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A Fourth-Century Shipwreck at Yassi Ada

GEORGE F. BASS AND
FREDERICK H. VAN DOORNINCK, JR.¹

PLATES 1-4

During the summers of 1967 and 1969, the University Museum of the University of Pennsylvania² all but completed the excavation of another of the shipwrecks examined by Peter Throckmorton in Turkey in 1958-59.³ The wreck lay about 100 m. south of Yassi Ada (Lodo), a small island (27°11'45" E, 36°59'30" N) between Greek Pserimos and the Turkish mainland, only 10-15 m. from the seventh-century Byzantine wreck we had excavated a few years earlier.⁴ During the course of excavation we found a much later (sixteenth- or seventeenth-century) wreck lying partly over the Roman remains, and this led to a search, in 1969, for still other wrecks which might be more deeply buried in the sand.

¹ The section entitled *The Hull* was written by van Doorninck, and the other parts of the article by Bass while a visiting scholar at St. John's College, Cambridge, aided by a fellowship from the American Council of Learned Societies. Object drawings are by G. Gölönü, except for figs. 9-11 and 40 (by J. Cook) and 12 (by S. W. Katzev).

² The National Geographic Society gave financial support to the excavation during both seasons. Additional support, in 1967, came from Mr. Nixon Griffis, the National Science Foundation, the Triopian Foundation for Archaeological Research, and the U.S. Navy (Office of Naval Research, Supervisor of Salvage, Deep Submergence Systems Project, Naval Oceanographic Office, and Naval Research Laboratory; this aid, including funds and loans of equipment, was for the further development of photogrammetric mapping techniques, and for the evaluation of various types of side-scanning sonar used in a related search project described in the articles cited in n. 5, *infra*). In 1969, additional sponsors were the Ford Foundation, for graduate students' expenses, the Haas Community Funds, and the Old Dominion Foundation; the Office of Naval Research continued to lend equipment.

Staff members in 1967 were G. F. Bass, director; Claude Duthuit, chief diver; Don Wilson and John Cassils, physicians; Susan Womer Katzev, Jane Cook, and Eric J. Ryan, artists; Charles Nicklin, Paul Fardig, Robert Hodgson, and Mustafa Kapkin, photographers; Bennett Jones and Matt Kaplan, architects; William Maggs, mechanic; Ann Searight, conservator; Donald M. Rosencrantz and Tony Boegeman, electrical engineers; Laurence T. Joline, Oğuz Alpözen, Peter Fries, Oktay Ercan, Belkis Mutlu, Gail Hillard, Birol Kutadgu, Judy Hodgson, Irene Maggs, Anna McCann, and Jack Sasson; and archaeology students Frank Bartell, W. Willson Cummer, Orhan Gurman, Jana Hesser, Cynthia Jones, Michael L. Katzev (administrative assistant), Regnar Kear-ton, Sanford H. Low, Hugh Mullenbach, David I. Owen, Nancy Palmer, Marilyn Rosenberg, Marie Ryan, Kenneth Sams, Stuart

METHODS

The great depth of the new site (36 to 42 m.), combined with our desire to complete its excavation in as few seasons as possible, led in 1967 to the development of new equipment and more efficient techniques than had been used previously; these have been described fully elsewhere.⁵ Some of the techniques were continued in 1969, but there were several changes: the large, aluminum air lift on tracks was replaced by three smaller, lighter air lifts of PVC irrigation pipe of a type first used at Kyrenia, Cyprus, the previous year;⁶ each could be moved easily by a single diver to any point on the site. By breathing pure oxygen during decompression, we were able to extend the lengths of dives

Swiny, Ted Worth, and Laina Wylde. LtCmdr. John Ulrich and Andrew Wright were assigned by the Supervisor of Salvage, U.S. Navy, to assist in expedition preparations at Yassi Ada.

Returning in 1969 were Bass, Rosencrantz, Fries, E. Ryan, Joline, Low, Duthuit, Kapkin, and Mutlu, joined by F. H. van Doorninck, Jr.; Robert Henry, chief diver; David Leith and John N. Miller, physicians; Jeremy Green, physicist; Carl Semczak, conservator; Fletcher Blanchard, engineer; Donald Frey; Gündüz Gölönü, artist; archaeology students Donald Callender, Ellen Ehrlich, and William McClintock; engineering students John Owen, Paul Dresser, and Warren Riess; geology students Ludwig Beckman and John Gifford; and Ann Bass, Barbara Leith, B. J. van Doorninck, Yildiz Gölönü, Nancy Fries, and Mary Jane Cotton.

Yüksel Eğdemir served as commissioner from the Turkish Department of Antiquities during both seasons, sharing responsibilities in 1969 with Oğuz Alpözen; both were actively involved in the diving and excavation.

³ P. Throckmorton, *The Lost Ships* (Boston 1964; London 1965); "Thirty-three Centuries Under the Sea," *National Geographic* 117:5 (May 1960) 689-690. H. Frost, *Under the Mediterranean* (London and Englewood Cliffs, N.J. 1963) 164, 169 with fig. 31 and pl. 24.

⁴ G. Bass, "Underwater Excavations at Yassi Ada: A Byzantine Shipwreck," *AA* (1962) 537-564; *Archaeology Under Water* (London and New York 1966) ch. viii with bibl. (hereafter *AUW*).

⁵ G. Bass, "New Tools for Undersea Archaeology," *National Geographic* 134:3 (September 1968) 402-423; G. Bass and S. W. Katzev, "The Turkish Aegean: Proving Ground for Underwater Archaeology," *Expedition* 10:3 (Spring 1968) 3-10; G. Bass and M. L. Katzev, "Tools for Underwater Archaeology," *Archaeology* 21:3 (June 1968) 164-168.

⁶ M. L. Katzev, "The Kyrenia Shipwreck," *Expedition* 11:2 (Winter 1969) 55-59.

and greatly increase the number of hours spent on the wreck each day. And mapping of the site was accomplished by an improved method of photogrammetry.

The visible cargo of amphoras had been partially mapped from the submarine *Asherah* during photogrammetry experiments in 1964,⁷ and part of the excavated hull was mapped by the same method in 1967.⁸ Most of the photographs used for making a plan in 1967 were, however, taken from a photo tower resting on a rigid scaffolding of angle-iron and pipe moved from the Byzantine site.⁹ In 1969 we returned to an improved version of a method we had first developed in 1963,¹⁰ and this proved to be the best method for mapping a deep wreck where working time is severely limited.

Basically, a camera was hung from gimbals which slid on a horizontal bar floated above the wreck (pl. 1, fig. 1), and vertical photographs were taken at predetermined points on the bar. The bar was moved as excavation progressed from one end of the site to the other. Improvements over our earlier system included a motorized Nikon F camera housed in a special case with a hemispherical port to eliminate the distortion when taking underwater pictures,¹¹ metal stakes driven into the site and carefully surveyed by triangulation and an underwater leveling tube¹² as ground control points, and a Multiplex borrowed from the U.S. Office of Naval Research. Black-and-white stereo pairs were printed as glass slides (diapositives) to be projected from the Multiplex, an instrument designed to produce accurate topographic maps from aerial photographs. Drawing the plans with this machine was not without its problems, for the Multiplex may be compared to a musical instru-

ment: one may understand its theory perfectly,¹³ but cannot play it very well without many hours of practice. Several of us took turns in a darkened corner of the workhouse, familiarizing ourselves with the simultaneous adjustments of over a dozen knobs and screws, while wearing spectacles with one red and one blue lens.

Once an area had been photographed, the frames (ribs) of the ancient hull lying under the stereo bar were removed and carried to Yassi Ada in a long wire basket by divers who walked with it up the long slope to the island.¹⁴ These and other timbers were cleaned, fitted together on a grid painted on a concrete floor, and measured and photographed in detail (pl. 1, fig. 2). The same area of the hull was then thoroughly cleaned and rephotographed, with white thumbtacks marking the positions of wooden dowels (treenails) (pl. 1, fig. 3) in the stereophotographs. Only then was the bar moved.

Rubber casts of iron objects, long since corroded away, were made in the natural molds of concretion which form on iron.¹⁵ Even complex objects, with moving parts, were reproduced perfectly by this method.

The discovery of a much later wreck lying partially over the Roman one, and nearly touching the site of the Byzantine shipwreck, emphasizes the obvious danger of the Yassi Ada reef over an extended period of time; both earlier and later wrecks lie on the reef itself, but most of them are too badly damaged by wave action to be worthy of excavation. The depth of sand encountered on the Roman wreck in 1967, much deeper than that on its Byzantine neighbor, suggested that other, perhaps earlier wrecks were buried beneath the sand; the coastline

⁷ R. Karius, P. Merifield, and D. Rosencrantz, "Stereo-Mapping of Underwater Terrain from a Submarine," *Ocean Science and Engineering*, Trans. of the Joint Conf., Marine Technology Soc. and Am. Soc. of Limnology and Oceanography, Washington, D.C., June 1965.

⁸ G. Bass and D. Rosencrantz, *A Diversified Program for the Study of Shallow Water Searching and Mapping Techniques*; a technical report for the Office of Naval Research (no. AD 686 487, Clearinghouse [CFSTI] Springfield, Va.).

⁹ G. Bass, "Underwater Archaeology . . .," *National Geographic* 124:1 (July 1963) figs. on 138-139, 144; *AUW* (supra n. 4) 151 fig. 44, and pls. 34 and 54; "The *Asherah* . . .," *Archaeology* 18:1 (Spring 1965) fig. on p. 9; E. J. Ryan and G. F. Bass, "Underwater Surveying . . .," *Antiquity* 36 (1962) fig. 5 on 259, and fig. 6 on 260.

¹⁰ Karius *et al.* (supra n. 7). Bass, *AUW* 112-113, with fig. 31 and pls. 33, 35-37; "The *Asherah*" (supra n. 9) 8-9, with figs. on 10 and 11.

¹¹ The camera housing was designed by Al Giddings, with

correction optics designed by Greg Morris. Our entire photogrammetry program has been under the supervision of D. M. Rosencrantz since 1964.

¹² P. Merifield and D. Rosencrantz, "A Simple Method for Surveying a Small Area Underwater," *Limnology and Oceanography* 11:3 (1966) 408-409; Bass, *AUW* 100-102, with figs. 25 a and b; P. Throckmorton, "Simple Underwater Surveying," 8-9, with pls. III a-c, and Colin Martin, "Surveying Underwater on a Wreck Site," 56-57, with figs. 6-7, both in *Surveying in Archaeology Underwater* (Colt Archaeological Inst. Monograph Series 5; London 1969).

¹³ *Multiplex Mapping*, Dept. of the Army Technical Manual TM 5-244 (Washington, May 1962).

¹⁴ "The *Asherah*" (supra n. 9) 13, upper fig.; *AUW* pl. 59.

¹⁵ M. L. Katzev and F. H. van Doorninck, Jr., "Replicas of Iron Tools from a Byzantine Shipwreck," *Studies in Conservation* 11:3 (August 1966) 133-142. The iron replacement was undertaken by Katzev in 1967 and L. T. Joline in 1969.

only a few miles distant is known to have been inhabited since at least the Early Bronze Age. To this end we searched beneath the sand with two instruments: a diver-operated corer, built in Bodrum on the design of John Sanders,¹⁶ and a metal detector brought and operated by Jeremy Green of the Research Laboratory for Archaeology and the History of Art, Oxford.¹⁷ Both instruments worked well, but nothing was found while searching away from the Roman wreck in a pattern marked off by long nylon lines. The two-meter cores struck bottom only on the upper slopes of the reef, however, and we are not discouraged from looking deeper with mud-penetrating sonar in the future.

The large, four-man, double-lock recompression chamber, which we had first installed on Yassi Ada in 1967, saved a life in 1969. Eric Ryan, a veteran of all our expeditions, suffered an air embolism and lost consciousness in twenty feet of water, just before entering our submersible decompression chamber (sdc) for decompression. Only the skill of his diving partner, chief diver Robert Henry, and an elaborate communications system of underwater telephone and two-way radios linking the sdc, the diving barge, and Yassi Ada itself, enabled us to place Ryan in the large chamber within a few minutes, preventing a certain fatality. Even so, numbness and some weakness in both legs and an arm remain, perhaps permanently.¹⁸

THE HULL

The wreck plan shown in pl. 4, fig. 4, is the Multiplex map made during the 1969 season modified by additions and corrections based on many detail photographs taken throughout the excavation, the partial wreck plan made during the 1967 season, and scale drawings of hull members raised in 1969.

The ship had come to rest on her keel and port bilge on a moderately steep slope which fell away in the direction of her port quarter. The sea bed in the area was of loosely packed sand, and the hull settled far enough into it so that most of the middle

third of the hull bottom on the port side immediately came into full contact with the sea bed. As a result, this portion of the hull was particularly well preserved. Substantial portions of the side of the hull to port were also preserved up to the fourth wale, which was probably set very near or at deck level. Starboard of the keel, where none of the hull initially had been in contact with the sea bed, little wood survived beyond the garboard.

Almost the entire length of the ship was in some way represented by the hull remains. Portions of 46 consecutive frames survived out of an estimated original total of 65. The A and B series of labels assigned to the surviving frames on the wreck plan is purely arbitrary, this designative system having been devised when the two extremities of the wreck were not yet uncovered. Approximately half of the total length of the sternpost survived in two well-preserved sections, which will make possible an accurate reconstruction of the stern. Only the foremost three m. of the hull had entirely disappeared, along with all identifiable traces of the stem.

The timbers raised during the 1969 season included all of the keel between its stern end and frame A-3, the two sections of sternpost, the starboard garboard, frames A-1 through A-15, B-1 through B-13 and B-21 through B-30, most of the surviving ceiling planking between frames B-7 and B-14, surviving sections of wales 1 through 3 between frames A-5 and B-11, and one small section of wale 4.

Two tentatively reconstructed sections of the hull have been drawn to date: one amidships at frame B-8 (pl. 1, fig. 5) and one a meter aft of the juncture of sternpost and keel at frame B-23 (pl. 1, fig. 6). An additional section has been drawn in rough outline form at frame A-7, which was located approximately half a meter forward of the juncture of stem and keel. These three sections combined with the known curvature of the surviving sections of the sternpost indicate that the ship's overall length was in the neighborhood of 19 m. The sternpost, keel and stem appear to have

¹⁶ J. E. Sanders, "Diver Operated Simple Hand Tools for Coring Nearshore Sands," *Journal of Sedimentary Petrology* 38:4 (December 1968). Our corer was built and operated by John Gifford.

¹⁷ C. Colani, "A New Type of Locating Device. I. The Instrument," *Archaeometry* 9 (1966) 3-8. E. Foster, "Further Developments of the Pulsed Induction Metal Detector," *Prospezioni Archeologiche* 3 (1968) 95-99.

¹⁸ The staff responded to the emergency with remarkable efficiency: David Leith, M.D., administered the latest Navy

oxygen treatment inside the chamber, which was operated by Laurence T. Joline (himself the victim of an embolism or the bends at Yassi Ada in 1961); John Owen was in charge of compressors and generators, and Sanford H. Low was time-keeper. Later in the summer we cured a local diver, brought to us for treatment, of paralysis from the bends; and still later, a local sponge diver died inside the chamber, almost certainly from a perforated ulcer rather than from the diving illness which he had also contracted.

made about equal contributions to the overall length. The hull's maximum width, ca. 6.6 m., occurred at or very near midships.

Turning now to a description of the various components of the hull that have survived in some part, we may best begin with the longitudinal spine of keel, sternpost and stem.

The keel was cut from a single full timber and had no vertical curvature toward its extremities. Its point of juncture with the sternpost can clearly be seen on the wreck plan just forward of frame B-19. Here the keel had a width of 9.5 cm., but it widened toward the bow at a strictly uniform rate, attaining a 12.2 cm. width 4.2 m. forward of the stern end. Measurements of width beyond this point are not as yet available. The keel was 22 cm. high. Throughout its length, it had a simple rectangular cross-section, with no rabbets for the seating of the garboards. Instead, the garboards were set flush to the upper face of the keel and were edge-joined to the keel by mortise and tenon joints of the same size as those throughout the hull's outer shell (pl. 1, fig. 5). Immediately beyond the keel's two extremities, however, where the sternpost and stem began, the upper face of the spine rose above the level of the garboards, and the latter were seated in rabbets cut into the sides of the spine and were fastened in place by iron nails driven through from the outside into the upper surface of the rabbets at 10-20 cm. intervals (pl. 1, fig. 6). The upper face of the spine, while still flush with the garboards at the juncture of keel and sternpost, attained a vertical height of ca. 8 cm. above the garboards some 40 cm. aft of this juncture and maintained this height above them thereafter. Since the rabbets were cut into the sides of the sternpost to a depth of 2-3 cm., the sternpost had to be somewhat wider than the keel was at the stern end. At frame B-23, the sternpost was 12.7 cm. wide, but it tapered slightly toward its upper end, the upper surviving section being only 11.6 cm. wide. The vertical height of the sternpost at frame B-23 was 28 cm. Although no identifiable remains of the stem were uncovered, a surviving portion of the forward end of the port garboard revealed that the garboards had been fastened to it in the same way that they had been fastened to the sternpost. This piece of

planking is located on the wreck plan just forward of frame A-7 and has been labeled G.

About 4.4 m. forward of its juncture with the sternpost, the keel was badly shattered into a great many small pieces (perhaps at the time of the shipwreck) and could not be directly traced further. Forward of frame A-5, however, a short but solid section of timber was found lying on the longitudinal axis of the keel. The exposed top surface of this timber, which unfortunately has not yet been raised, seems to have abruptly terminated just aft of frame A-6, and it is precisely at this point, 6.2 m. forward of the keel's stern end, that the juncture of the keel and the stem most probably occurred. The forwardmost portion of the starboard garboard to survive revealed that the garboards were not yet seated in rabbets here. The piece of planking labeled G, on the other hand, revealed that the garboards were seated in rabbets just 10-20 cm. forward of this point.¹⁹

While nothing is known about the nature of the juncture between keel and stem, the general configuration of the scarf joint joining keel and sternpost is known. At their juncture, the upper half of the keel and the lower half of the sternpost were cut back about 35 cm. to form the joint. The upper forward face of the sternpost was dovetailed into the upper after face of the keel. The tenon still survives. No traces of any fastening running vertically through the two halves of the joint have as yet been detected.

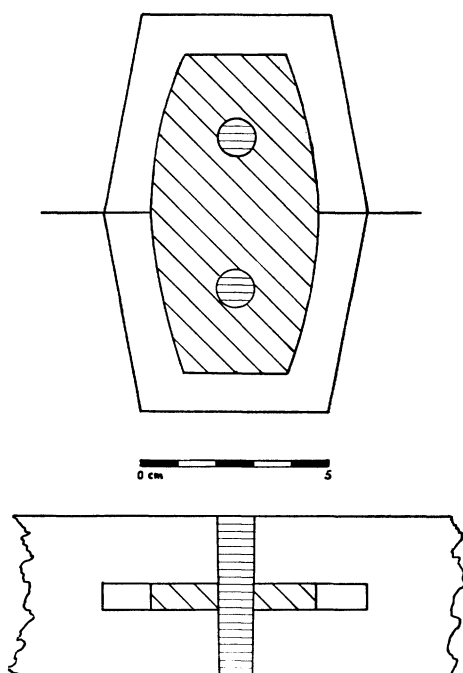
Apart from the garboards, which attained a thickness of 5.3 cm. along their inner edge, the outer hull planking had a thickness of 4.2 cm. There were twenty planking strakes in all between the keel and the first wale. The maximum width of the individual strakes ranged from 11 to 25 cm. The wales that have in part survived had the following cross-sectional (width x thickness) dimensions amidships: wale 1, 16x16 cm.; wale 2, 17x10 cm.; wale 3, 12x16 cm.; wale 4, ?x16 cm. Wales 1 and 2 apparently had a more or less horizontal attitude throughout from stem to stern, while wale 3, which curved up at either end, probably ran fairly parallel to deck and gunwale through much if not all of its length.

There is certain evidence that all of the outer

latter two pieces of planking were plotted on the Multiplex map, and they appear on the wreck plan. Plank fragment G is 1.15 m. long and had been seated in a rabbet throughout its length.

¹⁹ Although plank G was not found in situ, its original position within the hull was easily determined since it preserved a portion of the forward feather tip of the port garboard, and the forward ends of the neighboring outer hull strakes 2 and 3 on the port side had survived in situ. The positions of the

hull strakes up to and including wale 3 were edge-joined together. Pertinent evidence is as yet lacking for the strakes beyond this point. The distance between the mortise and tenon joints was essentially uniform throughout the outer shell, the normal interval from center to center between joints being about 25 cm. With few exceptions, the individual mortises cut into the edges of the strakes were 7-9 cm. wide at the surface, penetrated to a depth of 5.0-5.5 cm., were 0.7 cm. thick, and markedly decreased in width as they penetrated into the side of the strake (ill. 1). The tenons,



ILL. 1. Typical mortise and tenon joint

normally about 4.5 cm. wide and 8.5 cm. long, were much smaller than the mortises into which they were inserted and were strongly tapered at the ends. This gave the shipwright plenty of "play" while fitting the strakes one to the other. Once a strake had been properly fitted to the strake below, each tenon was permanently fastened in place by a pair of treenails. These treenails had a maximum diameter of 1.0 cm. at the inner surface of the strakes but tapered to a diameter of 0.7-0.9 cm. at the other end, and it is important to note that they were driven in from the *inside* of the hull, for a substantial number of them were located underneath frames when the hull was finished. Such

treenails were located under virtually every frame within the area of well-preserved outer hull planking, and some of them were so located as far up the side of the hull as wale 2. It is very possible although not as yet certain that one or two such examples occur within the surviving portions of wale 3 as well. These treenails must have been driven in before the overlying frames were in place. Thus the outer hull had certainly been completed at least up to the level of wale 2, and probably entirely completed, before the frames were inserted.

The sections of planking that went to make up each planking strake had diagonally-cut butts which were edge-joined together, two or three mortise and tenon joints normally being employed in the joining. Later, after the frames had been inserted, the feathered ends of the planking sections were fastened to frames by iron nails driven from the outside.

The ends of the planking strakes were fastened to the sternpost and stem rabbets with iron nails as were the garboards, but a different method appears to have been employed in fastening the ends of the wales. The upper section of sternpost to survive has near its upper end a hole for an iron bolt running through its thickness. This hole emerges at either side within the confines of the rabbets. It is likely that an iron bolt so located was used to fasten the stern ends of a pair of wales to the sternpost. In all probability the wale involved in this case was either wale 2 or 3.

The frames were set at uniform intervals throughout the length of the hull. The distance between the centers of neighboring frames was about 24 cm. Score lines made by the shipwrights to show where the frames were to be placed were abundant on the inner surface of the outer hull strakes wherever these surfaces were well preserved. Unfortunately such surfaces were lacking beyond the twentieth strake out from the keel. The frames had a normal width of 12.0 cm. The normal height throughout most of their preserved lengths was 12.5 cm., but directly over the keel the frames attained a height of 35 cm. amidships and heights approaching 40 cm. at either end of the ship.

Frames with floors alternated with frames without floors. This alternation is most clearly illustrated on the wreck plan by frames B-4 through B-9. The floors normally extended out as far as the sixteenth strake from the keel. The futtocks in most cases butted against the floors, but the butts usu-

ally were not carefully cut nor were the futtocks and floors ever fastened together. The port and starboard members of the frames without floors met directly over the center line of the keel in a carefully-cut vertical butt joint, but they too were not fastened together at this joint in any way. None of these members survived to their full length. One may note, however, that if they were the same length as the floors, they would have easily extended beyond deck level.

The floors of frames B-29, B-27 and B-23 were bolted to the sternpost, and the floors of frames B-17, B-11 and B-4 were bolted to the keel. The bolts were of iron with heads 3.7-4.5 cm. in diameter and shafts 2.0-2.6 cm. in diameter at the base of the head. The bolts were inserted from the bottom face of the sternpost and keel. If bolted floors were uniformly distributed along the length of the keel, then the floor of frame A-3 also was bolted to it, but direct evidence on this point is not yet available. The primary function of this series of bolts was undoubtedly to bind the spine to a keelson—which has disappeared without a trace along with the top ends of all the bolts. None of the frames other than those with bolted floors were fastened to the spine in any way.

Large treenails 1.6 cm. in diameter were used in fastening the frames to the outer hull planking. Each frame was fastened to each of the planking strakes by at least one treenail, while in the case of the strakes that exceeded ca. 15 cm. in width, two were used in every other frame. The positions of the treenails were staggered along the length of each strake so that long splits would not develop in the planking.

Long, slender iron spikes were used in fastening the frames to the wales. These spikes were driven through from the inside, and the ends were clinched over on the outer face of the wales. Only one section of frame that was fastened to a wale has been recovered from the wreck. This section belonged to the port futtock of frame B-8 (pl. I, fig. 6). An examination of this member revealed that a hole had been drilled through the futtock at the point where it was to be fastened to wale 1. A treenail was inserted in the hole, and an iron spike was then driven down through the treenail and through the wale. It is interesting to note that while each consecutive frame had been fastened to the sections of wale 1 that were raised, only every other frame had been fastened to the raised sections of wale 2, while

the intervals between fastenings in the raised section of wale 3 ranged from every other frame to every fourth frame.

There is some reason to believe that the ship's mast may have been stepped between frames B-9 and B-11. The alternation of frames with and without floors is interrupted here by frame B-10, which ends in a vertically-cut butt near the outer edge of the second outer hull strake. This peculiarity prompted an examination of photographs taken of the outer hull planking in this area. The photographs revealed that almost all of the inner surface of the port garboard between frames B-9 and B-11 had been slightly eaten away by teredo worms. Such eaten surfaces occurred everywhere on the inner surface of the outer hull planking where frames infested with teredo worms were resting upon it, but otherwise occurred very infrequently. It is quite likely, therefore, that a wooden member of some sort which has totally disappeared had been resting on the inner surface of the port garboard between frames B-9 and B-11. It is not known if evidence for the presence of such a member also existed on the inner surface of the second outer hull strake, since that strake did not survive between frames B-9 and B-11. If such a member did in fact exist, it might very well have been a part of the mast step complex. A mast step so located about one-half meter aft of midships and partly braced against the bolted floor of frame B-11 would have been well suited for a slightly forward raking mast set amidships. Perhaps the 26 cm. long piece of wood appearing on the wreck plan between frame B-10 and the keel was a chock used in bracing the mast. It is rectangular in cross-section and tapers both in width and in thickness. At its rounded end, it is 7.0 cm. wide and 3.2 cm. thick; at the other end, 8.5 cm. wide and 5.0 cm. thick. A hole 1.0 cm. in diameter, centered 8 cm. in from the rounded end, runs through the thickness of the wood.

Throughout the keel's length, a single limber hole, normally about 6 cm. wide and 9 cm. high, was cut through the underside of each frame directly above the keel's center line, permitting a free circulation of bilge water along the keel's upper face. This was the lowest point within the hull, since the hull bottom was V-shaped in cross-section and the garboards were set flush with the keel's upper face. Beyond the ends of the keel, however, the upper face of the spine rose above the level of

the garboards, and the flow of bilge water was diverted to either side of the spine, where it flowed through triangular openings formed by garboards, spine and frames. At the stern, these openings were more than adequate for the flow of water at frame B-23 (fig. 6), and would also have been adequate at frame B-22. At frames B-21 and 20, however, the spine was just beginning to rise above the level of the garboards so that the triangular openings were as yet quite small. To augment their size, triangular cuttings were made directly above them through the underside of the frames. The pair of cuttings in frame B-21 can be seen on the wreck plan, as can one of the pair of cuttings in frame A-7, which was located in a comparable position at the forward end of the ship.

A rather thick deposit of bilge sludge was found covering much of the keel's upper face. It contains among other things large amounts of sawdust, wood chips and twigs, undoubtedly remnants of dunnage used in stowing cargo in the hold.

Some fragmentary remains of the ceiling (inner flooring) had survived within the middle body of the wreck. These remains probably belonged to eleven contiguous strakes which ran above outer hull strakes 7-17. All these ceiling strakes were of 3.8 cm. thick planking, in most cases 13-16 cm. wide. Iron nails were used to fasten the planking to the frames. No cuttings were found on any of the top surfaces of the fragments.

Apparently only two basic types of wood were used throughout most if not all of the hull.²⁰ The sternpost, outer hull planking, wales, frames and floors, ceiling planking and small treenails used in the mortise and tenon joints were of Mediterranean cypress (*Cupressus sempervirens*). The tenons and the large treenails used in fastening the frames to the outer hull planking were of a wood belonging to the live oak group, the keel of a wood belonging to the white oak group. It is possible that at least some of the futtocks were not of the same wood as the frames and floors. This uncertainty will be resolved in the near future by the identification of additional samples.

A galley or cookhouse was located at the very stern. The find spots of objects from the galley are shown on the wreck plan: many of them were

found immediately aft of frame B-29, very few forward of it.

The distribution and orientation of the cargo amphoras on the wreck reveal that they certainly had been stowed within the hold as far aft as frame B-29 but probably not beyond it. Since the ship had come to rest on a sloping bottom with her bow facing upslope, the amphoras in the forward part of the hold had shifted back toward the stern so that their final orientation was for the most part completely random. The same was true of the upper layers of amphoras in the after part of the wreck, but here the masses of amphoras in the upper layers had prevented the bottom ones from shifting about a great deal so that most of the latter were still neatly arranged in rows (pl. 1, fig. 7). The after limit of amphoras still so arranged has been indicated on the wreck plan: up to but not beyond frame B-29. It was precisely along the line of this frame, moreover, that the density of amphoras at the stern of the wreck began to fall off rapidly. A total of only some 50 amphoras were found further aft, over 30 of these less than a meter beyond the frame in question.

Few if any of the objects from the galley were found lying above amphoras or large fragments of amphoras. To be sure, small objects commonly filter down through the amphoras on wrecks such as this, but large, bulky things do not. Among the objects recovered from the galley were about two dozen stone slabs, most of which had at least one dimension over 30 cm. They were all found within the galley area, and their size, shape and general composition suggest that they are the remains of a hearth. Those of the stones that were lying in areas occupied by amphoras were in every case found underneath the amphoras.

This evidence leads one to conclude that there had been a transverse partition wall within the hull at frame B-29. Forward of this partition was the hold; aft of it, the galley. As the ship broke up, the partition wall gave way, and a relatively small number of amphoras in the hold rolled down into the galley, coming to rest on top of objects within it.

One other point to note is that the floor of frame B-29 was bolted to the sternpost even though the next floor forward (frame B-27) also was so bolted. In all other instances that can be documented in

²⁰ Mr. B. Francis Kuchachka of the Forest Products Laboratory, U.S. Department of Agriculture, Madison, Wisconsin has once again very kindly undertaken the identification of wood

samples. His continued enthusiastic assistance in this matter is warmly appreciated.

the hull, there were either two or three intervening floors between those that were bolted. It is likely, then, that the shipwrights had a partition wall in mind in bolting the floor of frame B-29.

A sketch reconstruction of the ship's stern based on the known curvature of the bottom half of the sternpost indicates that frame B-29 was set approximately 3 m. forward of the stern end of the ship. The seventh-century Byzantine ship at Yassi Ada, which had the same overall length as this one, had a partition wall separating hold and galley 2.5 m. forward of the stern end, located at a frame whose floor was bolted to the sternpost.²¹ Perhaps longstanding traditions of shipbuilding are at work here.

THE FINDS

Approximately 1,100 amphoras were plotted and mostly removed from the wreck. These formed the bulk of the cargo, stacked upright as is seen in the bottom, undisturbed layer (pl. 1, fig. 7), but other amphoras lie still buried under sand where they have toppled downslope. The amphoras were of three types:

Type I is represented by RW 2 (H. .66, max. D. .40; pl. 2, fig. 8), of reddish-brown, well-fired fabric. Its horizontally ribbed body swells downward to a pronounced, low belly and ends in a conical knob; the triple-ribbed handles are attached below the lip and to the middle of the sloping shoulder. Random measurements of volume for this type ran between 37 and 40 liters.

Type II is similar in fabric, ribbing, and height (RW 4: H. .675, max. D. .29; pl. 2, fig. 9), but its body is nearly cylindrical, as is its ribbed knob at the base, and its handles are attached lower on its neck. No measurement of volume has yet been taken for this type.

Type III is much smaller, of orange-brown clay, and has its maximum diameter at its shoulder (RW 5: H. .451, max. D. .296; pl. 2, fig. 10); its base is rounded, with a tiny button or nipple in the center. The ribs may be closely or widely spaced (cf. RW 1: pl. 2, fig. 11). Volumes were measured as between 13.7 and 14.4 liters.

Stoppers were of roughly cut amphora sherds (pl.

2, fig. 12), although one wooden stopper was also found.

Only representative amphoras were raised to the surface, and no exact figure can be given for the number of each type. A study of the plans seems to show that approximately 40 per cent of the cargo was of Type I, 33 per cent of Type II, and less than 30 per cent of Type III; the percentage of Type III may well be even smaller. I have not found parallels for any of these types convincing enough to allow a reconstruction of the route of the ship.

The ceramic contents of the galley were two large plates, a smaller dish, one bowl, eleven pitchers, one cup, four cooking pots, one jar, three small storage amphoras, two very large amphoras (for water?), a funnel, and four lamps, all found some distance down the slope from the wooden hull remains, under a considerable depth of sand. There is therefore every reason to suspect that more pottery, and other small finds, would be found if the limits of the excavation were extended. Thus, although the group provides evidence for dating the wreck and perhaps clues to the ship's route, it cannot yet be claimed as a representative collection of pottery in a fourth-century merchantman; the small number of cooking pots, as compared to the numerous pitchers, is at variance with the better balanced group of the seventh-century Byzantine ship excavated near by.

One of the plates (RW 154: D. .40, H. .056; pl. 2, fig. 13a-b) is of pinkish-red, slipped fabric, with a nearly orange band on the exterior and top of its rim; wheel marks have left a pronounced spiral design on the bottom, inside the low ring base.²² The profile is similar to Antioch no. 836a (Late Roman A ware) which Waagé dates to the Early Phase of the Late Roman period, and the small diameter of the base suggests that the plate is probably early in the 836 series, possibly even from the last half of the third century,²³ much earlier than the other ceramic material in the ship. John Hayes suggests that the plate is most probably a crude Cypriot copy of Antioch 836; this, more than an early date, may explain the shape.

The other large plate (RW 174: D. .416, H. .039; pl. 2, fig. 14a-c) is somewhat similar in profile to

²¹ G. F. Bass and F. H. van Doorninck, Jr., "Excavations of a Byzantine Shipwreck at Yassi Ada, Turkey," *National Geographic Society Research Reports: 1964 Projects* (1969) 17.

²² Cf. R. Pagenstecher, *Expedition Ernst von Sieglin, Aus-*

grabungen in Alexandria II 3, Die Gefässe in Stein und Ton, Knochenschnitzereien (Leipzig 1913) 117 fig. 128.

²³ F. O. Waagé, *Antioch on-the-Orontes IV 1, Ceramics and Islamic Coins* (Princeton 1948) 49, 54-55, and pl. ix.

Antioch no. 817 (Late Roman B ware).²⁴ The interior decoration of stamped latticed squares is common on this class of pottery; similar, but half size, squares occur at Labraunda,²⁵ where Hellström assigns a late fourth or early fifth century date on the basis of comparisons with similar motives from Antioch,²⁶ the Athenian Agora,²⁷ and Alexandria.²⁸ The gouges on the exterior surface of the bowl are duplicated on a sherd from Athens.²⁹

The smaller dish (RW 162: D. .225, H. .044; pl. 2, fig. 15) of red-slipped fabric has been identified by John Hayes as an example of his Cypriot Red Slip ware (Waagé's Late Roman D, and also E);³⁰ he has mentioned a very similar piece in the Saloniki Museum (no. 488).

Lastly, Hayes has identified our single, salmon-pink bowl (RW 204: D. .225, H. .044; pl. 2, fig. 16) as being African Red Slip ware, from the mid-to late-fourth century. I have not found an exact parallel for the rim, but the basic shape of the bowl is that of Lamboglia's Shape 57 in "Terra Sigillata Chiara D."³¹ It must be remembered that what archaeologists in the western Mediterranean call "sigillata chiara" ("sigillée claire") A and D is exactly the same ware as "Late Roman B," in its earlier and later phases, in the eastern Mediterranean, and "sigillata chiusi" C corresponds to "Late Roman A Ware."³² J. W. Salomonson has recently summarized the strong evidence in favor of a North African origin for all the "sigillée claire" wares,³³ but they were so widely spread by the fourth century that the Yassi Ada ship could have picked up its examples in almost any port in the eastern or western Mediterranean.

Of the pitchers, one of dark brown, gritty fabric (RW 181: H. .235, max. D. .128; pl. 2, fig. 17) is quite similar to two painted oinochoai from the Athenian Agora;³⁴ its mouth more closely resembles that of the early fourth-century example (M 213), but the rest of the body is more like that of

the late fourth-century one (M 265). The variety of shapes and fabrics among the remaining pitchers is indicated by representative illustrations: RW 218 (H. .223, max. D. .197; pl. 3, fig. 18), of gritty, dark orange clay, is incised on its base with four crossing lines forming eight spokes, one of which forms the base for an incised semi-circle. RW 194 (H. .245, max. D. .156; pl. 2, fig. 19) is of mottled yellow- to orange-buff fabric; RW 187 (H. .275, max. D. .201; pl. 2, fig. 20) of fine, light pinkish-buff; and tiny RW 139 (H. .11, max. D. .076; pl. 2, fig. 21) of a coarse sandy fabric ranging in color from gray to pinkish.

The single cup found with these pitchers³⁵ differs in fabric from the rest of the pottery on board, being highly polished brown, and very thin (RW 243: H. .085; pl. 3, fig. 22).³⁶

The number of cooking pots found so far in the galley is much less than the twenty-odd carried on the Byzantine ship, which was approximately of the same size. The distinctive, angular profile of one of these (RW 167: H. .195, max. D. .215; pl. 2, fig. 23) is reminiscent of the somewhat earlier Type 2G from Vasa in Cyprus, as is the reddish fabric, but I do not know if this shape continued far into the fourth century on that island.³⁷ RW 171 (H. .215, max. D. .247; pl. 2, fig. 24), a sandy, dark gray to black pot, is the only cooking vessel found so far without handles.

At least two of the storage vessels in the galley find close parallels in the Athenian Agora. A dark, reddish-brown, highly micaceous jar with one handle (RW 168: pres. H. .482, max. D. .179; pl. 2, fig. 25) is similar in size, shape and fabric to M 255,³⁸ although its base more closely resembles that of M 256; both Athenian jars are dated to the middle of the fourth century. The other jar, a round-bellied amphora with carinated shoulder and low ring base, of orange to red-orange fabric (RW 173: H. .405, max. D. .293; pl. 3, fig. 26) is of the same

²⁴ *Ibid.*, 48, and pl. viii.

²⁵ P. Hellström, *Labraunda, Swedish Excavations and Researches II* 1 (Lund 1965) 42-43, 74 and pl. 16: pottery no. 327.

²⁶ Waagé, *Antioch IV* 1, fig. 29, nos. 4, 7 and 14.

²⁷ Waagé, "The Roman and Byzantine Pottery," *Hesperia* 2 (1933) 297, fig. 3, sherd no. 148; tentatively identified as A ware.

²⁸ Pagenstecher (supra n. 22) 115, with fig. 126.

²⁹ Waagé, *Hesperia* 2 (1933) 297, fig. 3, no. 182.

³⁰ Waagé, *Antioch IV* 1, 53, shape 928, and pl. x.

³¹ N. Lamboglia, "Nuove osservazioni sulla terra sigillata chiara (tipi C, lucente e D)," *RSiLig* 29 (1963) 204.

³² J. W. Salomonson, "Sigillée claire et céramique commune

de Henchir el Ouiba (Raqqada) en Tunisie centrale," *BABesch* 43 (1968) 89-90.

³³ *Ibid.* 91-95.

³⁴ H. S. Robinson, *The Athenian Agora V, Pottery of the Roman Period* (Princeton 1959) 104, 109 and pls. 27 and 29.

³⁵ Only one cup was found with the more than 15 pitchers in the completely excavated galley area of the 7th-century ship at Yassi Ada; G. Bass, *AA* (1962) fig. 11 on 550.

³⁶ Cf. P. Lazarithes, "Anaskaphai Neas Angialou," *Praktika* (1965) 22, with pl. 4,b (left).

³⁷ J. du P. Taylor, "Roman Tombs at 'Kambi' Vasa," *Report of the Dept. of Antiquities, Cyprus* (1940-48) 25, 45 and pl. 11.4; fig. 13 on p. 36.

³⁸ Robinson (supra n. 34) 108 and pl. 28.

type as M 254 in the Agora, dated also to the middle of the fourth century.³⁹ The remaining two small amphoras are quite different in shape and fabric: RW 175 (H. .246, max. D. .192; pl. 3, fig. 27) is of an orange to pinkish, gritty and pitted soft fabric, and its ovoid body, atop a crude ring base, is decorated with random shallow grooves. A piriform amphora, with high cylindrical base (RW 164: H. .535, max. D. .27; pl. 3, fig. 28) is marked by a lumpy, uneven silhouette, and an oval hole (.025 x .02) cut through the center of one side of the body at shoulder height; it is of a coarse, yellow to dark gray fabric mottled with orange. Lastly, the two extremely large, cylindrical amphoras with knobbed bases and curving necks must have stood side by side within the galley (RW 203: H. .925, max. D. .40; pl. 3, fig. 29); their smooth, gray to yellowish and reddish buff fabric is quite unlike that of the cargo amphoras.

Although funnels are not uncommon in the Aegean at this time, I have not found a good parallel for the Yassi Ada example (RW 163: H. .27, D. of mouth .29; pl. 3, fig. 30). It may be of interest that no funnel was found on the Byzantine ship, which did carry a wine thief.⁴⁰

The four lamps from the galley once more mark the paucity of ceramic material on this merchantman as compared to the seventh-century Byzantine ship which carried twenty lamps;⁴¹ it is possible, however, that there were also glass lamps on board, as we shall see below. The impressed signature KY on the base of one (RW 158: pres. L. .09, W. .071; pl. 3, fig. 31) marks it as from an Athenian workshop which flourished from the second quarter of the fourth century into the first quarter of the fifth;⁴² its shape, size and decoration are closely matched by an Attic example from the second half of the fourth century,⁴³ and the small circle im-

pressed on the nozzle is an Attic feature of the same period.⁴⁴

Lamps RW 178 (L. .11, W. .07, body H. .029; pl. 3, fig. 32) and RW 155 (L. .11, W. .07, body H. .028; pl. 3, fig. 33) are both African Red Slip Ware types (Hayes' Type I, which he dates to roughly the mid-fourth through early fifth century), and are quite like Salomonson's Type j,⁴⁵ made at Henchir es Srira and other workshops in North Africa during the second and third quarters of the fourth century; the examples from Yassi Ada do not have pierced handles, which are common in Salomonson's type. Such lamps were often exported, and their wide distribution is indicated by an example with running hare (?), otherwise similar to our RW 178, found at St. Lorenzen in Pustertal.⁴⁶ Both are also Pohl's Mediterranean Lamp Type 2.⁴⁷ RW 155 bears some resemblance to a lamp found at Corinth⁴⁸ which may be dated to the second half of the fourth or early fifth century by the signature ΕΠ on its base.⁴⁹

Lamp RW 128 (L. .10, W. .062, body H. .023; pl. 3, fig. 34) is of great interest. Its shoulder, base, and handle may be duplicated almost perfectly by lamps from the seventh-century wreck—so perfectly that we might wonder if it somehow drifted downslope from the later wreck and joined the lamps in the fourth-century ship's galley (unlikely, but not impossible, as will be seen in the description of the sixteenth-century ship below). Except for the design on its base, it is similar to a lamp of uncertain date from Samos.⁵⁰ It is also like an undated example from Lindos,⁵¹ and except for its handle very similar to a lamp from Delos⁵² which Bruneau compares to a sixth-century lamp from Ephesus;⁵³ its shoulder decoration and palmette handle are also represented by another Byzantine lamp from Ephesus.⁵⁴ On the other hand, its bottom closely resembles that of a lamp from Labraunda, of

³⁹ *Ibid.*

⁴⁰ G. Bass, *AA* (1962) fig. 7 on 546.

⁴¹ *Ibid.*, fig. 16 on 553-554.

⁴² J. Perlzweig, *The Athenian Agora VII, Lamps of the Roman Period* (Princeton 1961) 41.

⁴³ *Ibid.*, 154 and pl. 31, no. 1912.

⁴⁴ *Ibid.*, 154 and pl. 32, no. 1918.

⁴⁵ J. W. Salomonson (supra n. 32) 87, 94-95, with figs. 2:1 and 6:2.

⁴⁶ R. Noll, "Die antiken Lampen in Landesmuseum zu Innsbruck," *JOAI Beibl* 30 (1936-37) no. 59, p. 250 and fig. 82 on p. 247.

⁴⁷ G. Pohl, "Die Frühchristliche Lampe vom Lorenzberg bei Epfach, Landkreis Schongau," *Aus Bayerns Frühzeit* (Festschrift Friedrich Wagner; Munich 1962); compare RW 155

with pl. 24 no. 4; and RW 178 with pl. 24 no. 1.

⁴⁸ O. Broneer, *Corinth IV ii, Terracotta Lamps* (Cambridge, Mass. 1930) 238, no. 1034, fig. 167.

⁴⁹ Perlzweig (supra n. 42) 33.

⁵⁰ A. M. Schneider, "Samos in Frühchristlichen und Byzantinischer Zeit," *AthMitt* 54 (1929) 133, no. 37, with fig. 30:3 (upper).

⁵¹ Chr. Blinkenberg, *Lindos I. Les petits objets* (Berlin 1931) pl. 151, no. 3205.

⁵² P. Bruneau, *Delos XXVI, Les lampes* (Paris 1965) 141, no. 4714, and pl. 34 = W. Deonna, "Les lampes antiques trouvées à Delos," *BCH* 32 (1908) fig. 45.

⁵³ *Ephesus IV 2, Das Cômeterium der Sieben Schläfer* (Vienna 1937) pl. x no. 1878.

⁵⁴ *Ibid.*, pl. x no. 1880.

Asia Minor type, which may well date to the end of the fourth century or the first half of the fifth.⁵⁵ Thus RW 128 may be simply a very early example of a type which continued almost unchanged from the fourth to the seventh century.⁵⁶

Of the five glass finds on the wreck, two sherds may be rims of conical glass lamps⁵⁷ (RW 159: lip of yellowish vessel ca. .10 in diameter; pl. 3, fig. 35. RW 169: lip of almost clear glass vessel, estimated to be .10 in diameter, with metal stud set into the glass .028 below rim; pl. 3, fig. 36); both, however, may simply be from goblets.⁵⁸ Only one glass vessel, RW 220, was complete. This is a yellowish vase, .095 high, with rounded, nearly vertical ridges decorating its slightly asymmetrical body; a tiny raised ridge circles the neck obliquely from the shoulder to the flaring lip (pl. 3, fig. 37).

Metal finds from the galley area included two steelyards (one medium and one small) for weighing merchandise, and a copper jug. Seven of eight copper coins were also found here—the eighth being from the bow—but none were preserved well enough to allow identification. The date of the shipwreck, therefore, is at present assigned to the second half of the fourth century on ceramic evidence alone.

SEVENTEENTH-CENTURY SHIPWRECK

Long after the fourth-century ship went to the bottom, another ship sank and settled with one end extending into and over the area of the Roman ship's stern and galley. Substantial hull remains were uncovered in 1967, but neither armaments nor cargo were found, nor any clue to the date of the wreck. In fact, the hull was virtually empty except

for several glazed bowls. Three of these were nearly identical, the best preserved being RW 48 (H. .10, rim D. .18; pl. 3, fig. 38). This was light green outside, except for the unglazed brown pedestal base, and yellow-green with dark patches inside. The rim was decorated with a pair of incised lines on the exterior, and a pair of painted lines on the interior. An incised "tulip" was centered inside a pair of compass-drawn concentric circles at the bottom of the bowl.

Besides the "tulip" bowls there was only the sherd of a bowl (RW 51) glazed brown on the outside, with streaks of bright yellow looking like Kufic letters, and glazed a yellowish color inside (pl. 3, fig. 39). Found lying on the sand near by, and almost surely from this ship, was a complete bowl (RW 106) with "pie crust" rim; it was coated with a green glaze inside, but the outside was plain except for random places where the glaze had run (pl. 3, fig. 40).

The excavation of this later wreck was not continued in 1969, but a silver coin (RW 125), found very near the sternpost of the Roman wreck, has been identified by Philip Grierson as of Philip III of Spain (1598-1621). It is reasonable to assume, therefore, that other objects on the plan, lying even farther upslope than the coin, were from this later ship. These include a small amphora (RW 8) unlike those on the Roman ship, part of a cooking pot (RW 138), and two of the finest of the iron objects cast in rubber by Joline: gimbals RW 141 and axe-adze RW 119.

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⁵⁵ Hellström (supra n. 25) 83 and 52, lamp no. 72, with pl. 26.

⁵⁶ Perlzweig (supra n. 42) 10, dates the general type from the 4th to 7th centuries.

⁵⁷ D. B. Harden, *Roman Glass from Karanis* (U. of Mich. Studies, Humanistic Series 41; Ann Arbor 1936) 155ff, with pl. v, and pl. xvi nos. 436-460.

⁵⁸ *Ibid.*, no. 408 on pls. iv and xv.



FIG. 1

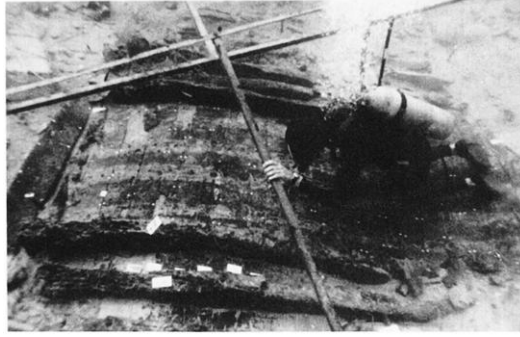


FIG. 3



FIG. 7



FIG. 2

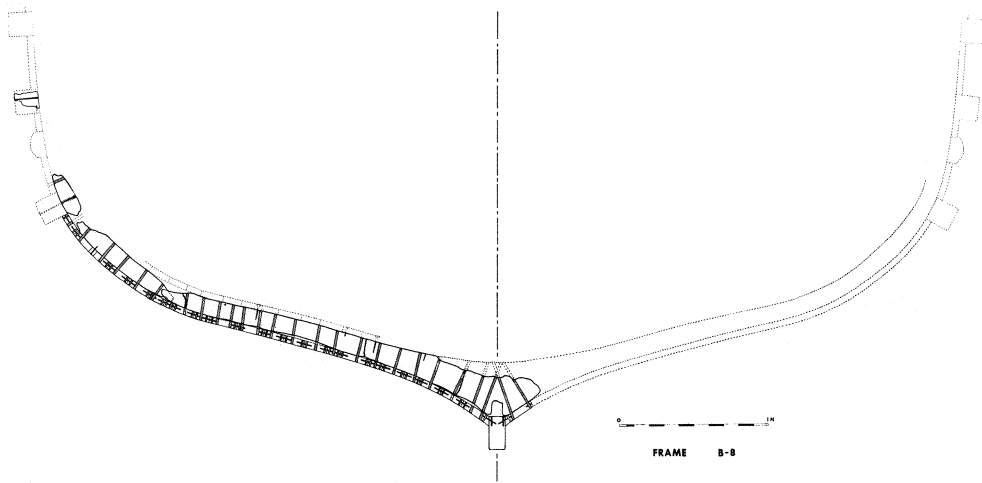


FIG. 5

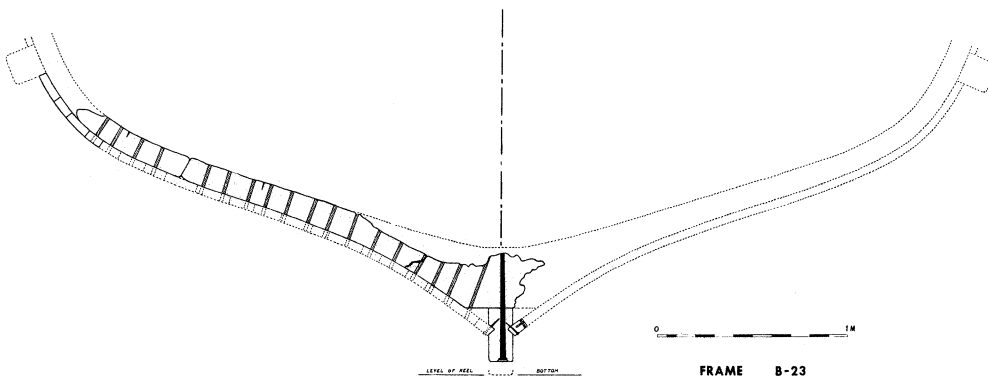


FIG. 6

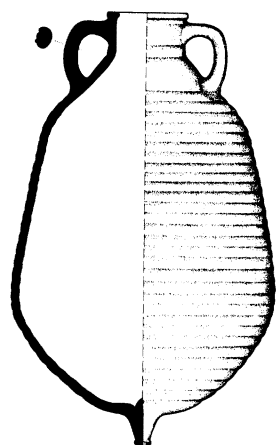


FIG. 8

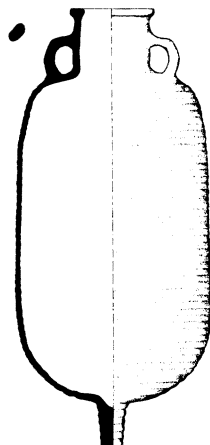


FIG. 9



FIG. 10

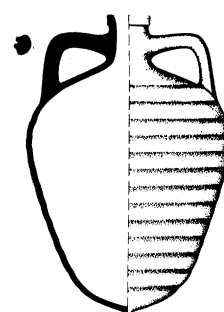


FIG. 11



FIG. 12

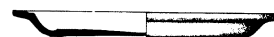


FIG. 14c

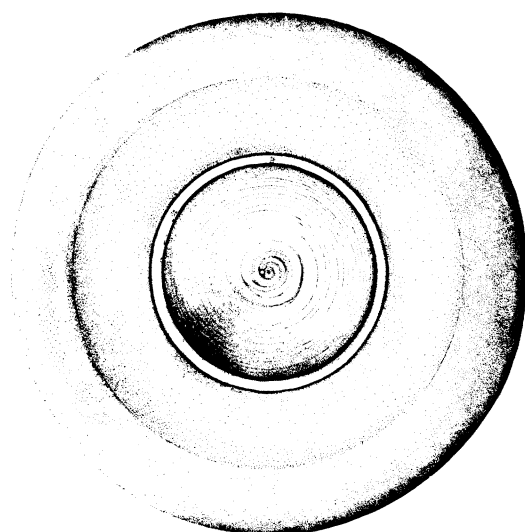


FIG. 13a

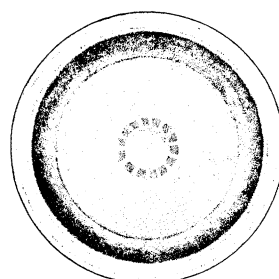


FIG. 14a

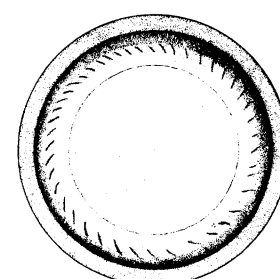


FIG. 14b

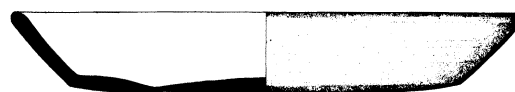


FIG. 13b



FIG. 15



FIG. 16

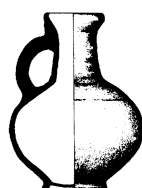


FIG. 20



FIG. 21

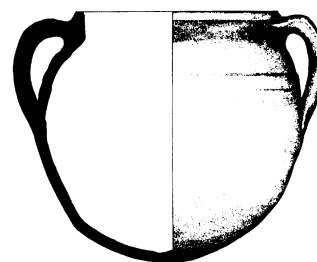


FIG. 23

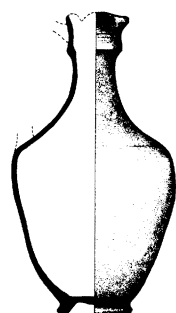


FIG. 17

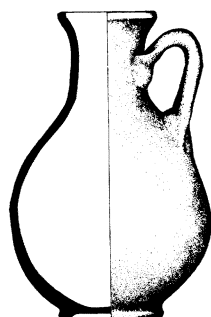


FIG. 19

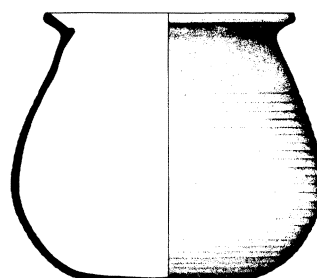


FIG. 24



FIG. 25

Figs. 8-11, 14a-c, 20, 25 are at one-half the scale of the others

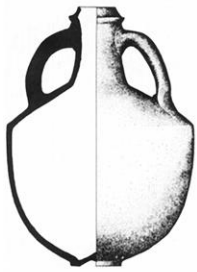


FIG. 26

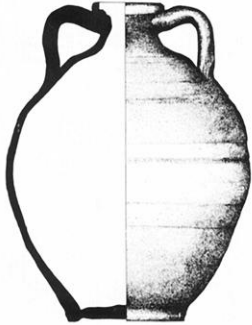


FIG. 27

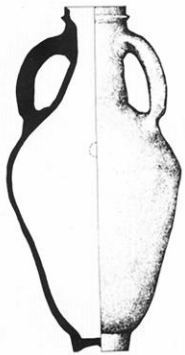


FIG. 28

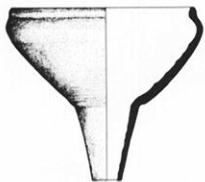


FIG. 30

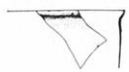


FIG. 35



FIG. 36



FIG. 18

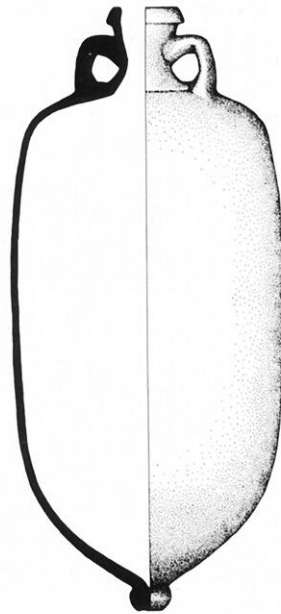


FIG. 29

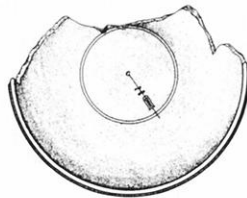


FIG. 38

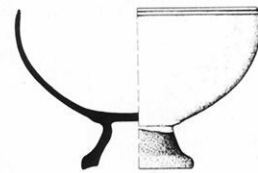


FIG. 38

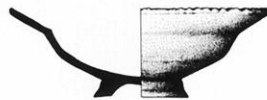


FIG. 40



FIG. 31



FIG. 31



FIG. 31



FIG. 31



FIG. 31

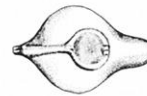


FIG. 31

FIG. 33



FIG. 32



FIG. 32

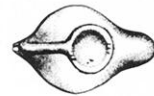


FIG. 32



FIG. 32



FIG. 32



FIG. 32

FIG. 34

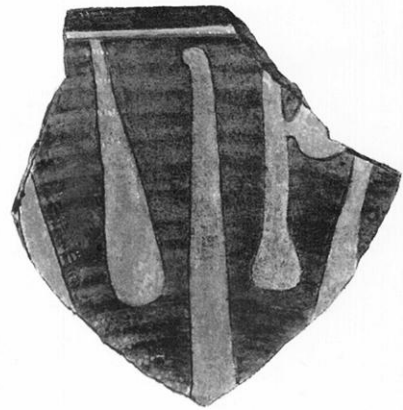


FIG. 39



FIG. 22

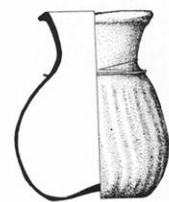


FIG. 37

All objects are not at the same scale

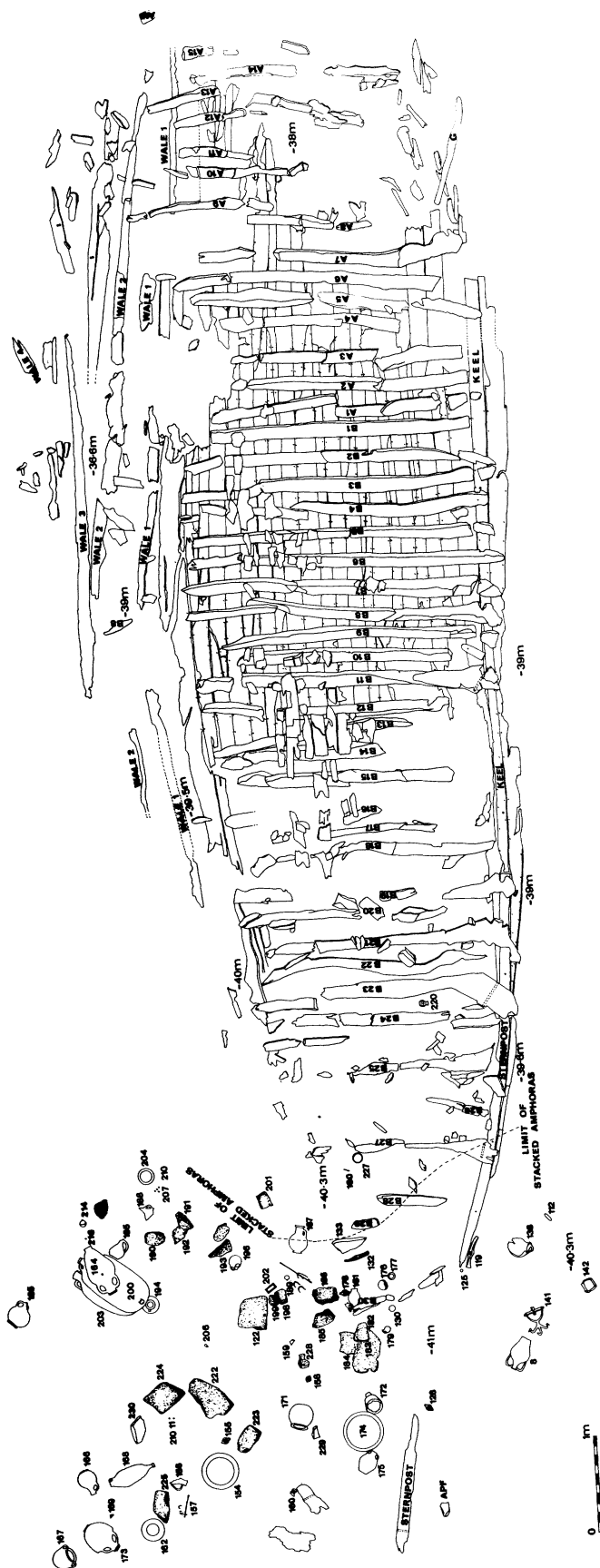


FIG. 4