range is needed at some of the WWNSS stations for, with the present configuration, the largest shocks (in many ways the most important) saturate the system and are not well recorded.

Certainly there are many desirable locations for seismograph stations throughout the world that are not currently occupied by instruments of the WWNSS or by other instruments. Better coverage of many areas, including the ocean floors, would be advantageous. Installations on the deep-sea floor are feasible; a station now operates in deep water off the California coast. But the cost per station is high, and the cost of a large, worldwide, deep-sea network is currently out of reach. The near future may, however, see additional installations on the ocean bottom in selected locations.

A very effective and economical way of adding to the value of the WWNSS would be to include a substantial number, say 100, of existing non-WWNSS stations in the data copying and distribution system. Such a procedure would make much more information widely available throughout the international seismological community, and the information would be of great value even though all the stations would not have instruments directly comparable to those of the WWNSS. The cost of the added operation would not be high; the value to society would be large.

Each devastating earthquake triggers a widespread "let's do something about earthquakes" reaction that is nearly always short-lived. But the never-ending series of such shocks calls for a level of effort that is persistent and that does not fluctuate with public concern. The WWNSS with modest improvements, or something comparable, is an essential component of the effort required to keep society informed about earthquakes and to develop protection against their dangers.

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20. W. J. Stauder, S.J., kindly provided information on the early Jesuit network. B. Isacks of the Earth Sciences Laboratories (NOAA) and Lamont-Doherty Geological Observatory, T. Matumoto of Lamont-Doherty Geological Observatory, and C. Kisslinger of the National Academy of Sciences' Committee on Seismology critically read the manuscript. Except for service on the National Academy of Sciences' committee and the Berkner panel, J.O. had little to do with the creation of the WWNSS; L.M. played a leading role in the activities of the Coast and Geodetic Survey in this regard. All credit for this accomplishment should go to the Advanced Research Projects Agency, the Coast and Geodetic Survey (now part of NOAA), the National Science Foundation, and the many cooperating institutions throughout the world. Lamont-Doherty Geological Observatory of Columbia University Contribution 1721.

Deep-Water Archeology

Ancient ships that may exist virtually intact on the deep-sea floor can be found, studied, and recovered.

Willard Bascom

The greatest remaining treasure-house of information about the ancient world —the bottom of the Mediterranean—is about to become accessible. In this article I explain why I believe that there may be many ancient wooden ships in reasonably good condition on the deep-sea floor, how these ships can be located and recovered, why they sank, and why their cargoes are clearly worth a substantial search and recovery effort. In addition, I present the rationale for deciding where to search in order to optimize the chances of finding long-lost ships.

A new form of underwater archeology will begin when a new kind of scientific ship and new techniques are used to explore the deep-sea floor for sunken ancient ships. The *Alcoa Seaprobe* (*1*) is such a ship—capable of reaching down with its sensors, which are in a pod at the tip of a pipe, and making a detailed examination of the bottom in water several thousand meters deep (Fig. 1). It is equipped with sonar to systematically search the sea floor at a rate of about 1 square nautical mile every 6 hours (1 square nautical mile = 3.4 square kilometers). Men at the surface will be able to inspect objects on the bottom with television, dusting away sediment by means of jets and propellers. Photographs can be taken and objects of interest identified (and perhaps recovered) by means of grasping devices. Because *Alcoa Seaprobe* will be capable of lifting from deep water loads weighing 200 metric tons, it may be possible, under some circumstances, to recover entire small ships in one piece. The overall capability of this new ship will be substantially greater than that of any previous device for search and recovery in deep water.

I deal here only with ships that sailed the Mediterranean Sea during the pre-Christian era, but it is evident that there are many other, more recent (but still very old) ships in that sea, and else-

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where in the world, to which these search and salvage methods can be applied.

Every ship is a small sample of the life and times during which it sails. On ancient ships, as on today's ships, the people aboard had all the utensils required for living, the weapons for fighting, and the tools for working. Much of this hardware and part of the cargo is virtually imperishable. Some of these objects can be dated and associated with peoples and ports to give information about the culture and commerce of the period. The hulls of the ships reveal the state of the art of marine technology in naval architecture and shipbuilding. Since each ship represents the surrounding civilization, and since most sink quickly, carrying down everything except minor flotsam, a complete ancient ship in good condition is the marine archeologist's dream—a sort of undersea Pompeii, in which dark, cold water instead of hot ashes has preserved a moment in time.

Until now, most of the old ships excavated have been represented mainly by piles of amphorae and the part of the ship's bottom structure that was protected by being submerged in mud. Most of these ships were wrecked on reefs in shallow water, and only the most resistant materials, such as ceramics, bronze, and glass, have survived (*2*). Exposed wood rarely survives the attacks of boring animals and waves for more than a dozen years. Only the wood buried safely beneath mud and sand can be studied and recovered.

Our picture of ancient shipping is, therefore, somewhat skewed by the materials that survive and by the corresponding blank spots in recorded history. A great deal is known about some aspects of the old ships, but virtually nothing is known about others (*3*); for example, knowledge of the upper structure is derived primarily from the generally inadequate renderings on bas-reliefs and vases. The scientific argument about how the rowers and oars were arranged on warships is still active after 100 years of debate. Although we are not certain what it meant to say a ship was an "eight" or a "thirteen," details such as the cost and length of oars are known. No example of the trireme, the most common warship for some 400 years, has yet been found and excavated, although the sinking of thousands of them has been recorded (*4*). Much remains to be learned about how ancient ships fought, were constructed, sailed, loaded, and crewed.

Survival of Wooden Hulls in Deep Water

In deep water (more than 1000 meters below the surface), the chance of survival of both the wooden and the fragile parts of a ship should be enormously improved; the temperature on the bottom is near freezing, and chemical reactions proceed slowly. It is dark, and the currents are usually minimal, thus allowing protective silt to accumulate on the upper surface. A ship lying there will be well beneath wave action, trawl nets, and divers. Since the cargo will not have moved after its original landing, it should not be scattered about nearly as much as it is in ships wrecked in shallow water.

The most uncertain aspect of wreck preservation in deep water has to do with the possible damaging effects of marine borers. Teredos are not known to go deeper than 200 meters, but in some places *Xylophaga*, a borer clam, lives at 2000 meters (*5*). Old wood untouched by borers has been found on the Pacific continental slope south of Panama, and an old ship was seen in deep water off Gibraltar by a small submarine looking for the lost H-bomb. In one Atlantic location off the coast of Florida, exposed wood from a Spanish wreck, 400 meters deep and about 300 years old, has not been attacked (*6*). Probably the reason that some hulks have borers and others do not is because of local variations in oxygen, nutrients, metallic ions, or currents. The very action of a ship landing on the sea floor might cause a cloud of mud to swirl up and around, falling back on the ship as a protective cover. Some ships had resistant wood, lead sheathing, paint, copper parts, and tarred decks or seams, all of which may have helped protect against borers, especially where currents are low. A wooden ship landing in an anaerobic area, such as the Black Sea, should endure indefinitely.

The amount of mud that accumulates on a ship because of normal sedimentation will vary considerably, since the rate of sedimentation depends on distance from a land mass, amount of runoff, and local currents. In the central basins of the Mediterranean where the water is 4000 meters deep, the rate of sedimentation is believed to be about 10 centimeters per 1000 years (*7*). In embayments close to shore, the rate may be more than ten times that amount (*8*); but intermediate depths, say 1000 meters, where muds, clays, and calcareous oozes are deposited, 20 centimeters per 1000 years is a reasonable estimate. Forty centimeters of sea dust since the start of the Christian era should give an ancient ship, if otherwise whole, the blurred appearance of a wagon after a snowstorm.

The degree of preservation of a ship in shallow water apparently becomes stabilized after about a dozen years, and then seems to remain unchanged for centuries (*8*, p. 19; *9*). One has good reason to hope for much less deterioration in deep water, both in those first years and afterward.

Almost certainly, special circumstances exist in the many places beneath the sea where very old ships have not decayed substantially where they still sit upright on the bottom and have barely changed from the way they looked when they first sank.

Salvaging Wrecks in Shallow Water

The salvage of ancient ships and cargoes for their archeological information and art treasures is not new. In 1832, the 5th century bronze Apollo which is now in the Louvre was brought up by a trawler from the waters off the island of Elba. In 1901 a wreck at Antikythera was accidentally discovered by sponge fishermen who had made an exploratory dive while waiting for the weather to moderate and found a spectacular collection of bronze and marble statues. They reported their find to the government, and an expedition was launched. Many statues were salvaged, along with an astronomical computer which set the date of the voyage at 80 B.C., suggesting that this special cargo was probably loot from Greek cities en route to Rome. This wreck was on top of an undersea cliff, and some of the cargo had slid off into water of far greater than diving depth before it was found.

Greek sponge divers also found a wreck at Mahdia in the Bay of Tunis in 1907. An entire temple was aboard, as well as many bronzes. Greek trawlermen—fishermen who drag nets along the bottom in water somewhat deeper than that divers work—brought up parts of bronze statues from Cape Artemision in 1926. An expedition was begun to recover other statues (including the larger-than-life bronze of a naked Zeus casting a spear—a replica of which stands at the entrance to the United Nations building in New York), but the water was too deep for the diving technology of the day, and after several serious accidents the site was abandoned and perhaps lost.

These finds of truly great statuary were, of course, tremendously exciting to the art world; but they were of less significance to classical archeologists, who did not feel that random finds of ships carrying art objects were very important in defining societies and cultures. It is also possible that much of the early undersea work was ignored because of its technical crudity in mapping, dating, and processing of finds. Peter Throckmorton (*10*) quotes a Turkish official in the Department of Antiquities in 1960 as saying: ". . . underwater archaeology is not very important or interesting. We archaeologists are interested in the culture of the people, not in minor details of ship construction, which is of interest only to a few specialists."

The beginnings of recent activity in salvaging old ships from shallow water seems to have begun with Jacques Y. Cousteau, who organized a team of divers in 1952 to excavate a wreck at Gran Congloué, not far from Marseilles. It was an exciting adventure, widely reported in the press and enhanced somewhat by Cousteau's colorful descriptions and motion pictures. In this excavation, which followed an undersea slope downward as deep as 50 meters, the Cousteau group pioneered many techniques that have since been greatly refined, including the use (for archeological purposes) of television, air lift, and the Aqualung (*11*). The excavators worked in the glare of publicity and could not be expected to foresee many technical problems of wreck excavation. Looking back on the work, it now seems possible that there were at the site two wrecks, one above the other, which got confused. This does not seem quite as serious now as it did at the time, when that site was thought to be unique.

The Congloué operation was a good beginning in the sense that it attracted the world's attention to a new source of historical material that has since revealed a great deal about ancient times. That excavation was followed by a flurry of artifact hunting by scuba divers, mostly along the French Mediterranean coast. These hunts were characterized by confusion of purpose and numerous diving accidents. In the early days, divers were not archeologists, nor vice versa. As wrecks were destroyed in the search for artifacts, few careful drawings were made and most of the data were lost forever. But in 1958, Throckmorton and, shortly afterward, George Bass, decided that classically correct underwater excavations were technically feasible and that a Bronze-Age wreck off Cape Geledonia, Turkey, was a good place to attempt one. This very successful archeological work, in which the first precision, three-dimensional surveys of ship and cargo were made, has been described in detail by Bass (*12*). It was followed by similar work by Throckmorton (*8*) in Italy and Greece, and Katzev (*13*) in Cyprus; thus a technology for precise excavation of wrecks in shallow water has been established.

Fig. 1. The *Alcoa Seaprobe*.

However, the depth at which such work is practicable is set by the usual physiological problems of diving. Even today, in doing extended work deeper than, say, 50 meters, there is a real chance of diver-archeologists getting the bends or having other kinds of diving trouble. True, it is possible to put down living quarters and remain at depth for weeks at a time, to use complex mixed-gas apparatus, or to use a saturated diving system, in which one lives under pressure at the surface and is carried to and from the depths in a pressure chamber. Doubtless these methods will eventually be used and the archeological diving work will be extended as deep as perhaps 200 meters; but the costs and problems increase greatly, while the archeological advantages do not improve at the same rate.

Bass and others successfully used side-looking sonar for detecting wrecks off the coast of Turkey in water depths to 130 meters; they identified the targets with television (*14*). Bass also used the small submarine *Asherah,* equipped with stereophotographic mapping cameras, to take overlapping photographs from which accurate maps could be made. Although further development of the equipment was said to be required, these techniques were effective. However, they are not known to be in use at the present time. Throckmorton and others have used bottom-penetrating sonar to find wrecks beneath harbor muds.

So much for the history of undersea work and the present state of work in shallow water. The operations in deep water will be quite different.

Where to Look for Sunken Ships

There will be an essential difference in the means of finding deep-water wrecks. Wrecks in shallow water have generally been found accidentally by sponge divers, trawlers, or sport divers. Throckmorton, who probably has located more wrecks in the Mediterranean than anyone else, has relied largely on talking to sponge divers in waterfront bars. He pleasantly engages them in Turkish, Greek, or Italian over ouzo or raki and eventually turns the conversation to "old pots in the sea"—amphorae. Every sponge diver in the Mediterranean knows where there are a few mounds of such pots marking the site of an old wreck. Eventually they tell him and he records the location. He has personally checked many of these, and his charts now show hundreds of sites.

In deep water there is no similar mechanism for getting a lead on a promising wreck. Instead, it will be necessary to rely on statistics that are based on knowledge of the ancient ports and population centers, the kinds of cargoes and location of trade routes, and the nature of the old ships and the way they were sailed. Probably the last of these is the most important, since the mariners of old did not sail in straight lines between ports as a modern ship would. The ships were small and they sailed between protected bays, sometimes stopping to avoid the strong afternoon winds. They would minimize runs in the open sea by sailing within a few miles of the coast, anchoring during the calm, and sailing with the favoring winds as much as possible. Often the outward voyage would follow a different route from the return, and both might change seasonally or stop entirely during the months of November to March because of the increased risk during bad weather. The size of the ship and the way it was rigged, as well as the destination of its cargo, also influenced the route.

The story of what is known about the ancient ships is well told in the works of Lionel Casson (*15*) and others, but there is also much that is not known about the many varieties of ships and cargoes over a period of several thousand years.

A very brief review of the history of Mediterranean shipping before the Christian era is appropriate. This was an age when empires were formed, established their colonies, collapsed, and were replaced. Because rough terrain and unsettled political situations made land travel very difficult and risky, there may have been more ships afloat in some periods then than there are now. The objective is to find places along well-traveled sea lanes where ships would have troubles that would cause them to sink in deep water. Then a search for sunken ships can be conducted where the statistics are more favorable.

Egyptian ships were trading along the eastern Mediterranean at least as early as 2500 B.C., one of their first imports being cedar from Lebanon for shipbuilding. Minoan Crete was the first great sea power in the Mediterranean. In the years 1800 to 1500 B.C., its ships explored the Aegean and Black seas and pioneered the trade routes, as far west as Sicily, that were destined to last for centuries. By 1500 B.C., the Mycenaeans controlled the seas, giving way in about 1200 B.C. to the Phoenicians, who extended the trade routes into the western basin and built colonies at least as far west as Cadiz, which is beyond Gibraltar. Their sailing technology was remarkable, and some people think that they may have sailed on across the Atlantic. On their return eastward, they carried metals—tin, silver, lead, and iron—mainly from the mines of Spain.

Gradually, by about 800 B.C., dominance of the sea shifted to Greek shippers, who dealt more in such bulk commodities as olive oil, wine, wheat, pottery, and hides. The Greeks founded hundreds of colonies and linked these to the homeland by ship traffic; thus, by 500 B.C. Athens (Piraeus) was a major trade center. Its influence gave way to that of Rhodes and Alexandria, until, in the century before Christ, the Romans dominated the sea (Fig. 2). Presumably all of the countries around the sea had ships that were involved to some extent in trading, piracy, and intermittent wars. The point is that there were a great many different kinds of ships at sea, manned by crews of differ-

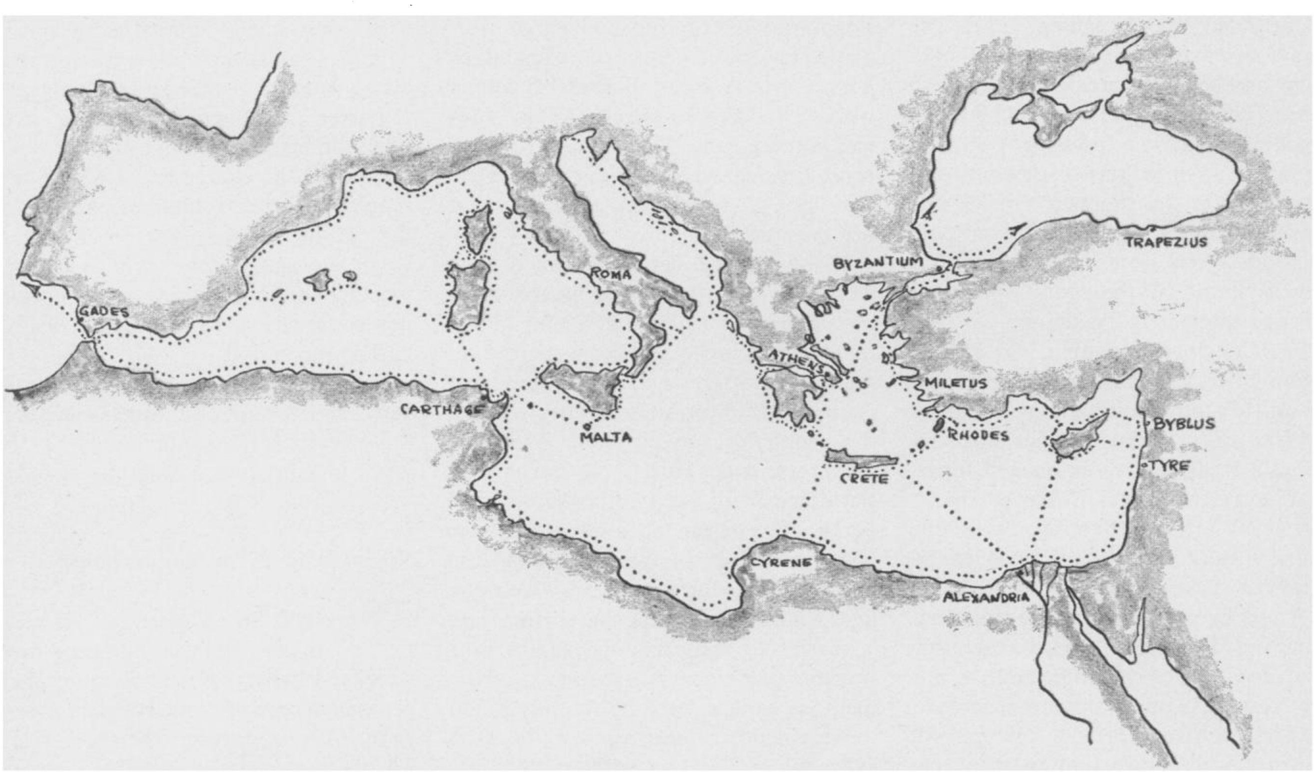

Fig. 2. Trade routes in the Mediterranean, from about 500 to 200 B.C. (*24*).

ent nations, during the millennium B.C. The routes they followed remained virtually unchanged for thousands of years.

Why Ships Sank in Deep Water

Why would a ship suddenly sink in deep water—especially considering the fact that the routes they followed were generally near shore and that risks were minimized by anchoring in protected waters when the weather was bad? There were accidents of many kinds. The weather in the Mediterranean is known for sudden, violent change, and the old ships could not respond rapidly or sail into the wind very well. In the Aegean, they feared the meltime, a northerly, afternoon wind that has gusts to gale force and that dies down again, to leave the sea calm by midnight (*16*). It would be very easy for a ship to be blown well offshore and sunk in a sudden squall. In the Adriatic these northerly gales are called boras, and they reach force 10 (*17*). In the late fall and winter there is the sirocco, which can blow at a steady force 6 for a week, with gusts to force 8 or more. In 1966, a modern steamer went down in one, with a loss of 166 people. These violent and unexpected winds are known to have been the principal cause of losses of sailing ships in the eastern Mediterranean in the 19th century A.D.—and they doubtless were in previous centuries as well.

The ancient ships were generally small (less than 40 meters long) and made of wooden planks held edge to edge, caravel style, with mortised joints. If the planks came apart, the weight of cargo and ballast would take a ship down in a few minutes. This kind of accident might be aggravated by a shift of cargo, a weakening of the wood by marine borers, or by one large wave. Generally the ships did not have much freeboard, and many were not completely decked. In heavy weather they could take water over the sides and quickly founder or capsize.

Pirates were the scourge of shipping for many hundreds of years; they doubtless sank many of the vessels they caught. Fire was also a frequent cause of loss—coals would fall from the galley stove as the ship pitched, or a carelessly held torch would start a blaze. Some nations had strict safety laws about fire on shipboard. In later centuries, there were several occasions when whole fleets were lost by fire. Besides the other hazards, warships had a chance of being rammed in battle or being scuttled after capture.

One concludes that ships sank in ancient times for the same reasons they did in the 19th century. Because the old ships were smaller, less well built and rigged, and sailed by less well-trained crews, the statistics must have been worse. Throckmorton (*8*, p. 34) points out that, in the years from 1864 to 1869, 10,000 insured merchant ships were lost—1000 without a trace. Of the 372 British naval ships lost by mishap between 1793 and 1850, nearly half were lost by running onto unmarked shoals, and 78 of them, or 21 percent, foundered at sea, usually in deep water with all hands. He also notes that on a single reef at Yassi Ada he and Bass found more than 15 wrecks, ranging from 3rd century B.C. to the 1930's.

The number of ships involved in commercial traffic during the millennium B.C. can be used to estimate the number of wrecks lying in deep water. Yalouris (*18*) believes there were over 300 active ports by the 4th century B.C., with an average capacity of 40 ships each, and that half of these ships were at sea. If so, the standing crop of ships was about 12,000. This number increased markedly in Roman times, although it was much less at the beginning; therefore, a conservative estimate

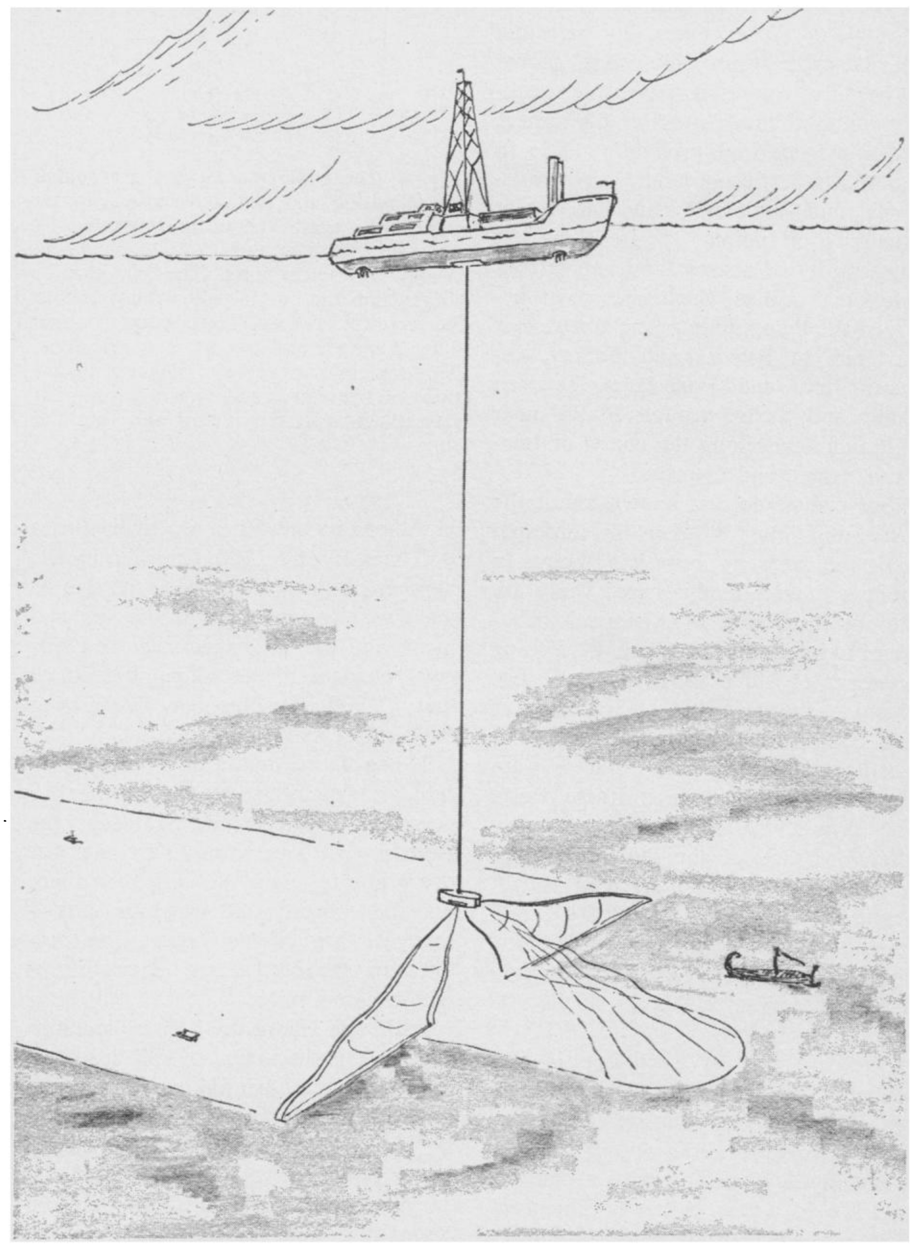

Fig. 3. Searching with *Alcoa Seaprobe*. A pod containing both a forward and a side-looking sonar, as well as television, is attached to the tip of a weighted pipe. Together the sonars sweep a pathway about 400 meters wide at a speed of about 1 meter every 2 seconds.

would probably be that there were, on the average, 6000 ships in trade over the 1000-year period. If one judges the average life of a merchant ship to be 40 years, some 150,000 ships were built.

Being guided by the statistics of ship losses during the 1800's, one can guess that half eventually retired safely and the other half were lost on voyages. If, of those lost, 20 percent foundered, then there are 15,000 ships down offshore—many in deep water. If the total length of the trade routes in the eastern Mediterranean were 6000 nautical miles (1 nautical mile = 1.9 kilometers) and the average width 10 nautical miles, there is a reasonable chance of one ship in every 4 square nautical miles of bottom along those routes. By selecting specific areas where ships were known to get into trouble, it is possible to improve the chances considerably. There are numerous high-probability sites in the straits between islands, between islands and mainland, and at major "jumping off points," where ships left the security of nearby land and set out into open waters. Such sites exist between the Peloponnesus and Crete, east of Crete to Rhodes and Turkey, between Italy and Yugoslavia, between Tunis and Sicily, around Malta, near Gibraltar, and along the coasts of Lebanon, Israel, and Cyprus.

Somewhat more is known about the losses of military ships in the same period, and there are more fixed points to guide estimates in this case. There are literally hundreds of historical references to sea battles in which astonishing numbers of ships were involved. For example, at the battle of Ecnomus in 255 B.C., 250 Roman ships faced 200 Carthaginian ships; only 16 ships were lost in the battle (which Rome won), but in a storm off Camarina shortly afterward, 250 of the remaining ships were wrecked. When Agrippa fought Sextus at Naulochus in 42 B.C., 600 ships were engaged. When Anthony and Cleopatra met Augustus at Actium in 37 B.C., about 100 ships of the 900 involved were lost.

The life-span of a trireme is estimated at 20 to 30 years (*18*), if it were not destroyed by warfare or storm. Thus a force of 300 ships would be maintained by building ships at the rate of 10 to 15 a year. A law of Themistocles decreed that 20 ships should be constructed each year, in order to ensure replacement of the old ships. We do not know how long it was enforced, but the total number of warships built

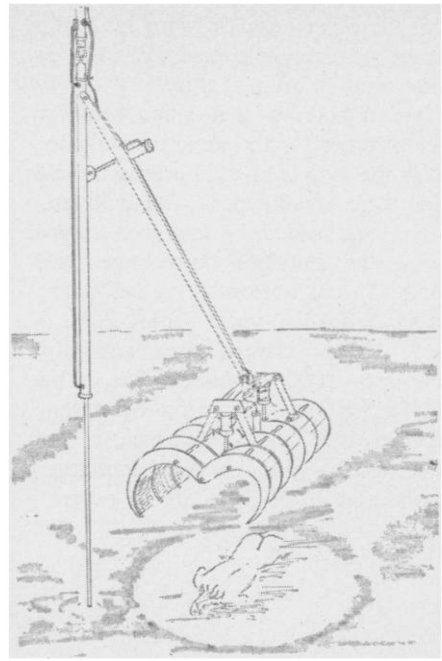

Fig. 4. The exploratory tongs are guided by television and powered by a seawater hydraulic system. They are supported by an adjustable arm and are held steady by a pin 10 meters long. The pin can be driven into the bottom when the object to be recovered is seen. Tongs open to about 3 by 3 meters and can lift 5 metric tons. This system can perform delicate operations of lowering, rotating, and closing. It retracts through the center well into the ship.

in Athens in the 5th and 4th centuries B.C. was around 1200. Considering the number of states with fleets, the size of the fleets, the rapidity of the replacement, and the life expectancy and survival chances of the ships, I estimate that 25,000 warships may have been built before the time of Christ.

If one figures battle losses at 10 percent and losses at sea for another 10 percent [Casson (*3*, p. 157) says the Romans lost four ships to weather for every one to enemy action], then there may have been 5000 warships sunk—many of them in deep water. The locations of the battles are often known within a few miles.

Although I have used the millennium B.C. in this discussion of ship losses, it is obvious that the sinkings continued, at least through the age of sail, at about the same rates. The ships were larger, better built, and easier to sail, but the storms and wars and accidents went on. Ships that sank much later than the ancient ones may be even more interesting. For example, the Battle of Lepanto was fought not far from Actium 1608 years after Anthony and Augustus fought there; another 100-odd ships went down, this time with a very different array of artifacts. Sunken ships have been accumulating in the Mediterranean for 4000 years. Sorting through them on the bottom and identifying those of interest to archeological salvors may be a bit of a problem.

The Ship and Its Equipment

Having decided that very old ships and their cargoes were among the most valuable objects to be found on the sea floor, and knowing the limitations of other possible methods, I proposed in 1962 the search and recovery system described here (*19*). With few changes it has been developed into the *Alcoa Seaprobe*.

Alcoa Seaprobe is like a drilling ship with a center well and is propelled and maneuvered by two Voith-Schneider vertical-axis propellers, fore and aft. It is 75 meters long, 17 meters beam, and draws about 4 meters. The ship is all electric, with a power plant forward; it has quarters for 50 persons aft. (It is the world's largest aluminum structure —constructed mainly of 5456 aluminum, to demonstrate the excellent marine properties of that material.) The ship is steered by means of a console on the bridge, which controls the propellers and makes it possible to exert thrust in any direction almost instantaneously. Thus it can be dynamically positioned (*20*) manually or, with certain navigational inputs, automatically.

Above the 4 by 12 meter center well, there is an aluminum derrick that can lift up to 400,000 kilograms. The available working load of the derrick and draw works will be 200,000 kilograms (200 metric tons, with a safety factor of 2).

The derrick and pipe-handling system is capable of lowering or recovering drill pipe at an average rate of about 0.25 meter per second, to a depth of 6000 meters (although only about 2400 meters of pipe will normally be aboard). Depending on the operational situation and the depth, the lower end of the pipe will be weighted with up to 20 metric tons of drill collars. The drill pipe ordinarily carried is 11.5 centimeters in diameter, in 10-meter joints; it is handled as pairs, or "doubles," 20 meters long. It can be raised or lowered with precision a centimeter at a time, or rapidly at several meters a second (if necessary to avoid obstacles). The pipe can be rotated slowly to change the orientation of the instrument pod or tools at its lower tip (*21*).

The information and control cable that connects the instrument pod to the scientific control center is attached to the outside of the pipe by special clips at 20-meter intervals. Within that cable, sonar and television signals come up coaxial conductors; power and instructions go down adjacent pairs. The information is recorded on paper recorders and on television tape; because precise position and time are recorded marginally at short intervals, it is possible to refind objects on the bottom.

The principal searching instruments are two sonars mounted in the pod; one scans directly ahead, and the other sees the bottom on each side at right angles to the motion of the pod (Fig. 3). The side-looking sonar has a frequency of 177.5 kilohertz and a beam width of 0.3 degree. It sends and receives sound pulses in such a fashion that objects that project above the bottom (such as a rock or a ship) will better reflect the sound and produce a darker spot on the record. Because the sea floor immediately beyond an object is in the sonic shadow, the record of that area remains white. As the ship (and the pod) moves, the line-by-line record of a succession of pings builds a sonic picture of the bottom; thus, the size and position of any object can be determined within a few meters, as can the approximate height of the object. The resolution is such that, at a distance of 200 meters, the sonar can distinguish between two objects that are more than 1 meter apart.

Since the principal information obtained is a white shadow, it is evident that the sonar beam must strike the bottom at a substantial angle (there are no shadows near the nadir). This means that a pathway immediately beneath the pod must be searched by the forward-scanning sonar. This sonar works in a similar fashion; but, because it scans an area rather than a thin slice of bottom, it is not practical to record this information. Instead, any objects seen on its plan-presentation scope are noted for time and position; later they are plotted by hand on the record from the side-looking sonar.

The necessary precise navigation will be done in one of several ways, depending on the distance from land, the depth of the water, and the size of the area to be searched. For short-range work in depths to 2000 meters when an area of up to 50 square nautical miles is to be searched, the following method will ordinarily be used. Two taut-moored, subsurface buoys will be installed some 10 miles apart outside the search area; a surface buoy with radar transponder will be tied to each. Under most circumstances, the movement of a transponder buoy relative to a point on the surface above its anchor will be less than 20 meters. The ship will then obtain its position relative to these fixed buoys by ranging on them with radar. The digitized distance to each buoy will be recorded at 1-minute intervals, which are also coded automatically on the margin of the recordings. The maximum uncertainty of position will be about 40 meters (half the length of the ship).

Searching, Inspection, and Recovery

When the ship arrives at a site selected for search, the transponder buoys are installed and the area is surveyed with an ordinary echo sounder, in order that the search can be conducted approximately along contour lines. The instrument pod is lowered on the weighted pipe until it is about 60 meters above the bottom. Then the ship begins to move along the planned course at a speed of about 0.8 meter per second. At this height above the bottom, the sonar scans a pathway about 400 meters wide. At this velocity, it searches an area of about 20,000 square meters per minute, a square kilometer every hour, and a square nautical mile every 4 hours. Allowing for an overlap in pathways of 50 meters, to make up for the navigational uncertainty, and allowing time for turns and adjusting pipe length, the average time needed to search 1 square nautical mile will be about 6 hours.

Doubtless, many objects will be detected in each square nautical mile searched. These will be given priorities for inspection, based on experience in interpreting such records. Ships that rest upright on the bottom should be relatively easy to identify as ships. Deciding whether or not they are valuable as salvage targets is a more difficult problem.

The pod that holds the sonars also holds the television camera and lights, but the sonar height of 60 meters above the bottom is beyond the range of the

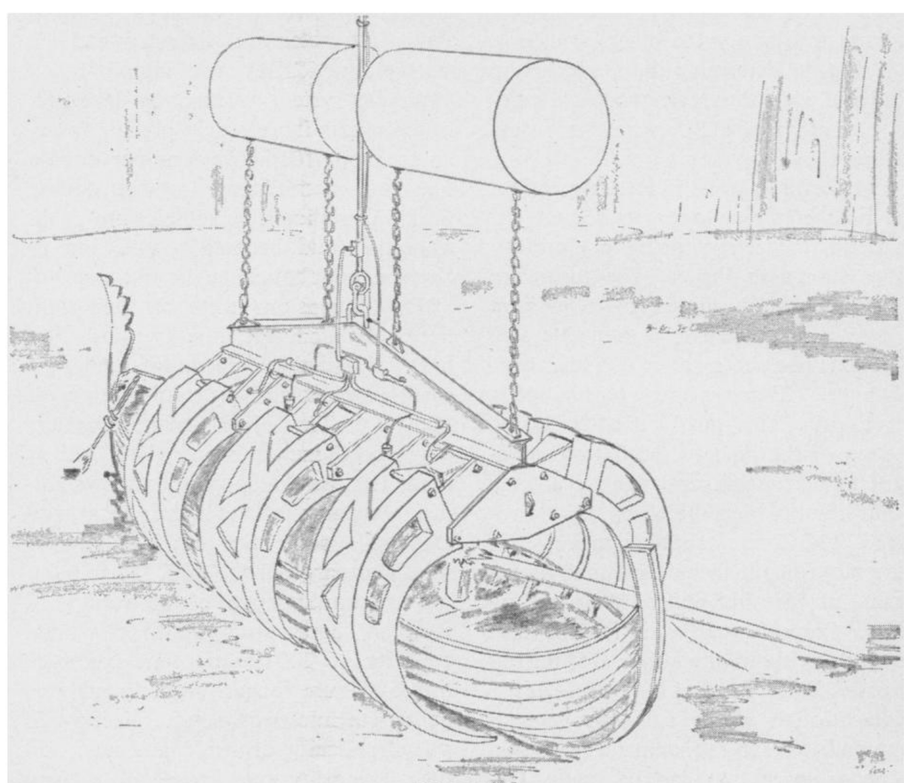

Fig. 5. The super-tongs shown are lifting a small vessel from deep water. Guidance is by television; closing power comes from seawater pumped down the pipe at high pressures. These tongs (which weigh 50 metric tons) would be towed to the salvage site on their own flotation and used in a nearly neutral condition of buoyancy.

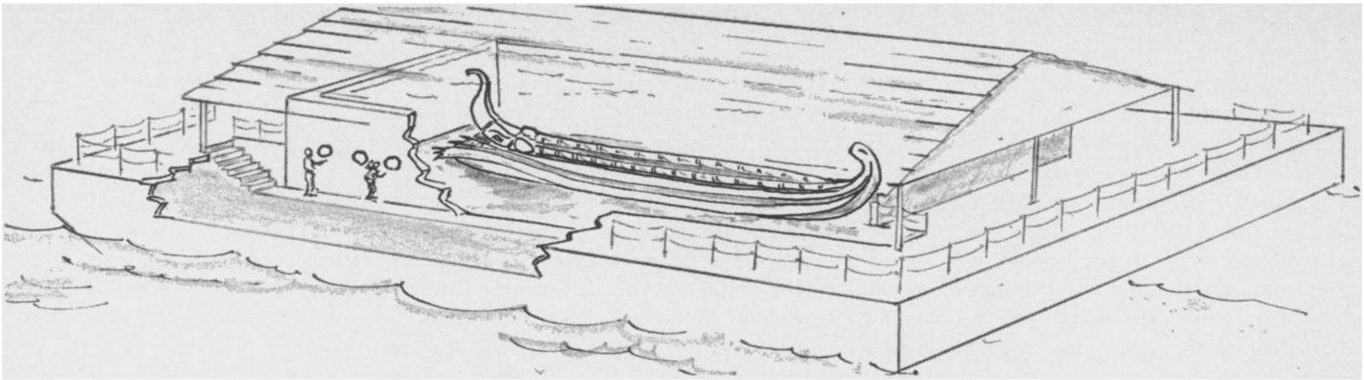

Fig. 6. A museum barge could be constructed to support a tank in which an ancient ship could be carefully rebuilt underwater and displayed. A crane that can lift 200 metric tons (and that is available around most major ports) would be used to lift the super-tongs and the ship from shallow seawater into the tank and then return the tongs to the sea.

television (about 15 meters is the maximum range in clear water).

Therefore, when a visual inspection is to be made of the objects found with sonar, the pod is lowered until it is a few meters above the bottom. The ship navigates by radar back to the priority site, and a more localized search begins. While the ship holds position, the tip of the pipe is maneuvered by means of a propeller just above the pod. This propeller, driven by seawater pumped down the pipe, is capable of moving the pod up to 50 meters in any direction (depending on depth and pipe weight). Watchers on the ship will look for and attempt to identify the object and, if it is a ship, to determine the approximate kind and age. All wrecks would be carefully photographed for whatever information they contain.

If the ship is worth close inspection, the next step would be to retract the pod and replace it with the exploratory tongs shown in Fig. 4. The tongs are a grasping tool guided by television. They are supported by a movable arm that extends out from a cylinder containing a 10-meter-long, hydraulically driven pin. This pin is used to fasten the tip of the pipe to the bottom adjacent to the wreck, and to give a fixed point about which the tongs can be rotated. The tongs can thus make slow, sure movements, in spite of small movements of the ship above. Watchers on *Alcoa Seaprobe* can wait for the dust to settle without the ship's drifting off course. Each of the tong tips has a pipe through which clear seawater is pumped to wash sediment away so that a better inspection can be made. Objects weighing less than 5 metric tons can be grasped and lifted with considerable delicacy. Specific objects of art or items of cargo can be recovered with these tongs and withdrawn through the center well into the ship.

When an entire ship suitable for recovery is located, the super-tongs will be towed to the site. These tongs would weigh about 50 metric tons and would be supported on the surface by their own pontoons, whose buoyancy can be adjusted. On site, the tongs may be slung beneath the ship, secured to the tip of the pipe, and lowered. As with the exploratory tongs, these will have television equipment mounted so that those on the ship can see the object to be seized. When fully closed, these tongs will surround a cylinder about 10 meters in diameter and 12 meters long. They are closed by a hydraulic system worked by leverage, which exerts increasingly greater force, up to about 10 metric tons per double tine (60 metric tons for six double tines). This should be sufficient to penetrate the mud beneath a hull and to close without touching the old ship.

The dimensions were selected with the sizes of ancient ships in mind. Figure 5 shows the super-tongs holding a small Phoenician-like trading ship of 1000 B.C. The ship is about 16 meters long and 7 meters beam. (Half full of mud, this would approach the weight-lifting capacity of the *Alcoa Seaprobe*.) Depending somewhat on the amount of mud and cargo in the hull, the remaining structural strength of the wood (*22*), and the shape, ships up to the rated capacity of 200 metric tons could be lifted. Much longer ships would be neatly cut into two or more pieces with a hydraulically driven chain saw, and the lifting process repeated. These pieces can be reassembled later, probably with less difficulty than the fragments of ships found in shallow water to date.

When the super-tongs have been retracted to a position just below the ship, the *Alcoa Seaprobe* will slowly move into quiet, shallow water and set the burden on the sea floor. There the mud, ballast, and cargo can be removed by divers, thus lightening and strengthening the hull for its final move.

A special museum barge (Fig. 6) would then be brought in, and an ordinary, large capacity marine derrick will lift tongs and hull from the sea bottom to the barge's tank, which is a few meters deep and filled with water. The super-tongs are removed (and possibly sent back for the rest of the hull), and the archeologists can complete the reconstruction underwater, with controlled conditions of light and chemicals. The ancient ship will be visible to the public, but will remain submerged in a controlled environment. Because the barge would be mobile, it can be conveniently moved about the world for display.

Legal Considerations

The objects being considered for salvage are clearly part of the general heritage of our civilization and should eventually become the property of the world's great museums. Since the countries and kingdoms that once owned these ships are long gone, it may not be easy to say who owns them, and it may not even be possible to determine what flag the ship sailed under. However, in most cases the following general principle will apply.

Many countries subscribe to those Law of the Sea conventions that specify a 3-mile zone of territorial waters (measured from a base line drawn between promontories) and, beyond that, a contiguous zone to 12 nautical miles. The laws of most countries would prohibit ships of a foreign power from conducting salvage operations within these zones without specific permits.

Beyond the 12-mile limit are the high seas, where a vessel may generally be said to possess the right to conduct scientific research and to search for sunken property. Private vessels derive the right of the country whose flag they fly.

A coastal state may lay special claims to the sea floor on the continental shelf (whose limit is generally considered to be 200 meters). This kind of claim is intended to protect a state's natural resources to the limits of exploitability, but sunken property can hardly be considered a natural resource. Since the depths of greatest interest for *Alcoa Seaprobe* are well outside both the 12-mile limit and the 200-meter contour, it would seem that the ship will clearly be operating on the high seas. This would be true under U.S. law, off our own coast.

However, as a matter of scientific courtesy, one might invite archeologists from nearby states to participate. In some cases, the ship may be invited into territorial waters to perform search and recovery in the interest of international science or for a local government. Depending on the nature of the material salvaged and its origin, it should be possible to negotiate a reasonable arrangement for distributing the finds among the appropriate museums. The unique capability of the *Alcoa Seaprobe* makes it likely that several of the countries around the Mediterranean will be interested in cooperative archeological ventures.

Conclusion

Obviously this kind of work is expensive; so is any work in modern science, compared to what it cost a few years ago. But the results will justify the expense. Salvaging one ancient ship from deep water will probably cost no more, for example, than salvaging the *Maine*, or the *Vasa*, or the Roskilde Viking ships. The daily cost of *Alcoa Seaprobe* will be about half that of an ordinary tanker, destroyer, or deep-sea drilling ship. The preservation and maintenance of the ship salvaged will be a fraction of similar costs for the *Texas* or the *Queen Mary* (*23*). It is quite possible that a museum of ancient ships can be made self-supporting. Certainly it will attract the general public as well as the scholars, the tourists as well as the natives.

Who can say what a Roman trireme, or a Phoenician trader, or a Cyprean pirate ship is worth in terms of a better understanding of history? By these standards, it would seem that our civilization can afford to recover those ancient ships that can provide insights into the living and working conditions of another civilization, especially when they are not discoverable by other means. A new intellectual adventure that is understandable by the public and that generates interest and excitement can contribute to the appreciation and support of science as a whole.

Summary

There is reason to believe that some old wooden ships on the deep-sea floor have survived for thousands of years without much change. They will not be covered with much sediment, and it will be possible to find them using new searching techniques. These are embodied in the system of the *Alcoa Seaprobe*, which is also equipped to identify and raise old ships.

References and Notes

1. *Alcoa Seaprobe* is owned by the Aluminum Corporation of America and operated by Ocean Science and Engineering, Inc., for Ocean Search, Inc., a wholly owned subsidiary of Alcoa. It was designed by Ocean Science and Engineering, Inc., and built by Peterson Builders, Inc., in Sturgeon Bay, Wisconsin. It has just begun operations.
2. The following objects can survive under the sea for 2000 years. General: metal ingots (bronze, tin, copper, and silver), tools, coins, amphorae, pottery, glass, and inscribed stone tablets. Ship's gear: anchors, bronze tools, tiles, utensils, metal fasteners, ballast rock, firepots, leg-irons, navigational equipment, and lead sheeting. Military equipment (if bronze): armor, swords, spears, shields, helmets, chariots, axes, boarding grapples, Greek fire tubes, and ramming beaks. Art: sarcophagi; columns; obelisks; statues of bronze, stone, or clay; bracelets, rings, and other jewelry; and musical instruments.
3. L. Casson, *The Ancient Mariners* (Minerva New York, 1959).
4. H. Frost is excavating a hull off Sicily, believed to be that of a trireme.
5. J. S. Muroka, *Deep Ocean Biodeterioration of Materials—Six Months at 6,000 feet* (Technical Note N-1081, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., 1970); R. D. Turner, *Some Results of Deep-Water Testing* (Annual reports, 1965, American Malacological Union, Allen, Lawrence, Kans., 1965).
6. R. Marx, personal communication. In deep water off Florida, Marx found a Spanish wreck with the wood in good condition.
7. Y. Herman, *Late Quaternary Mediterranean Sediments*, in press.
8. P. Throckmorton, *Shipwrecks and Archaeology* (Little, Brown, Boston, 1970), pp. 152–155.
9. H. Frost, *Under the Mediterranean* (Routledge, London, 1963), pp. 122–129.
10. P. Throckmorton, personal communication.
11. J. Y. Cousteau, *Nat. Geogr.*, January 1954, p. 125.
12. G. F. Bass and P. Throckmorton, *Archaeology* **14**, No. 2 (1961), p. 728; G. F. Bass, *Expedition* **3**, No. 2 (Winter 1961), p. 131.
13. M. L. Katzev, *Nat. Geogr.*, June 1970, p. 841.
14. G. F. Bass, *A Diversified Program for the Study of Shallow Water Searching and Mapping Techniques* (University of Pennsylvania Museum, Philadelphia, 1968); M. S. McGehee, B. P. Luydendyk, D. E. Boegman, *Location of Ancient Roman Shipwreck by Modern Acoustic Techniques* (Report No. MPL-U-98/67, Marine Physical Laboratory, Univ. of California, San Diego, 1967).
15. L. Casson, *Ships and Seamanship in the Ancient World* (Princeton Univ. Press, Princeton, N.J., 1971).
16. H. M. Denham, *The Aegean* (Murray, London, 1963), p. 63.
17. Force 10 is a whole gale with winds of 50 knots; it can make (fully developed) waves 7 to 10 meters high. Force 6 is a strong breeze with winds of 25 knots; it can make (fully developed) waves 3 to 4 meters high.
18. F. Yalouris, unpublished data.
19. W. Bascom, U.S. Patent No. 3,215,976 (2 November 1965).
20. Dynamic positioning is a phrase first used by the author in 1960 to describe the process of equipping a ship with multiple propellers whose net thrust can be controlled from a central console, enabling the ship to hold position in deep water, relative to a fixed marker, in spite of winds, waves, and currents.
21. In addition to scearch and recovery, the *Alcoa Seaprobe* is capable of drilling for geological cores in deep water, generally following the method devised by the author and his associates in 1960 (W. Bascom, Ed., *Experimental Drilling in Deep Water* (Publication No. 914, National Academy of Sciences, Washington, D.C., 1961).
22. R. Marx, personal communication. Marx found the complete lower ribs of a 300-year-old galleon covered with sand in shallow water. The oak ribs were 20 centimeters square; beneath the outermost 1 centimeter, they "looked like new" and were in a condition so good that furniture could be made of them. He notes that this is unusual but not unique, and that the Spanish wreck he found in deep water (*6*) seems to be equally sound.
23. The *Maine*, sunk in 1898, was salvaged from the floor of Havana harbor in 1911; the *Vasa*, sunk in 1628, was raised from Stockholm harbor in 1961; the Roskilde Viking ships, sunk about 1400, were raised from a Danish harbor in 1962. The cost of each of these was several million dollars. Daily charter rates for a medium-sized tanker of 50,000 tons are now about $20,000; rates for destroyer, if computed on the same basis as those for a civilian ship, would be about $22,000 per day, plus depreciation and shore support. The day rate of the *Glomar Challenger* is about $16,000. The battleship *Texas*, now on public display at San Jacinto battlefield, was made into a presentable monument for a cost of about $1 million. The *Queen Mary*, now a convention center–museum at Long Beach, California, has cost over $50 million to date.
24. A. A. M. Van der Heyden and H. H. Scullard, Eds., *Atlas of the Classical World* (Nelson, London, 1959).