NEW TOOLS for UNDERWATER ARCHAEOLOGY

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THE ARCHAEOLOGIST WHO WISHES to recover historical knowledge from the floor of the sea faces enormous problems. Despite dramatic advances during the past decade, underwater archaeology is still in its experimental stages. Better methods of finding, surveying, excavating, and conserving ancient shipwrecks must be found. The University Museum of the University of Pennsylvania has continued to experiment in all four areas.

Just how inefficient underwater excavation has been was clearly shown by our excavation of a Byzantine shipwreck at Yassi Ada, Turkey, between 1961 and 1964. This, the first complete excavation of an ancient hull and its cargo on the bottom of the Mediterranean, gave us the unique opportunity to make an efficiency study of present underwater techniques. A careful study of our diving logs revealed that, during the four summers, a total of 1,244 hours was actually spent on the wreck. This was accomplished by 3,553 individual dives during 211 diving days, or about seven months.

Additional months were spent at Yassi Ada preparing boats, barge and machinery each year for the operation. The staff usually included between ten and fifteen divers.

Simple arithmetic shows that had the same been on land, only five men working eight-hour days could have finished the same excavation in just one month. The necessity for our constant concern with new techniques and equipment is obvious.

Total work time on the Byzantine ship, lying about 120 feet deep, was broken down into specific jobs: the making of plans on the site before and during excavation, for example. totaled 204 hours, or nineteen percent of our time on the sea bed; the removal of sand and shell took 691 hours, or sixty-four percent of our total time, and of those many hours we know that 224 were spent using the air lift, or suction hose, and 470 hours simply sweeping sand away from the remains by hand. Removal of amphorae, anchors, small finds, and bullae stones, and the raising of hull remains, took most of the remaining hours.

In planning the excavation of a Late Roman wreck at Yassi Ada in 1967, we determined to take advantage of our past experience. Underwater archaeology remains relatively expensive, but we realized that we might have such annual expenses as insurance, transportation of personnel and equipment, rental of boats, and salaries of specialized technicians, if we could excavate the ship in two summers rather than in four.

There are two approaches to reducing the number of summers spent on any one ship: the first is to try to squeeze more hours of work into each summer; and the second is to try to accomplish more work during each hour spent underwater, thereby reducing the necessary number of hours. We decided to try both approaches.

THE SIMPLEST WAY TO INCREASE HOURS of work on a site is to increase the number of divers, and this we did. Although this new wreck lies at depths between 120 and 140 feet, about the limit at which we can excavate with ordinary diving equipment, we did not change our resolve to staff the expedition with those people who might best understand and interpret the work. Accordingly, we did not seek out professional divers, but offered instead a training to our university students a graduate seminar in Ancient Seafaring; three of us discussed ship construction, maritime trade, port and harbor facilities, and aspects of naval warfare in antiquity. From this and other courses, we gathered a staff consisting largely of students, including six women students, who learned to dive in a local swimming pool and received further training at Yassi Ada. By the end of the summer our divers, mostly newly trained, had made over 3,700 dives on the wreck.

The number of dives does not relate directly to the total amount of work time, however, as the deeper one dives, the less time he may spend on the dive. Dives on this Roman wreck, lying about twenty feet deeper than the Byzantine wreck, would normally be limited to only fifteen or twenty minutes a piece, twice a day. Any gain in overall efficiency by an increased number of divers would be lost by these decreased diving times.

Time limits, however, are set only by the lengths of decompression possible at the end of each dive. The deeper one dives and the longer he stays on the sea bed, the greater the amount of pressurized air that is absorbed by his body. In order to prevent this air, and especially the nitrogen in it, from forming bubbles in his bloodstream as he rises to the surface, the diver must come up slowly, in stages. This slow ascent, following a rigid schedule, is known as decompression; it prevents the formation of bubbles which cause the crippling, often fatal, disease known as the bends.

We had always decompressed by hanging at various points to a rope beneath our diving barge. On this deeper wreck, however, dives of much more than half an hour would require decompression periods of an hour or more. We realized that it would be impractical to decompress in open water for such lengths, twice a day. Consequently, we designed a submersible decompression chamber which allowed divers to enter at various depths for extended decompression periods. This chamber is basically a steel sphere, slightly over six feet in diameter, with an open hatch in its bottom. Up to four divers at a time could swim up inside where they could sit in dry comfort, able to talk to each other, read, or take notes. Fresh air was pumped into the sphere by means of a hose running to a compressor on nearby Yassi Ada, the small island on which we had established a camp. A telephone line also ran from the chamber to the island camp.

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The Asherah, outfitted with a closed-circuit television camera, and pairs of lights and photographic cameras, rests on sea bed next to the Roman shipwreck. Photograph by Robert Hodgson.

Half of a pair of stereophotographs taken from the Asherah at a depth of 130 feet. The square frames constructed over the partially excavated Roman hull are each two meters on a side. Photograph by Donald Rosemanite.

The depth of the chamber beneath the surface was controlled by a cable which ran down from it to a pulley on the sea bed. The pulley was attached to about five tons of steel ballast which held the buoyant, air-filled sphere under water. The cable then ran on up to Yassi Ada where it was attached to a chain hoist. One man, operating the chain hoist, could pull the chamber downward or let it up. Thus the divers could enter at a depth of thirty or twenty feet to begin their decompression, which would end just ten feet below the sea.

We had solved the problem of getting more time on the wreck by increasing the number of divers and lengthening diving times. Our next problem was to determine how we might get more work done during those dives. This required new tools. We examined each stage of an underwater excavation—mapping, sand removal, cargo removal—to decide what tools and techniques might speed up each stage.

We intended to reduce hours spent in mapping by using aerial photographs from our submarine Asherah. We had already devised a method of mapping in three dimensions by taking stereo-photographs with a pair of cameras mounted on the submarine (see ARCHAEOLOGY 18 [1967] 7-14), but we wished to improve this. Unfortunate delays in the construction and shipping of our new cameras prevented us from mapping each stage of the excavation from the Asherah, although the exposed wooden remains were mapped from the submarine with excellent results.

Most of the cargo of amphoras was mapped by means of a photographic tower resting on a metal scaffolding constructed over the site.

Sand removal was our next problem. This had taken most of our time during the excavation of the Byzantine ship. We had felt that an air lift, or suction hose, was too dangerous to use directly on fragile hull fragments, and had spent much of this time simply sweeping the sand by hand, away from the ancient wood. The current made by a sweeping movement of the hand will not carry sand a great distance, however, and far too many hours were spent moving the same piles of sand slowly down the slope on which the Byzantine ship lay.

On the new Roman wreck, we decided that if we could keep a trench opened along one side of the entire site, we might sweep sand over into it for later removal with a very large air lift. Consequently, we built seventy feet of "railroad tracks" along one side of the wreck. The track was made of a pair of industrial monorails, the sort on which equipment moves overhead on wheeled trolleys in factories, attached together by wooden ties. The rails were inverted so that the large air lift, buoyed at its top by an air-filled oil drum, literally "hung upward" from the tracks. The air lift, itself, was an aluminum pipe, ten inches in diameter and seventy feet long.

To complement the air lift, we added a high-pressure water jet to our tools for sand removal. This was essentially a fire hose running down from a water pump on the barge anchored over the site. By adjusting the nozzle on the hose, it was possible either to cut a trench in the sand under the tracks, or to move sand across the wreck to this trench. By setting the nozzle properly, we even learned to use a more gentle spray directly on the wooden hull without damaging it.

Removal of a cargo consisting of hundreds of amphoras we knew would be another time consuming job. For this we constructed a large wooden basket capable of holding twenty amphoras at a time. The basket was attached to a balloon which, when filled with air on the sea bed, could lift up to half a ton to the surface.

Another new tool for greater efficiency was our "underwater telephone booth." This is a hemisphere of clear plastic, four feet in diameter, mounted on iron legs just a few feet from the wreck. A constant supply of air enters this plexiglass dome through a hose from the surface, so that there is an entrapped bubble of fresh air into which divers can thrust their heads and shoulders to talk to one another. A televi...
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phone provides communication with the barge above, so that divers can even discuss their problems with colleagues on the surface. The "telephone booth" proved in its first summer of use to add greatly to the safety of our work. More than one diver swam to it when out of air for one reason or another. There he could calmly change to another aquilung which we left inside the booth for such emergencies.

Using these new tools, we accomplished far more in one season than ever before despite the fact we were diving deeper. The wreck proved to be remarkably well preserved, and we should gain from it a most accurate picture of a Roman merchant vessel of its time. As the ship's gallery has not yet been located and excavated, we do not yet have the coins and other small finds which allow an accurate dating of the wreck, but the sphere is now to the fifth or sixth century of the modern era.

IN MID-SEASON WE RAN INTO AN UNEXPECTED problem. Lying over part of the Roman wreck, beneath the sand, we found the remains of another later ship which had fallen onto the Roman wreck in antiquity. Its timbers are also well preserved, but it is without cargo and almost without small finds; only a few pottery vessels, covered with green glaze, suggest a date of the fourteenth or fifteenth century. The careful excavation of both these wrecks will present a real problem in archaeological stratigraphy.

During the course of the excavation, we continued to develop new search techniques. The Roman wreck, and those wrecks which we have previously studied, were all found by Turkish sponge divers and shown to Peter Throckmorton in the late 1950's. We wanted to be able to locate other, perhaps deeper, wrecks with scientific techniques.

We were looking for two specific ships: that which produced the bronze bust of a goddess, perhaps Demeter, now in the Irimi Museum, and that which yielded a bronze Negro boy, now in the Bodrum Museum. Both wrecks lie about 300 feet deep, far too deep for search by divers. The bronze vessels had been raised in sponge nets, but because sponge captains publish their nets for several miles at a time before bringing them to the surface, these captains cannot know exactly where any artifact has been netted on the sea bed. After long conversations with the captains, however, we were confident that we knew where each of these wrecks lay within about a four square mile area.

In 1965 we had begun our search, towing an underwater television camera along the sea bed. Inside the cab of the trawler we watched the sea bed go by for up to eight hours a day for two months, but we did not see any sign of either wreck. During that summer we also tried a new invention called a "Towsite," a one-man observation capsule. The wings, or vanes, on the sides of the capsule can be tilted by means of wheels inside the pilot. When the capsule is towed through the water at about a thousand feet of nylon cable, the pilot depresses the vanes, causing the Towsite to plane down through the water to the sea bed. Inside the capsule is an air supply and a telephone which runs to the towing vessel on the surface. Although the device worked well, again we saw no signs of either wreck.

Experience had taught us that the search paths seen by both television and the Towsite, sometimes no more than fifteen feet wide, were far too restricted. We realized that we could not possibly navigate our towing trawler on the surface without any near the accuracy required to run two-mile search paths only fifteen feet apart. We needed much greater range. We

wanted to try in 1967, therefore, side-scanning sonar with its great range, but this requires expensive equipment. The sponsors of our overall project, the National Geographic Society, the National Science Foundation, the United States Navy (the Office of Naval Research, the Supervisor of Salvage, the Deep Submergence Systems Project, the Naval Oceanographic Office and the Naval Research Laboratory), the Triestian Foundation, and Mr. Nazko Grohs, President of the Towvane Company, made it possible for the University Museum to experiment with not one, but two, side-scanning units. Both proved successful.

The first sonar system was brought and operated by a team from the Scripps Oceanographic Institute of the University of California. The sonar head, towed under water behind a trawler, scanned the sea bed out to 600 feet on either side, thus providing a search path 1200 feet wide. Transmissions on the flat sea bed were recorded on paper in two recorders on board the trawler.

An accurate search pattern was realized by the use of three land-based transit operators, about a mile apart, and all equipped with radars by which they could relay bearings to the ship. Bearings were quickly triangulated on board to fix the position of the target. Thousands of feet of a green glazed chart were inspected and analyzed by the Scripps scientists. In the area of the Demeter wreck there are fifteen promising targets, but only one good target exists in the area of the Negro Boy wreck; because of its nearness to Yassi Ada, this target was selected for first inspection.

Following weeks of bad weather, the submarine Asherah was towed out to the site. Martin Klein, of E G & G, International, had now arrived with another type of side-scanning sonar and this was used to further pin down the target.
Two transit operators guided the trawler carefully along calculated bearings, by radio, and a buoy was dropped where the target was again spotted. The *Arsevah*, piloted by Yüksel Eglner of the Turkish Archæological Service, and co-piloted by Donald Rosenzweig of Lockheed Space and Missiles, followed the buoy string to the bottom. At 285 feet, the submarine landed directly on top of the cargo of an extremely large shipwreck! We assume that this is the wreck which carried the Negro Bay statue, but only further research will tell.

Poor weather and lack of time prevented our inspecting any of the targets in the area of the Demeter wreck, over 100 miles away, but these we hope to inspect with television in the near future. What is of greatest significance about our new find is that now there is every reason to believe that such ships as those which yielded the Marathon Boy in the Athens Museum, and the Pirişhino Kouron in the Louvre, will be found by similar methods in the future. No other area of archaeology offers greater hope for the study of Classical sculpture.

At the conclusion of the excavation and search described above, the University Museum expanded its program of underwater research to Cyprus, where different tools were needed. With the kind permission of the Department of Antiquities of that island a team of ten archaeologists and technicians searched the coast for ancient shipwrecks. This University Museum expedition was sponsored also by the Cyprus Mines Corporation, the National Geographic Society, the Dietrich Foundation, and the Houghton-Carpenter Foundation.

The remains of five ancient shipwrecks were found, ranging in date from the Late Classical to the Early Byzantine periods. Off the western coast of the Akamas Peninsula, near Koppo Island, a wreck of the Late Hellenistic period was first located. Since the wreck lies in eight to ten feet of water, it has been badly broken up by wave action. However, it can be noted that four different types of amphorae made up its cargo, and that the predominant type is Late Hellenistic Rhodian. Broken pieces of coarse ware cooking pottery, the rim of the ship's water jar, and a fragment of a molded glass bowl lie close together and suggest the location of the galley.

Near Cape Andreas the expedition discovered three shallower water wrecks. The first of these was found by using the underwater magnetometer of Dr. E. T. Hall, Director of the Research Laboratory for Archaeology and the History of Art, Oxford. The wreck is thirty-five feet deep and is scattered into the crevices of the rocky bottom. Because of the shallow conditions, its amphorae were so shattered and cemented together that their types could not be distinguished. However, fragments of kylikes dating from the fourth century B.C. indicate a date for the ship's destruction.

The second and third wrecks at Cape Andreas lie to the north of the second outlying island off that peninsula. The first of these was found by snorkeling and is widely scattered. The depth is twenty-five to thirty-five feet over a sloping rock bottom. The amphorae are houn-glass in shape and of the Early Byzantine period. Three triangular stone anchors were observed.

The second of the wrecks off this island is the most interesting of the Cape Andreas group. It was located while using an "aquaplane," a device which we used successfully in searching down to about eighty feet; it is a wooden wing onto which divers held while being towed from a rubber dinghy with an outboard motor. The debris of the wreck has lodged in the crevices of the sharply sloping rock between a depth of thirty-five and seventy-five feet. The amphorae are again of the Early Byzantine houn-glass type. However, a part of the cargo was composed of terracotta boxes without lids. These may have served as a type of small amphorae.

These four wrecks are not sufficiently intact to warrant excavation. However, their value lies in the fact that they contain cargoes of identifiable objects which can be dated. In the future when sufficient numbers of such wrecks are charted, they may form the basis for a statistical analysis of ancient trade in the Mediterranean.

A shipwreck of the second half of the fourth century B.C. came to light as the team's fifth and most significant find. This Classical ship is located near the harbor town of Kyrenia along the northern coast. It lies at a depth of ninety to ninety-five feet on a flat
A diver inspects the fourth century B.C. wreck of Kyrenia.

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bottom composed of sandy mud overgrown with eel grass. Buried in this way, it is likely that the wood of the hull remains well preserved. Indeed, the ship is ideally suited for excavation.

The visible portion of this merchant ship extends three by five meters. Its main cargo comprised three different types of amphoras dating to the second half of the fourth century B.C. Miss Virginia Grace of the American School of Classical Studies at Athens, Agora Excavation, believes that the most predominant type was produced on Rhodes. It seems, indeed, to be of the earliest known style of wine amphoras produced by that island.

Realizing the importance of the find we immediately began a preliminary study of the wreck without disturbing any of its cargo. The subsequent survey added a logical, but missing, step in the excavation of ancient ships. The scaffolding and air-lift tracks, built over and beside the Roman wreck at Yassi Ada, had been placed with regard only to the visible portion of its cargo. Subsequent excavation revealed that the actual orientation of that ship bore little relation to the pile of amphoras protruding from the sandy bottom. A preliminary survey of the site would have saved precious hours spent in moving and extending fixed frames and grids.

At Kyrenia, we laid out a simple cord grid ten by twenty-eight meters, divided into two-meter squares, to serve as orientation. Using a metal rod, we probed the soft bottom to determine roughly the extent of the wreck beneath the sand. It was found that the total dimension of the amphora cargo is approximately 10 by 19 meters. Further, we learned that the true axis of the ship varies considerably from the axis of the mound of cargo visible above the sand. Knowing both size and orientation of the wreck will enable us to position reference frames over the site quite accurately when excavation begins.

A survey was next begun using a metal detector (see cover) developed by Mr. Jeremy Green of Oxford. The instrument pinpointed nine metal concentrations beneath the sand. The positions of these deposits were then triangulated using three fixed points on the visible mound. Finally, using Dr. Hall’s magnetometer, we identified two of the metal deposits as ferrous material, approximately three feet below the sand. It is conjectured that these iron concentrations represent the ship’s anchors, tools, or weapons.

The University Museum plans to begin excavation of the “Kyrenia wreck” in the late spring of 1968. The work will, we hope, reveal not only the ship’s cargo but also evidence for the design and construction of this Greek merchant vessel. At the same time, we will continue to develop and test new tools for the use of archaeologists who work beneath the sea.

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Michael Katzen has participated in the Turkish underwater excavations of the University Museum since 1964 and has been a Research Associate at the University Museum since 1967. He was in charge of the Cyprus search expeditions during the past autumn. While a student at the American School of Classical Studies at Athens, he excavated at Neros in the Spring of 1964. He is now a doctoral candidate in Classical Archaeology at the University of Pennsylvania.

For further reading: