M16-N19.[21] Since these fragments were cut up for a purpose, probably for trading in smaller increments, it would make sense to keep them all together, like a change box.

Mold group 3 only has two ingots, KW 3000 and 4277, were found in close proximity to each other among the spill of row 4, near the oval ingots and a stash of glass ingots. Both ingots were covered by the uppermost preserved layer of row 4.

Mold groups 4 and 5 have only one ingot each. KW 3701 was found between rows 3 and 4, covered by the spilled ingots from row 3. It probably slid down slope alongside the boulder-like rock outcrop at the center of the site along with several other bun ingots from the post-wreck artifact-collecting area in square M16. KW 3418 was on

[21] The fragments found in squares N17-19 probably spilled down from the area of square M15. Fragments also include incomplete and half ingots.

the port side of row 3. It was probably stored with a cluster of bun ingots found just upslope of this location.

KW 823 is the only complete ingot for mold group 6 and was not found in the same area as the fragments belonging to this group. It was located farther downslope, in front of row 1, with the mold 2 ingots. Fragment KW 709 was not found with the other bun fragments, but was located astern of the Canaanite jar pile. This fragment is the only fragment of a copper bun ingot found in the stern area of the wreck; all the other pieces were located farther downslope. Its joining piece, lot 429, is the next closest fragment, located in square P14.[22] It is uncertain why only these two fragments were found aft and to the north of the main cache of bun fragments in square M16.

The ingots of mold 7 were widely spread on the site. The two ingots (KW 3073, 3470+4259) that best characterize this group, however, were found in the area of ingot row 4. The assignment of bun ingots KW 724, 781, 1535, and 3283 to this group is highly tenuous since these ingots were poorly preserved. All three of these ingots were situated in different locations, especially KW 3283, which was in square K22, where only a few other artifacts were found. Nevertheless, with the exception of KW 724 (O14UR2), the other three ingots seem to form a trail around the rock outcrop from L16UL3 (KW 781) to K22UR2 (KW 3283).

Mold 8 consists of five fragments and one large ingot. Fragments KW 3020, 3494, 3656, 4453, and lot 6882, which join together to make one complete ingot, were found in square N20. It is conceivable that they were kept with the other fragments, but

[22] The precise location of lot 429 is uncertain since it was not drawn on the site plan, but the 1985 field notebooks place it somewhere in grid square P14.

were somehow kept separate since they all landed very close together on the site. The complete ingot, KW 1563, was near the other bun ingots just forward of row 1.

The sole ingot in mold 9 (KW 1535) was reassigned to mold 7 after a careful review of the original field notes.[23] Mold 10 consists of two ingots: KW 1054, a half ingot located with the other fragments in square M16, and KW 4264, an intact ingot found with the group of ingots on the port side beneath row 3. Mold 11 has only one ingot, KW 4586, which was found forward of row 4 with a few other bun ingots.

Mold 12 includes five ingots, three of which (KW 2756, 2758, 3466) were found in the same area, on the port side, near rows 2 and 3, while the other two ingots (KW 2836, 3097) were on the starboard side. Ingot KW 3097 was found below the spilled ingots of row 3 and KW 2836 underneath those of row 4. Since these ingots were found on opposite sides of the oxhide ingots, it does not seem that they were stored together as a mold group but that they were split among other ingots.

Mold 13 includes ingot KW 649, which was raised during the initial 1983 survey of the site and whose precise provenance is uncertain. Of the other three ingots in this mold group (KW 69, 191, 394), KW 394 was found at the stern-most pile of bun ingots (M-N10), KW 69 was immediately behind the main pile of Canaanite jars, and KW 191 was located farther downslope with the overspill of Canaanite jars. Although these ingots were not found together, it is possible that they were originally stored with KW 394 before the other two ingots tumbled downslope.

[23] The mold group number, however, was preserved to avoid possible confusion and error if subsequent mold group numbers had to be changed.

Mold 14 has five ingots, of which three (KW 192, 822, 875) were on the port side of row 1. Ingot KW 3287 was at the deepest end of the wreck; it probably slid around the south side of the boulder-like outcrop along with some of the pithoi. KW 509 was located on the opposite end of the site, at the very top of the wreck with some of the other bun and tin ingots. The likelihood that this group was stored together is slim, although it does appear that they all came from the stern area.

Mold 15 is the largest group with 23 ingots and shows clustering in different areas. Since this is also one of the most diagnostic groups of ingots cast from the same mold, the positions of these ingots might shed some light on the spill path. An ingot from this group (KW 395) was found at the very top of the main artifact pile with KW 405 just downslope. The next closest group was by the port side of row 1: KW 397, 631, 799, 2134, 2145, and 2178. This group then branched out on the starboard and port sides: 10 ingots, KW 1191+3804, 1558, 1564, 1572, 3003, 3108, 3810, 3998, and 4381, were found around square P18 on the port side of row 4 and on the top of anchor KW 4002. The next largest group was on the starboard side of rows 2 to 4, with 5 ingots: KW 3277, 3285, 3304, 3645, and 4756. This scenario may imply that these bun ingots were originally stored at the stern, behind the Canaanite jars, then were dislodged by the wrecking of the ship and slid down either side of the oxhide ingot rows. The existence of so many ingots identified as mold siblings in the same locations on the wreck strongly points to some orderly method of organizing and stowing these ingots according to mold groups.

Mold 16 has three ingots found at separate locations. KW 630 was located by row 1, KW 825 by row 3, and KW 2905 was on the boulder-like outcrop side.

Mold 17 has two ingots (KW 629, 1122) found in the Canaanite jar overspill area, four ingots (KW 1536, 2364, 2568, 4409) found forward of row 4, and one (KW 3698) by the port side of row 3. Although it is unlikely that this group shared the same container, it does not seem to be mere coincidence that they were found in groups of two and four.

Mold 18 is another good example of a group of mold siblings that were kept together. Although there are large ingot groupings in other areas of the wreck, it is interesting that all the ingots attributed to this mold group were found in the same area at the very stern. Several other ingots that do not belong to this mold group were also found in this area: KW 394 (#13), 395 (#15), 411 (#20), and 509 (#14). All four are medium-sized ingots and none belong to the same mold groups. The fact that these ingots remained in the stern suggests that they may have been kept separately, perhaps in a small compartment along with some of the other metal ingots, which prevented them from dispersing farther down the slope into deeper sections of the wreck.

Mold 19 includes four fragments predictably found around square M16.[24] In addition, a group of three ingots (KW 1573, 2587, 2602) were uncovered forward of row 4, and a lone ingot (KW 66.1) was located just forward of row 1. The proximity of the first group of three ingots indicates they were most likely stored together. As for KW 66.1, this ingot was not kept with its mold siblings for a reason discussed later.

[24] Fragments are KW 963 (M16LR4), 1055 (L16UL3), 2569 (M16LL1), 5212 (M16UL3).

Mold 20 ingots were separated into two main clusters: one (KW 104, 108, 842) was located near anchor KW 3335 in M14 and the second (KW 131, 132, 196, 411) was found by the uppermost group of glass ingots in square N11, just downslope of the mold 18 ingots. The other three ingots in this group (KW 821, 1045, 2757) were spread out in other areas of the wreck.

Mold 21 consists of KW 998 and KW 623, which was found in a Canaanite jar base located in N11. Ingot KW 998 was found in the area of fragments (square M16), although it is not a fragment itself.

Mold 22 ingots were discovered in separate places. One cluster of three ingots, (KW 105, 841, 845) was found near anchor KW 3335 in square M14, and ingot KW 107 was located just downslope of that group. Further south of the first group were two ingots (KW 193, 195), while another group (KW 96, 3691) not in the vicinity of these ingots was located in the main Canaanite jar pile in square N12LR3 and on the port side of row 3 in P16LL2, respectively.

Mold 23 ingots were also widely spread across the site. Two fragments in the group were located in square M16. One fragment, KW 3456, was outside the fragment area, farther down in a deeper location in N21. Ingots KW 809 and 4394 were both near row 3 on the port side and KW 2852 to starboard of row 3, but KW 106 was farther upslope, near anchor KW 3335. It does not seem likely that these ingots were stored in the same container when loaded on the ship.

Mold 24 has three ingots, with two (KW 826, 3758) on the port side of row 3 and one (KW 2906) on the rock-outcrop side of row 3.

Mold 25 has two ingots (KW 109, 824) on the boulder side of the oxhide ingots but separated by approximately 1 m. It is probable that they were originally stowed together.[25]

Mold 26 also has two ingots: KW 109 was found near the uppermost group of glass ingots in N11 and KW 824 was on the port side of row 3. It is doubtful that these two ingots were stowed together in the same container, but it is possible that they were both in the stern area of the ship.

Lastly, molds 27 and 28 consist of a single ingot each, KW 3690 and KW 396, respectively. Two ingots (KW 828, 1088) from Mold 29 were located relatively close together, near anchor KW 3335, while one ingot KW 2792 was farther down by row 4 on the boulder-like outcrop side. This last ingot could conceivably have slid down to the deeper part of the wreck from where it was stored with the first two ingots.

Distribution according to incised marks

Among the copper bun ingots, a total of 64 (56 percent of intact ingots) were incised with various marks after they were cast. With three exceptions, the marks were always incised on the ingot's mold surface. Eight incised marks were identified and shown in figure 4.13,[26] of which five were also found on the oxhide ingots. Of the 64 marked ingots, only the oval ingots (KW 2715, 2799) were incomplete buns that received a mark. Precisely what these markings signify has yet to be determined. That they were incised with a chisel rather than stamped during the casting process suggests

[25] Lots 767 and 3251 were unable to be located on the site plan.
[26] The two quarter-rudder-like marks (4d, 4f) are most likely variations of the same mark.

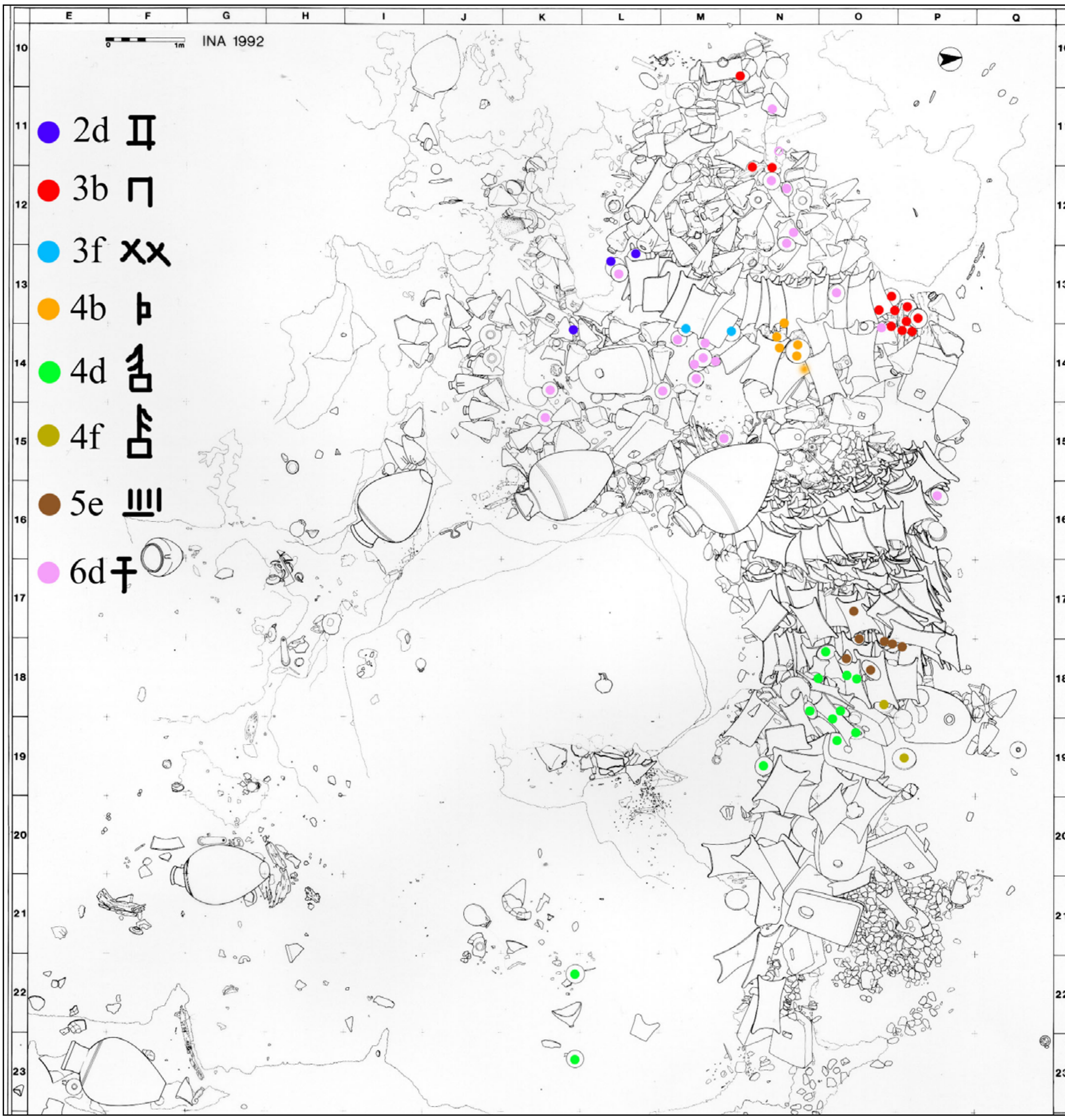

Fig. 4.13 Distribution of copper bun ingots according to incised marks. (After Pulak 1998, 192, fig. 4).

that they were made at trading centers after they had been collected instead of at the primary production center.[27] This is supported by the fact that bun ingots from different mold siblings were incised with the same mark, but some production stations could have used more than one mold to cast the bun ingots. A more conclusive argument for traders' marks is that some of the marks were also found on the Uluburun tin ingots, which were mined in a different geographical region, possibly as far away as Afghanistan.[28] It is unlikely, therefore, that any form of centralized authority exercised control over such a wide region that similar marks were placed on metals mined from completely diverse regions.[29] More likely, these marks were incised by the merchants who received a certain shipment of ingots at a production or collection center in order to separate them for a specific purpose, which is unknown at this point.

The marked bun ingot found highest upslope (M10LR3) is KW 395, incised with a U-shaped (3b) sign. It was found among other copper and tin ingots in this area although none of them bear the same mark, but its location may indicate where bun ingots of this group were stored originally near the stern. Eleven other ingots were also incised with the same mark but they were located farther downslope. The main locus of 3b ingots was in the area corresponding to grid squares O to P13-14. Nine ingots were clustered by the port side of oxhide ingot row 1, some of which were covered by the oxhide ingots, Canaanite jars, and ebony logs. Bridging the gap between these two find spots are two ingots (KW 396, 405) in square N12, which suggests KW 395 was not

[27] Pulak 2000b, 146.
[28] Pulak 2000b, 153.
[29] Pulak 2000b, 146.

simply a similarly marked ingot that was kept separately at the stern of the ship, but rather it was part of the same group of ingots that were originally stowed near the stern, with the path of spillage shown by the downslope trail of these ingots.

Also found in the stern section of the wreck, but more widely dispersed, are the ingots with the double-T (6d) sign. The location of bun ingot KW 411 in grid square N11UL shows that the group of ingots with this particular mark was also originally stored in the stern. Slightly forward or downslope of this ingot, five others of this group were found in the main Canaanite jar pile, with two at either extremity of oxhide ingot row 1. While KW 207 (6d) was found in the middle of the main group of ingots with 3b signs, seven other ingots with 6d signs were scattered to starboard just downslope of row 1, two upslope of pithos KW 252, and one other just upslope of pithos KW 251.

Only three other groups of marked ingots were discovered in the stern section of the ship and they are all fewer in number. Two of the three bun ingots with 2d signs were located on the starboard side of ingot row 1 with the third very close by, having fallen just over the ledge into grid square K14 along with some Canaanite jars. The only two buns bearing the double-cross mark (3f) were likewise found in close proximity, in square M14. To the north of them were the six 4b ingots, tightly clustered in grid square N14.

The remaining two groups of marked ingots were found in the forward half of the wreck with no discernible trail to the stern area. The smaller of the two groups consists of oval ingots with the 5e sign, whose distribution was mentioned earlier, and the larger group contained 12 ingots with the 4d sign strewn among the overspill of oxhide ingot row 4 in grid squares N to O18-19.[30] Two other bun ingots belonging to the latter group fell farther down slope to squares K22 and 23.

As noted above, the incomplete and half bun ingots, as well as the fragments of bun ingots, were almost certainly stored together in a container. This container was probably stored in the after half of the ship but fell downslope to square M15 when the ship sank. After the container had disintegrated or opened up, its contents slid underneath the oxhide ingots held up by the boulder-like outcrop, and the bun ingot fragments became dispersed throughout squares M16 to N20. One notable occurrence briefly mentioned earlier is the proximity of five fragments that join to form a complete bun ingot in squares N19-20 (KW 3020, 3494, 3656, 4453, lot 6882). Although this is the best example, other joining fragments were also found in close proximity. Bun ingot fragments KW 1191 and 3804 were not found with the others, but they were both on the starboard side of oxhide ingot row 4, a little more than half a meter apart. Fragments KW 780 and 999 were also similarly situated in square M16, but their last and joining piece, KW 3456, was farther downslope in square N21. It seems likely, therefore, that the pieces of fractured bun ingots were kept together, and it is clear that all of the copper bun ingot fragments were stored collectively, possibly in a single container.

[30] Noteworthy, but probably not significant, is the fact that two of these 12 ingots (KW 1573 and 3000) had their quarter-rudder-like marks (4f) drawn facing opposite directions from the rest (4d). Since the mark is very similar in all other respects, this probably does not represent a different mark.

Discussion

Once the bun ingots were plotted on the site plan by mold group, it became evident that a pattern existed between the locations of the ingots on the wreck and their physical attributes. This correlation is clearly observed for ingots constituting mold groups 1, 2, 15, and 18, which account for 36 percent of the bun ingots. While this is a minority of all the bun ingots, many ingots from the other mold groups were also found in clusters of at least two or three. Generally, the bun ingots were found only in certain areas of the wreck, with concentrations occurring at the very stern, just forward of ingot row 1, along the starboard and port sides of rows 2 and 3, and mixed among the overspill of row 4. Only four ingots (KW 191, 193, 195, 629) that were found in the Canaanite jar overspill area, and two others (KW 3283, 3287) that were located in squares K22-23, represent bun ingots found outside the major distribution areas. Even in these cases, none of the bun ingots or their fragments are separated by more than 1 m. Taken together, this suggests that the ingots were stored in a small number of baskets or sacks, not in a random fashion, but mostly based on their mold groups. These ingots were probably thus grouped when transported from their place of production to the commercial distribution center where they were obtained for the Uluburun ship.

While the majority of the bun ingots were probably stored according to their mold groups, the clustering of the 64 marked ingots indicates that storage by marks supersedes that of mold groups. A vivid example is seen in a comparison of the mold-group 2 ingots that consisted of five ingots with the 4b-sign group, which constituted the same assemblage of ingots, but was made up of six ingots (KW 66.1, 66.2, 1554, 1604, 3600, 3675). The extra ingot, KW 66.1 (mold group 19), did not belong to the same mold group as the other five, but it did have the same mark so they were stored together.[31] In addition, the assemblage of ingots in squares O to P13-14 yields a number of different groupings when sorted by mold siblings; nine of the 13 ingots there, however, have the 3b sign (the only other marked ingot was KW 207 with the 6d sign). A similar case involves mold group 17 (collectively termed the “mud pie ingots”) that consists of seven ingots, two of which have sign 2d incised on the rough surface of the ingot, while four have the 4d sign.[32] The two ingots with sign 2d (KW 629, 1122) were in the vicinity of square K13 along with bun ingot KW 1088 (of mold-group 29, with the same mark on its rough surface), while the four ingots with the 4d sign were all found in grid squares N18-19 along with other similarly marked ingots. Another example is the two bun ingots KW 3283 and 3287, found in squares K22-23. Not only are these two ingots from two different mold groups but the other members of their groups were found much farther upslope on the site. When considering their marking, however, it becomes clear that they had slid from the group of ingots marked with the 4d-sign in square N18. Lastly, the large number of ingots comprising mold group 15 was found in two large clusters, which may have been arbitrarily separated when stacking them. This is evidently not the case when the marks are taken into account because all the ingots found in square P18 were unmarked, whereas the ones that were marked were stored together in square P13 as a separate group.

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[31] None of the other bun ingots with the 4b sign or any ingot belonging to mold group 2 was found anywhere else on the site, which suggests an effort was made to keep the ingots together by their mold groups as well.
[32] The seventh ingot, KW 3698, was not marked.

Since the ingots appear to be sorted and stored according to their marks first and then by mold groups, it is hypothesized that these ingots were probably transported to the commercial centers from the primary production center by their mold groups. It is reasonable to assume that once an ingot was cast and removed from the mold, it would be placed with other ingots cast in the same mold, and these would be transported together—even if more than one mold was used at the production center. Once collected at the recipient commercial center, merchants selected certain ingots, sometimes by entire mold groups or simply as individual ingots from different groups, and marked them according to the criteria they were following. Thus, similarly marked ingots were placed into individual containers and stowed on the ship, while the remaining containers were filled with unmarked ingots still in their mold groups. The detailed exercise of determining how the bun ingots were distributed on the Uluburun shipwreck site has one primary purpose for this study: to document where the ingots were stowed to understand their contribution to the trim of the ship.

Stowage and weight distribution

The location of these bun ingots on the ship has the greatest bearing on this study. I believe that most, if not all, of the bun ingots were initially stored in the stern and possibly some also near the row 1 ingots. For the sake of explanation, a line of demarcation can be drawn at the junction between grid squares 14 and 15. The bun ingots above this line are undoubtedly from the stern of the ship. These ingots were clustered in seven general groups: the aftermost assemblage has 13 ingots; downslope of that are nine ingots mixed with the Canaanite jars; 13 are on the port side of ingot row 1; just south of that are six ingots mostly from mold group 2; another group of nine ingots are found to the northern face of stone anchor KW 3335; three are among the spilled pile of Canaanite jars; and the last group has three ingots on the starboard side of ingot row 1.

Why there was a stash of copper oxhide, bun and tin ingots behind the Canaanite jars is unclear, but it is known that of the 120 complete bun ingots, at least 22 (group 1 and 2 from above) were kept in this stash at the very stern. The two clusters on either side of ingot row 1 probably also originated somewhere aft of where they were found, which might help to explain why many of the port ingots were underneath row 1. It is more difficult to imagine how the two groups of ingots directly in front of row 1 could have gotten there if they originated in the stern. It is possible that they were placed on top of the row 1 oxhide ingots or just in forward of them.

For the ingots below the dividing line, the possibility exists that they were stored in the midships or bow area. Not only is this undesirable since the bow is already loaded with copper oxhide ingots, but there is reason to believe that these bun ingots could have also originated from the stern area. Understandably, these ingots are not as neatly clustered as those found in the stern since this area of the wreck experienced greater disturbance. Generally, the ingots were found on either side of ingot rows 2, 3, and 4, and some were underneath and mixed in with the spilled ingots of row 4. The bun ingots on the sides of ingot rows 2 and 3 seem more likely to have arrived there from sliding along the sides of the hull rather than falling there from the tops of the oxhide ingot rows. The ones mixed with the row 4 oxhide ingots, however, may have a better prospect of having been on top of the rows of oxhide ingots. Because of the relatively few ingots found in the starboard spill area, the bun ingots were probably displaced early in the wreck-formation process and the sides of the hull prevented the ingots from spilling outward. This may explain the dispersion of the bun ingots along the sides of the rows of oxhide ingots and among the scattered ingots of ingot row 4. Circumstantial evidence indicating that the ingots were shifted to the forward portion of the ship rather than stowed there is the presence of intact Canaanite jars and numerous Canaanite jar sherds scattered throughout the row 4 region.[33] As discussed in chapter VI, the Canaanite jars were almost certainly confined to the stern. Therefore, if the Canaanite jars reached this forward portion of the wreck, then feasibly, the bun ingots could have also.

From studying the site plan, it is valid, although not conclusive, to propose that the bun ingots in the bow arrived there by sliding along the sides of the hull, around the rows of oxhide ingots while still in their containers. Where exactly in the stern these ingots were located is much more difficult to answer, but two of the larger mold-sibling groups, 17 and 19, were found on either side of ingot row 1. This, of course, was most likely not the original location of the ingots, and an original location farther aft in the stern is implied. A total of 20 intact copper bun ingots were found abaft the main pile of Canaanite jars, suggesting that the other bun ingots were originally kept there as well.

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[33] KW 2802, a nearly intact Canaanite jar, is in grid square N18LR1, just forward of ingot row 4. Also, a large number of Canaanite jar sherds were found among the row 4 oxhide ingots.

The total post-excavation weight for the copper bun ingots is 774.6 kg. With an average weight of 6 kg per intact ingot, approximately six to twelve ingots can be placed in a basket or sack (roughly 36-72 kg.), which could be managed by one or two people while loading and unloading from the ship. Coincidentally, a breakdown of the ingots by marks indicates that ingots with signs 4b and 5e were found in groups of 6, and those with signs 3b and 4d had 12 each (two of the 4d ingots were located farther down slope). Two of the more tightly clustered non-marked mold groups (15 and 18) had 9 and 10 ingots each, respectively. It seems likely that each of these bun ingot assemblages represent the contents of one container. A trail of ingots with the same sign or mold siblings could denote spillage from such containers, while separate assemblages of mold siblings may suggest that the ingots were carried in two different containers.

If all of the bun ingots and the 13 oxhide ingots aft of the Canaanite jar pile had been placed originally on row 1, then the entire row would have a cumulative weight equal to that of rows 2 or 3 (2349 kg compared to 2350 kg and 2375 kg). Clearly, the original stowage location of these copper bun ingots is crucial to determining the trim of the vessel. It seems almost necessary for the copper bun ingots to have been stored in the very stern of the ship to counterbalance, rather than contribute to the weight of the three rows of oxhide ingots in the bow. Unfortunately, the archaeological evidence is not conclusive, although it certainly indicates that all the bun ingots could have been stowed in the stern of the ship.

Tin Ingots

Background

An unknown quantity of tin in oxhide, bun, and rectangular slab forms was carried aboard the Uluburun ship. Due to a transformation of their crystalline structure,[34] many of the tin ingots assumed the "consistency of toothpaste,"[35] and crumbled or dissolved when disturbed during excavation. Therefore, only an estimate of one ton of tin can be given at this time, which is of sufficient quantity to alloy with the nearly 10 tons of copper to produce 11 tons of bronze in the appropriate proportions.[36] The Uluburun tin ingots are the earliest and most securely dated tin ingots found from the Bronze Age to date. Although the source of tin in the Late Bronze Age is still uncertain, we know from these ingots and from certain Egyptian tomb paintings that some tin was cast in the same shapes as copper.[37] Only three intact tin ingots of the oxhide shape were found, but 46 percent (51 fragments) of the tin ingots recovered from the wreck (110 total) were oxhide ingots cut in antiquity into quarters, while an additional four ingots were cut into halves. The second most common ingot form are oxhide slab fragments (36), of which only two intact examples were recovered. The remaining preserved tin ingots came in a variety of shapes including three complete buns, two bun fragments, three wedge-like ingots, and a unique anchor-shaped ingot. Regarding this collection of mostly fragmented ingots, Pulak states:

It is unlikely that tin ingots aboard the Uluburun ship were cut into smaller

[34] Maddin 1989, 102-4.
[35] Pulak 2000b, 152.
[36] Pulak 2000b, 152.
[37] Bass 1967, 62-4.

> quarter-oxhide sections for convenient handling, as the ship also carried more than 350 complete oxhide ingots. Similarly, it seems unlikely that they had been cut into pieces *en route* for trading purposes during the voyage, as that would not explain the near absence of intact tin ingots among the many cut fragments on the shipwreck. Surely, these ingots would have been cut as needed rather than all at once during or at the beginning [of] the voyage. Tin ingots may have been cut down to smaller sizes at their point of receipt, however, perhaps for use in various transactions. If this is the case, then we may assume that the Uluburun tin ingots do not represent a shipment of ingots procured directly from a single source, but rather an assemblage that was distributed for use and then subsequently gathered by barter, levies, taxes, gifts, or some other mechanism before being placed on the ship.[38]

Could the state in which the tin ingots were shipped indicate a different type of trade from that of the copper ingots? To answer this question, more research on Late Bronze Age trade will be necessary, but the tin ingots' fragmentary state and their lead-isotopes analysis results point to two distinct sources for this shipment of tin, unlike the copper, which seems to have come mostly from a single source.[39]

<u>Distribution on the wreck</u>

A concentrated group of 29 tin ingots (KW 35, 110, 202, 391, 392, 393, 398, 399, 400, 401, 409, 410, 412, 422, 511, 515, 516, 518, 519, 633, 637, 638, 639, 640, 641, 642, 643, 644, 1760: 17 quarter-oxhides, 6 slab fragments, 2 complete buns, 2 bun fragments, and 1 plate) were found at the stern mixed with a group of large copper bun ingots from mold group 18 (fig. 4.14). Another smaller group of tin ingots were recovered in grid squares N11-12 with nine ingots (KW 403, 712, 718, 719, 720, 721,

[38] Pulak 2000b, 152-3.
[39] Pulak 2000b, 153.

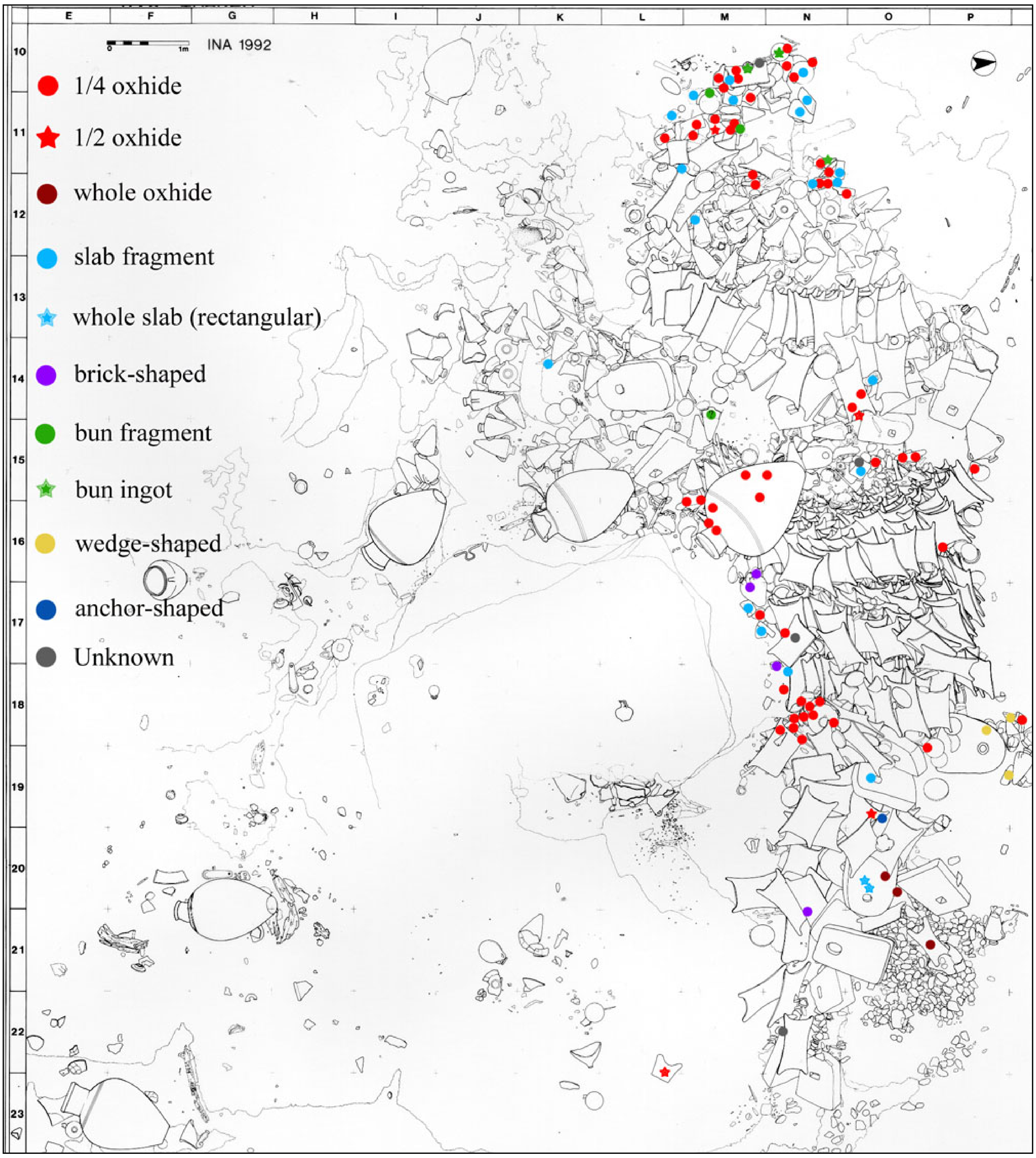

Fig. 4.14 Distribution of tin ingots by shape.
(After Pulak 1998, 192, fig. 4).

722, 1321, 1326: seven quarter-oxhides, one bun, and one slab fragment). Most likely this second group of ingots was initially stored with the first group. There were three other tin ingots in the same area, but found slightly downslope, that presumably came from the above mentioned groups. Of these, KW 133 and 197, both quarter-oxhides, were located among the glass ingots located highest up the slope. One miscellaneous slab fragment (KW 341) was situated just forward of the glass ingots and mixed with the Canaanite jars. This makes a total of 41 ingots not dispersed from the stern region, which is believed to be the primary storage place for most of the tin carried aboard the ship.

One of the aberrant tin ingots was KW 315 (slab fragment) found in the Canaanite jar overspill area. It was the only tin ingot found in that area of the wreck and the next closest tin ingot (KW 847) was at least 2 m away. Tin ingot KW 847 itself was also somewhat isolated from the rest of the tin in the midships area and may also be the only tin bun ingot (possibly, identification uncertain) fragment not located in the stern. Aside from these two stray tin ingots, the midships area contained three distinct, but possibly associated groups.

The first group is composed of five tin ingots, found just down slope of the copper bun ingots located in front of oxhide ingot row 1. Tin ingots KW 67, 198, 1371, and 1357 (one half-oxhide, two quarter-oxhides, and one slab fragment) were found on the port side, between stone anchors KW 4009 and 3336. Close to these four ingots were two more groups of tin. One of these assemblages (KW 702, 704, 1061, 2143, 2408, 4419, 4484, 4485; all quarter-oxhides) was found under pithos KW 251, while the other assemblage (three quarter-oxhides, KW 199, 205, 206; one slab fragment, KW 95; one unknown, KW 203) actually lay on top of the main hull remains. Tin ingot KW 3157 most likely belonged to this group although it was located farther north, found underneath copper bun ingot KW 809 in square P15. All three groups were close enough that they may have originally been kept together. The last two groups seem to be an extension of the first group of five ingots.

The bulk of the tin ingots found in the forward part of the wreck were strewn between grid square M16 to N18. There were a total of 20 ingots found in this area (KW 946, 2699, 2739, 2774, 2777, 2789, 2796, 2874, 2887, 2902, 3048, 3061, 3094, 3703, 4166, 4265, 4276, 4469, 4575, 4576: 14 quarter-oxhides, 5 slab fragments, and 1 unknown—KW 4265). Also found here were 11 pieces of small tin scraps (KW 3113, 3197, 4470, 4515, 4561, 4592, 4809, 4810, 4853, 4864).

Opposite these ingots, on the port side, were three wedged-shaped tin ingots (KW 2329, 2332, 2365), the only ones found on the wreck, and two quarter-oxhides (KW 2255, 3014). Ingot KW 1932 (oxhide) lay on a pile of ballast stones, while ingots KW 2911 and 2915 (slab ingots), and KW 2922 and 2924 (oxhide) were lodged under stone anchor KW 2921. A third intact slab ingot, KW 4000, was located farther upslope below stone anchor KW 4010. Just down slope of that, underneath anchor KW 4012, was the one-third tin oxhide KW 3934 and the anchor-shaped tin ingot KW 3935.

Lastly, there were three miscellaneous tin ingots in the deeper end of the wreck. Ingot KW 3433 was a brick-shaped ingot and was found farthest downslope (N20LR3) of all four ingots of this type. The other three were located within the boulder-like rock outcrop—gully area (squares M16-17), so it is reasonable to believe that this ingot also belonged to that group. An unknown tin ingot (KW 1772) was even farther down slope than ingot KW 3433, found underneath stone anchor KW 3332 in square N22. It probably also belonged to the group of three ingots found in the gully. The tin ingot located deepest on the site is a half oxhide (KW 3297) found 1 m south of stone anchor KW 3332 in L22LR. It was discovered in an isolated area with few artifacts, which included two copper bun ingots and some broken pieces of pottery.

Looking at the overall distribution of the tin ingots, several trends can be observed:

- There are no bun ingots or bun ingot fragments in the forward section of the ship. All of the fragments were found in the stern except for a very small fragment (KW 847), of questionable identification.
- The number of slab ingot fragments is greater upslope than downslope, while the situation is reversed for the quarter-oxhide ingots (if the midships ingots are included with those found downslope). In all likelihood, the cache of tin quarter-oxhides in grid N18 was originally located higher upslope, perhaps in grid M16. Therefore, the midships ingots in grid square L16 probably belonged to this group.
- The tin ingots of uncommon shape were stowed together as a group. Of these, all three wedge-shaped ingots were on the port side of the bow and only one quarter-oxhide tin ingot was found near them. Four brick-shaped ingots were located on the starboard side, two (KW 2699, 3703) of which were found together by oxhide

ingot row 2; one (KW 2887) was found just slightly downslope by ingot row 4; while the fourth (KW 3433) was farther away near the complete oxhide and slab tin ingots in grid square N20.

- Of the four half-oxhide ingots, one appears to be located in each major section of the wreck: KW 3297 was at the deeper end of the wreck near grid square M22, KW 3934 was interspersed with the spillage from ingot row 4 in square O19, KW 1371 was found at midships in square O14, and KW 644 was located at the stern in square M11.
- With the exception of the bun ingots, all of the other complete tin ingots were located in close proximity in the forward section of the wreck.

Stowage and weight distribution

Since an unknown amount of tin was lost due to corrosion, the actual amount of tin carried aboard the ship cannot be determined with certainty. The tin ingots came in a greater variety of shapes and sizes than the copper bun and glass ingots found on the ship, so it is difficult to generalize their weights according to shape. Based on the estimated figure of one ton, however, the tin ingots play a substantial role in the trimming equation of the ship.

As with the copper bun ingots, there is sufficient evidence to suggest that the tin ingots were originally located at least aft of oxhide ingot row 2, if not totally in the stern as hinted by the 42 tin ingots recovered from that area. While conclusive evidence is lacking at this time, if it can be assumed that the half-oxhides were stored together, the distribution of these ingots might point to a similar situation with the rest of the tin ingots; namely, that they were stowed in the stern and were eventually dispersed during the wrecking of the ship. The proximity of Canaanite jars to the tin ingots in almost every instance (M11, K14, M16, P15, M17 to 18, Q18, P21, and K21) where tin was found may be viewed as good circumstantial evidence that this category of cargo was kept in the stern.

This may not apply, however, to the intact and anchor-shaped tin ingots, which were found near the bow. Six of the seven tin ingots in this area were underneath copper oxhide ingots and stone anchors, which would be difficult to explain if they had slid down from the stern. Although it has been argued that other artifacts such as glass and copper bun ingots managed to percolate to the bottom of the oxhide ingot rows after the ship sank, neither of these artifact groups were found in the area in question (squares O20 to P21), so their patterns of distribution do not apply to the tin ingots in this region of the wreck. However, glass and copper bun ingots were found adjacent to tin slab ingot KW 4000, which was slightly higher in grid square O19. It is conceivable that these large intact ingots of tin were kept with the similarly shaped copper ingots in this area for the duration of the voyage, either for ease of stowage or some other reason. We do know, however, that even if they were stored together with the copper ingots, an attempt was made to keep them together and not simply disperse them among the other copper oxhide ingots comprising ingot row 4.

Where in the stern were these ingots kept if indeed that is where much of the tin on the wreck originated? A compilation of the copper bun, tin, and glass ingot distribution charts exhibits a heavy concentration of these artifacts at the uppermost extremity of the wreck. There does not appear to be any specific clustering of the copper oxhide, bun, or tin ingots, as all three categories were found jumbled together, but the glass ingots are clearly separate and cluster slightly down slope, just aft of the Canaanite jars. It does not appear that the Canaanite jars were stored aft of this pile of metal ingots, as a base fragment of a Canaanite jar was recovered from square M11, while the metal ingots were mostly centered upslope in square M10. The ingots that remained in this area probably corresponded to those lowest in a stack of baskets or sacks partly held in place by additional baskets placed above them, and also by their relatively lower potential energy, compared to those baskets stacked higher up the steep sides of the hold. These stacked baskets full of metal ingots could have acted as a support for the upper layer of Canaanite jars if they were tightly packed, which might explain the close proximity of the Canaanite jars and copper bun, tin, and glass ingots throughout the wreck.

The Glass Ingots

<u>Background</u>

Ingots of glass in the form of a truncated cone were found dispersed along the length of the main axis of the wreck.[40] They average 14 cm in diameter on the wider end and vary in thickness between 3.5-4.5 cm for the smaller ingots and 6-7 cm for the larger

[40] For a more detailed discussion of the glass ingots, their composition, origins, and parallels to other examples from the Late Bronze Age Mediterranean, see Pulak 2001, 25-30.

examples.[41] The great majority of the preserved glass ingots were of a cobalt blue color, a limited number were of turquoise, purple, and amber colors. Approximately 112 relatively intact ingots were found on the wreck, while 33 found were in fragmentary form, ranging from one-fourth to three-fourths of a complete ingot. Not all of the ingots discovered on the wreck were well preserved, as excavation logs register at least 175 ingots in varying states of preservation. Some were not recoverable since they had become hydrolyzed and disintegrated during excavation. Consequently, the exact number of glass ingots carried aboard cannot be ascertained.

Distribution on the wreck

The glass ingots found highest on the slope (KW 3 and 4, both cobalt colored) were in square J11, just downslope of pithos KW 250 (fig. 4.15). They were found along with Canaanite jar base (KW 372) and a dagger blade (KW 1). Although it is unlikely, it cannot be ruled out conclusively that these ingots were originally stored in pithos KW 250. Along with the next group of glass ingots, there is evidence to show that at least some of the glass ingots were stored in the stern area, behind the Canaanite jars. The second highest group consists of 20 ingots (KW 80, 81, 82, 83, 84, 85, 112, 113, 129, 135, 136, 140, 173, 333, 383, 385, 507, 508, 622, 898) located around grid squares M-N12, eight of which are definitely cobalt-colored, three possibly cobalt-colored, and nine are of uncertain color. These ingots were located just aft of the main pile of Canaanite jars and were mixed with a few copper bun ingots and tin quarter

[41] Pulak 2001, 27.

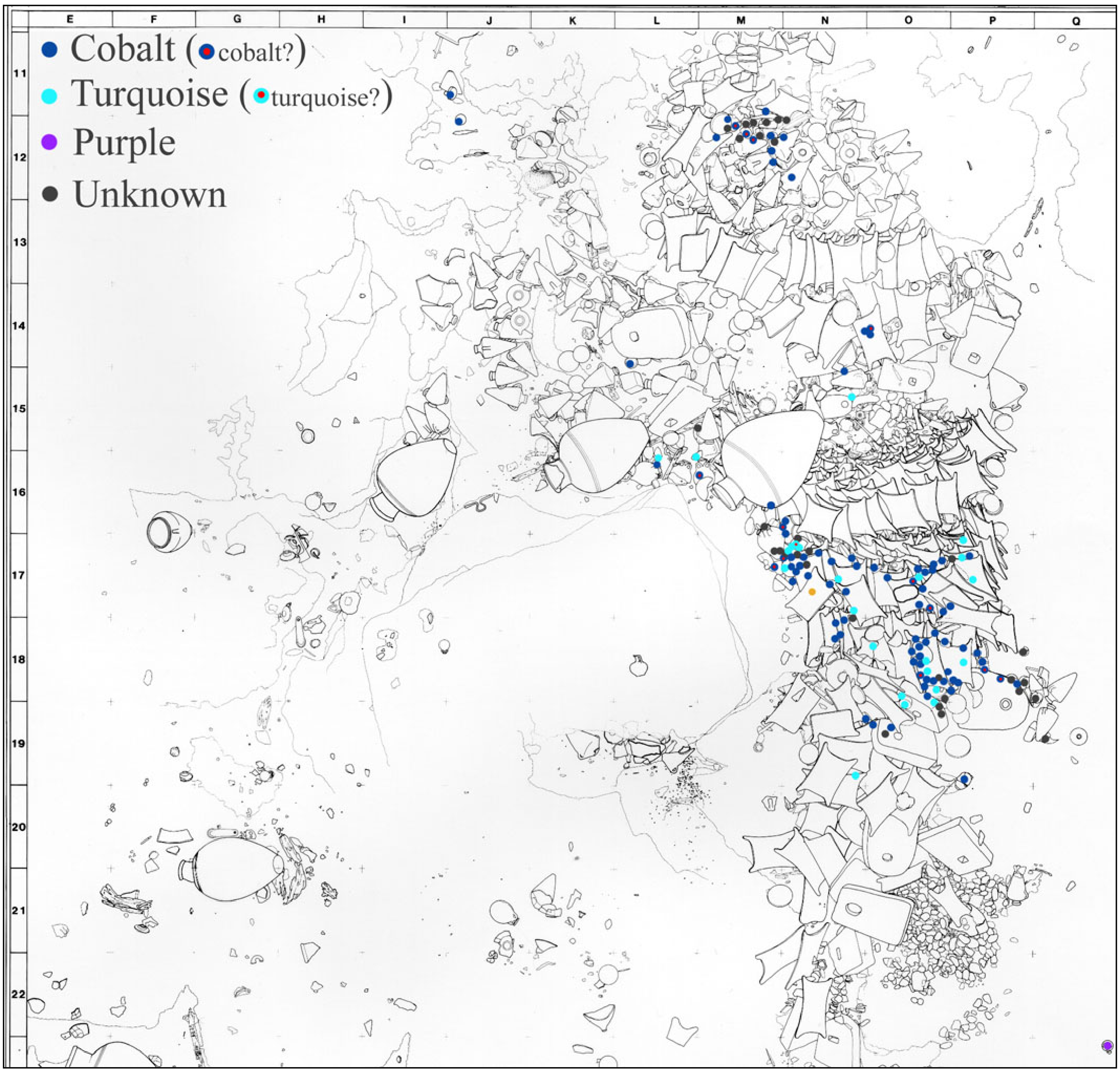

Fig. 4.15 Distribution of glass ingots by color.
(After Pulak 1998, 192, fig. 4).

oxhides. The ingots in this group were distributed horizontally, as if the container which held them came crashing against a barrier, perhaps the Canaanite jars or a hull structure, and then were scattered laterally. Evidence for stacking of the glass ingots is tenuous since they obviously had spilled from somewhere farther aft in the ship and were therefore quite displaced, but the in situ positions of ingots KW 81 and 85 suggests that some of the ingots were placed with the larger diameter face on top of the smaller diameter surface. Glass ingots KW 80 and 385, and KW 84 and 173 also appear stacked in the same manner. Another pair, KW 113 and 136, were found on top of one another but it is not possible to tell from the drawing how they were stacked.

The next batch of ingots was found in a tight cluster forward of the first row of oxhide ingots. Three broken ingots (KW 1471, 1472, 1473) were among a bunch of small lead net sinkers, a few tin oxhide ingot fragments, and ballast stones. This assemblage was located between stone anchors KW 3336 and 4009; three other glass ingots were covered by displaced oxhide ingots from row 1. Two other glass ingots (KW 1319, 1896), possibly also a part of this group, lay just downslope, between stone anchors KW 4009 and 4418. Glass ingot KW 1896 is the highest confirmed turquoise ingot on the site.

Between the previous group of glass ingots and the next large stash were six other ingots. Five of these (KW 762, 1000, 1399, 1562, 2577) were caught between pithoi KW 251 and 252, while a lone ingot (KW 34) rested against stone anchor KW 3335 and on top of pilgrim flask KW 600 in square L14UL3. Glass ingots KW 762 and 1562 are the second highest turquoise ingots on the wreck. It is strange that these ingots were so isolated from the other glass ingots. Perhaps these ingots spilled as the basket containing them rolled downslope and came to rest between oxhide ingot rows 2 and 3.

The next large group of glass ingots was found in grid squares M to N16-17. Most likely a container carrying these ingots, perhaps also including the previous group, tumbled downward along the starboard side of the hull to the second row of oxhide ingots before becoming lodged between the second and third rows of oxhide ingots. When the keel broke at the upslope edge of ingot row 2, rows 3 and 4 were sent crashing down the slope, resulting in a large gap between rows 2 and 3 for the glass ingots to fall into. As for the glass ingots found underneath the oxhide ingots of row 3, it is possible that when the oxhide ingots in the third row fell downward, gaps opened between the oxhide ingot layers, and the glass ingots that were wedged between ingot rows 2 and 3 fell into these crevices. When the hull disintegrated completely, much of the cargo fell into the crevice along the side of the boulder-like rock outcrop, which explains the discovery of glass ingots underneath the lowest layers of oxhide ingot row 3. The largest group of glass ingots was covered by a group of 54 oxhide ingots from row 4. These glass ingots were found both under and above the entangled oxhide ingots and stone anchors downslope of ingot row 4.

The deepest discovered ingot is KW 2409 (cobalt-colored), which rolled all the way down to square M23LR4. There are no other glass ingots in this area, except for KW 3535 (purple-colored), which is located farther north in square Q23UR2 and is isolated from other artifacts. Glass ingot KW 2409 was found among some ballast stones and next to the deepest stone anchor (KW 2917). A copper bun ingot (KW 3287) and half a tin ingot (KW 3297) were located in an area in grid squares K-L23, so it possible that some of these artifacts simply slid all the way down the slope. In all, 77 percent of the glass cobalt ingots and 91 percent of the glass turquoise ingots were found forward of oxhide ingot row 2. The only examples of amber- and purple-colored ingots were also found in the bow area.

Stowage and weight distribution

Where were the glass ingots originally stored? We know from the pile of glass ingots located farthest upslope that at least some were stored in the stern, abaft the Canaanite jars. The two cobalt ingots found near pithos KW 250 suggest the glass might have been stored even farther aft than the large cache found in grid square M12, possibly at the very end of the stern. The discovery of a small number of glass ingots between oxhide ingot rows 1 and 2 is insignificant, since they probably settled there when the containers carrying them fell forward. Their location on the wreck site, therefore, is not indicative of their original stowage on the ship. The containers holding the glass eventually spilled most of their contents among the three forward rows of oxhide ingots. The heavy concentration of glass ingots in grid squares N17 and O17-18 could represent the contents of one or more of these containers. If each glass ingot weighed approximately 2 kg,[42] a practical load of 20 to 35 ingots (40-70 kg) in a basket or sack would have been convenient for one or two persons to carry. Using this assumption, the more than 100 glass ingots found in the bow of the ship would have been contained in

[42] A survey of the best preserved ingots showed that the average weight of an ingot was 1.93 kg. I would like to thank Edward Rogers for his providing information on the glass ingots for this study.

three to six baskets, a number consistent with the clustering of glass ingots seen on the site plan.

Could baskets of glass ingots have been initially placed on the forward three rows of oxhide ingots? Had this been the case, then more glass ingots should have been found in the deeper part of the wreck, where only two examples were found. Judging by the intensity of the force that dispersed the oxhide ingots in row 4, if the glass ingots had been placed on top of the oxhide ingots, the majority of them would not have simply fallen through the gaps between the rows and ended up below them as they did, but at least one or two baskets would have fallen farther downslope and landed with the oxhide ingots down in grid squares 21 or 22 or even farther downslope. The proximity of some Canaanite jar fragments (squares N and Q18, 19) to the glass ingots demonstrates the likelihood that these ingots were stowed in the stern rather than at the bow.

CHAPTER V

CYPRIOT POTTERY

Pithoi

Location on the wreck

A cursory glance at the site plan shows seven relatively intact large storage jars or pithoi of various sizes distributed throughout the wreck (fig. 5.1). KW 250, the pithos found highest up on the site (J10), is also the smallest. It is also of a different fabric and shaped differently from the other pithoi, with a short neck and wide flaring rim, and lacks the finger grooves present on the shoulders of other pithoi. The other pithoi can be divided into two sizes; the smaller of these two groups is designated as medium-sized to avoid confusion with KW 250. The most noticeable pithoi are the three aligned in a northwest by southeast direction at midships, upslope of the rock outcrop. From north to south, they are: KW 251 (large), 252 (large), and 253 (large). Neatly continuing the path of spill trajectory are KW 254 (medium) in grid squares G20-21 and KW 255 (large) in F23. The final pithos to follow this course was KW 256 (large), which rolled too far south (square B32) to appear on the main site plan. KW 4596 (large) is in square I32 on the site plan although only one half of the pithos is discernible; its other half is close by in square K30.

At least two other, less well-preserved, pithoi were reconstructed from fragments in the conservation lab. Tentatively labeled pithos #8 (medium?) and #9 (medium?), they are currently incomplete as no other fragments were recovered that could complete the mending process of the two jars. Pithos #8 was scattered throughout squares I to

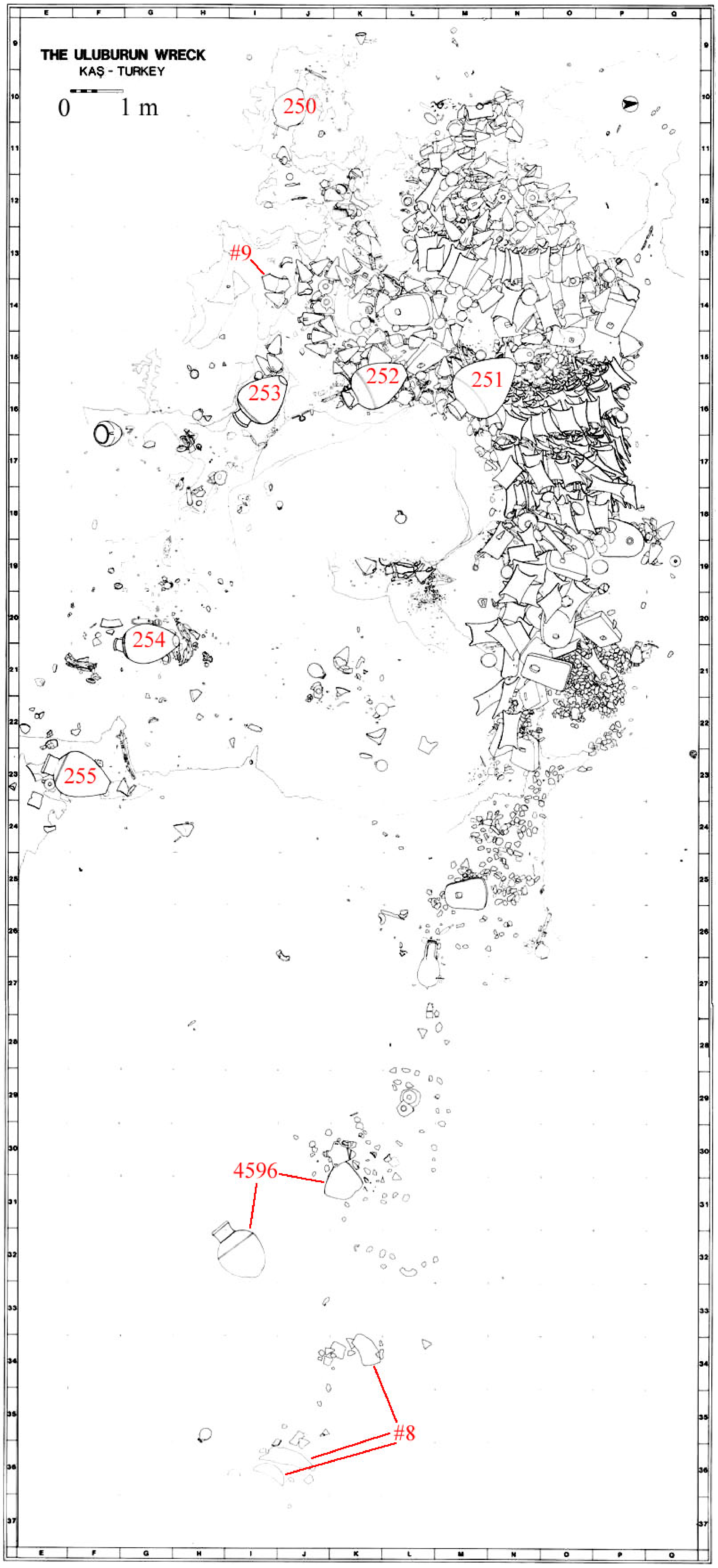

Fig. 5.1 Location of pithoi on wreck site. KW 256 off the site plan. (After Pulak 1998, 192, fig. 4).

K28-37, with the largest fragments recovered from squares K34 and J36. These fragments represent approximately 70 percent of the pithos. The fragments of pithos #9 were so widely dispersed that the existence of a tenth pithos was unknown until the summer of 2002, when a large shoulder section was mended from numerous pieces that could not be fitted to any of the other pithoi.[1] The largest fragment of pithos #9 is lot 246, which was found farthest upslope in squares I-J13 while the deepest fragment is lot 6339 in square G22LR. The rest of the sherds making up this pithos were scattered between these extremities throughout the southern half of the wreck.[2] The force of dispersion, therefore, must have been quite violent; thoroughly cracking the pithos while it was still on the higher parts of the seabed and causing fragments and its contents to fall out as the pithos tumbled downslope.

Possible lids for these pithoi were also recovered from the wreck. One in particular (KW 222 + lot 1900) is almost certainly a lid because it was custom made and not one that was fashioned from a base of a pithos.[3] There are three other possible lids but none are preserved as well as the first. These do not look like custom-made lids but rather appear to be pithoi bases that were recycled and used for this purpose. One such lid (lot 8484), however, eventually joined the lower base of pithos #8, which brings into question the identification of the other two pieces as lids. Another lid, KW 68 was situated about 2 m northwest of lot 246 in square K12, the largest fragment of pithos #9,

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[1] It was not the lack of joins that prevented the assembled shoulder section from being fitted to the other pithoi, but rather it was too large for any of the vacant areas in the incomplete pithoi (KW 4596 and pithos #8). (Pulak, personal communication).

[2] There are a number of pithos sherds in this area of the wreck that may be part of pithos #9 but due to its incompleteness, they do not join the confirmed pithos #9 sherds.

[3] Pulak, personal communication.

and may either be part of its base or possibly a lid for any of the five pithoi in the southern portion of the wreck. If all three supposed lids turn out to be pithos bases, then there must have been yet an additional 11th pithos for which little other evidence exists.

<u>Location on the ship</u>

The location of the pithoi on the ship is crucial to the trim of the vessel since they are the largest and potentially heaviest objects aboard the ship whose placement can be adjusted, unlike that of the oxhide ingot rows and the Canaanite jars whose location on the ship are established with relative certainty. Their similar orientations suggest that the pithoi were stacked in rows and were most likely stored together in one area. A possible exception is KW 250. Not only is the shape of this jar different from that of the others, it was also found away from the other pithoi. Judging from its position on the wreck, it was undoubtedly stored in the stern, possibly even on the stern deck, perhaps in the same way as the large jar seen on the bow of the Kenamun ships (see fig. 2.2). There simply is not enough evidence to draw a conclusion, although this small jar does appear to have been stowed separately from the other larger pithoi. The positions of KW 251, 252, and 253 indicate that the pithoi were stored at least aft of oxhide ingot row 2. The open area amidships might have been a good location for the nine pithoi of medium and large-sizes, but this configuration would have contributed little to the trim of the ship, which appears heavily loaded toward the bow. Also, they would have hindered access to the mast and associated rigging elements, a situation that would have been avoided since the rigging needed frequent adjustment and perhaps also to the spare stone anchors stored just forward of oxhide ingot row 1.[4] Therefore, evidence must be sought for a more suitable location.

From the trimming perspective, the farther aft the pithoi are located, the more leverage they could exercise to counter the heavy oxhide ingots in the bow. There is, however, very little in the way of direct evidence, such as pithos fragments, to suggest that the pithoi were stored aft of ingot row 1. Understandably, even if they had been placed in the very stern, it is unlikely that they would have left any traces since the pithoi were quite robust, and most of them appear to have been displaced by the initial impact while remaining fairly intact.

The uppermost pithos fragments comprise one of the pithos bases previously thought to have served as a lid: lot 138 (N-O12), lot 221 (K13-14), lot 248 (four pieces, M11-12), and lot 7604 (?).[5] KW 68, another possible lid found in K12, may have been originally located even higher up on the slope. Other than these few pieces, there were no direct indications that the pithoi were stored aft of ingot row 1. In fact, there were very few pieces of pithoi found along the main portion of the wreck (quadrants 10 to 23). Aside from the first base discussed above, there were only a few other pithos assemblages within the confines of the original ship: lid KW 222 and lot 1900 in square M15, pithos base lot 8484 in square O21, and pithos rim fragments lot 8589 in square N20. To support the argument that the pithoi were stored behind the first row of oxhide

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[4] Pulak, personal communication.
[5] This sherd is incorrectly labeled since the excavation records indicate that lot 7604 was not a pithos sherd. Therefore the artifact number and provenance of this piece is unknown, but it is likely that it was found close to the other fragments.

ingots, indirect evidence must be examined, namely the Cypriot pottery contained in some of these jars.[6]

Cypriot Fine Ware

At least 131 pristine vessels of export fine ware pottery from Cyprus were found among the wreckage of the ship, scattered throughout the entire area of artifact spillage. Of this assemblage, five types of pottery were represented within pithos KW 251: White Shaved juglets, White Slip II milk bowls, Base Ring II bowls, oil lamps, and Bucchero jugs (fig. 5.2).[7] A tentative count yields 35 White shaved juglets, 32 White Slip II milk bowls, 22 Base Ring II bowls, 39 oil lamps, and 3 Bucchero jugs. A more definitive tally will be available once all pottery fragments are cleaned and mended. Cypriot pottery types not directly found inside KW 251 but whose distribution is still closely connected to that of pithos fragments and the five types discussed above include 10 wall brackets, 7 trefoil-mouth pitchers, 2 small lug-handled bowls, and several other single unit vessels.

If fine ware vessels were found neatly stacked inside pithos KW 251, it can be assumed that the rest of the Cypriot fine ware assemblage was originally stored inside other pithoi. The distribution of these vessels on the site closely mirrors that of the pithoi and their fragments. It is estimated that at least three of the pithoi contained Cypriot pottery as their primary contents.[8] KW 251, located at the junction of the rock

[6] Not all the pithoi carried Cypriot pottery; some contained liquids and pomegranates (Pulak 2001, 40).
[7] Pulak 2001, 41.
[8] Pulak 1998, 204.

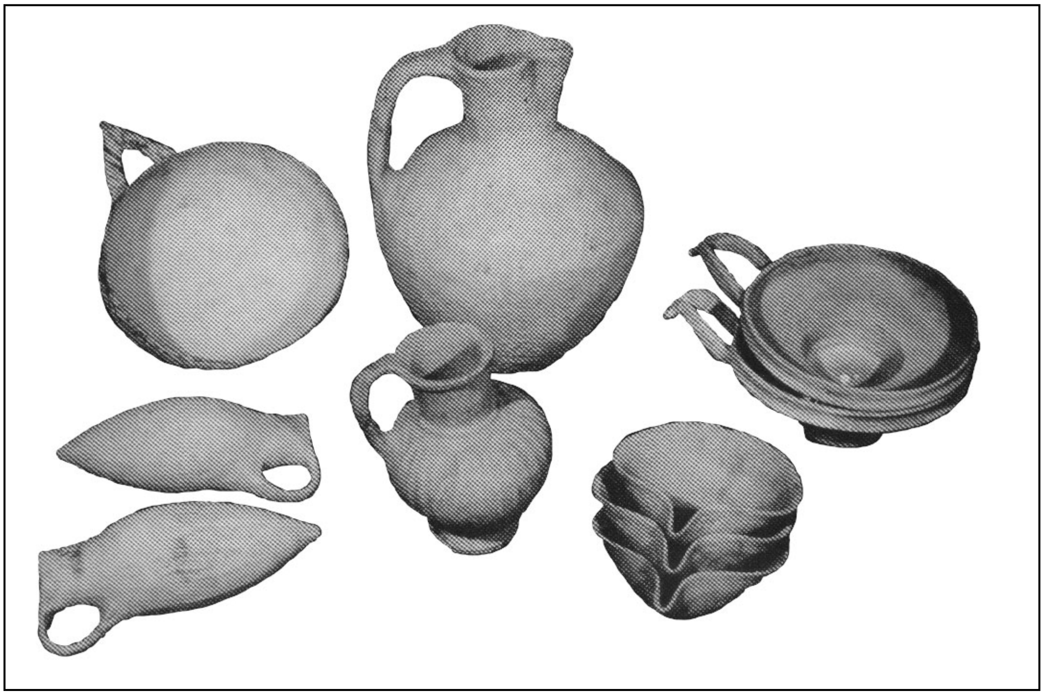

Fig. 5.2 Types of pottery found inside pithos KW 251. Shown above: White Shaved juglets (left front), White Slip II milk bowls (left back), Base Ring II bowls (right back), oil lamps (right front), and Bucchero jugs (center front). Trefoil mouth pitchers (center back) were also closely associated with the pithoi. (After Pulak, 2001, 41, fig. 3).

outcrop and ingot row 2, contained 3 White Shaved juglets, 5 White Slip II milk bowls, 3 Base Ring II bowls, 4 oil lamps, and 3 Bucchero jugs.[9] The other two pottery-carrying pithoi must be deduced because they were completely fragmentary, pithos #9 and one of the two deepest located pithoi, #8 or KW 4596. Fortunately they were located in different areas of the site; otherwise it would have been extremely difficult to discern whether these Cypriot vessels were contained in one or two pithoi.

The best evidence for the storage of Cypriot pottery in pithos #9 was found in square H17, where pithos sherds lot 5033 were lodged in the middle of an assemblage comprising milk bowl KW 2008, Base Ring II bowls KW 2024 and 2047, and wall bracket KW 2049, among many other fragments (fig. 5.3). A casual glance at the site plan suggests that this group of vessels, and another just down slope of it consisting of wall bracket KW 1539, White Shaved juglets KW 1502 and 1593, oil lamp KW 1597 (fig. 5.4) and Base Ring II bowl KW 1949, spilled out of pithos KW 253 in square I16. This conclusion would have been valid except for the lack of evidence of Cypriot pottery within that pithos (and all the other pithoi in the southern half of the wreck), and a large dark stain in the sand originating at the mouth of pithos KW 253 and spreading down to square H17. This stain is believed to have been produced by organic contents of the pithos, possibly a liquid, as it spilled out and soaked into the sand. Also, the trail of Cypriot vessels along the southern slope of the seabed was consistent with the distribution of the fragments of pithos #9, both upslope and downslope of pithos KW

[9] Although not represented inside the pithos, a trefoil-mouth pitcher was found just outside the mouth of KW 251 (Pulak 2001, 41).

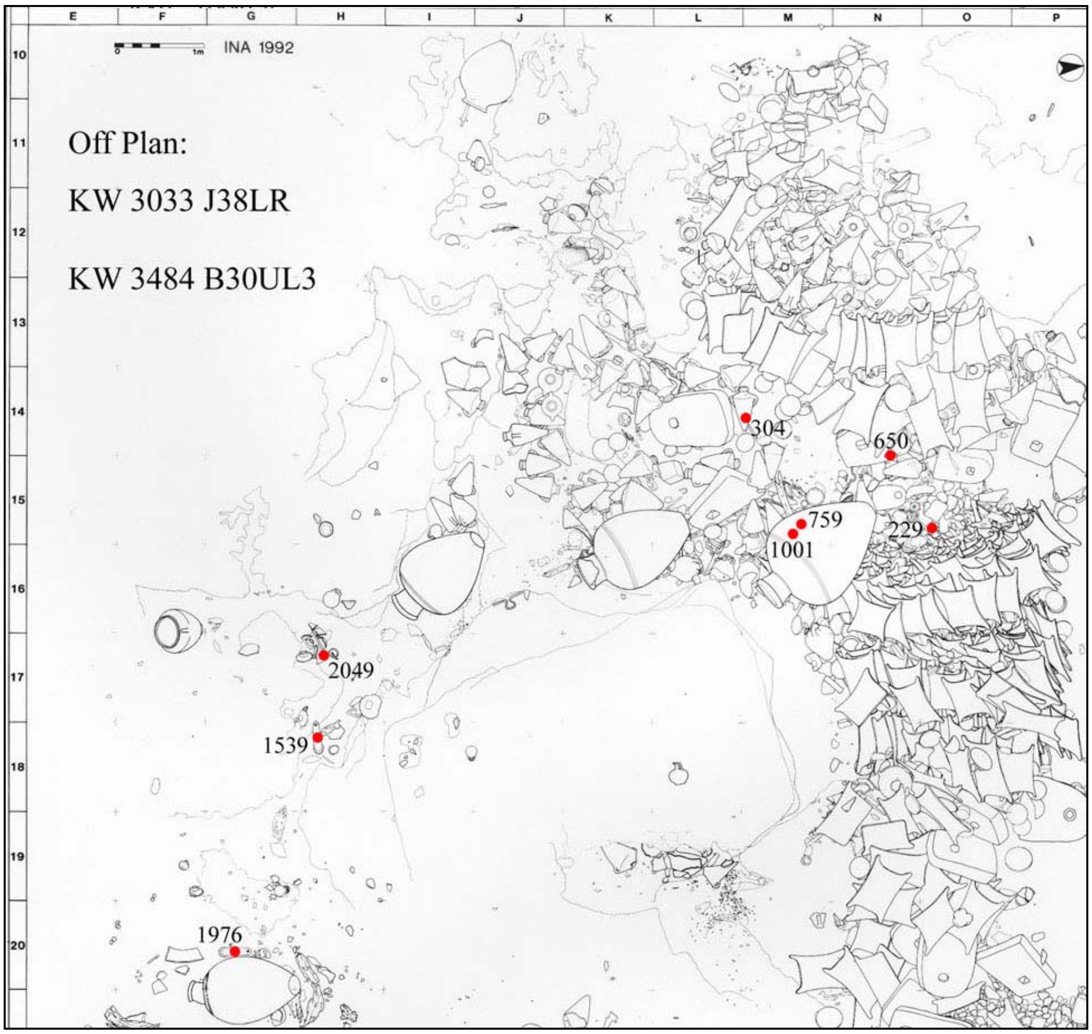

Fig. 5.3 Distribution of wall brackets.
(After Pulak 1998, 192, fig. 4).

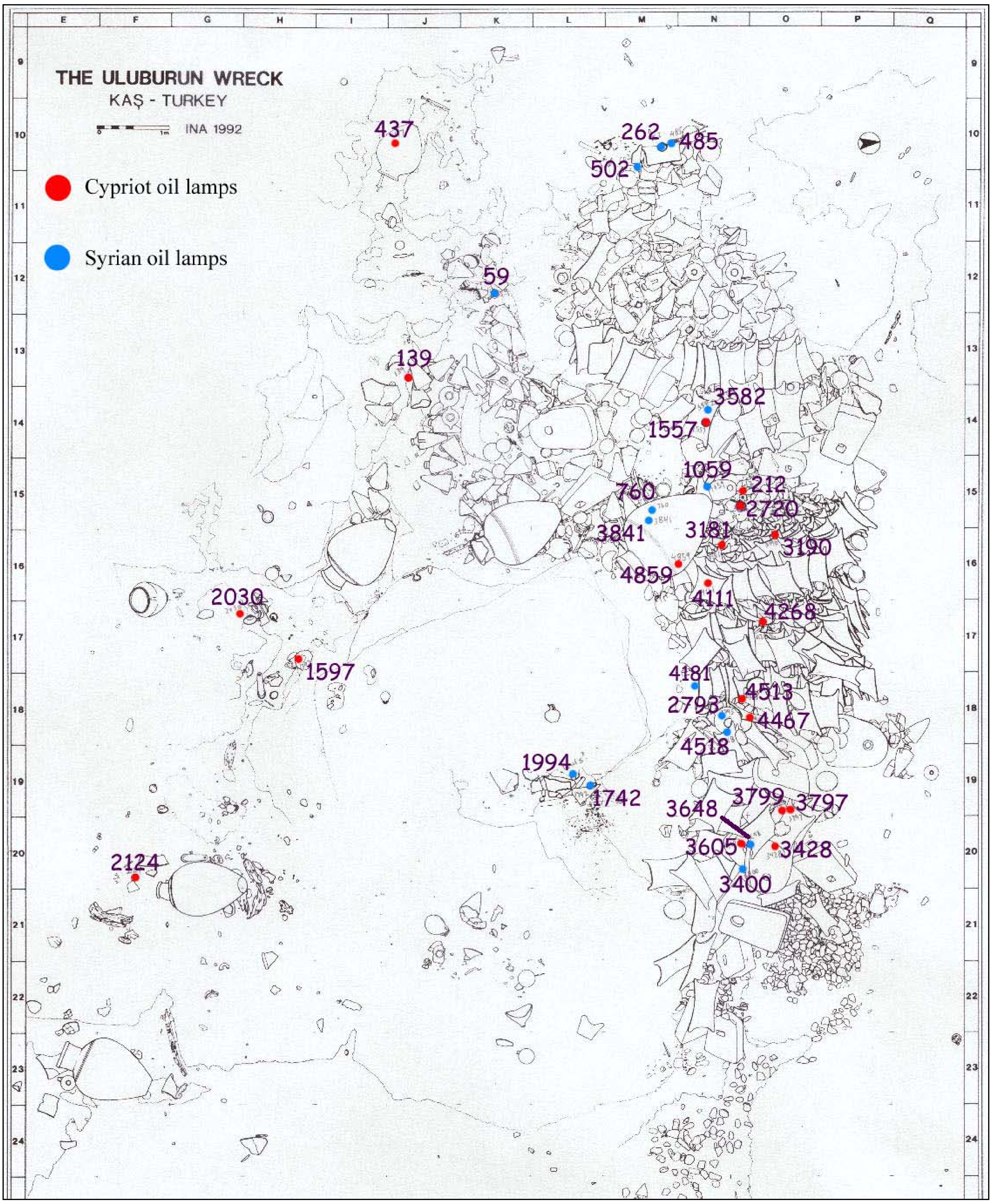

Fig. 5.4 Distribution of Cypriot and Syrian oil lamps.
(After Pulak 1998, 192, fig. 4).

253. Therefore, based on the available evidence, it is fairly certain that pithos #9 also carried Cypriot pottery.

Two fragmentary pithoi, KW 4596 and pithos #8, located at the deepest end of the excavation site (squares I32 and K34-J36, respectively) were also closely associated with Cypriot fine ware vessels. A trail of intact and incomplete White Shaved juglets, milk bowls, trefoil-mouth pitchers, and oil lamps along the main axis of the wreck gives an indication of these pithoi's path of travel. Noticeably absent were Base Ring II bowls and wall brackets. Unfortunately, these two jars landed within a short distance of each other and the Cypriot vessels were scattered in a manner that makes it difficult to determine which of the two pithoi contained the ceramics. First, supporting the case for KW 4596 are two White Shaved juglets, KW 3301 (K30LL4) and lot 7597 (K31UR1) found just to the north of lot 9468, a large base fragment of pithos KW 4596 (fig. 5.5). Two milk bowl fragments, lot 7637 and lot 8232, possibly from the same vessel (KW 5882), were also found in close proximity to KW 4596. No Cypriot vessels were found as close to the main portions of pithos #8 as these juglets and milk bowl fragments were to KW 4596. Pithos #8 is located near KW 3659 (J33UR), a White Shaved juglet and KW 4007 (H35LR), a trefoil-mouth pitcher but these were both approximately 1 m away; the closest Cypriot pottery fragment was lot 9110 (I36LL), a milk bowl fragment. Even though these three objects were spatially closer to pithos #8, it is entirely possible that they continued to slide or roll downslope after spilling out from pithos KW 4596.

Despite the proximity of pithos KW 4596 to these Cypriot wares, it can be argued that it was pithos #8 that originally contained them. The first indication for this

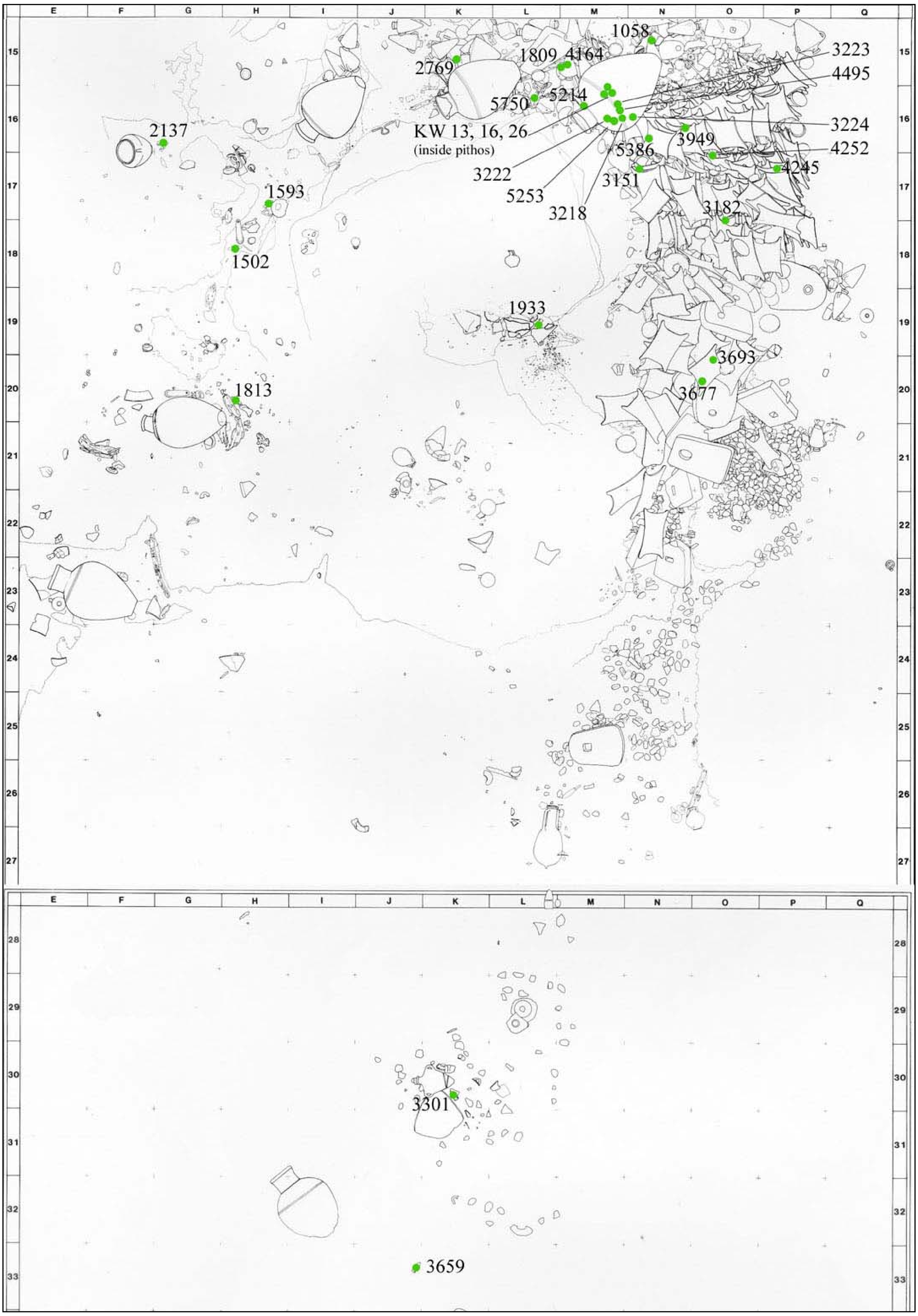

Fig. 5.5 Distribution of White Shaved juglets.
(After Pulak 1998, 192, fig. 4).

is the fragmentary condition of pithos #8 versus the relative intactness of pithos KW 4596.[10] The state of the latter suggests that this pithos did not break up until it had nearly reached its final resting place; no joining sherds were identified upslope of square K30. In this case, how can the trail of Cypriot pottery leading up to this pithos be explained? It is possible, although unlikely, that every single Cypriot vessel found along this trail, except for two White Shaved juglets could have tumbled out of the mouth of the pithos before it finally broke apart where it was discovered. However, it seems more plausible to expect the majority of the contents of the pithos to spill out after it broke open. Therefore, if the Cypriot wares had been stored in pithos KW 4596, then more of them should have been found around that pithos, or even down slope of it. The following scenario with pithos #8 as the carrier of Cypriot pottery fits the evidence much better: as the pithos hurtled downslope from the stern, it left a trail of Cypriot pottery behind it because it had already been cracked and damaged during the initial turbulence of the wrecking. By the time it reached its resting place, the body of the pithos was shattered into many fragments and the majority of its contents had already been released. This scenario is further supported by two small body sherds, lot 7635 and lot 7669, belonging to pithos #8 that were found adjacent to milk bowl fragment lot 7637 and White Shaved juglet KW 3301, which has also been attributed to pithos KW 4596.

The main weakness of this hypothesis is the complete lack of sherds from pithos #8 found in association with the trail of Cypriot vessels in the upper and middle regions of the wreck. A portion of the base, lot 8484 found in O21UL2, was very close to a

[10] KW 4596 was "intact" only in the sense that the fragments consisted of large continuous sections of the pithos as opposed to small disarticulated pieces.

group of Cypriot oil lamps and White Shaved juglets in square O20 but upslope of that, no sherds belonging to pithos #8 were found. It is perhaps not a coincidence that both pithoi #8 and #9 were very fragmentary and lacked large portions of their bodies if both carried Cypriot wares.[11] Perhaps these two pithoi were so thoroughly smashed that their poorly fired fragments simply did not survive, or, more likely, they were so violently expelled from the stern area of the ship that their fragments fell in areas far from the main concentration of wreckage and were not found. Nevertheless, despite the lack of conclusive evidence, it is fairly certain that both pithos #8 and #9, along with pithos KW 251, carried Cypriot pottery as their primary contents.

Accepting this close relationship between Cypriot pottery and certain pithoi, the search for evidence of these fine wares aft of oxhide ingot row 1 can commence. For the sake of discussion, the archaeological evidence will be superficially divided into two groups, those within the original confines of the ship and those that have spilled outside it. In the first category, there are no less than 26 fragments of various wares,[12] as well as one nearly intact trefoil-mouth pitcher and a Base Ring II bowl. Although the fragments were diverse, only three specific vessel types were represented: Base Ring II bowls, White Slip II milk bowls, and trefoil-mouth pitchers. The presence of this quantity of Cypriot pottery behind ingot row 1 suggests that these were not miscellaneous pieces of

[11] Pulak (personal communication) has suggested that the pithoi carrying Cypriot pottery were more prone to damage because of possible air pockets trapped within the pithoi, causing the jars to break more easily when they hit a hard object due to the compressible air pockets not providing sufficient dampering; as opposed to the pithoi possibly carrying liquid that would have provided more damping for the body wall of the jars. Pithos KW 251 is the exception probably because it traveled a significantly shorter distance than either pithos #8 or #9.

[12] Thirteen Base Ring II bowl fragments, eight trefoil-mouth pitcher fragments, and six milk bowl fragments (lot 1018 consists of two fragments).

pottery that were somehow swept upslope into that area of the wreck, but that this was likely their original location. Therefore, based on the intimate relationship between the Cypriot fine ware and the pithoi, it can be assumed that some, if not all (since they were all probably kept close together), of the pithoi were stored aft of ingot row 1. But what information, if any, can these fragments tell us about the pithoi that contained them and their spatial relationship to some of the other cargos known to have been stored in the stern such as the Canaanite jars, copper bun ingots, glass ingots, and tin ingots?

Base Ring II bowls and their fragments had a limited distribution on the wreck, aside from the many fragments in the stern (fig. 5.6). A trail of these vessels and their sherds was found along the southern end of the wreck, extending from squares K13 to E23 (the same path taken by pithos #9). In the middle area of the wreck, however, there were only three loose bowls (KW 730, 2704, 2705, in square N15) while the lower portions were completely devoid of any intact vessels or scattered fragments. Could this mean that pithos #8 did not contain any Base Ring II bowls, or if it did, that it only carried three bowls all of which were spilled at midships? It is impossible to determine whether the three bowls amidships came from KW 251 or from pithos #8, but I am inclined towards the former since vessel types almost certainly associated with pithos #8 (milk bowls, oil lamps, wall brackets, and trefoil-mouth pitchers) were found along the length of the trail and not a single location as were the Base Ring II bowls. The majority

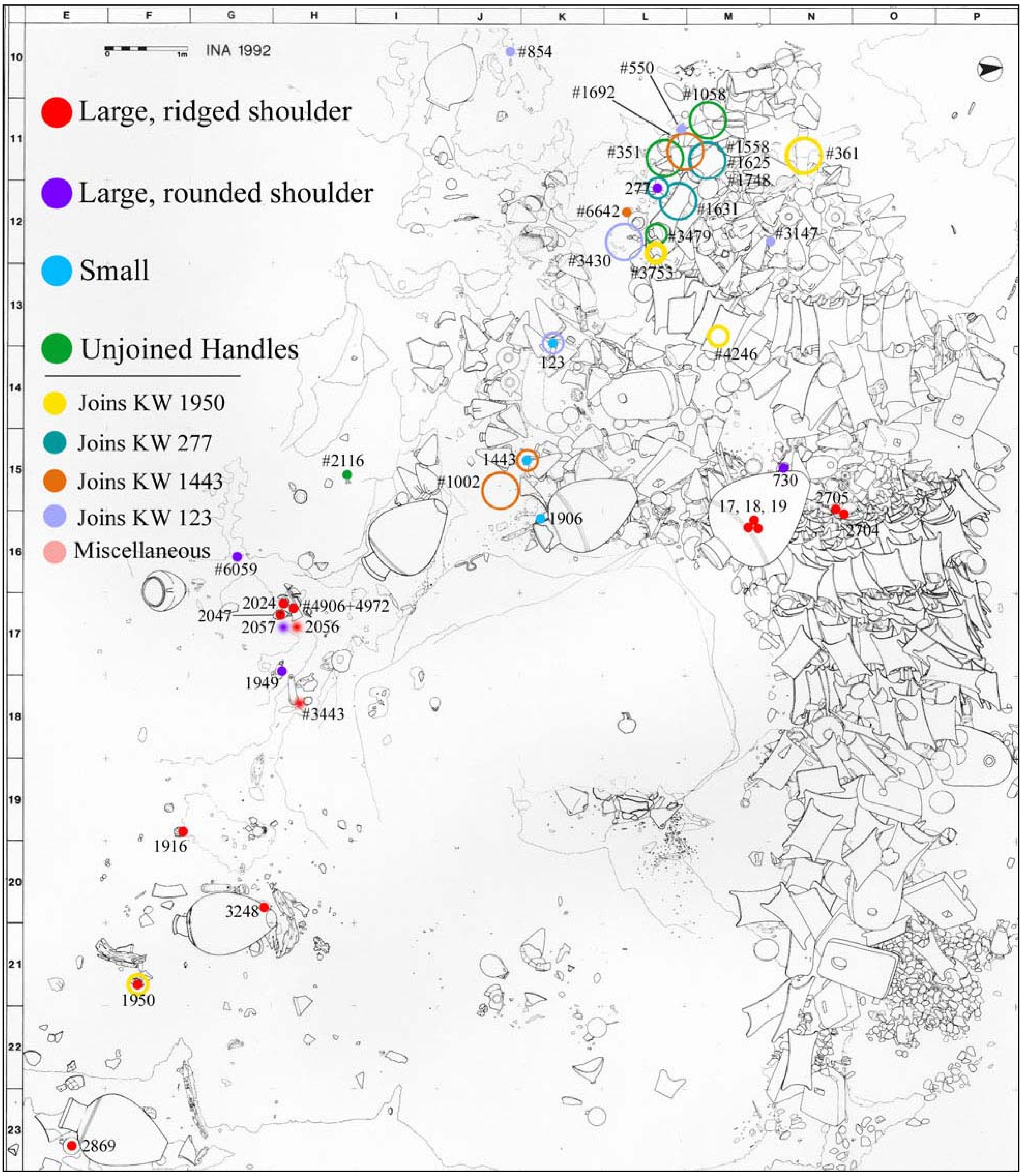

Fig. 5.6 Distribution of Base Ring II bowls according to shape, size, and fragments. (After Pulak 1998, 192, fig. 4).

of these bowls, therefore, were probably stored inside pithos #9,[13] as evinced by the number of bowls and fragments whose distribution closely coincide with that of sherds belonging to pithos #9. If this were the case, then all the Base Ring II bowl fragments from the stern must have originated from pithos #9, which is conceivable since pithos #9 seems to have broken up very early on, before it rolled beyond the confines of the ship.

Unlike the Base Ring II bowls, the White Slip II milk bowls were found on both the main axis of the ship and in the southern spill area (fig. 5.7). Based on their distribution pattern, at least four vessels, KW 124 (J12UR4), 2008 (H17UL2), 2743 (G21UL1), and lot 6752 (K15UR3) were contained in pithos #9.[14] Another bowl, KW 5884, pieced together in the conservation laboratory has a handle from square M12LL (lot 3347), a sherd from square M14LL3 (lot 3762) and another from somewhere in the K to L14-15 area. It is probable that this bowl also came from pithos #9. Only two Base Ring II bowls can be said for certain to have come from pithos #8, KW 5882 (largest fragment in N23) and lot 9110 (I36LL3), since the others were located fairly close to pithos KW 251 to clearly discern which jar they originated from. The number of Base Ring II bowls in pithos #8 could, however, be as high as eight,[15] including the two mentioned already. The uppermost milk bowl fragments (lot 1018) have not yet been joined to a specific milk bowl so further comments regarding their attribution to pithos #8 or #9 will be deferred until restoration has been completed.

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[13] Pithos KW 251 contained three Base Ring II bowls and three additional bowls at midships were either from that pithos or maybe pithos #8, which leaves at least 16 Base Ring II bowls for pithos #9.
[14] Milk bowl KW 3480 was found in square C29LL4, which qualifies it as a candidate for pithos #9, but this bowl showed indications of possible use, in which case it most likely was not stored inside the pithos.
[15] KW 1474, 3199, 4267, 4577, 5882, lot 8986, lot 9110 and lot 10103.

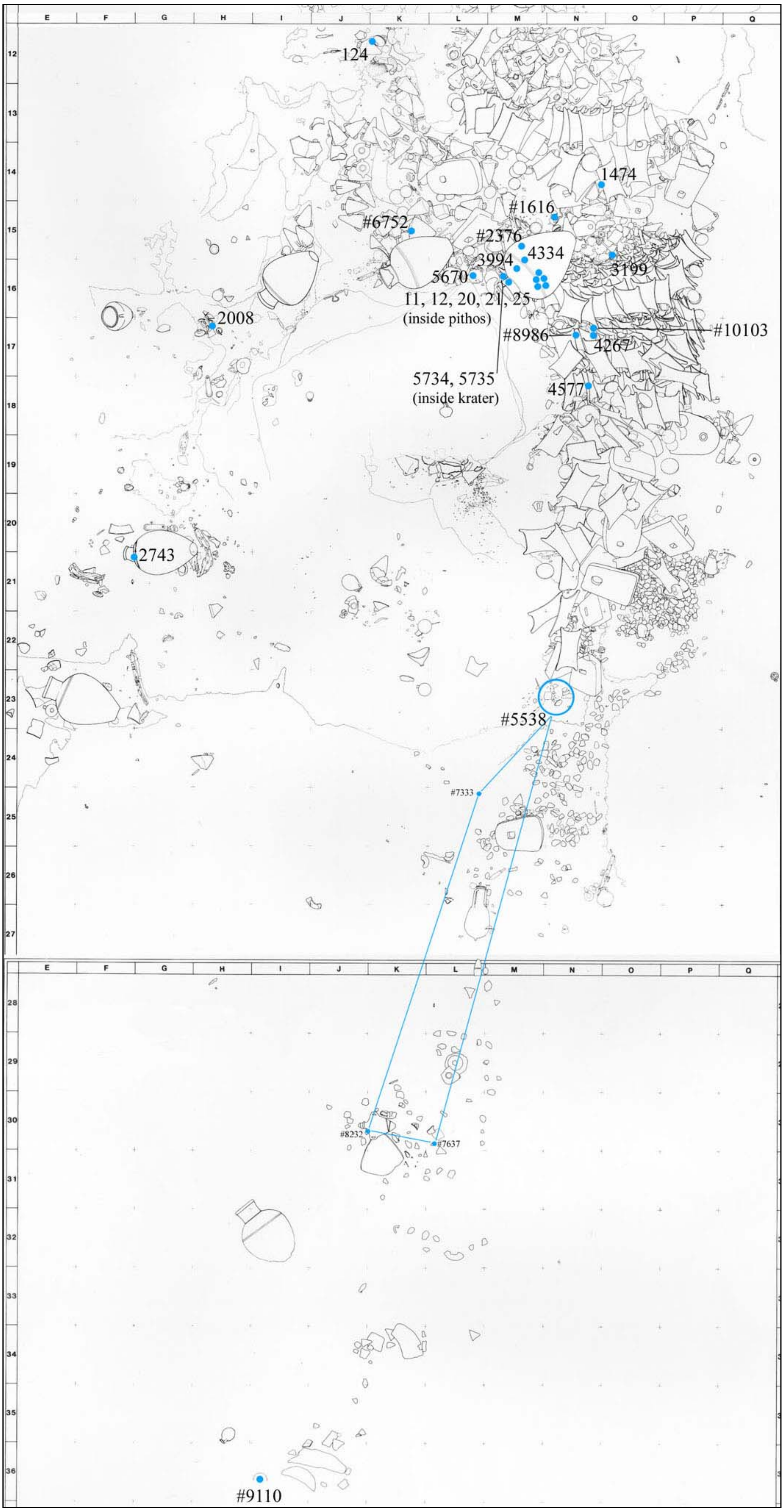

Fig. 5.7 Distribution of White Slip II milk bowls.
(After Pulak 1998, 192, fig. 4).

The distribution of the trefoil-mouth pitchers and their associated sherds suggests they were only stored in pithos KW 251 and pithos #8, and possibly exclusively in the latter (fig. 5.8). The farthest south fragment of a pitcher (lot 8167) was found in square G21. This sherd joined pitcher 1181, but all of the other joining fragments of this pitcher, however, were found in square K16. It is possible, therefore, lot 8167 might have been redeposited there by airlifting during excavation. In any case, the location of this single sherd is probably not an indication that pitcher KW 1181 was stored inside pithos #9. Five nearly intact pitchers were also recovered (from upslope to down slope): KW 230 (N12), KW 812 (N15LR), KW 1181 (K16LR), KW 2897 (O26LR), and KW 4007 (H35LR). Another pitcher (KW 239) was pieced together in the laboratory. Most of its joining sherds were found in the N-O12 area, [16] but one sherd, lot 6319, was recovered from square Q19UR2. While this too is only one sherd and may have been redeposited by airlifting during excavation, the finding of at least three other trefoil-mouth pitchers on this side of the wreck bolsters the supposition that these pitchers came from pithos #8. The evidence of the trefoil-mouth pitchers, therefore, also points to a location aft of ingot row 1 for pithos #8 and, possibly also the other pithoi.

Stowage and Weight Distribution

The location of the pithoi in relation to the other cargo laden in the stern is still somewhat inconclusive. Cypriot pottery fragments were found both among and aft of the Canaanite jar pile, making it difficult to determine which group was located farther

[16] Lots 96, 127, 138, 143, 174, 176, 181, 725, 1861, 2402, 4966, 6319, 8167.

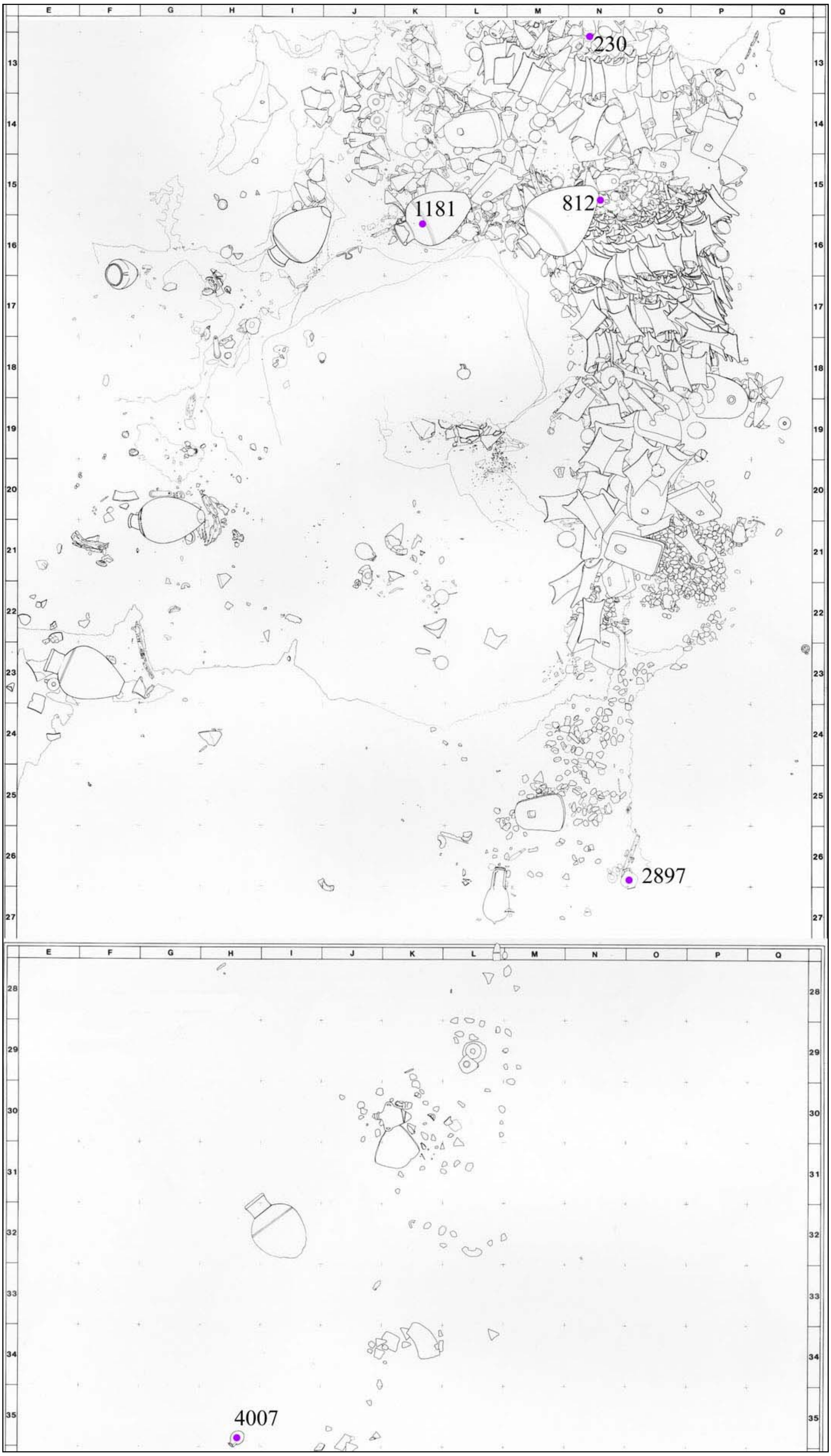

Fig. 5.8 Distribution of the trefoil mouth pitchers.
(After Pulak 1998, 192, fig. 4).

forward. An extrapolated trajectory for a body sherd (lot 246) from pithos #9, possible pithos lid KW 68, and milk bowl KW 124 toward the main axis of the wreck suggests the pithoi were stored aft of the Canaanite jar pile. This does not automatically conclude the inquiry since the Canaanite jars, as discussed in the next chapter, experienced massive displacement and could have cascaded from behind the pithoi to form the mound as found, only after the pithoi had vacated the area. An argument in favor of the pithoi being aft of ingot row 1 and just forward of the Canaanite jar stacks is the narrowing shape of the hull and the assumed existence of a partial deck at the stern. It would be easier to stack the larger pithoi at the wider portion of the hull than to try to squeeze them into the narrower section, especially if the vertical space is reduced by the deck.[17] Since the Canaanite jars are smaller, it is potentially easier to fit them into odd spaces whereas the pithoi are not nearly as accommodating in their placement. In addition, the pithoi made a better barrier for the two-tiered stacking of the Canaanite jars than would have the first row of oxhide ingots, which would have only provided support for only half of the first layer of Canaanite jars or more if cargo was placed on top of the ingot row. From the little evidence that we have and what seems feasible, it is tentatively proposed that the pithoi were stowed in front of the Canaanite jar stack.

Detailed studies on the volumetric characteristics of the pithoi have yet to be undertaken so a discussion regarding their impact on the trim of the vessel must remain largely hypothetical. Their empty weights, however, have mostly been measured and are as follows: KW 250, 43 kg; KW 251, 120 kg, KW 252, 98.75 kg; KW 253, 103 kg; KW

[17] Pulak, personal communication.

254, 80 kg; KW 255, 120.25 kg, KW 256, 103 kg; and KW 4596, 104.50 kg. Only pithos #8 and #9 have not been weighed since they are mostly incomplete and fragmentary. An alternate method of estimating pithoi capacity was done by modeling the interior space of pithos KW 255 (fig. 5.9) (one of the few pithoi for which a cross-sectional drawing is available) up to the base of the neck in Rhinoceros and then calculating its volume, which yielded a value of 293 liters. Therefore, if filled with liquid, a large pithos would have an estimated weight of 413.3 kg. A similar procedure for a medium-sized pithos and small pithos KW 250 resulted in a volume of 279.5 liters and 110.6 liters, and the corresponding filled weight of 360 kg and 153.6 kg, respectively. If there were six large and three medium-sized pithoi,[18] then they would have a cumulative weight of 3559.8 kg, had they all been filled with a liquid with the density of water. However, this was clearly not the case since three pithoi contained Cypriot pottery. It is not possible at this point to say how many pieces of pottery each pithos actually carried or are even capable of carrying. Neither do we know how these fine wares were packed inside the pithoi that might have contributed to the overall weight through the addition of packing or padding materials. Therefore, a very rough estimate of 136 kg[19] is assigned to KW 251 and 96 kg each for pithoi #8, and #9. The final weight estimate for the nine pithoi (excluding KW 250) is 2754.5 kg. Perhaps one of the stronger arguments for placing the pithoi aft of the first row of oxhide ingots is the potential leverage they have for keeping the ship trim. If these jars had been placed any

[18] Large: KW 251, 252, 253, 255, 256 and KW 4596. KW 254 (medium), pithos #8 (medium?), pithos #9 (medium?).

[19] An estimated weight of the total Cypriot export pottery assemblage is 48.2 kg, based on weighed vessels from each category. Divided by 3 pithoi, this yields 16.1 kg.

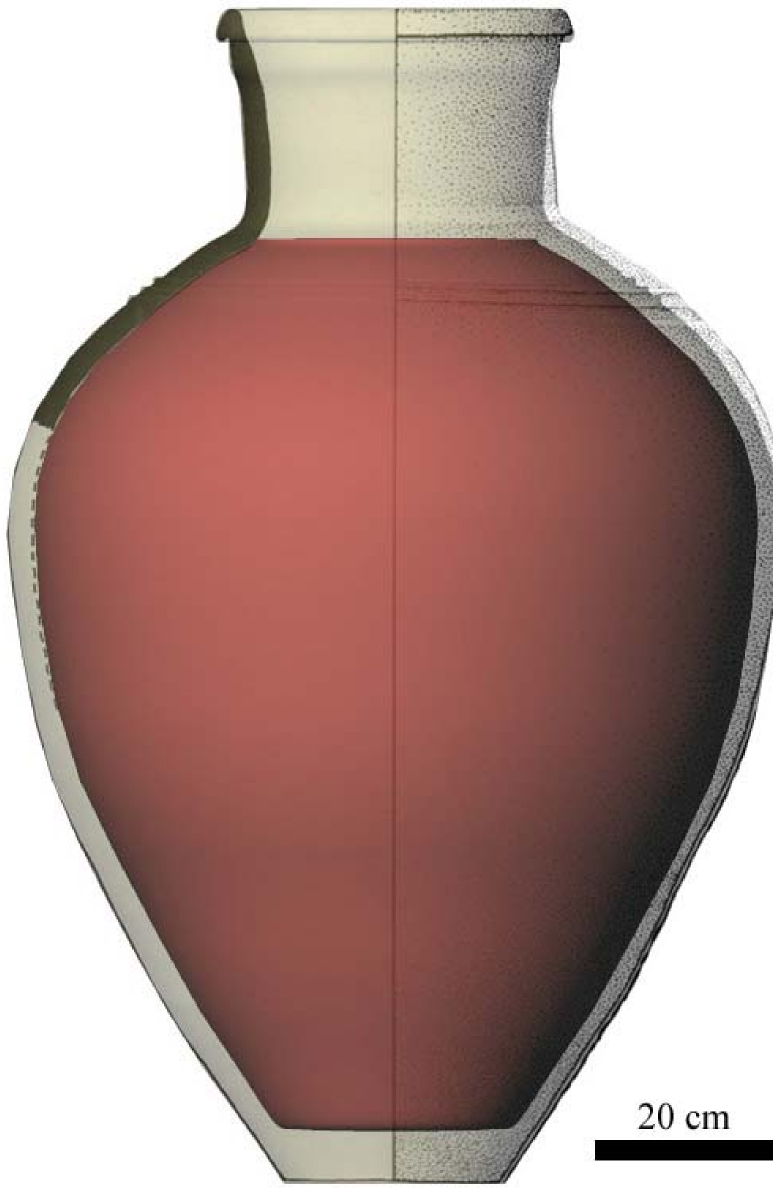

Fig. 5.9 Drawing and 3D rendition of pithos KW 255 with inner volume in red.

nearer to the longitudinal center of gravity of the ship, then it would have been impossible for the ship to set sail.

CHAPTER VI

CANAANITE POTTERY

Canaanite Jars

Approximately 150 Canaanite jars in three different sizes were carried aboard the Uluburun ship. An exact count is not currently available as many fragmentary pieces remain to be mended. As of the summer of 2002, there are 91 small-sized (6.7 l), 18 medium-sized (12 l), and 14 large-sized (26.7 l) Canaanite jars, as well as 8 whose size is currently unknown (fig. 6.1). At least 19 additional jars can be accounted for due to the preservation of their toes, and this number may be as high as 27.[1] Most of these jars contained terebinth resin,[2] at least one carried glass beads,[3] another orpiment,[4] and several others were filled with olives.[5]

Location on the wreck

Forty-nine Canaanite jars behind the first row of copper oxhide ingots (all of the small size except for two medium [KW 152, 591], one large [lot 1723], and four unknowns [ADY,[6] lots 165, 166, and 1179]), made up the main pile of the Canaanite jars in this area (fig. 6.2). It is this group of Canaanite jars that gives the clearest indication that all of these jars were originally stowed in the stern. Fifty-eight additional Canaanite

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[1] Based on the 2002 conservation records in the Bodrum Museum of Underwater Archaeology.
[2] Pulak 1988, 11; see also Pulak 1997, 240-1; Pulak 1998, 201-2; Pulak 2001, 33-6.
[3] Bass 1986, 278.
[4] Bass 1986, 278.
[5] Pulak 1997, 240.
[6] This Canaanite jar's KW number is missing and unknown at this point so its alphabetic designation is used instead.

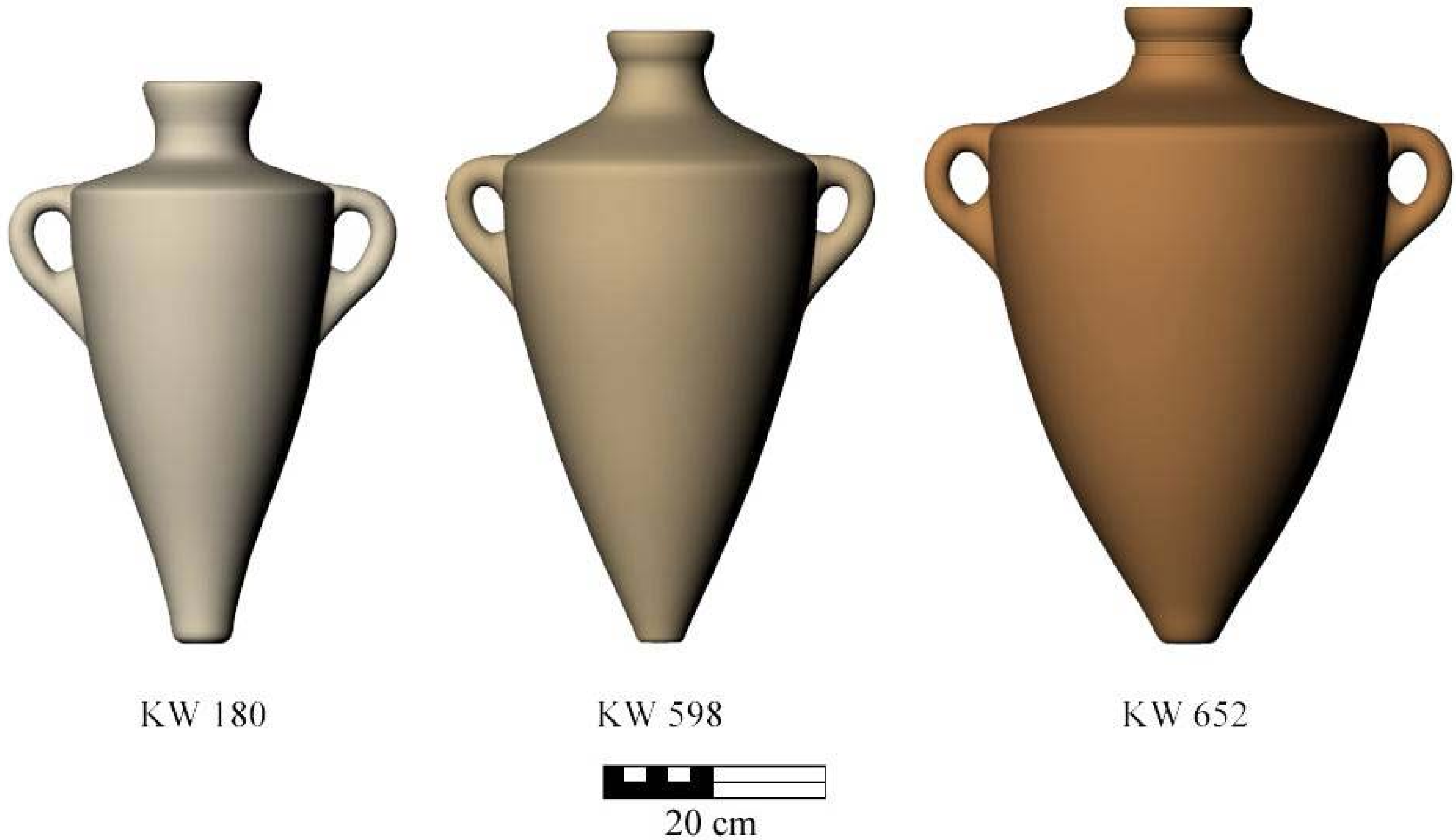

Fig. 6.1 Examples of the three different sizes of Canaanite jars.

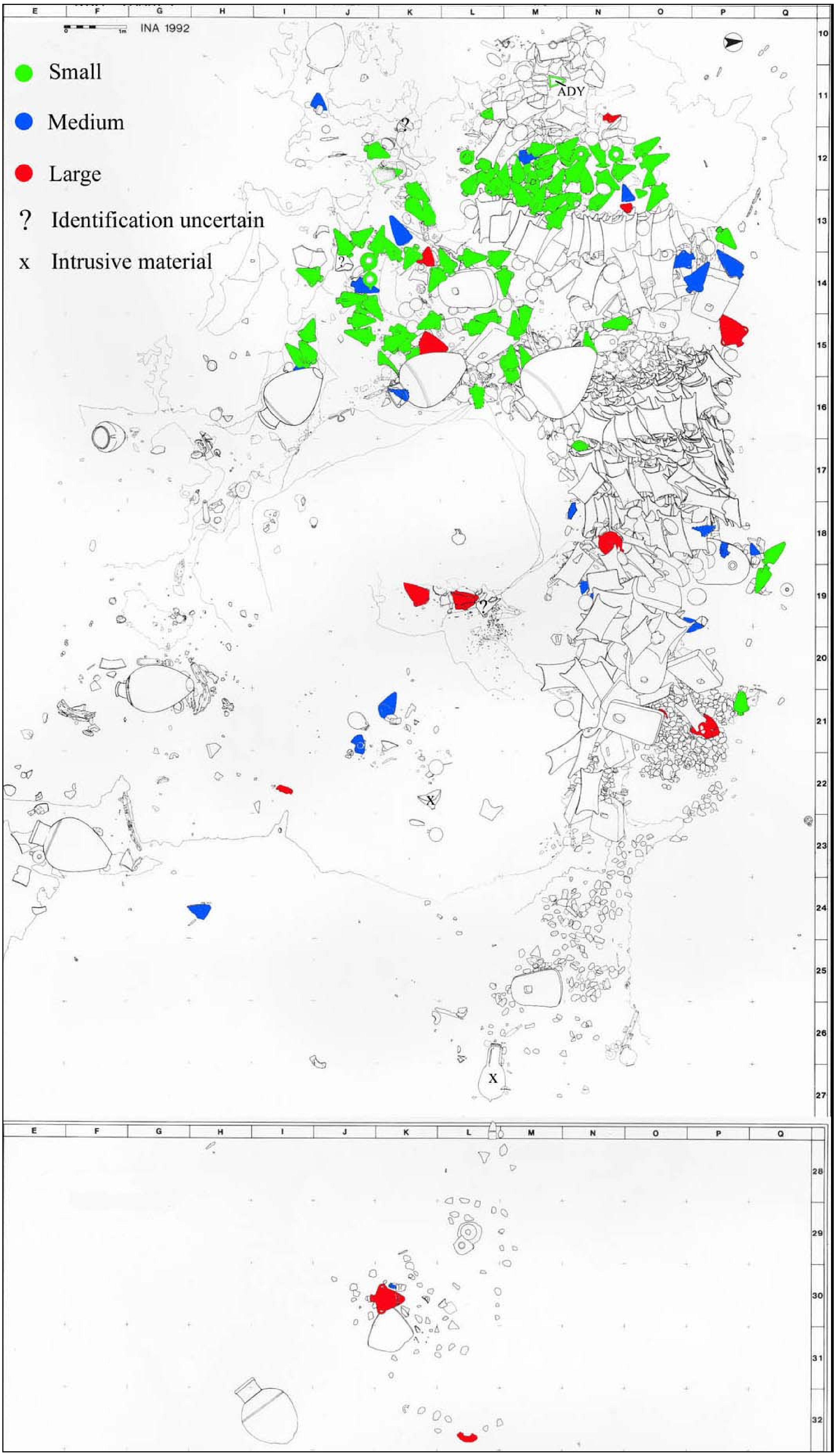

Fig. 6.2 Location of the Canaanite jars on the wreck site.
(After Pulak 1998, 192, fig. 4).

jars had spilled to the starboard of ingot row 1—most were confined between grid squares J13 to M15, three were close to pithos KW 251, five remained on the port midships, and a few others were found in the upper regions of the southern portion of the wreck in squares J11 to K12.[7] It is the projection of this latter group's trajectory that suggests the Canaanite jars were located farther aft than the main pile indicates.

The number of intact Canaanite jars dropped off significantly forward of oxhide ingot row 2. Figure 6.2 shows the relatively complete Canaanite jars found in the deeper portions of the wreck. A group of six Canaanite jars by stone anchor KW 4002 (square P18) seems to be a continuation of the spill of Canaanite jars to the port side of ingot row 1, and this trail extended down to grid P21 with a large and a small-sized Canaanite jar resting on the ballast mound. The deepest found intact Canaanite jar along the main axis of the wreck is KW 3298, located next to the body sherd (lot 9468) of a pithos in square K30. A shoulder fragment (lot 8234) of another large-sized Canaanite jar was found even deeper at square L32, while its adjoining pieces were strewn along the length of the wreck.[8] The southern portion of the wreck was devoid of any intact Canaanite jar but sherds recovered there showed that Canaanite jars also tumbled down this way. Off the site plan are Canaanite jar toe lot 6737 and a few other sherds that were found near pithos KW 256.[9] These pieces have not yet been joined to any Canaanite jar, so estimates of the size of the jar they represent has yet to be determined.

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[7] At least one intrusive Canaanite jar was found in the upper regions of the wreck (K9), which caused some initial confusion regarding the stowage of the Canaanite jars on the ship.

[8] Located joining sherds include: lot 8237 (I22), lot 4204 (O21), and lot 6440 (O18).

[9] Lot 8455 Canaanite jar sherd (B29UR2), lot 8503 Canaanite jar shoulder fragment (C28UL4), lot 8504 Canaanite jar shoulder fragment (A27LR1), lot 8505 Canaanite jar sherd (C29LR3), lot 8655 Canaanite jar sherd (B28UL1)

<u>Stowage and stacking</u>

After the positions of the copper oxhide ingots and stone anchors, the location of the Canaanite jars on the ship is the most certain among all the artifact groups recovered. The tight clustering of the Canaanite jars aft of ingot row 1 is a hint that they did not travel far from their original location, especially when compared to the jars that had spilled over the ingots of row 1. There are no other significant concentrations of Canaanite jar to suggest that they were kept at a secondary location. It has been argued that the pointed toe of a Canaanite jar was designed to facilitate stowage on a curving hull.[10] That being the case, the Canaanite jars would have had to have been stored together in groups for support since not even two or three jars would be able to stand on their own unless they were leaning against something else or tied down securely with ropes. In the end, there is no contradicting evidence or compelling reason to indicate that the Canaanite jars were not all stowed together in the stern.

The jumbled condition of the Canaanite jar mound gave little hint to their original configuration. Trial and error with the 1:10 scale model, however, left us with the conclusion that the Canaanite jars must have been stacked in at least two layers. Initial trials with single-layer stacking left no room for any other cargo in the stern because the 150 Canaanite jars simply occupied nearly all the free space (fig. 6.3). As discussed in previous chapters, the Canaanite jars had to share this space with pithoi, copper bun ingots, glass ingots, and tin ingots, and the single-layer stacking did not allow for this. Therefore, a two-layered pattern with the second level of Canaanite jars

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[10] Pulak, personal communication.

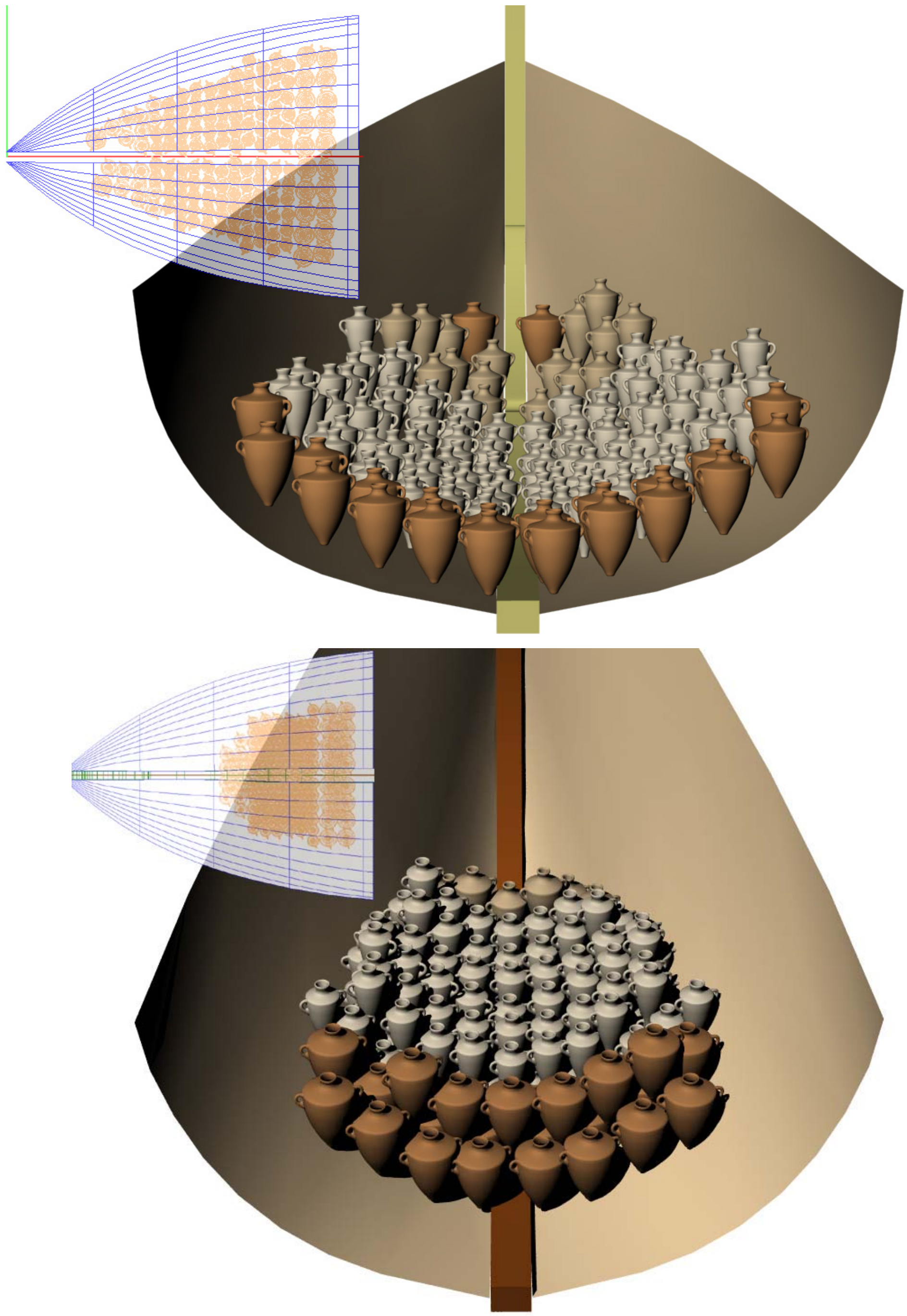

Fig. 6.3 Single (top) and double-layer (bottom) arrangement of Canaanite jars.

resting in the space between four adjoining Canaanite jars below them was attempted, and this opened up significantly more space for the other cargo. Unfortunately, there is no archaeological evidence for multi-layered Canaanite jar stacks in the Bronze Age;[11] and among the most obvious multi-layered stacking are seen among much later ships.[12] Why, then, not simply extend the stern of the vessel to accommodate all of the Canaanite jars in a single layer? To increase the length of the ship by the minimum length needed (approximately 1.5 m) to fit in all the jars would increase the displacement of the vessel to nearly 45 tons with a full-load draft of 1.3 m. This vastly exceeds the archaeological evidence for the amount of cargo carried on the ship, as discussed in chapter II. Therefore, the two-layer stacking solution is the most logical explanation.

What can the artifact distribution reveal about how the Canaanite jars were stowed? The specifics of the Canaanite jar's stacking arrangement are just as, if not more, enigmatic than the general layout. The majority of the intact Canaanite jars in the main pile and overspill area consisted of the small-sized jars. Since this was the most numerous group and would have occupied the greatest amount of space among the Canaanite jars, it is likely that they were stacked in two layers. Actual examples of this on the wreck site, however, were non-existent, but perhaps many of the jars spilled over in the southern part of the wreck originated from the second layer. The medium and large-sized Canaanite jars are much fewer in number and also more widely spread throughout the wreck site. Their distribution does not lend itself to a clear-cut

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[11] Excavations at Ras Shamra yielded an assemblage of 80 Canaanite jars, the only other Late Bronze Age assemblage close in number to those found on the Uluburun shipwreck, and they give no direct indication of multi-layered stacking (Schaeffer 1932, 3, pl. III, 3).

[12] Well-documented examples of ships carrying multi-layered amphora stacks include the Kyrenia shipwreck (Swiny and Katzev 1973, 340) and the Madrague de Giens ship (Tchernia, et al. 1978, 21-7).

conclusion, but it is the author's conjecture that the large-sized Canaanite jars were probably stored directly behind the pithoi, forward of the main Canaanite jar stack. Along the main axis, the trail of the largest jars seems to parallel the trajectory of the pithoi. Fragments of a possible large Canaanite jar were found in the same area as pithos KW 256 in the southern region of the wreck (square C29). The medium-sized jars also seem to follow a similar distribution pattern as the large jars (see fig. 6.2), which might suggest they were placed as a second layer on top of the large-sized jars. In addition, some of the medium-sized jars might have been placed on the sides of the main Canaanite jar stack, presumably to hem in the smaller jars, suggested by the peripheral locations of these jars in the midships and stern area of the wreck site. Unfortunately, the archaeological evidence cannot give a more conclusive answer to the stacking question but based on the information available, a hypothetical arrangement is proposed in figure 6.4. Further studies after all the Canaanite jars have been mended and the joining fragments plotted on a distribution map will most likely yield more information regarding the jars' stowage and stacking.

Pilgrim Flasks

The current count of the pilgrim flasks carried on the ship is 51, excluding the single example made from tin (KW 1085). Most of the sherds have been joined, or attributed to certain vessels, but it is possible that this number can increase if more fragments are found and more vessels are restored. Nevertheless, this should not greatly affect the distribution patterns of this vessel type. These flasks all had the same general

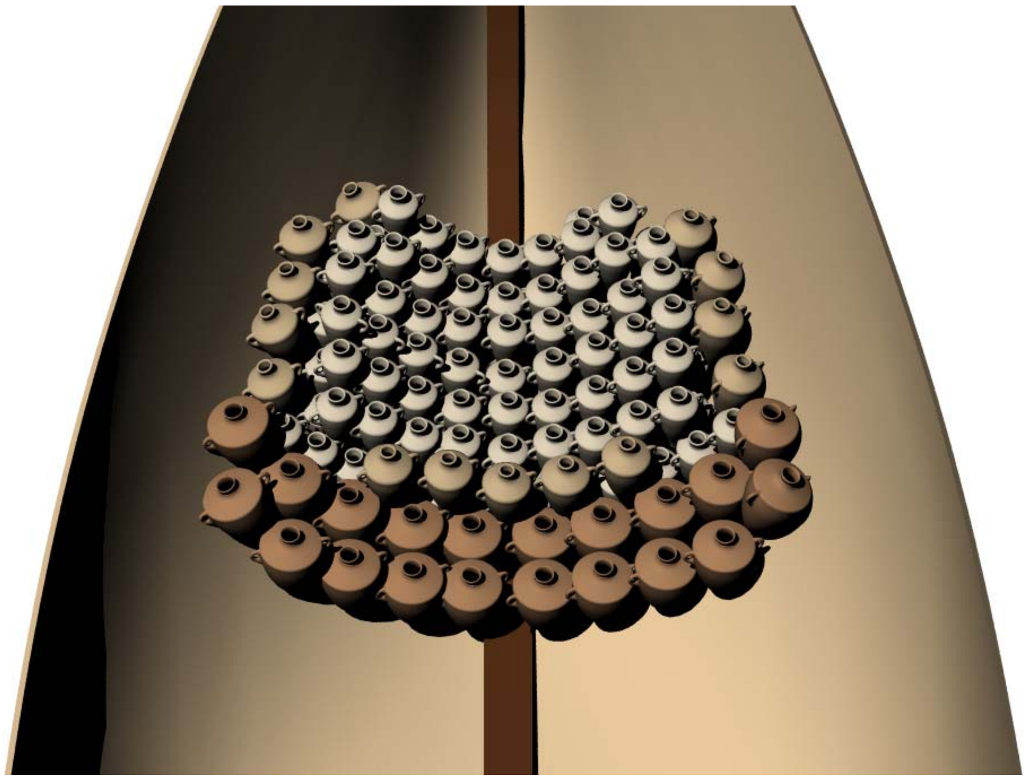

Fig. 6.4 Proposed arrangement of Canaanite jars.

appearance but came in a variety of sizes, ranging from very small (KW 604: ht. 0.153 m, diam. 0.123) to larger-sized (KW 114: ht. 0.336 m) (fig. 6.5). The sieved contents of intact jars consisted mostly of fig seeds; although it is uncertain at this time whether they represent the original contents of the flask, contamination from other sources on the wreck, or possibly came from a fig stopper that might have been placed over the flask's mouth.[13] Detailed capacity measurements have yet to be conducted on these vessels, but volumes were taken of representative vessels in the assemblage. Because of this, and the unknown nature of the flask's contents, weight estimations are tenuous.

Location on the wreck and ship

Over 50 percent of the 39 relatively intact pilgrim flasks were recovered from the midships region, between squares K15 to O15 (fig. 6.6). They clustered in groups of two to six vessels and this concentration amidships suggests these flasks were kept together, though not necessarily in a container. The uppermost pilgrim flask on the seabed is an anomaly: KW 438, a small-sized flask, was found inside pithos KW 250, along with a Cypriot oil lamp (KW 437). This is the only case where a pilgrim flask was found in such direct connection with a pithos. However, closely mirroring the trail of scattered pithos sherds and Cypriot fine wares were other pilgrim flasks along the length of the southern portion of the wreck. Notable examples include: KW 58 and 114 were lying very close to possible pithos lid KW 68 in square K12; KW 434 neighboring lot 556 from pithos #9 and nearly adjacent to a non-joining pithos sherd (lot 787) in square

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[13] Bass 1986, 285; see also Pulak 1988, 13.

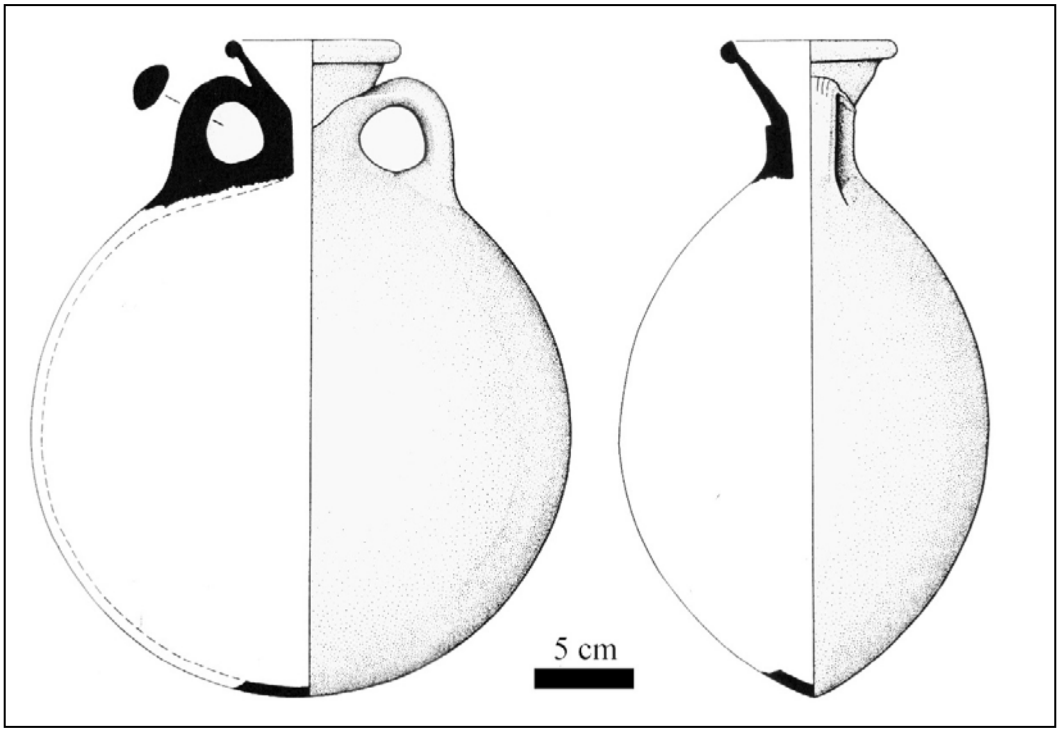

Fig. 6.5 Example of a pilgrim flask KW 114. (After Bass 1986, 286, fig. 21).

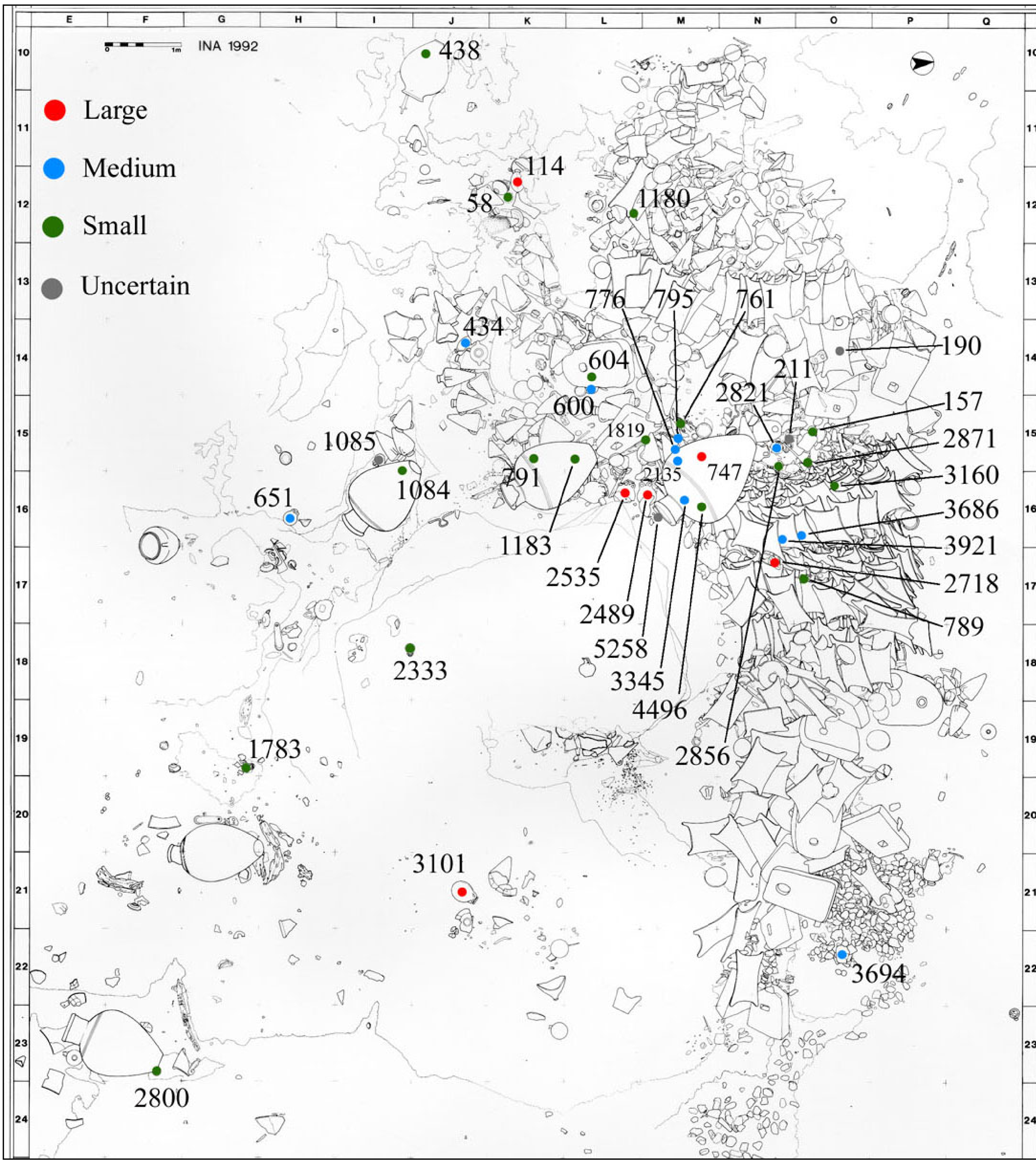

Fig. 6.6 Distribution of intact pilgrim flask according to size.
(After Pulak 1998, 192, fig. 4).

J14; KW 1084 and nearby sherd lot 2579 in square I15; KW 651, which was closer to the pithos sherds lot 5033 and Cypriot fine wares in square H17 than to another group consisting of a Base Ring II bowl, wall bracket and White Shaved juglet in square H18; and, finally, KW 1783, was lying directly on top of sherd lot 7145 from pithos #9.

A comparison of the distribution charts between these intact pilgrim flasks and Cypriot oil lamps, Base Ring II bowls, trefoil mouth pitchers, wall brackets and milk bowls, shows a common area where at least one sample of each vessel type were represented in a small pocket between squares N-O15. Also, these different vessel types were found in close association with each other in the vicinity of pithos KW 251. This region of the wreck, however, was a catchment basin for a great variety of artifacts that had slid from the stern area of the ship and retained there by the second row of oxhide ingots. Greater support for the inclusion of pilgrim flasks among the contents of pithoi would be available had some flasks been found at the deep end of the site, next to pithos #8 for example,[14] since such small items would not have made it down there under their own inertia.[15] An experiment that would be helpful in determining whether or not this was a possibility would be to load pithos #8, #9, and KW 251 with all of the Cypriot fine ware, wall brackets, trefoil mouth pitchers and pilgrim flasks to see if they would be able to accommodate these vessels in a safe, transportable manner.

If the pilgrim flasks had been carried inside the pithoi, then their location on the ship would have been the same as the pithoi, as discussed in chapter V. Since this is

[14] While it casts some doubt on the matter, the absence of pilgrim flasks in the deeper end does not automatically exclude them as a pithos cargo, since no Base Ring II bowls were found there either.
[15] Pulak, personal communication.

uncertain, other stowage options must be explored as well. The flasks on the southern slope of the wreck, even if they were not inside pithos #9, were probably from the same general location as the pithoi since they followed a similar path of travel down the slope. In this given scenario, it is the flasks at midships whose origins are most uncertain, although this might change once all broken sherds are mended and trajectories can be traced. Possible stowage locations for these midship pilgrim flasks include the area just forward (based on KW 190) or actually on top of the oxhide ingots in row 1. From the locations of flasks KW 58 (K12UL4), 114 (K12UL2), and 1180 (L12LR2), it is known that at least some of the flasks were behind ingot row 1. Their position in relation to the pithoi and Canaanite jars is uncertain, but it seems they were placed just forward of the copper, tin, and glass ingots located at the very stern of the ship. A ventured guess is that the pilgrim flasks were among the Canaanite jars, perhaps placed on top of them or used to fill in some gaps between them.

Weight distribution

Each Canaanite jars weighed around 6 kg regardless of size. Thus the weight of the filled Canaanite jars equals 12.7 kg, 18 kg and 32.7 kg for the 3 sizes. If tentative counts of 112 small, 18 medium and 20 large Canaanite jars are accepted for the total number on the ship, then their corresponding weights would be: 1422 kg, 324 kg and 654 kg, respectively. This is roughly equal to the weight of only one of the oxhide ingot rows in the bow of the ship, and yet takes up three times the space. A drawback of stacking the Canaanite jars in two layers is the slight forward shift in the ship's centroid.

This necessity, however, is compensated by the additional cargo that can be stowed behind the Canaanite jars from the increase of available space when the Canaanite jars are double stacked.

The pilgrim flasks came in a variety of sizes so it is difficult to place them in distinct categories. Nevertheless, these vessels were generally divided into 10 groups. Table 6.1 gives the weight of each type of empty flask, its general capacity and estimated filled weight. Due to the unknown nature of the flasks' original contents, only an approximation can be made of their contribution to the trim of the vessel. Since their openings are very small and not conducive for carrying solid objects, they must have contained a liquid commodity. Based on these assumptions, the total weight of the pilgrim flasks filled with liquid is calculated as 168 kg.

Table 6.1 Sizes and weights of the pilgrim flasks.

Small 1	Weight (kg)		Est. Filled Weight	
1180	0.372		0.552	
2333	0.434		0.614	
1783	0.428		0.608	
4496	0.298	(inc. ~35% missing)	0.591	
2800	0.402		0.582	
1183	?	(on display)	0.589	avg. of above
3686	?	(on display)	0.589	avg. of above
0.180 l				
604	0.414		0.684	
3160	0.418		0.688	
190	0.372		0.642	
157	0.398		0.668	
0.270 l				
58	0.324		0.694	
1819	0.374		0.744	
789	0.374		0.744	
791	0.394	(missing rim)	0.770	(0.400 wt)
2871	0.576	(concreted inside)	0.740	(avg. wt. 0.370)
0.370 l				
Small 2				
1084	0.476		0.976	
0.500 l				
761	0.438		1.044	
0.600 l				
438	0.606	(concreted inside)	1.007	(avg. wt.0.457)
Medium 1				
5258	0.904		1.904	
651	0.794	(inc. ~5% missing)	1.836	
1.000 l				
3694	1.088		2.438	
2856	0.942		2.292	
1.350 l				
3345	0.684		1.684	(used 1000 ml)

Table 6.1 (cont'd).

	Weight (kg)		Est. Filled Weight	
Medium 2				
776	0.702		2.322	
795	0.974		2.594	
2975	1.060	(inc. ~7% missing)	2.760	(used 1.140)
1.620 l				
5904	0.658	(inc. ~55% missing)	3.082	(1650 ml + 1.462)
5890	2.592	(concretion inside,	3.082	same as above)
		missing ~45%)		
Medium 3				
2821	2.396	(concreted inside)	2.886	(same as above)
3349	1.008	(inc. ~5% missing)	2.886	(used 1.061)
1.825 l				
2718	1.418		3.613	
2135	1.374		3.569	
2.195 l				
Medium 4				
3921	2.476	(concreted inside)	4.061	
		inc. ~15% missing)		
2926	1.616	(inc. ~5% missing)	4.061	(used 1.701)
2.360 l				
4089	1.518	(inc. ~20% missing)	4.257	(used 1.897)
2604	1.158	(inc. ~50% missing)	4.676	(used 2.316)
Medium 5				
434	1.344	(inc. ~40% missing)	6.290	(used 2.240)
600	1.394	(inc. ~20% missing)	5.792	(used 1.742)
4.050 l				
Large 1				
5892	1.748	(inc. ~20% missing)	7.885	(used 2.185)
5891	1.826	(concreted inside,	8.380	
		inc. ~60% missing)		
2489	2.89	(inc. ~20% missing)	9.312	(used 3.612)
5.700 l				

Table 6.1 Sizes and weights of the pilgrim flasks (cont'd).

	Weight (kg)		Est. Filled Weight	
5893	2.612		8.112	
5.500 l				
211	2.448	(inc. ~15% missing)	8.580	2.880, 5.700 l)
2535	2.002	(inc. ~20% missing)	8.202	2.502, 5.700 l)
Large 2				
114	2.542		9.222	
6.680 l				
3101	3.37		10.050	(6.680 l)
747	?	(on display)	9.636	est.
Large 3				
4088	2.994	(inc. ~7% missing)	11.419	(used 3.219)
8.200 l				
Total			**170.409**	

CHAPTER VII

HYDROSTATIC AND STABILITY ANALYSIS

Evaluation of the Cargo-Laden Hull

The revised hull proposed in chapter II was tested based on the reconstructed lading and weight of the cargo, anchors and stone ballast. The first assessment was whether all of the cargo described in the previous chapters could physically fit into the proposed hold in their hypothetical configurations. Figure 7.1 is a computer rendition of the proposed cargo arrangement, and table 7.1 gives the final weights of the cargo and shipboard items and center of gravity for the fully-laden ship. The first problem encountered was that there was not enough space in the bow for the ballast stones if the anchors were arranged in the 5-4-3-2 configuration (see fig. 3.11). Less than 1 x 1 m of space is available to hold nearly 600 kg of ballast. Several small measures can be implemented to resolve this issue without resorting to a total relocation of the artifacts. The distance between ingot rows 1 and 2 is somewhat flexible since it is uncertain how much displacement row 2 experienced. Instead of using the maximum distance of 2.49 m, the minimum value for the distance between rows 1 and 2 of 2.25 m can be used, thus shifting the entire assemblage of oxhide ingots and stone anchors rearward and creating more space for the ballast stones. The anchors can also be shifted slightly since their original arrangement is unclear from the archaeological record. If the four rows of anchors are reduced to three, the area available for the ballast is greatly increased (see

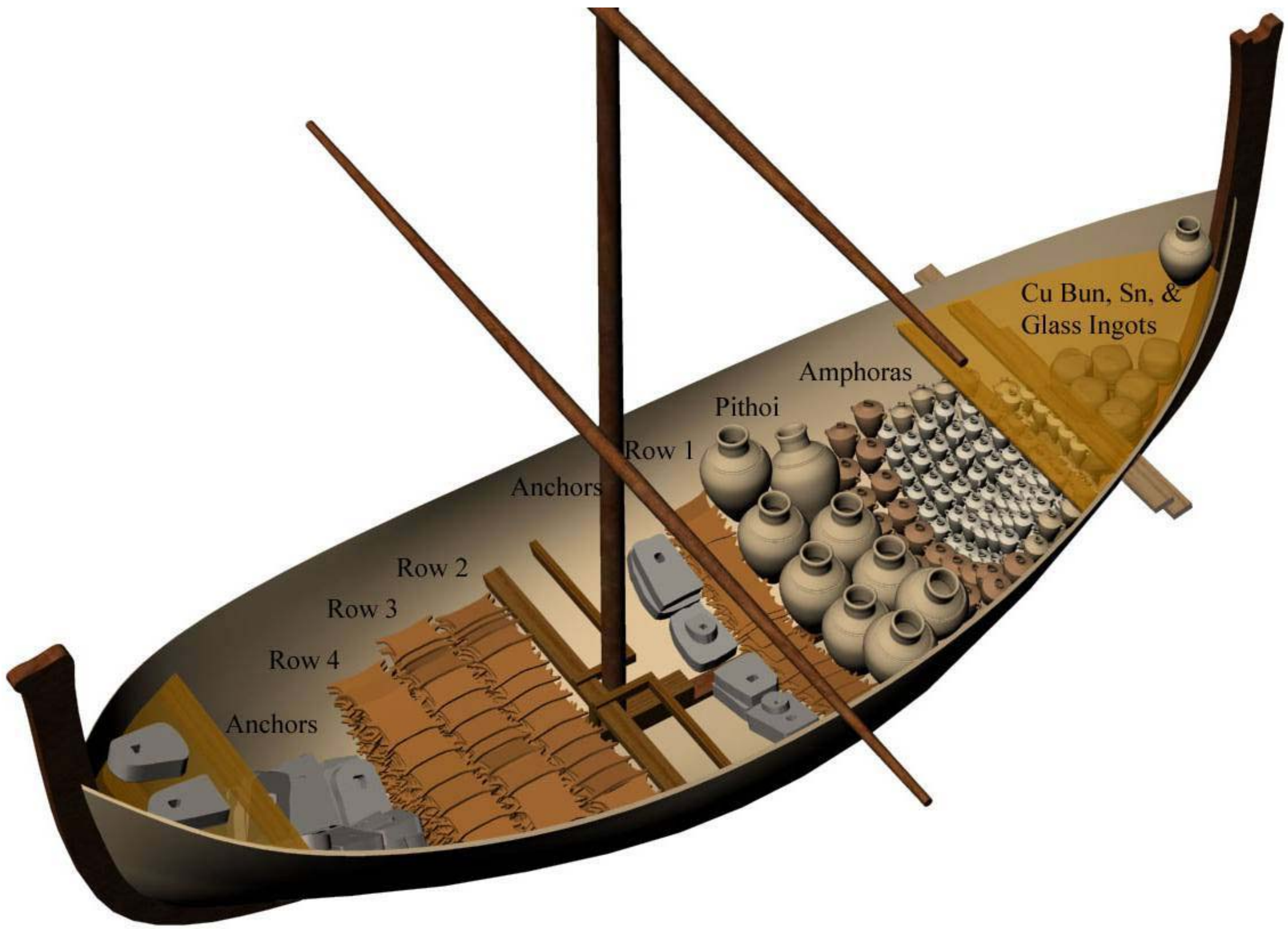

Fig. 7.1 Proposed cargo and anchor arrangement.

Table 7.1 Final calculation table of ship, cargo, and passenger weights and centers of gravity.

Hull Prototype 2							
Item Name	Weight (kg)	X	Y	Z	X-Moment (kg-m)	Y-Moment (kg-m)	Z-Moment (kg-m)
Oxhide ingots Row 1 (50)	1250	6.31	0	0.55	7887.5	0	687.5
Oxhide ingots Row 2 (96)	2350	9.34	0	0.65	21949	0	1527.5
Oxhide ingots Row 3 (93)	2375	10.15	0	0.8	24106.25	0	1900
Oxhide ingots Row 4 (101)	2525	10.95	0	0.92	27648.75	0	2323
Ballast (bow)	558	14.09	0	1.68	7862.22	0	937.44
Ballast (midships)	131.7	7.5	0	0.3	987.75	0	39.51
Ballast (stern)	26.2	3.18	0	0.35	83.316	0	9.17
Anchors (bow)	2391.65	12.43	0	1.17	29728.209	0	2798.231
Anchors (stern)	905.63	7	0	0.56	6339.41	0	507.1528
Amphoras (small)	1422.4	3.18	0	1.12	4523.232	0	1593.088
Amphoras (medium)	324	2.67	0	1.28	865.08	0	414.72
Amphoras (large)	654	4.25	0	0.95	2779.5	0	621.3
Pithoi (main pile)	2754.5	5.41	0	1.12	14901.845	0	3085.04
Pithoi (sterndeck)	154	0.55	0	3.55	84.7	0	546.7
Pilgrim flasks	170	3.18	0	1.12	540.6	0	190.4
Tin ingots	1000	1.62	0	1.45	1620	0	1450
Glass ingots	350	1.62	0	1.45	567	0	507.5
Copper Bun ingots	774.6	1.62	0	1.45	1254.852	0	1123.17
Oxhide ingots in stern	250	1.73	0	0.69	432.5	0	172.5
The Ship							
Planking	5535.6	7.5	0	1.5	41517	0	8303.4
Keel and end posts	952	7.182	0	1.982	6837.264	0	1886.864
Foredeck & through-beams	134.4	13.67	0	2.73	1837.248	0	366.912
Aft deck & through-beams	448	2.26	0	2.56	1012.48	0	1146.88
Mast components	930	8.52	0	5.49	7923.6	0	5105.7
Lightship	8000	7.39	0.00	2.10			
Total Weight/*cg* =	28366.68	7.519	0.00	1.31			
Standing Passengers							
passengers (stern)	60	0.91	0	4.09	54.6	0	245.4
passenger (stern)	60	2.67	0	3.63	160.2	0	217.8
passengers (amidships)	60	6.31	0	1.91	378.6	0	114.6
passengers (amidships)	60	9.29	0	2.09	557.4	0	125.4
passengers (amidships)	60	10.93	0	2.29	655.8	0	137.4
passengers (bow)	60	13.31	0	3.77	798.6	0	226.2
Total w/ Passengers =	28726.68	7.515	0.00	1.33			

fig. 3.11 for the revised arrangement of the anchors). More space can be gained by reducing the gaps between the forward three rows of oxhide ingots,[1] but they cannot be completely eliminated since the archaeological evidence indicates that some space between each row was present. In all, these measures are sufficient to make room for the ballast, although it cannot be completely verified without physically modeling the complete assemblage of ballast stones and placing them in the bow.

The final displacement of ship, cargo and six passengers is 28726.68 kg at a draft of 1.07m.[2] This is short of the projected 1.29 m maximum draft for this hull shape, but is expected since items such as sweeps, anchor cables, ropes for actual and spare rigging, possible spare yards or booms, galley materials, personal objects, ebony logs, and other perishable items, ivory objects, value-laden gift cargo, metallic vessels, gold and silver jewelry, fishing equipment, nets and associated weights, weapons, tools, and foodstuffs, were all unaccounted for in this calculation.[3] Undoubtedly, many of these items, especially personal possessions and objects of greater value, would have been kept in the stern, as verified by their find spots on the site. This creates the problem of a shortage of space in the stern for non-raw material items. It seems reasonable that there might have been a small compartment below the stern deck to store valuable and personal items, but with the hull and cargo configuration as proposed, this is not possible.

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[1] Reduced approximately by half, to 5 cm space between each row.

[2] The weight of the hull was increased to 8000 kg since a weight of 6469.9 kg is much too light for a 15 m-long ship (weight added to planking since its center of gravity is closest to midships: 4005.5 kg > 5535.6 kg). The Kyrenia II weighed approximately 8000 kg even though it was a smaller ship, but its frames and futtocks would have contributed additional weight. The Uluburun ship may or may not have had frames but its planking was 6 cm thick compared to the Kyrenia ship's 4 cm and the former's keel was also considerably more robust than the latter. Therefore, 8000 kg can be considered a minimum weight for the Uluburun ship.

[3] For a more detailed discussion of these artifacts, see Pulak 1998, 203-10.

While unable to address all issues, this configuration has shown that the immense weight of the three rows of copper oxhide ingots forward of the mast can be counterbalanced by the extant cargo. Since the locations and weights of ingot row 1 and the Canaanite jars were relatively certain, the major deciding factors to the trim of the vessel were the weight and location of the pithoi and the placement of the copper bun, tin, and glass ingots. The projected weight of the pithoi was approximately 38 percent of the weight of the forward three rows of oxhide ingots. But had the pithoi been separated and one row placed forward of the midship anchors (fig. 7.2), those pithoi would have been too close to the ship's center of gravity to contribute to the trim of the vessel despite their great weight. The combined weight of the copper bun, tin, and glass ingots totaled only 29 percent of the three ingot rows but due to their distance from the ship's center of gravity, they are able to exert more leverage and have a greater contribution to the trim of the vessel than their weight suggests.

Trim and Stability

The trim of the hypothetical vessel using the proposed arrangement of cargo yields a longitudinal center of gravity value of 7.52 m. This makes it just slightly bow heavy compared to the value of 7.39 m obtained for the dry ship when trim in the water (a mere 0.04 degree off-trim). Regardless of the fact that many items carried onboard were not included in this calculation, the difference in trim is already minimal and is barely perceptible to the eye (fig. 7.3). The results suggest that this configuration of

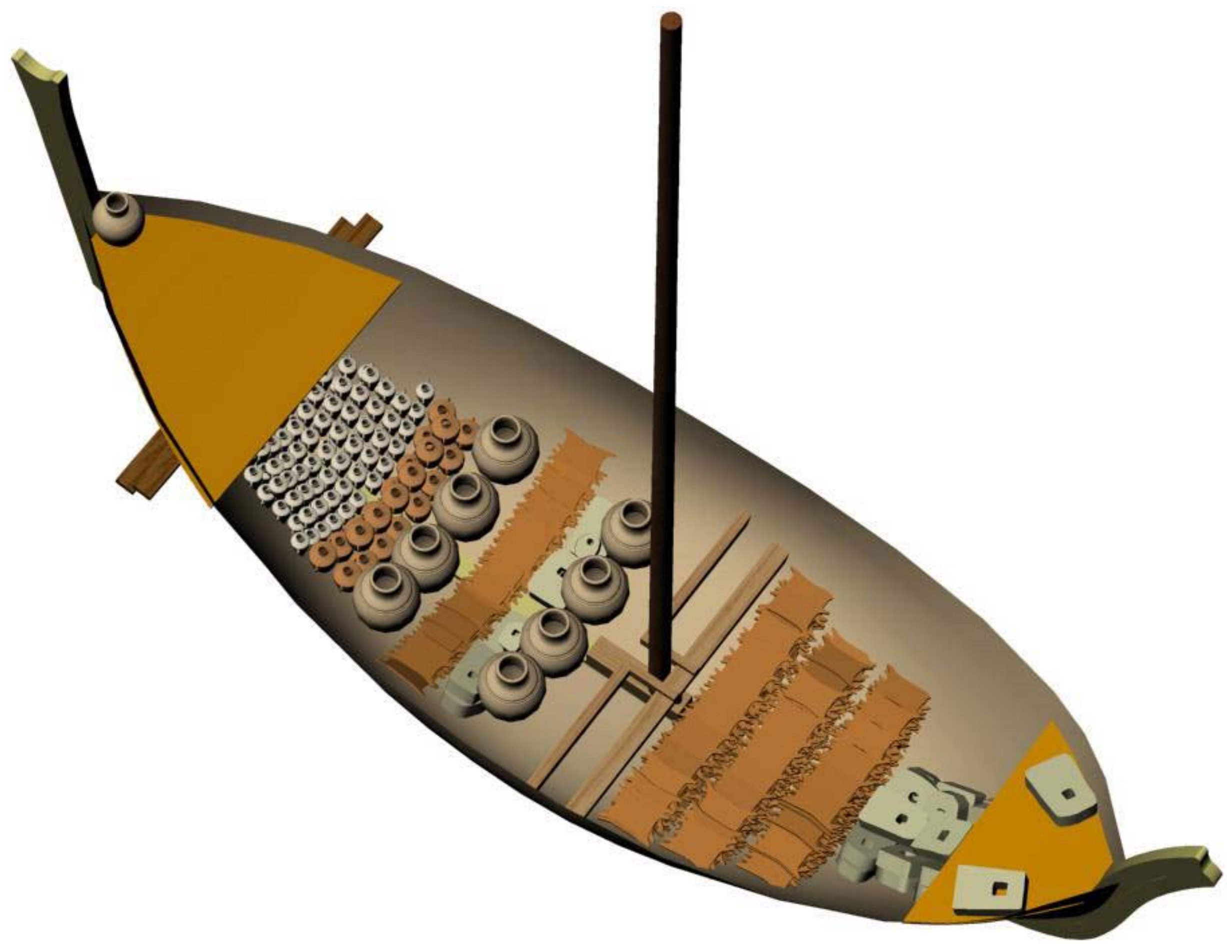

Fig. 7.2 Alternate placement of pithoi in two rows.

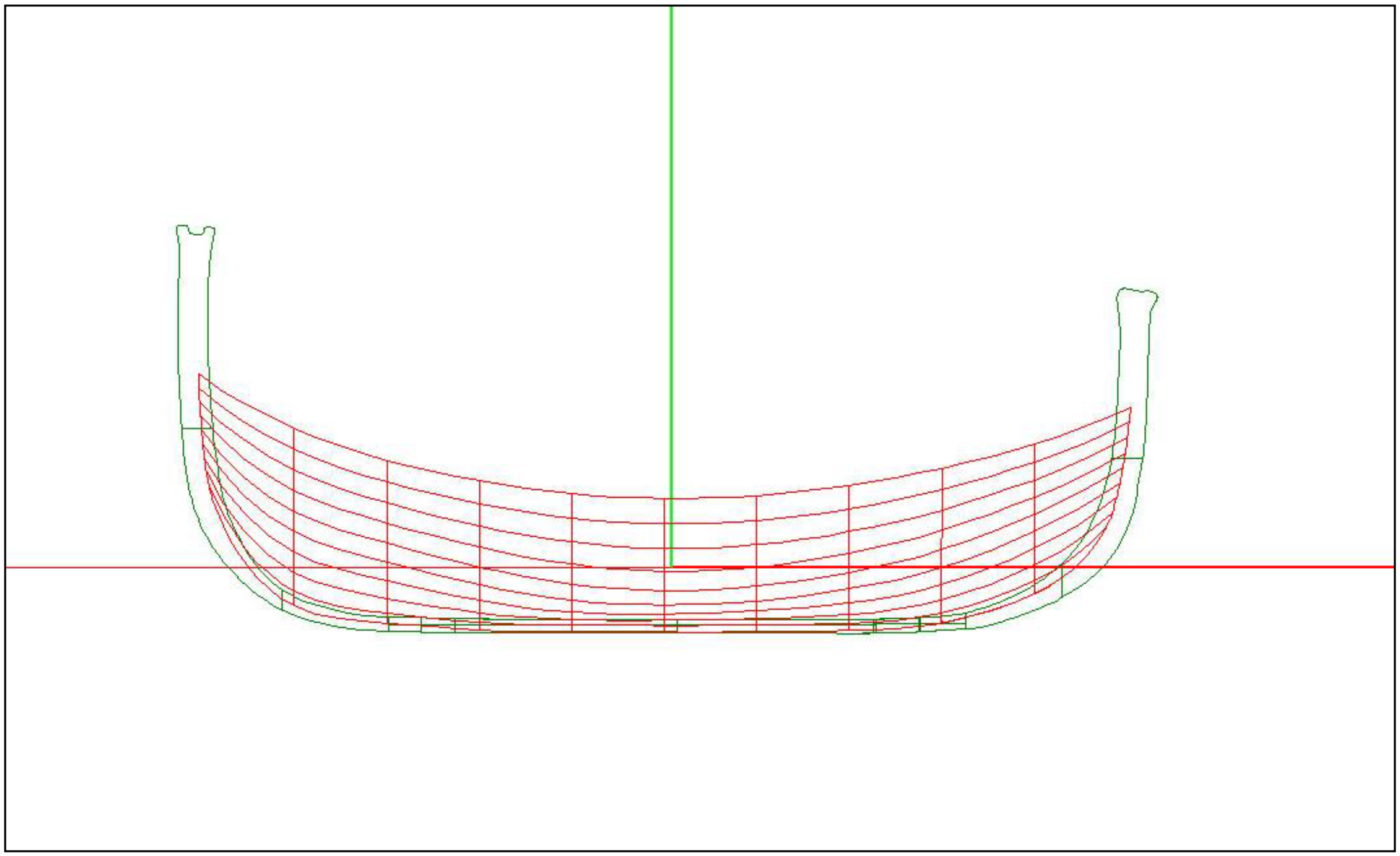

Fig. 7.3 Final flotation plane of proposed hull and cargo arrangement.

cargo placement may be valid, although it is still subject to experimentation and further research before any definitive conclusions can be reached.

In addition to trim, the static stability of the ship must be tested. Stability is defined as the ability of a ship to return to an upright position after it has heeled to one side. The stabilizing characteristic of a ship is derived from the underwater shape of the hull, which, in turn, determines the location of the metacenter. The metacenter of a heeled vessel is identified as the intersecting point between the vertical plane of the original center of buoyancy (no longer upright but slanted) and that of the new center of buoyancy (fig. 7.4). It is the longitudinal distance between the ship's center of gravity and the metacenter that determines if and how the ship will return to an upright position. As long as the metacenter is higher than the center of gravity, the ship will right itself as the new center of buoyancy acts through the metacenter until it (metacenter) is once again vertically aligned with the center of gravity. If the GM (metacentric height) is low, the ship will be slow to return to an upright position, which can lead to instability at greater angles of heel or with heavier loads.[4] With this present configuration, the GM of the Uluburun ship is 1.16 m[5] (fig. 7.5). Possibly, as a measure to lower the center of gravity and thereby increase the GM by keeping the *cg* low, the Uluburun ship was built with an immense square inboard keel, as opposed to the much lighter and narrower keels of later times. Perhaps this was necessary to counterbalance the narrow, but tall, stem

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[4] McGrail, 1987, 15.

[5] No comparative data could be found to evaluate whether or not this was a reasonable figure for a hull of this size except for a statement by McGrail regarding the reconstructed Graveney boat: "...in a certain loaded state [the boat] has a GM of 2 m which is large for a boat of this size and could result in considerable roll being generated." (McGrail 1987, 15). The Graveney boat's overall dimensions are: 13.5 x 3.3 x 1.4 m.

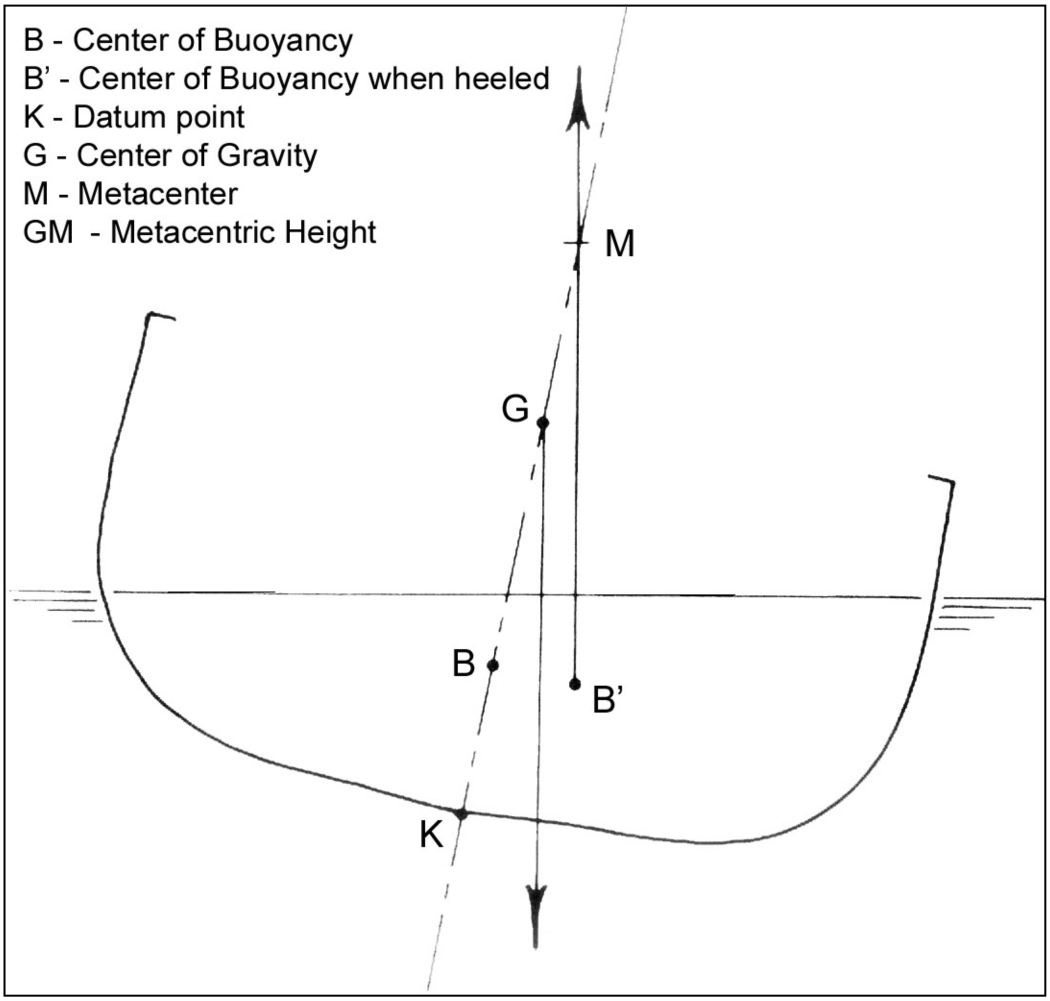

Fig. 7.4 Diagram illustrating the factors of transverse stability. (After McGrail 1987, 15, fig. 3.3).

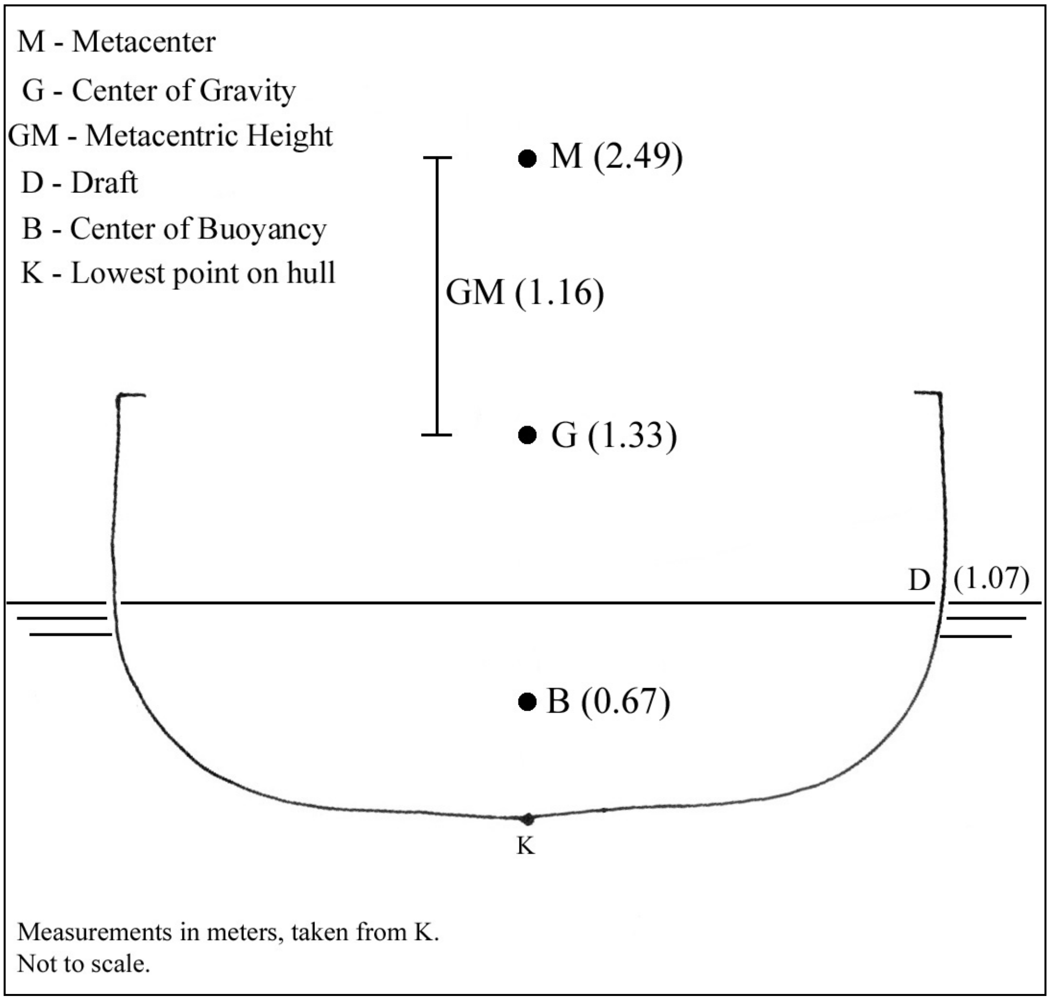

Fig. 7.5 Diagram illustrating hydrostatic values of hypothetical hull no. 2 with proposed cargo lading arrangement.

and sternpost. Wicker work fencing, as depicted on the tomb paintings of Kenamun and Nebamun (see fig. 2.2), was another means of keeping the center of gravity low by using lighter material along the sides of the ship to increase freeboard rather than using heavy planks. Such fencing was also found on the wreck.[6] The proposed hull's acceptable GM value indicates that the overall shape of hull, especially the submerged portion, is a reasonable and viable conjecture (table 7.2).[7]

It has been assumed that the items on board were placed on the ship evenly along the transverse plane. The archaeological evidence does not contradict this, despite the starboard list. From the examination of ingot rows 1 and 2 and the midships anchors, it seems that the crew were careful to ensure that the ship was properly laden. Even when the ship was in motion, it can be assumed that the cargo was probably secured to prevent significant shifting of its weight. However, the passengers and crew aboard the ship were not stationary, and therefore, their effects to the transverse stability of the ship has to be calculated to ensure that the vessel is safe. Assuming that a total of six people were on board this ship,[8] sufficient freeboard is needed to allow all six to move from one side of the ship to the other without the sheer strake becoming awash.[9]

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[6] Pulak 1999, 212.

[7] PHASER reports the metacenter (M transverse) value as the distance between the metacenter and the flotation plane (water line) and not from the lowest point of the hull. Therefore, the M value shown in fig. 7.5 is the number produced by PHASER plus the draft.

[8] Pulak 1997, 251-6. While Pulak does not directly state the number of passengers aboard the ship, his discussion of the personal items points to the presence of at least three Syro-Canaanite merchants most likely doubling as crew, two Mycenaean mercenaries or officials, and a possible Bronze Age Bulgarian or Romanian, who may also have been a mercenary or official.

[9] McGrail 1987, 14.

Table 7.2 Hydrostatic output of hypothetical hull no. 2 with proposed cargo lading arrangement.

Free Float Hydrostatics

Date/Time:	March 20, 2003 11:20:53 AM	**Version:**	Phaser 2.0.9
Input file:	C:\Documents and Settings\Sam\Desktop\test mule.3dm		
Output file:	E:\Rhinoceros\Plug-ins\Phaser\Phaser\default.htm		
Parts Mirrored:	No	**Fluid Type:**	Sea Water
Up-direction is:	Positive	**Fluid Density:**	1025.9 kg/m^3

Flotation Plane

PlnConst	NrmlX	NrmlY	NrmlZ
1.064	-0.001	0.000	1.000

Overall Dimensions

Units (meters)

Name	Value
Length OA	15.913
Length WL	14.185
Beam OA	5.256
Beam WL	4.727
Depth	6.621
Draft	1.071
Freeboard	5.550

Integrated Properties

Units (meters, meters^2, meters^3, kilograms)

Name	Value
Volume	28.001
Displacement	28,726.678
LCB	7.516
LCB Percent LWL	49.905
VCB	0.666
TCB	0.000
Wetted Surface Area	61.370

Table 7.2 (cont'd).

Waterplane Properties

Units (meters, $meters^2$, kilograms/cm, meters-kilograms/cm)

Name	Value
Area WP	41.672
LCF	7.579
TCF	0.000
VCF	1.070
M Transverse	1.419
M Longitudinal	13.451
BM Transverse	1.823
BM Longitudinal	13.855
Weight to Immerse	427.513
Moment To Trim	245.471

Form Coefficients

Name	Value
Cb	0.390
Cwp	0.621

Stations

Units (meters, $meters^2$)

Long'l Loc	WetGirth	WetArea

Stability Data

Units (meters, degrees, kilograms-meters)

Name	Value
Heel	0.000
Trim	0.043
GM Transverse	1.159
GM Longitudinal	13.191
Righting Mom1Deg	580.886

Six passengers were placed along the length of the ship, with two on the stern deck, one standing on ingot row 1, another on ingot row 2 and one more on ingot row 4, and the sixth on the fore deck. An average weight of 60 kg and a height of 1.60 m were used for each person. To test the stability of the hull, they were placed as far to starboard as possible and their centers of gravity were calculated in Rhinoceros. As McGrail has stated:

> If men…maintain an upright position by shifting their balance to oppose the heel of the boat their effective C of G is at the level of their feet when standing, or seat when sitting and the problem [stability] is less. However, if they move rigidly with the motion of the boat by steadying themselves against the boat structure, their effective C of G should be taken to be their C of G.[10]

To test the least desirable condition, the passengers' center of gravity while standing was used, although in such a static condition, passengers and crew would more likely shift their balance to counter the heel rather than brace themselves against a hull structure. Figure 7.6 shows the result of this stability test: even with six people aboard the ship standing to one side, they were only able to induce 1.12 degrees of heel. The same experiment was repeated with the ship loaded to its optimal draft of 1.29 m and the results were nearly identical. Another test was applied to the laden vessel with a range of heel angles (0 to 48 degrees) at a draft of 1.07 m to determine how much heel the vessel can sustain before capsizing (fig. 7.7). The results show that the righting arm peaks at 30 degrees and would experience imminent capsizing at 48 degrees, so from a hydrostatic perspective, the hull is able to safely accommodate six free-moving

[10] McGrail 1987, 15.

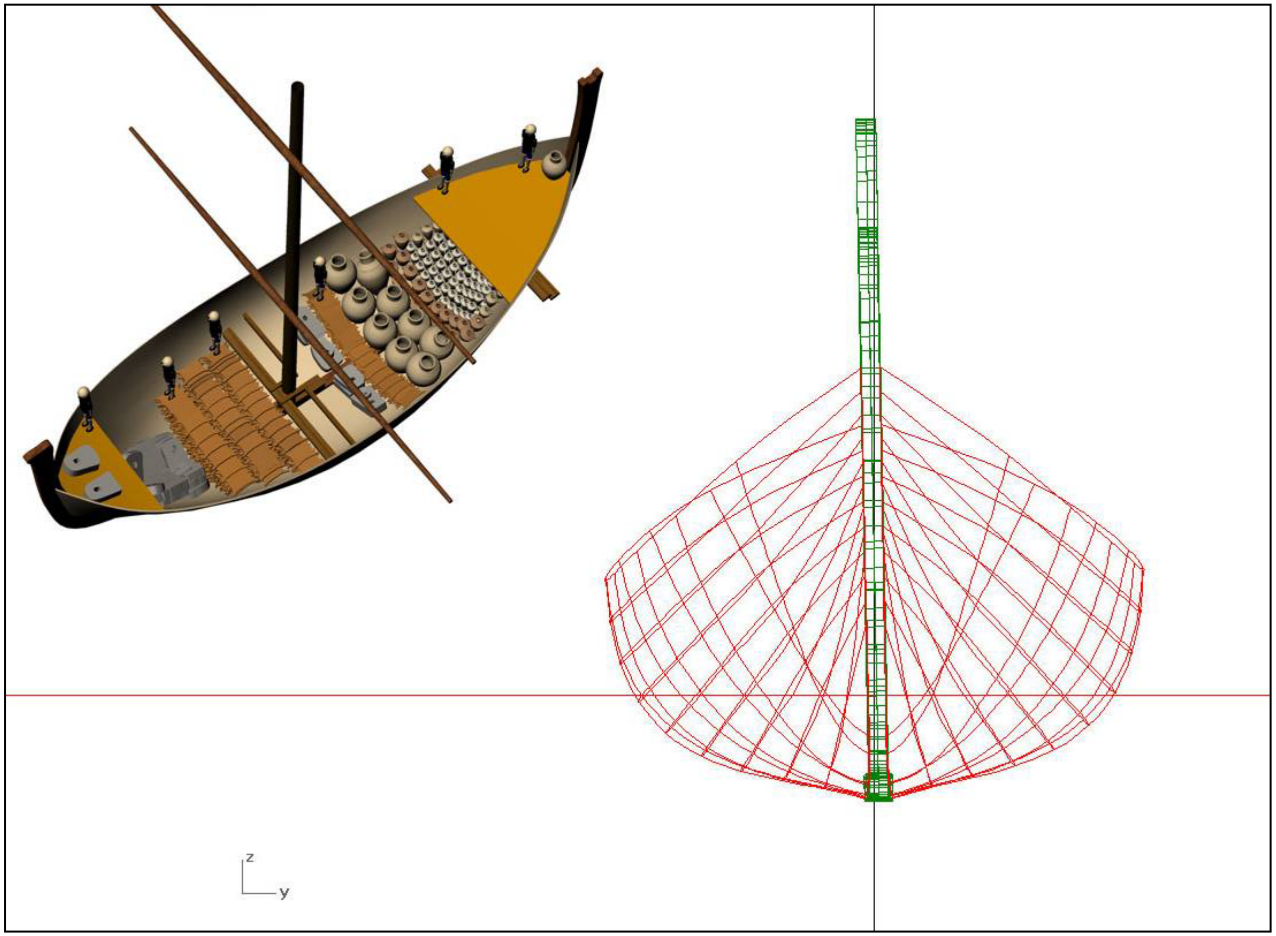

Fig. 7.6 Vessel with 1.12 degree heel to starboard.

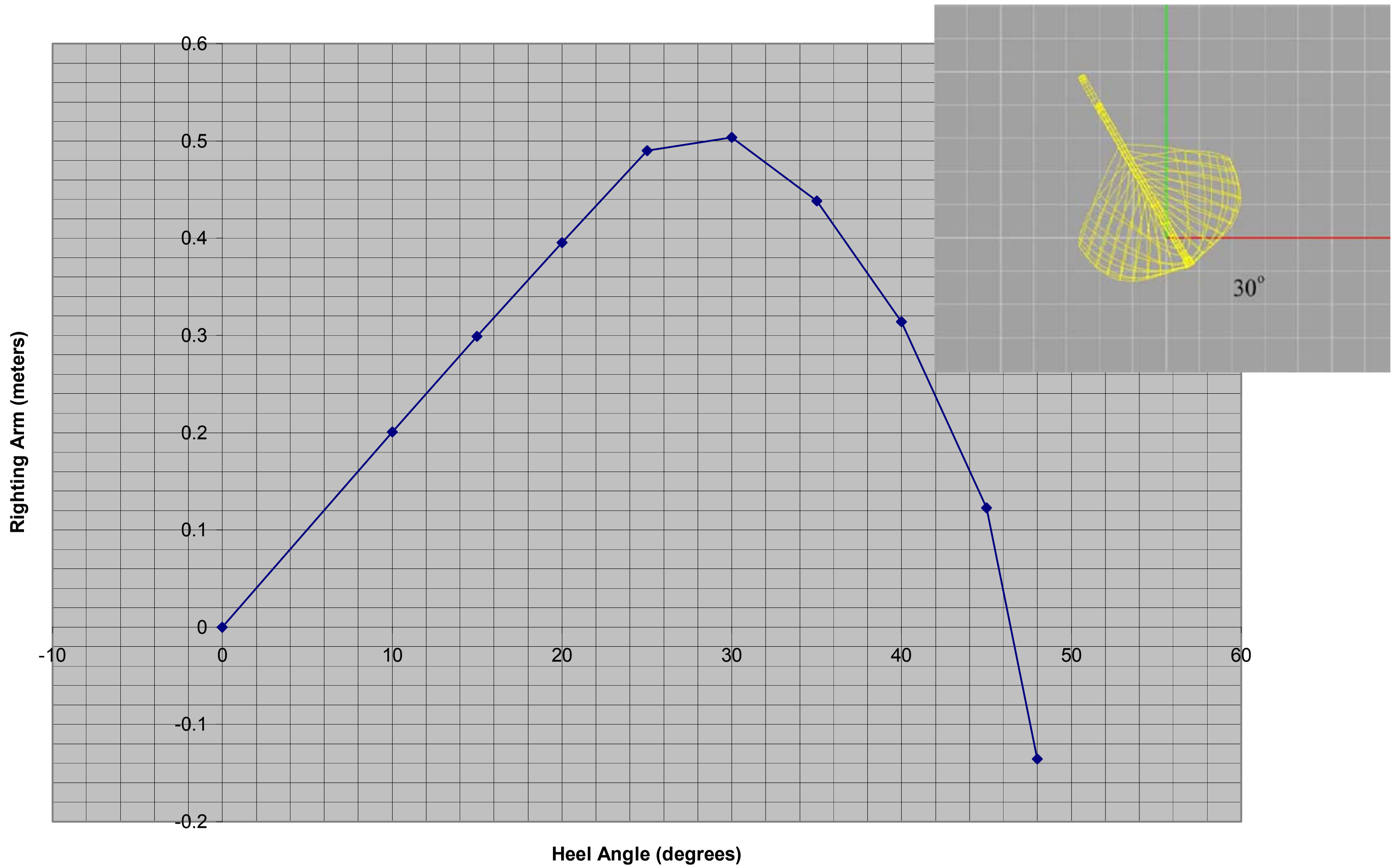

Fig. 7.7 Righting arm curve for hypothetical hull no. 2 at 1.07 m draft.

passengers. Whether or not these conditions are safe on the open seas will have to be tested in a later study, but the presence of the wicker work fencing would have helped to increase the freeboard and prevent the ship from taking in water at angles of heel greater than 30 degrees.

Evaluation of Results

The proposed hull has thus far demonstrated that it has the physical capacity to contain all of the artifacts found on the shipwreck without being too large; the ability to sit relatively trim in the water with all the major weight-bearing cargo and shipboard items placed inside the hull; a GM that is neither too stiff nor too tender; and a load waterline that can easily accommodate the heel induced by six passengers aboard. Despite these successes, there remain areas where improvements, further experimentation, and additional archaeological data will lead to potentially more satisfying results.

In particular, further refinement of the hull shape is needed. If the two-fifths freeboard rule is applied to the vessel's depth of 2.15 m, a displacement of 38.6 tons is calculated at a draft of 1.29 m. This is still significantly heavier than suggested by the recovered artifacts. One possible solution is to lower the sheer line to reduce the displacement without sacrificing storage space. Such a procedure yielded an even lower displacement of 34.3 tons with a depth amidships of 2.0 m, and a draft of 1.2 m (fig. 7.8). Perhaps it is because of this low sheer that both the Kenamun and Nebamun wall paintings show weather fencing stretching from end to end. Since so little is known

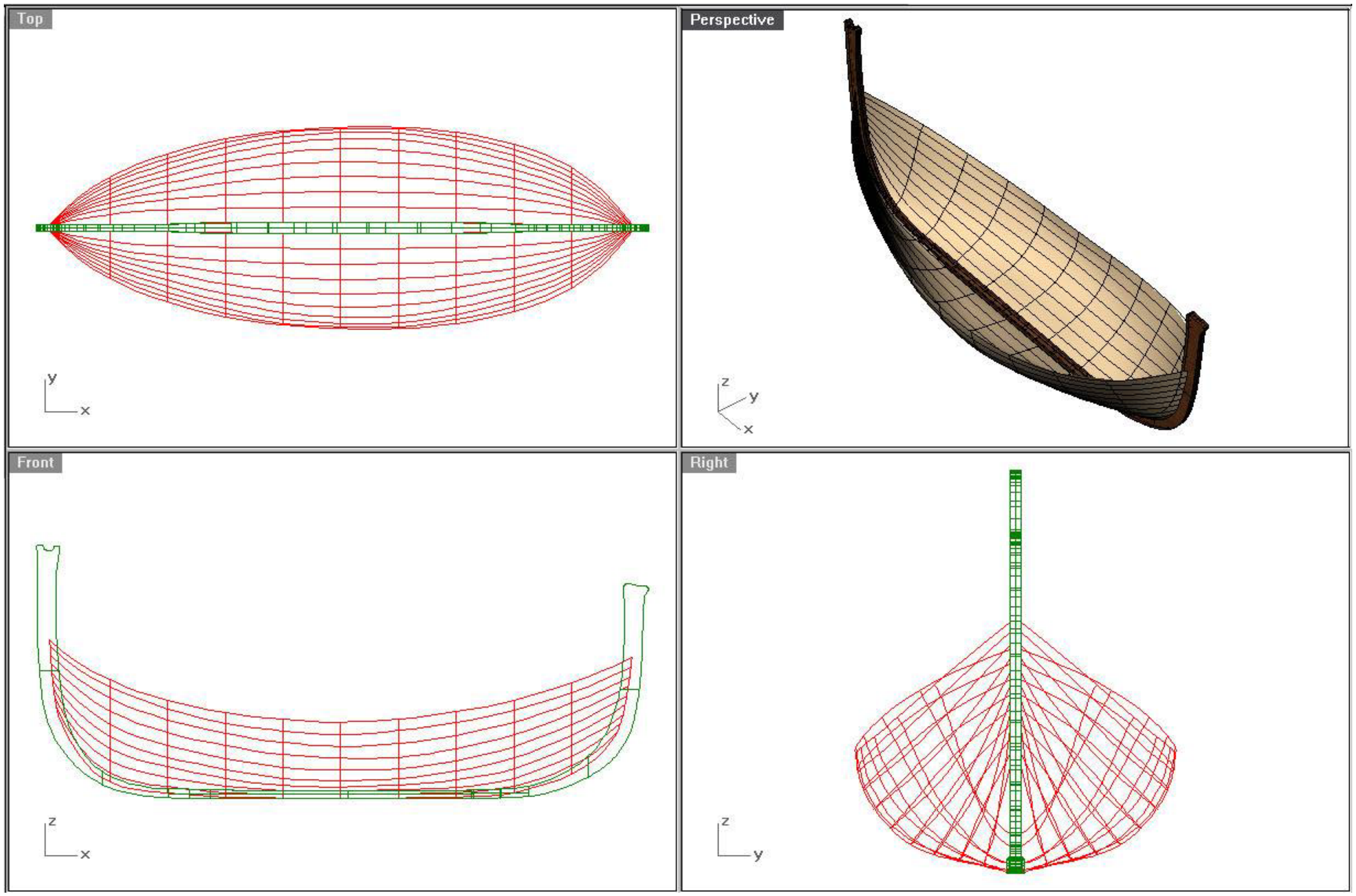

Fig. 7.8 Hypothetical hull no. 3.

about Late Bronze Age ships, the factors that can be experimented with are numerous. The method of creating and testing hypothetical models has already been demonstrated, so only more archaeological data is needed to reconstruct a more accurate Late Bronze Age merchant ship.

Another area that warrants further investigation and new data is the distribution of artifacts in the stern. While necessary to accommodate the other artifacts, evidence for the double stacking of the Canaanite jars is still wanting. The reason for the segregation of 13 copper oxhide ingots astern the amphora pile is still unanswered. Aside from the five pillow-shaped ingots, these oxhide ingots were similar to the others located elsewhere on the ship. Were they a private collection or possibly placed at the very rear for trimming or dunnage purposes? Also, was there a compartment in the stern for the storage of personal effects and valuables or were these items somehow secured on the stern deck? The answers to these questions may not be unrealistic expectations if another Late Bronze Age merchantman is ever discovered.

CHAPTER VIII

SUMMARY AND CONCLUSION

This study has demonstrated that there is sufficient archaeological evidence to surmise a general form for the Uluburun ship and the cargo arrangement where no sound reconstruction seemed possible. The scarcity of the ship's physical remains, dearth of knowledge about Late Bronze Age ships, and deficiency of contemporary archaeological data all posed obstacles to any meaningful reconstruction. Furthermore, the settling of the ship on a 30 to 45 degree slope caused objects within the vessel to disperse along 29 m of seabed. In addition, the ship came to rest with at least a 15 degree list to starboard, spilling a number of large storage jars, Canaanite jars, and other smaller items along the southern portion of the site. As found, there were not enough in situ artifacts in the stern of the ship to equalize the concentration of copper oxhide ingots, anchors, and ballast stones located in the bow region. Therefore, the greatest challenge in this study was determining which of the displaced artifacts were originally stowed in the stern.

The meticulous excavation of the shipwreck and detailed record keeping provided the necessary data to tackle this problem. The site plan shows that a row of 50 copper oxhide ingots, 49 Canaanite jars, 1 small pithos, and an assortment of copper oxhide, copper bun, tin, and glass ingots were found in the stern region. Evidence was sought for other artifact categories that might have also originated from the stern. A number of intact and fragmentary pilgrim flasks and Cypriot fine wares were scattered throughout the main pile of Canaanite jars. This provided secondary evidence for the placement of the large pithoi behind the first row of oxhide ingots, since the contents of pithos KW 251 clearly demonstrated the close relationship between the Cypriot pottery and the pithoi. A plotting of the copper bun ingots by mold and mark groups showed that there was a definite clustering of ingots incised with the same mark and, to a lesser degree, ingots cast from the same mold. Trails of similarly-marked ingots suggested that the copper bun ingots were also stored in the stern behind the Canaanite jars. The tin and glass ingots, likewise, were demonstrated to have connections to the stern area of the ship, although many of them were widely scattered among the forward three rows of oxhide ingots. The containers with copper bun, tin, and glass ingots probably slid downslope along the sides of the hull and eventually spilled their contents in the bow, some of which percolated to the lowest layers of the oxhide ingots. There were, however, a number of intact tin oxhide and slab ingots that may have been stowed with their copper counterparts at the bow.

In order to test the cargo arrangements suggested by the archaeological evidence, a basic hull shape was needed. Based on the distance between the ballast stones and artifacts found at the shallow end of the wreck, a length of 15 m was proposed for the vessel. A width amidships of 5 m not only gives the ship a desirable 1:3 ratio, but is also supported by the width of the first and second oxhide ingot rows. The general shape of the ship was adapted from wall paintings of the Egyptian officials Kenamun and Nebamun. A three-dimensional model of the ship and the artifacts were made in Rhinoceros, which then allowed for testing the placements of cargo and their effect on the draft and trim of the vessel, with PHASER, a plug-in program designed for use with Rhinoceros. Hydrostatic calculations for the ship also indicated that a hold depth of 2.5

m resulted in a vessel with too large a displacement (46.9 tons) for the artifacts recovered if freeboard was to be maintained at the generally accepted value of two-fifths of the hold depth. To lower this value, the sheer line was lowered in the three-dimensional model until a more reasonable displacement (34.3 tons) was obtained, but further refinement in light of future archaeological data will be necessary. Evidence also suggests that not a significant amount of unknown perished cargo needs to be relied on to trim the vessel. Even with a number of the smaller, personal objects and foodstuff unaccounted for in the calculations, the ship was only bow heavy by 0.04 degrees according to the arrangement of artifacts developed during this study.

The use of computers in this study proved useful in a number of ways. Rhinoceros and PHASER were instrumental in providing a means to quickly calculate hydrostatic properties as well as to output the results in a graphic way for easier visualization. This facilitated the testing of various lading configurations so that the method of determining the appropriate loading conditions became an iterative process, a method that would have been extremely time-consuming and taken laborious manual calculations without the aid of the computer. The initial learning curve might hinder the adaptation of this method for many projects, but once implemented, these tools are versatile, effective, and presentable.

The crucial factor that made this study possible, however, was the corpus of field data, including thousands of artifact measurements, years of conservation, the mending and repairing of fragmentary finds, and the thoroughness of the excavation. The length and width of the ship hinged on defining the borders of the wreck site; the placement of the pithoi was determined by the location of tiny pottery fragments; the number of Canaanite jars, pithoi, pilgrim flasks and other pottery was ascertained by the piecing together of thousands of sherds; and the grouping of the copper bun ingots by mold siblings required months spent physically examining the ingots. Clearly, the archaeological evidence provided both the substance and the parameters for this project. The incorporation of computer technology, however, has also greatly contributed to this study and the potential should continue to be explored.

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