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Sonar—
a modern technique for ocean exploitation

In recent years, sonar has emerged as an important commercial and scientific tool for ocean exploration and exploitation. From finding fish to scanning strata, it is providing its users with underwater eyes

Martin Klein *Klein Associates*
Harold Edgerton *Massachusetts Institute of Technology*

Three important parameters are among those governing the application of the many versatile sonar techniques. Penetration and resolution depend upon pulse length and frequency. The angle of the transducer is also important—a perpendicular beam will resolve geological strata, whereas a side-looking beam will provide a "relief map" of the ocean terrain. Finally, several different types of transducers are available, both hull-mounted and towed, to provide the user with the best instrument for a specific application.

Until the past few years sonar was considered mainly as a depth finder or for military applications such as submarine detection. The military sonars were, and still are, generally large, expensive, and unavailable to the general public for geology or archaeology studies. There has been an aura of mystery about the military uses of sonar because of secrecy. Then chart-recording depth sounders became available for small ships, enabling fishermen to "see" their elusive quarry in the sea. This application of sonar has been most successful; it is said that some fishing ships carry two sonars, one for a spare, and will not leave port unless both are in operating condition. Sonar systems have become popular with both commercial fishing fleets and private fishing boats that cater to either a single owner or a charter fishing party. Fishermen have become quite adept in locating schools of fish from sonar traces produced on even the simplest of equipment.

More recently, many other types of sonars have become commercially available, and these sonars are finding, and will continue to find, numerous applications for diversified users who wish to study, explore, or exploit the ocean's resources. Sonar has a great role to play in the sea, with such applications as geological studies, wrecked-ship locations, archaeology, downed-aircraft locations, water flow and pollution study, and harbor mapping.

Geologists of the deep sea and oil prospectors have long used explosives to create the powerful sound pulses that are necessary to penetrate the earth. There is an array of sound sources for this work, such as the boomer, the sparker, the air gun, most of which involve a large ship and equipment; but there is also smaller equipment for special uses in shallow water that is adaptable to smaller craft.

The equipment

All effective sonar systems, we believe, should have a memory system, that is, a chart recorder of some type to put down on paper all of the information that is received back from the echoes in the water. In this way the observer has the entire story of the experiment in front of him for review in graphic form. He can examine visually the information and gain an insight of a complicated situation that is not immediately obvious. The charts then can be filed as permanent records.

Some recorders are more capable than others of displaying information. There are several types in widespread use; each has its disadvantages and advantages. One of the most commonly used is the dry-paper type, in which returned signals are amplified enough to melt a thin layer on the surface of the paper, revealing a dark layer underneath. Vapors are released that can be very objectionable in a confined area, such as a small submarine. Another type of recorder uses the electrochemical effect of current into chemically moist paper. Many problems are encountered if the paper becomes dry under hot operating conditions, so that care must be exercised by the user to keep the paper moist at all times. Hersey discusses these instruments in greater detail in his review article in the book *The Sea.*

The sonars used by the authors utilize a continuous strip chart recorder with moist electrochemical paper. This paper permits high resolution and continuous tone shades for detailing the ocean bottom. A moving helix wire mounted on a revolving drum sweeps a point of electrical contact across the paper. When signals are present the helix is energized, current passes through the paper to a second electrode (a continuous loop blade), and an electrochemical reaction produces a mark on the paper. At the beginning of each sweep a trigger pulse, generated through a photooptic pickup from a reference baseline, energizes the transmitter to emit a sound pulse in the water.

The transmitters use a capacitor-discharge arrangement in which energy is slowly stored in a capacitor and then quickly dumped into the transducer. This technique produces very-high-power (multikilowatt) pulses of very short duration, and thus is ideal for sonar applications. The actual acoustic frequency, pulse length, and transducer-beam pattern depend on a variety of factors that can be controlled to some extent by the design of the transducer. As a general rule, high-frequency pulses give high resolution and low range, whereas lower frequencies give lower resolution but longer range (or penetration of the bottom) due to the properties of sound transmission. Sonars that look into the water or at or along the bottom use frequencies from 10 kHz up to several hundred kHz; sonars that penetrate, or look through, the bottom employ frequencies from 1 Hz to 20 kHz, depending on the resolution and depth of penetration desired. The type of ocean bottom also is important. Some examples are discussed in the following paragraphs.

The Charles River Basin, just in front of the Massachusetts Institute of Technology, has a bottom that cannot be penetrated, owing to large amounts of gas in the surface layer. Sounds of 12 kHz, 5 kHz, and possibly lower, are almost completely reflected from the bottom surface. A similar situation was found in the Sea of Galilee in Israel, except at the shoreline.

Sand on a shoreline is especially difficult to penetrate, unless there is clay with the sand. Clay or fine sediment (mud), if gas-free, is very easily penetrated, and excellent results are obtained.

Limestone layers are usually penetrated with great effectiveness at 2 kHz, and even 5 kHz. The classical area

FIGURE 1. Battery-operated dual-channel portable 200-kHz side-scan system. Robert Henderson of EG&G International, Inc., is holding the towfish. The entire system can be used from the Boston Whaler shown at the M.I.T. sailing pavilion.

of this type is the sediment-free English Channel, where the ocean current keeps the limestone exposed. It must be emphasized that one must experiment with local conditions wherever one wishes to employ a sonar penetration system.

Transmitting and receiving transducers are often attached to the hull of the ship or hung from a vertical pole off the ship's side. However, we prefer to tow the transducer from a cable off the side or stern of the ship, as this makes the transducers relatively independent of the ship motions and allows them to be lowered near the bottom for a closer "look" at details. The transducers are generally mounted in some kind of "fish," which affords protection and towing stability. Figure 1 shows a side-looking sonar with a towfish containing the sonar transducer. The equipment is simple and compact, and can easily be accommodated by a small boat.

Transducers can be made of arrays of piezoelectric crystals, pulsed through a tuned transformer. This is a circuit that rings both electrically and mechanically at the frequency of interest. In some applications the transmitting transducer can be used as a receiver with a transmit–receive gate. In other applications a separate hydrophone (underwater microphone) is towed near the transmitter. The sound pulses go out into the water and echo off objects or geological features. The echoes are received, filtered, amplified, and processed in suitable form for marking on the graphic recorder.

Geological studies

Sonar can be used to observe the characteristics along the surface of the ocean bottom, or to delineate layers of sediments or other materials below the bottom. To look along the bottom, a side-looking or side-scan sonar technique is used. Transducers are aimed sideways in a direction perpendicular to the motion of a ship (see Fig. 1). This technique gives a plan view, which shows the ocean floor directly below the ship as well as the adjacent terrain. A fan-shaped beam, narrow in the horizontal plane and wide in the vertical plane, generally is used. However, a conical beam can also be used, with excellent results, in some circumstances. In order to look through the bottom, the transducers are pointed straight down and a conical beam is generally used.

Figure 2 shows a record made with a dual-channel

FIGURE 2. Dual-channel 200-kHz side-scan record made near Marblehead, Mass. Scale lines are spaced at 50-foot (15.5-meter) intervals. Ripple areas near the center are sand waves, dark areas to the left of the photo are sharp rock outcrops, smaller rock outcrops are seen on the right side. Blank areas represent smooth mud bottom with low acoustic backscatter.

side-scan sonar similar to the type shown in Fig. 1. The transducer is suspended by its electric cable below a small ship. The unit uses 200-kHz pulses in fan beams sent out simultaneously on both sides of the ship. Note that the record resembles a crude aerial photograph, and that several types of terrain can be seen. There are rocky areas, very smooth nonreflecting areas (probably flat sand), and areas of sand dunes or "sand waves." The "continuous tone" quality of the image yields great resolution of detail.

Figure 3 shows a subbottom profile made near Logan Airport in Boston Harbor. This record was obtained with a 5-kHz pulse aimed downward; the result gives an idea of the general pattern one would see if a giant knife cut into the ocean bottom and permitted one to observe a cross-sectional slice. Such profiles can often be observed on land when one is driving along highways that have been cut through geological formations.

Figure 4 shows a subbottom profile made from the research submarine *Alvin* on a dive in the Bahamas about a

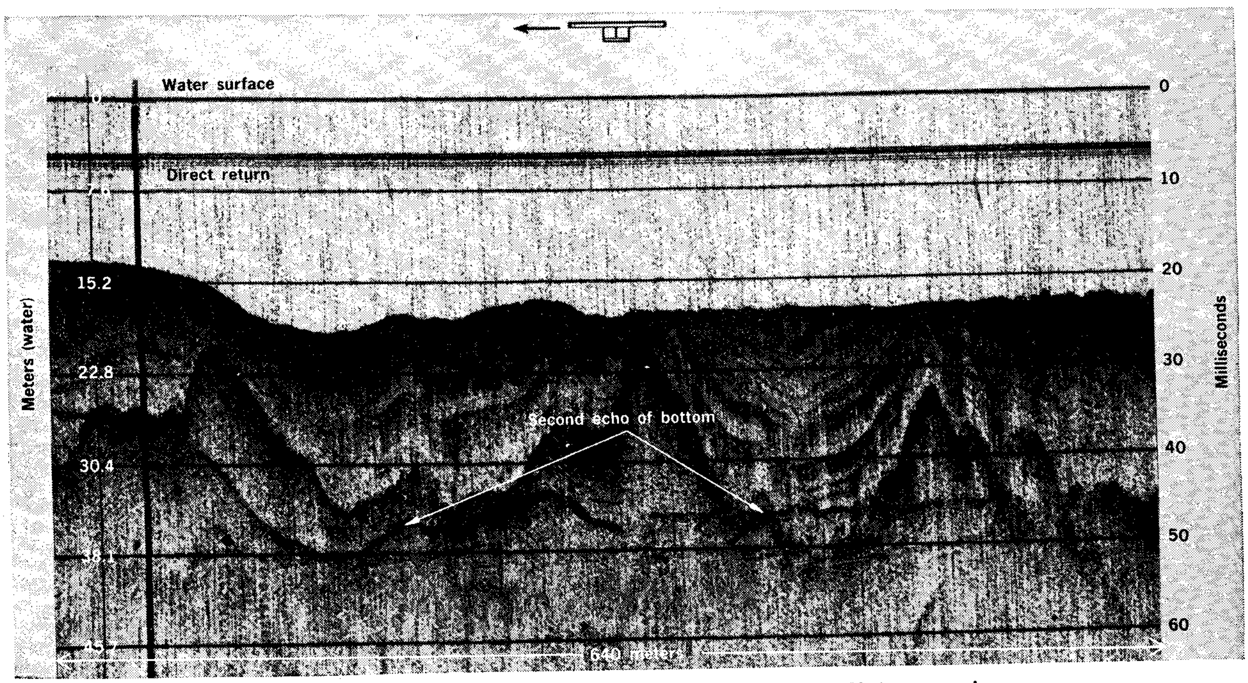
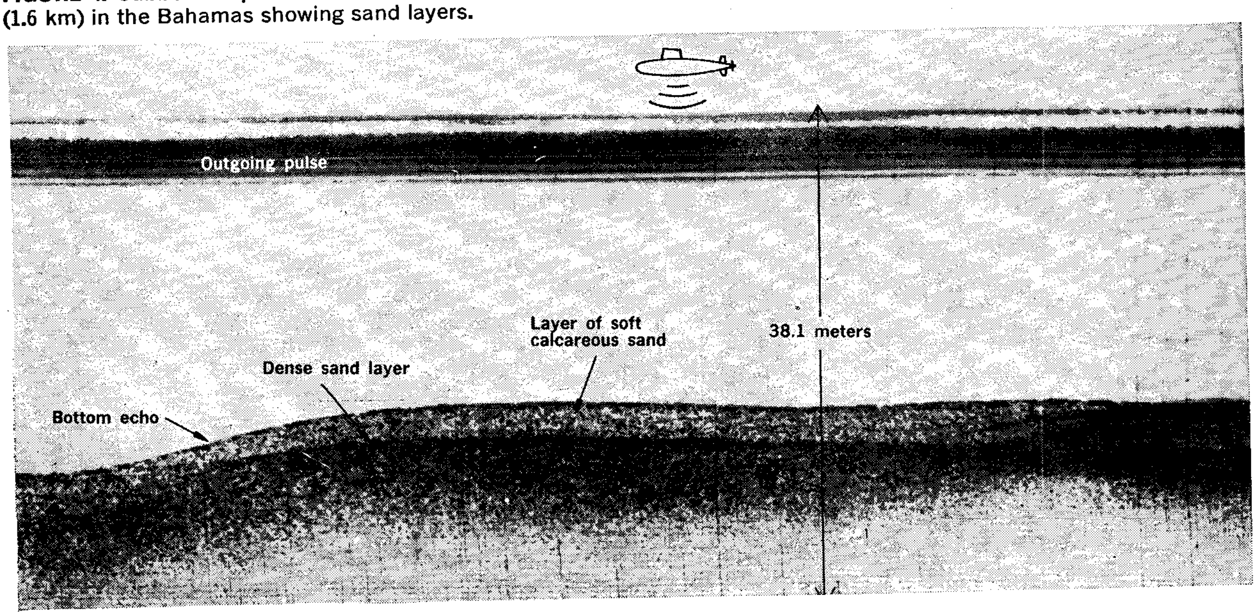


FIGURE 3. A subbottom profile made in Boston Harbor with a 5-kHz transducer. Note second echo and the profile of the subbottom layers.

FIGURE 4. Subbottom profile made from the submarine *Alvin* at a depth of about a mile (1.6 km) in the Bahamas showing sand layers.



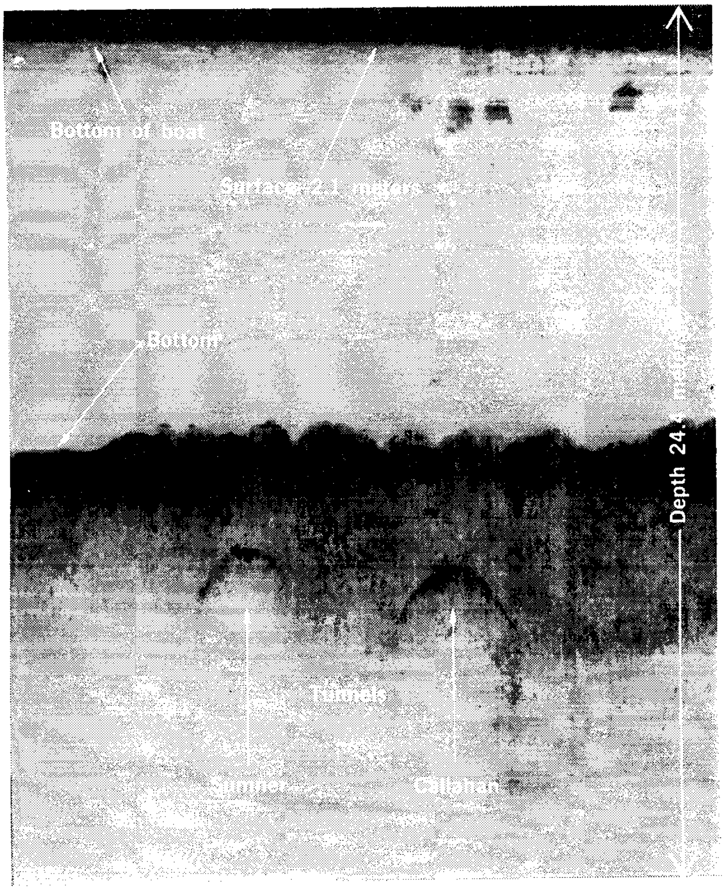
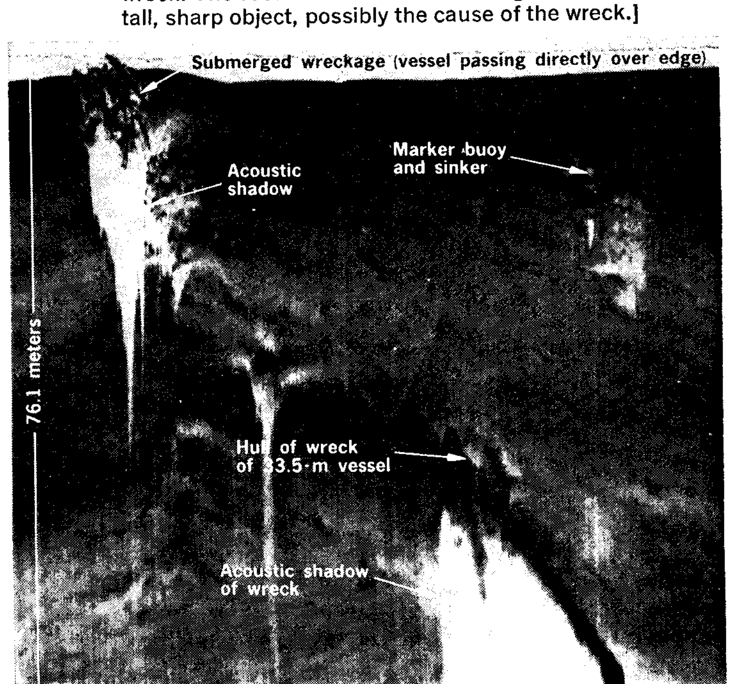


FIGURE 5. This record was made with a 12-kHz down-looking sonar in Boston Harbor. The chart clearly shows the outline of the Sumner and Callahan vehicular tunnels, which run below the harbor. Note that the Callahan Tunnel is slightly deeper than Sumner Tunnel.

FIGURE 6. A 260-kHz side-scan record made on the Potomac River. The record shows a shipwreck and its marker. [Note that the marker is nearly 100 feet (30.48 meters) from the wreck. The record also shows submerged wreckage and a tall, sharp object, possibly the cause of the wreck.]



mile (1.6 km) deep. The record was made using a miniaturized battery-operated recorder and a 12-kHz pulse aimed downward. Note that two distinct layers of the same general type of sand can be observed. Figure 5 shows an interesting down-looking sonar record made over the Sumner and Callahan Tunnels in Boston Harbor. The scan was made with a 12-kHz sonar.

The geologist using a down-looking or side-scanning sonar, or both, can thus make a rapid qualitative observation of the surface and subbottom terrain in an area of interest. If core samples reveal a certain layer of one type of material that can be identified on the sonar records, he can then follow the layer of that material with a sonar easily over large areas instead of taking hundreds of core samples.

Locating wrecked ships

Sonar has proved very successful in the location of sunken ships. If the wreck is recent and not buried, a side-looking sonar is used, although an ordinary depth sounder is often useful if the position of sinking is well known (a rare circumstance). Navigation at sea is rarely accurate, and currents are often strong, particularly in conditions that cause ships to sink, so that wrecks are often far from where the ships were supposed to have gone down.

In 1964 the *Vineyard Lightship* was found by Harold E. Edgerton, Edward P. Curley, and John Yules, far from its reported location on the navigation charts. The ship had been lost in a hurricane in 1944. This search was made with a 12-kHz transducer with a conical beam in side-scan mode. After the wreck was located, some 1000 feet (305 meters) from the indicated location on the chart, the transducer was pointed downward and the ship passed directly over the wreck, revealing the exact location.

Some time ago the authors had a call from a Boston tugboat owner who had lost his tug in one of the frequent harbor storms. The search was unusually fortuitous. A 12-kHz sonar was used and the wreck was spotted very quickly. Then the ship's depth sounder was positioned directly over the wreck and the owner was told to throw over a buoy. The buoy knocked loose a gas bottle on the tug that floated to the surface and began to puff in circles as if to announce that the right target had been found. The astonished owner was told that the operators usually aim for the nameplate of the ship!

Figure 6 shows an interesting record in which a wreck can be seen, as well as a sharp underwater structure that probably caused the wreck. This record was made using a 260-kHz side-scan sonar with a one-degree-wide horizontal beam on the Potomac River.

Archaeology

When a wrecked ship is ancient, it becomes of extreme interest to archaeologists because it represents a small chunk of history ended by sudden disaster rather than by slow decay. Figure 7 shows a sonar record, made by Martin Klein near the coast of Turkey on the Aegean Sea, of a wreck that was the object of a search by a team from the Museum of the University of Pennsylvania. The team, lead by Dr. George Bass, was interested in the ship because a sponge fisherman had dragged up an interesting bronze statue in the area. This record seems to show a large net that the sponge fishermen snagged on the ancient ship and lost. Individual floats of the net can be seen. The ship was 280 feet (77.5 meters) deep—too deep for scuba divers, so the little submarine *Asherah* dived to confirm the find. The sonar was used to position two buoys on the wreck. Then the submarine, piloted by Yuksel Egdimir and Donald Rosencrantz, followed the buoy lines and landed directly on top of the ancient shipwreck. Plans are now in progress to make further sonar and underwater television studies, and possibly to excavate the wreck for its archaeological value.

Late in 1967 the authors participated in an archaeological study in the Mediterranean near Ashdod, Israel. This area was the sight of an ancient Philistine shipping port, and the object of the mission was to use sonar to try to locate the ancient harbor, and, if possible, a Canaanite shipwreck. A 12-kHz sonar was used both for side-looking and for bottom penetration. For deeper penetration, a 5-kHz sonar was used, as well as the "boomer," an electromechanical sound source with a very clean, high-intensity pulse having a frequency of about 2 kHz. Although neither the port nor a ship was located, some items were found that bear further investigation. First an interesting chain of underwater rock projections was found about 3 km from the coast. Then the expedition divers, Hayim Stav and Shuka Shapiro, found three ancient Canaanite stone anchors, as well as some old pottery. It is suspected that the rocks may once have been the ancient shoreline when the level of the Mediterranean was lower; and the anchors may indicate the presence of shipwrecks below the sand. Further studies with bottom-penetrating sonar may reveal the presence of buried wrecks of archaeological importance that are capable of being recovered for additional investigation.

Locating downed aircraft

Side-looking sonar has proved very successful in the location of downed aircraft. Whenever possible, an attempt is made to recover aircraft wreckage so that the cause of the accident may be investigated.

Side-scan sonar was used to locate a radar picket plane, a DC-121-H, that went down off Nantucket in 1967. Figure 8 illustrates the traces made with a 260-kHz sonar. This record was made by Frederick Anderson, Lee Furse, and Donald Krotser of EG&G International, Inc. In this search the sonar was used in conjunction with underwater television equipment made by Ocean Engineering Corporation. After the wreck was picked up on sonar, a bearing was taken and the ship headed toward the wreck to get a look with the television. Video tapes were made of the wreckage for detailed analysis by the Air Force investigators.

Water flow and pollution

Just as air pollution has become a serious urban problem, river and harbor pollution is increasing. Figure 9 shows a sonar cross section made near a sewer outlet near Deer Island Light in Boston Harbor. The record, made by Harold Edgerton and Hartley Hoskins, shows the actual outlet, the flow of warm fresh water into cold salt water, and the many fish who come to feed on the sewer garbage. Note that there is sufficient difference in the acoustic character of fresh and salt water to create an echo-producing interface.

This phenomenon is shown more clearly in an interesting record made in the lagoon across from M.I.T., on the

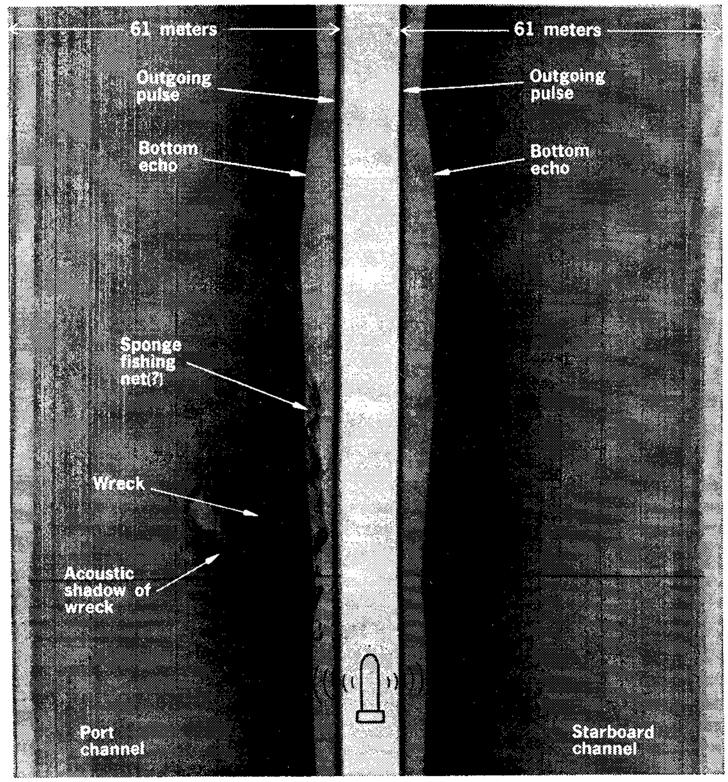


FIGURE 7. This record was made with a dual-channel 200-kHz side-scan sonar. The record was made near Bodrum, Turkey, in the Aegean Sea and shows an ancient shipwreck that may have been carrying bronze statues.

FIGURE 8. A side-scan record showing aircraft wreckage.

Charles River in Boston. The depth of the Charles River basin is controlled by a lock connecting the basin to Boston Harbor. When the tide is high, the lock introduces a considerable quantity of salt water each time it opens. The cold salt water apparently flows under the fresh water. Figure 10 shows that, in the relatively stagnant lagoon area, the layer is undisturbed; and the fresh-water–saltwater interface appears as a discernible line of demarcation on the sonar record.

Sonar is also proving useful in other areas of pollution control. Recently there has been a serious problem on the East Coast of the United States as a result of old ships releasing trapped oil as they decompose, thereby fouling the water and beaches along the coast. Side-scan sonars are being used to track down these ships systematically for inspection so that precautionary action can be taken. It might be possible to salvage the oil from wrecked tankers.

Conclusion

Anyone who plans to work in the ocean needs a means to see his environment. Since light and radio are severely attenuated under water, sound is used to recreate a graphic display that the eye and brain can interpret. We have shown a few areas in which sonar is just beginning to be used. As more sonar becomes commonly available we feel that it will become an increasingly useful tool.

The systems used by the authors have only been briefly outlined. We recommend that the interested reader consult other articles in the bibliography for further details of the equipment, techniques, and applications of sonar systems.

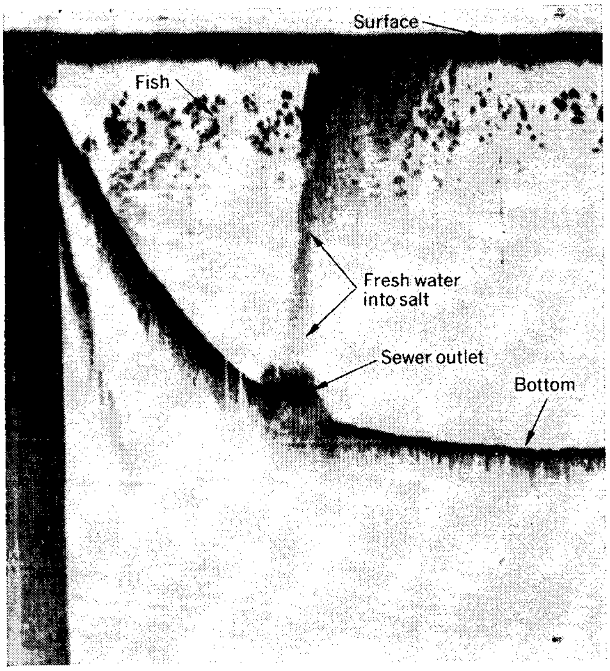
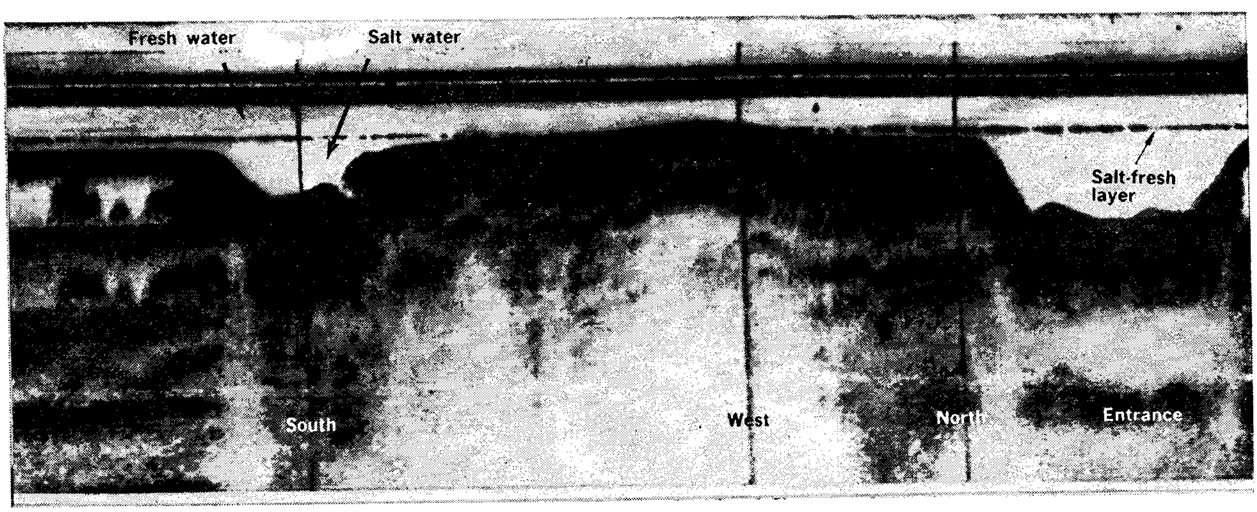


FIGURE 9. Record made with a 12-kHz down-looking sonar, over a sewer outlet near Deer Island Light, Boston Harbor. Note that the escaping fresh water can be seen, as well as the fish. There is sufficient acoustical difference between fresh and salt water to create a delineative echo.

FIGURE 10. Record made with down-looking 12-kHz sonar in the still lagoon near the Community Boat Club on the Charles River in Boston. The record reveals a sharp acoustic echo from the interface between a dense, stagnant pool of salt water and the fresh water above and toward the surface. The salt water apparently flows under the fresh water; the interface appears as a line on the record.



BIBLIOGRAPHY

Clay, C. S., Ess, J., and Weisman, I., "Lateral echo sounding of the ocean bottom on the Continental rise," *J. Geophys. Res.*, vol. 69, Sept. 15, 1964.

Edgerton, H. E., "Exploring the sea with sonar," *Discovery*, Sept. 1966.

Edgerton, H. E., "Sub-bottom penetration of the Boston Harbor," *J. Geophys. Res.*, vol. 70, p. 2931, June 15, 1965, and vol. 68, p. 2753, 1963.

Edgerton, H. E., and Hayward, G. G., "The boomer sonar source for seismic profiling," *J. Geophys. Res.*, vol. 69, p. 3033, Aug. 1964.

Hersey, J. B., "Continuous reflection profiling," in *The Sea*, M. N. Hill, ed. New York: Interscience, vol. 3, 1963, p. 47.

Horton, J. W., "Fundamentals of sonar," U.S. Naval Institute, Annapolis, Md., 1957.

Klein, M., "Side-scan sonar," *Undersea Technol.*, April 1, 1967.

Tucker, D. G., *Underwater Observation Using Sonar.* London: Fishing News (Books) Ltd., 1966.

Tucker, M. H., "Sideways looking sonar for marine geology," *Geo-Marine Technol.*, Oct. 1966.

Yules, J. A., and Edgerton, H. E., "Bottom sonar search techniques," *Undersea Technol.*, Nov. 1964.

Authors

Sonar—a modern technique for ocean exploitation (page 40)

Martin Klein (M) is the president and founder of Klein Associates, Lexington, Mass., where he is engaged in product development and consulting related to undersea search and survey. He was formerly program manager for sonar systems at EG&G International, Inc., in which capacity he was responsible for the design and field testing of several sonar systems including an up-, down-, and side-looking sonar for the bathyscaphe *Trieste II*. He has participated in numerous search and survey operations in the English Channel, in the Bonaparte Gulf in Australia, and Israel. In 1967 he used his side-scan sonar to assist a team of archaeologists in locating an ancient sunken ship. He received the B.S.E.E. degree from the Massachusetts Institute of Technology in 1962 and is a member of the Marine Technology Society and Institute of Navigation.

Harold Edgerton (F) received the B.S. degree from the University of Nebraska in 1925 and the M.S. and D.Sc. degrees from the Massachusetts Institute of Technology in 1927 and 1931, respectively. His pioneering research work in the field of stroboscopic photography was the foundation for the development of the present-day electronic speed flash. He has designed watertight cameras with electronic flash lamps, is a consultant on underwater flash photography and stroboscopy, and has been working with Capt. Jacques Yves Cousteau in explorations of the floor of the Mediterranean Sea. He holds the position of institute professor at M.I.T. and also serves as honorary chairman of the board of EG&G, Inc. Currently Dr. Edgerton is developing sonar devices for positioning equipment in the sea and for the exploration of the subbottom structure.