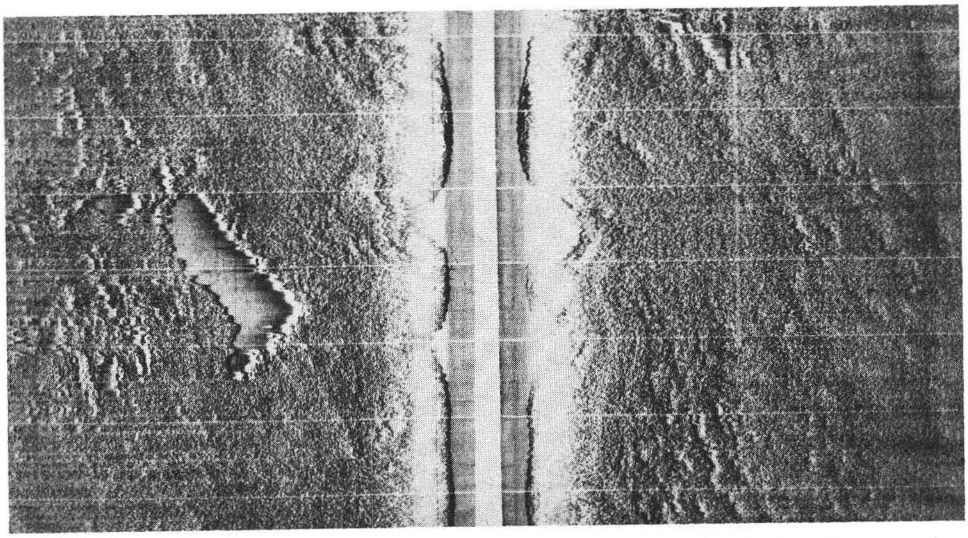

FIG. 1. SLS Image of the Ocean Bottom. The side-looking-sonar record at the top of the page shows a half-mile-wide section (left to right) of the ocean bottom at a depth of more than 8000 feet. The long lighter-colored region (center left) shows a depression about 200×600 feet. Sand mounds can be seen in the upper right corner. The lines crossing the record are reference marks superimposed on the image at specified time periods to aid the measurement of distance. (*Courtesy, Hudson Laboratories of Columbia University*).

JOACHIM G. STEPHAN†
Battelle Memorial Institute
Columbus, Ohio 43201

Mapping the Ocean Floor

Side-looking sonar may yield a speedier means for undersea reconnoitering and mapping.

THE GROWING AWARENESS OF THE importance of the seas, and the land under the seas, is creating new demands for knowledge of that virtually virgin area that makes up three-fifths of the earth's surface. And as man consumes the resources of the dry land areas, he, of necessity, must turn increasingly to the largely untapped ocean areas for mineral and other resources.

The continental shelves are already the scene of varied activities including some of a military nature, oil-well drilling, and the gathering of food and other products. Though these call for only limited human activity on the ocean bottom, there is growing recognition of the desirability of detailed and accurate maps of the areas. Thus, maps would be useful in locating drilling sites and in selecting routes for pipelines and cables.

The area of the continental shelves, let alone the remainder of the oceans, is so great that to map them requires techniques comparable in speed and range to those used by photogrammetrists in the mapping of dry land. Today's aerial mapping aircraft, for example, are capable of photomapping thousands of square miles in one day. Photogrammetry, of course, normally deals with the re-

† Reprinted from *Battelle Technical Review* with the kind permission of Battelle Memorial Institute. Permission was also received for reprinting illustrations from: Hudson Laboratories of Columbia University, Dobbs Ferry, New York; and Electro-Acoustic Research, Westinghouse Electric Corp., Pittsburgh, Pennsylvania.

duction of precise data acquired by photographing objects, areas, or phenomena under controlled conditions with highly specialized and calibrated photographic equipment. However, conventional photogrammetry is not now applicable to the mapping of the land covered by water. The photographically useful portion of sunlight is absorbed in the top few meters of water. Even with artificial light and under the most favorable conditions, photographic images cannot be made of areas greater than about 100 feet in diameter. It is unthinkable that the vast land masses under the oceans could be reconnoitered and mapped with such limited photographic means. Somehow, man must be able to "see" over relatively wide areas underwater.

ABSTRACT: *Unconventional photogrammetric procedures may be feasible for mapping the ocean floor. Based on side-looking sonar, the procedures promise a speedier means for undersea reconnoitering and mapping than are available currently. Two basic types of equipment are available. In its present stage, a "fish" may be towed at 4 knots about 225 feet above the ocean bottom, having a range of about 1,230 feet on each side and a resolution of about 4 feet. So far, the system is unable to yield three dimensions, and a method is needed for accurate underwater navigation.*

In this article, equipment that holds promise of enabling man to "see" relatively long distances underwater will be considered. Such devices have been developed by both U. S. and British technology for underwater observation and exploration (Figure 1). The following discussion will describe the devices and suggest how they might be adapted for use in underwater mapping.

MAPPING WITH SOUND

The only means now available for extensive observation of the ocean floor is a device known as "side-looking sonar" (SLS). It is an acoustical device that scans land underwater much as side-looking radar, an electronic device, scans the earth's surface.

Side-looking sonar was applied successfully by the British in the 1950's in making geological surveys of the English Channel. Utilizing the so-called Towed Surveying ASDIC,* the British made SLS records that display in remarkable detail the geological characteristics of the channel floor.

In the United States, the Ocean Bottom Scanning Sonar Device, built by Westinghouse, was employed in the search for the submarine *USS Thresher* and for reconnoitering off the coast of California and Alaska after the great 1964 earthquake The device is reported to have the capability of operating at depths of 20,000 feet, which would enable its use in mapping much of the ocean bottom.

HOW SLS OPERATES

Conventional sonar equipment, which is analogous to rotating radar, consists of a rotatable transducer and a synchronized display. During operation, the transducer is continually rotated to produce a circular map of the ocean bottom. The location of any object on such a map may then be determined as a function of range and angle from the ship.

Side-looking sonar devices generally utilize a transmitting transducer that is either housed in a streamlined body called a "fish" or is built into a surveying or exploring craft. When a fish is used, it usually is towed behind the exploring or surveying craft.

During SLS operation, sound pulses of high frequency and short duration are emitted from one or both sides of the fish or craft. The pulses, focused in a relatively narrow beam, are directed at the ocean floor a few

* Named after the Antisubmarine Detection and Identification Committee.

ABOUT THE AUTHOR

J. G. Stephan has been conducting research on a wide spectrum of photogrammetric, geodetic, and related problems varying from military mapping and reconnaissance techniques to methods of conducting marine geodetic surveys. Before joining the Battelle-Columbus staff, he was associated with North American Aviation, Inc., where he was involved in the research, development, and evaluation of advanced electronically controlled photogrammetric systems used by the United States Navy for reconnaissance.

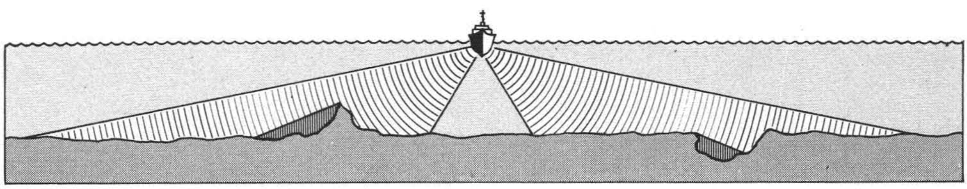

FIG. 2. Mode of Operation of SLS. The acoustic beam fans out from the source (here located in a ship) much like a light beam. The reflected pattern reveals high points and the nearer edge of depressions on the ocean bottom as shadows. These images are traced continuously on a paper record or displayed on a scope.

degrees below the horizontal in a direction perpendicular to the ship's course. The beam sounds the bottom of the ocean in a scanning pattern much as the slanted beam of a light source elevated above the topography would sidelight the panorama below it. The narrowness of the beam, along with other factors, determines the smallness of the object that can be detected (i.e., the better the resolution).

When the sound reaches the ocean bottom, it is reflected in a pattern that indicates the bottom topography. Each echoed sound pulse is displayed by an oscilloscope or a paper recorder. Elevations produce shadow zones behind them, relative to the sound source. The length of the shadow depends upon the height and overall size of the elevations and their distance from the sonar source. Depressions, on the other hand, produce shadows just beyond the rim closest to the sonar scanner. Smooth topography is indicated by uninterrupted, even lines.

AVAILABLE EQUIPMENT

The two basic types of sonar equipment referred to above and now available for underwater scanning operate in the same fashion, although they differ in details.

The ASDIC equipment consists essentially of a towed underwater unit and a dash-mounted dry paper recorder. The underwater unit contains a 27-element transducer operating at a frequency of 48 kc/sec. The sonar beam width is 7.5° in the vertical plane and 1.6° in the horizontal plane. The typical records produced by the ASDIC equipment depict an area 800 yards wide and 2 to 3 miles long. ASDIC devices have been used principally for geological and fishing purposes.

The SLS developed for the U. S. Navy is designed to search at great depths. For such searches the sound source is placed in a towed fish. Figure 3 illustrates the general makeup of the scanning system. The energy for the unit is provided by four identical transducers, each 45 inches long, which emit beams from both right and left sides of the fish. The horizontal beam width of 0.31° produces an overall resolution of about 4 feet. The opposing transducers in the fish operate at frequencies of 215 and 225 kc to avoid cross talk between the returning signals. These may be displayed on a cathode ray tube or recorded on paper or magnetic tape.

Towed SLS devices are normally moved at speeds up to four knots and operate about 225 feet above the ocean floor. Overall SLS range at this height above the bottom is about 1,230 feet on each side of the fish. Accurate measurement requires that the SLS be moved at uniform speed.

SLS equipment has been installed in the hull of the *Trieste II*, the U. S. Navy's bathyscope. This equipment is capable of either short-range or long-range operation,

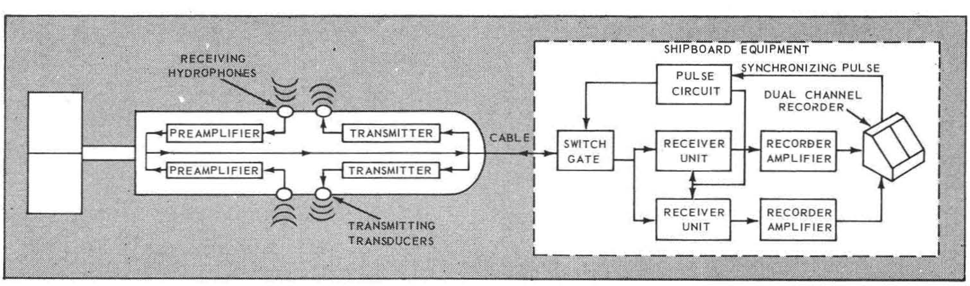

Fig. 3. Arrangement of Fish and Shipboard Elements of Side-Looking Sonar Equipment. (*Courtesy, Westinghouse Underseas Division*)

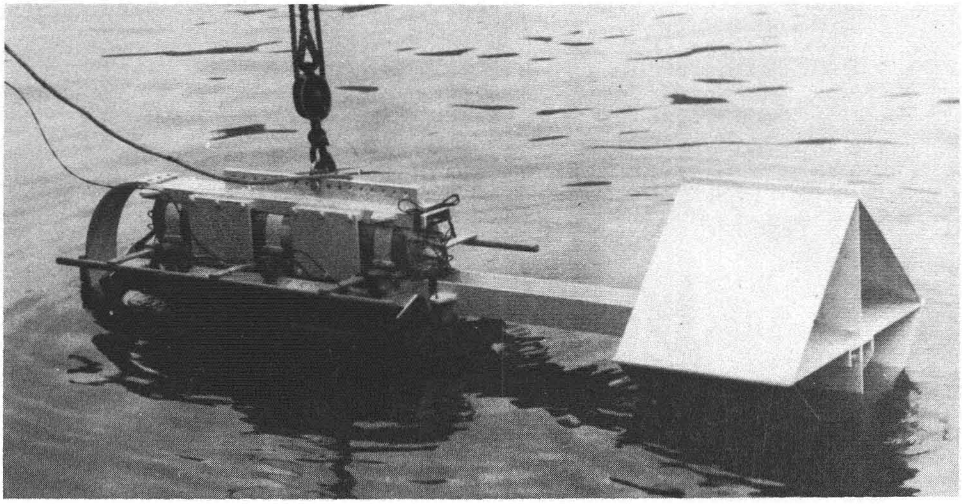

FIG. 4. Ocean Bottom Scanning Sonar. The structure of an SLS "fish," being lowered into operational position, can be seen here. The main body and tail assembly of the device are held together by a 6-inch I-beam, which is visible above the water. The electronic unit assembly is above the beam; the batteries that operate the assembly are below the beam. The transducers are located on each side of the beam. (*Courtesy, Westinghouse Underseas Division*)

but is usually operated at 20 or 225 feet above the ocean floor, with side ranges of 207 and 1,230 feet, respectively.

PROBLEMS AND POTENTIALITIES OF SLS

In side-looking sonar, even at its present stage of development, we have a promising instrument for utilization in underwater mapping. Obviously, many technical refinements will be required. At present, the SLS state of the art is similar to that of aerial photography about 40 years ago. The following discussion indicates some of the probable directions of research on and development of SLS.

One of the very real shortcomings of SLS as a mapping instrument is the current inability to produce three-dimensional images with it. In the precise topographic mapping of land surfaces, overlapping photographs are now used to produce what are stereo images in the eyes of the observer. In order to map the photographed terrain, a movable reference point (the so-called "floating point") is superimposed through the optics of the photogrammetric instrument. With the movable reference point, the operator can plot and record differences in elevation very precisely. Points of the same elevation may then be connected to produce the familiar contour lines of topographic maps.

Similar techniques will be required in order to produce precise maps of underwater areas. Three-dimensional viewing with SLS will be necessary. Mathematically, such images are feasible with SLS, but a practical method for producing them has not yet been developed.

A means for precisely navigating the seas also must be provided before underwater mapping is feasible. The bench marks and other reference points available for plotting all the details that make accurate land maps possible do not now exist for navigators at sea. Thus, sonar mapping of the ocean bottoms would require the presence on the ocean floor of precisely located bench marks that could serve as control points. Establishment of such bench marks would require a survey program of large dimensions.*

In order to fulfill the requirements associated with undersea mapping, SLS will, of course, need a number of refinements. Thus, the ability to use stable film emulsion in place of paper in recording sonar readings will be a necessity. If SLS is to become an effective mapping device, photogrammetrists will require such new equipment as special SLS viewers and plotters to plot, measure, and evaluate SLS records. Also, automatic or semiautomatic means of processing large volumes of recorded data must be devised.

New mapping techniques also will be called for. Mapping topography at depths of 20,000 feet obviously will require more precision than would mapping within a harbor. One of

* Steps in the establishment of such a system are considered in George Mourad, "Marine Geodesy," *Battelle Technical Review*, February 1965.

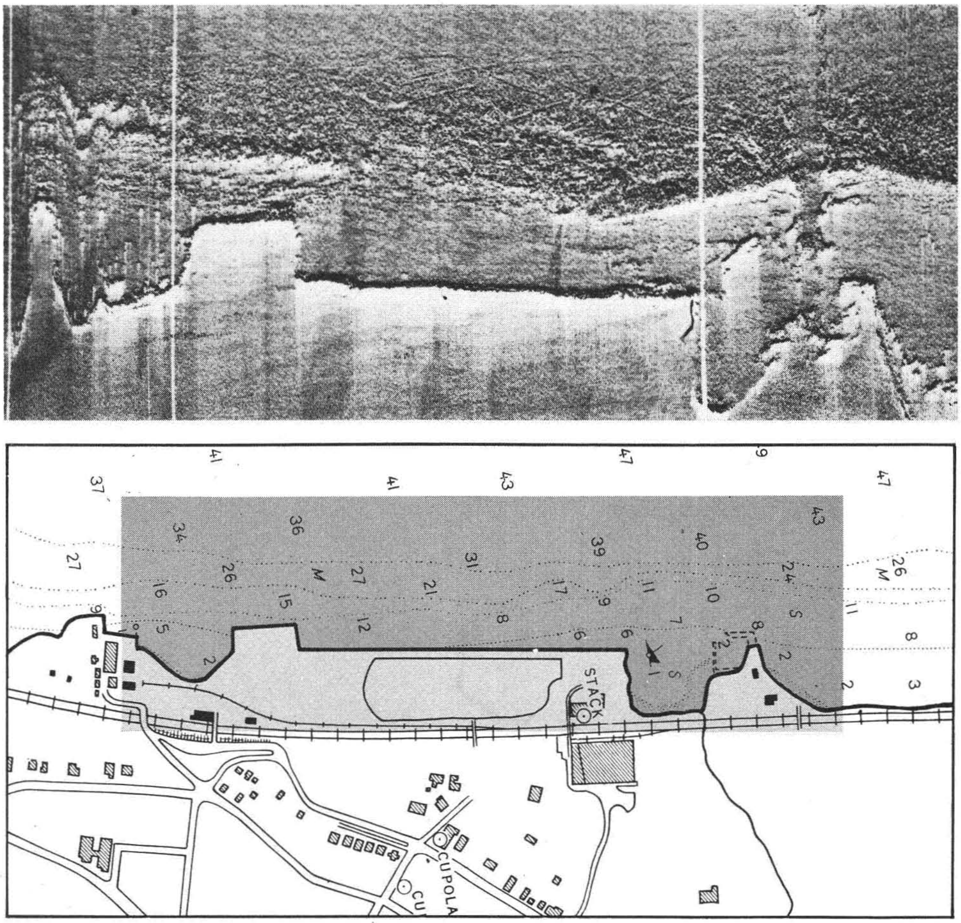

FIG. 5. Comparison of SLS Record With Survey Chart. The mapping abilities of SLS are demonstrated in this comparison. The SLS image of a section of the Hudson River at Dobbs Ferry is shown at the top. A section of the Coast and Geodetic Survey chart with the same area screened for identification is shown at the bottom. Note the marked similarity of the profiles of the shore and also the location of the sunken barge marked on the chart near the stack (center, right). It can be recognized by its shadow in the SLS scan. (*Courtesy, Hudson Laboratories of Columbia University*)

the desired developments would be a means for mapping at speeds higher than the four knots possible at this time.

LOOKING TO THE FUTURE

Even in its present stage of development, side-looking sonar is a most promising device for providing needed information about the surface of the land masses underwater. Devices that will make possible the topographic mapping of inland waterways and the coastal shelf as well as the floors of the ocean are also needed.

Instead of depending on painfully slow, spot soundings of such areas, map makers could use side-looking sonar to rapidly create detailed, accurate maps. Harbor and rivers could be surveyed continuously, comprehensively, and quickly to determine the amount of silting and to provide other current data for hydraulic harbor and river models. On the basis of such information, for example, the best routes for pipelines could be determined and the best channels for shipping could be pinpointed.

In another use and with a variation of SLS, forward-aimed scanning sonar would be helpful to ship navigators in avoiding reefs and other underwater obstacles much as low-flying aircraft use radar to avoid land obstacles. The military use of such devices can, of course, only be suggested here.

In short, the greatest potential of the SLS device lies in the fact that it is capable of recording relatively large land areas underwater, a capability that man may soon be able to utilize in exploiting the seas and the land at the bottom of the seas.

Conclusions

The growing interest in and concern about the exploration and exploitation of the seas is leading to research studies in many fields. These concern all the possible areas of the oceans' usefulness. But in the last analysis, man's ability to make the fullest use of this underwater world depends upon his being able to exist in the environment and to find his way about the vast regions beneath the seas.

The importance of charting undersea areas has been well demonstrated by the problems growing out of needs for well-mapped harbors, locating oil drilling sites and pipelines, and for such more dramatic tasks as locating and rescuing sunken submarines.

Mapping under the seas will require tremendous effort, even with the availability of the improved devices and equipment envisioned in this article. With the growing recognition of the desirability of undersea maps in various parts of the world, it is important that the necessary technology be developed so that the photogrammetrist may get on with his task.

References

1. C. S. Clay, John Ess, and Irving Weissman, "Lateral Echo Sounding of the Ocean Bottom on the Continental Rise," *Journal of Geophysical Research*, vol. 69, no. 18, Sept. 1964.
2. "Toward Surveying ASDIC," Bulletin, Kelvin Hughes Division of S. Smith & Sons Ltd., London.
3. M. J. Tucker and A. R. Stubbs, "Narrow-Beam Echo-Ranger for Fishery and Geological Investigations," *British Journal of Applied Physics*, vol. 12, March 1961.
4. "Ocean Bottom Scanning Sonar," Underseas Division of Westinghouse Defense and Space Center, Baltimore, Md.
