GEOPHYSICS, VOL. XXIV, NO. 4 (OCTOBER, 1959), PP. 749–760, 8 FIGS.

SUB-BOTTOM DEPTH RECORDER*

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ABSTRACT

The Sub-bottom Depth Recorder (SDR) has been developed to study the underlying geologic structure of water covered areas. The SDR is essentially a broad-band, high-powered echo sounder which utilizes one of two sound sources.

The first, an electrical spark discharge (Sparker), has produced penetrations in excess of 600 ft in 50 ft of water. The second, a combustion chamber using a mixture of propane and oxygen (RASS), has produced penetrations in excess of 1,400 ft in 80 ft of water.

Results obtained from the SDR have been found to be in excellent agreement with test boring and seismic refraction data.

INTRODUCTION

Since the summer of 1957 an active program has been underway at the Lamont Geological Observation directed toward the study of sub-bottom structures underlying water-covered areas through the use of high-powered echo sounders. Emphasis has been placed on the use of broad-band, low-frequency sources to produce the necessary acoustic energy.

The present Sub-bottom Depth Recorder (SDR) utilizes as a sound source an electric spark discharge (Sparker) or the combustion of a mixture of propane and oxygen in a small chamber (RASS). The SDR is constructed so that one may choose the particular source best suited to the area and structure under survey. One can further select the passband of the receiving circuit to provide an optimum signal-to-noise ratio.

A number of equipments designed to obtain sub-bottom echoes have been reported in the literature (McClure, Nelson, and Huckaby, 1958; Smith, 1958; and Padburg, 1958). Each of these has used rather large crystal or magnetostrictive transducers. The trend has been to utilize lower frequencies, of the order of 1–9 kc, in order to achieve more penetration. This has resulted in rather large equipments, particularly the transducer sections. Hence, the portability is limited, and installation is time-consuming and involves rather expensive modifications to the ship's hull.

Of the two sources available with the SDR, the electric spark discharge is the more common. It has been used for studies of underwater sound propagation by Anderson (1953), among others, and has been applied to the study of sub-bottom structures with notable success by members of the Woods Hole Oceanographic Institute, Knott and Hersey (1956), and Hersey[1] to the study of sub-bottom

* Lamont Geological Observatory Contribution No. 361. Manuscript received by the Editor June 16, 1958.

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[1] Personal communication.

structures. A simplified spark discharge has been used by Press and Oliver (1955), and Hall (1956), among others.

The combustible gas sound source, called the RASS for Repeatable Acoustic-Seismic Source, is a newer concept and has not been reported in the literature, to our knowledge. Single shot, non-repeatable gas sound sources have been reported in patents by McCollum (1951) and Merten (1955), but these have been rather large, complex machines not suited for a continuously operating, shipboard sound source.

The Sparker is used primarily when emphasis is to be placed on the study of relatively shallow, complex sub-bottom structures. The acoustic signal produced contains significant energy between 300 and 5,000 cps. The use of these frequencies (considered here to be high) permits excellent definition of small gradients or changes in sub-bottom sediments. A record made using the Sparker in Long Island Sound is shown in Figure 1. Penetrations in excess of 600 ft in 50 ft of water have been recorded.

The RASS is used when more energy is required in order to study deeper layering. The fundamental frequency of the RASS is 35 cps; the signal includes this frequency and the harmonics above. Frequencies up to 3,000 cps are used to record the sub-bottom reflections. A record made with the RASS in Long Island Sound is shown in Figure 2. Penetrations in excess of 1,400 ft in 80 ft of water have been made. Here the geologic structure has been the limiting factor; a probable limit of the instrument is 2,000 ft in coastal plain sediments.

Geologic surveys have been made using the SDR in Long Island, Block Island, and Rhode Island Sounds, Chesapeake Bay, the Red Sea, the Beagle Channel (Cape Horn), and on the Atlantic Coastal Plain. A distance of some 3,000 miles has been covered and has given valuable data of the areas involved.

DESCRIPTION OF EQUIPMENT

The equipment consists of two parts, the transmitting section and the recording section. The transmitting section consists of a choice of either the Sparker or the RASS sound sources (see Figure 3).

An electro-chemical type recorder provides a synchronized trigger pulse corresponding to a writing stylus position at the left of the recording paper. In the case of the Sparker, this triggering pulse switches a capacitor charged to 8,000 volts across the Spark Electrode Assembly shown in Figure 4. The spark discharge from the center electrode to the concentric ring produces a loud, short-duration sound. The electrode is towed directly in the water by the electrical connecting cable. In the case of the RASS, the triggering pulse energizes a spark coil producing an ignition spark in the combustion chamber to which propane and oxygen are continuously fed (see Figure 5). The combustion chamber is towed in the water in a small paravane at a depth of 2 to 5 ft.

A receiving hydrophone encased in a hose is towed behind the ship. The reflected signal detected by the hydrophone is pre-amplified, passed through a vari-

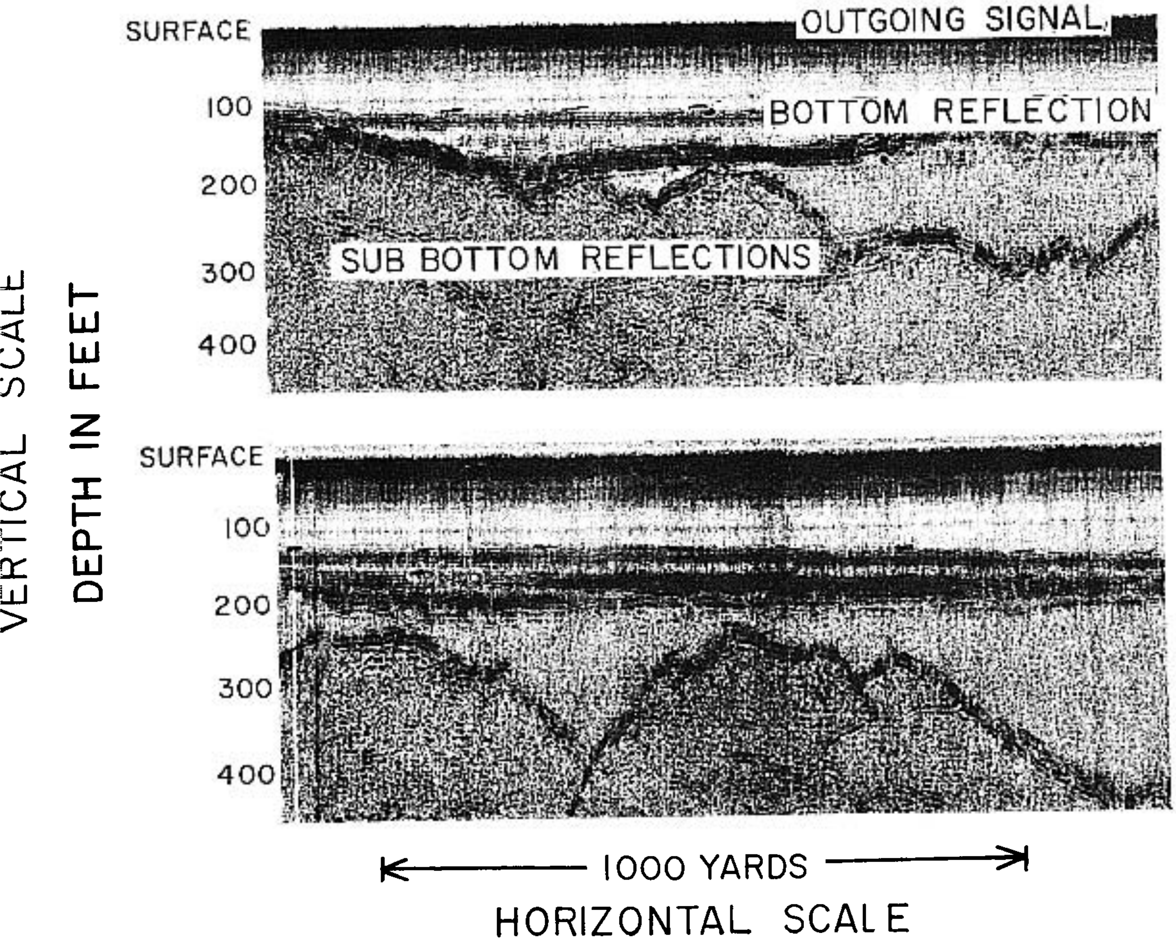

FIG. 1. A portion of a SDR record made in Long Island Sound using the Sparker sound source. The top of the record corresponds to the water surface, the first reflection to the water bottom, and the successive reflections to the various sub-bottom horizons. These later events correspond to an intermediate horizon presumed to be the interface between the Recent and Pleistocene deposits and to the underlying bedrock.

able passive filter, then amplified and printed on the recorder. A time variable gain (TVG) print amplifier is used so as to permit one to see clearly the deeper horizons without blacking out the shallow, and hence stronger, arrivals. The TVG is controlled by the trigger pulse from the recorder, once per second.

A recorder stylus traverses the width of the recording paper in one second, giving a depth of 400 fathoms (2,400 ft) across the paper, for a velocity of 4,800 ft/sec. The repetition rate of the Sparker can be made four, three, two, or one per second by utilizing auxiliary trigger pulse contacts. That is, several records

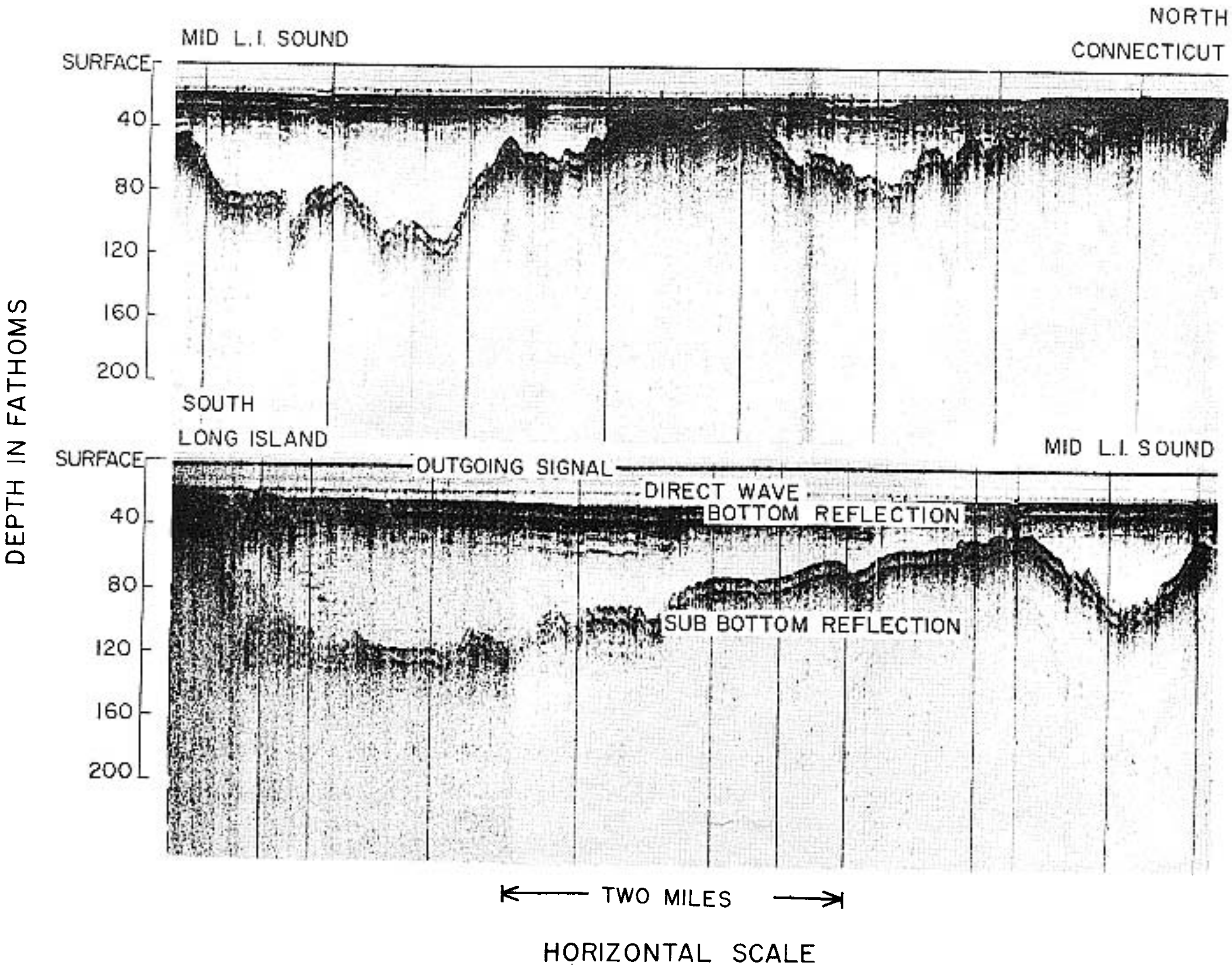

FIG. 2. A portion of a SDR record made in Long Island Sound using the RASS sound source. Because of a separation between the RASS and the receiving hydrophone, the direct sound-path arrival is present. Succeeding reflections are the water bottom and bedrock. Some intermediate horizons are shown, although not clearly. The double character of the reflections is a result of the fundamental frequency of the RASS signal. The double character is a considerable aid in identification of reflections under

can be made across the paper having depth scales which are divisions of 400 fathoms (2,400 ft).

In the case of the record shown in Figure 6, a repetition rate of three per second was used to give three records each having a total depth scale of 800 ft. The use of TVG permits one to obtain several complete records at increasing gain on the same record paper. It has been found that this system is more satisfactory than a single TVG record, the reason being that shifting depth scale from 100, to 200, · · · , to 400 fathoms can be done simply by selection of the repetition rate of the trigger pulse and does not involve speed changes of styli or paper transport. In addition, it provides a greater time-variable gain range for each reflection horizon.

The repetition rate of the RASS can be made two or one per second giving depth scales of 200 or 400 fathoms. Much of the thinking behind this recording scheme has been influenced by work in the Long Island area where the deepest reflecting horizon (bedrock) slopes gently from Connecticut to the south southeast. A typical survey line then was begun by the Sparker at four per second and then switching to the RASS at two per second as the bedrock deepened. The

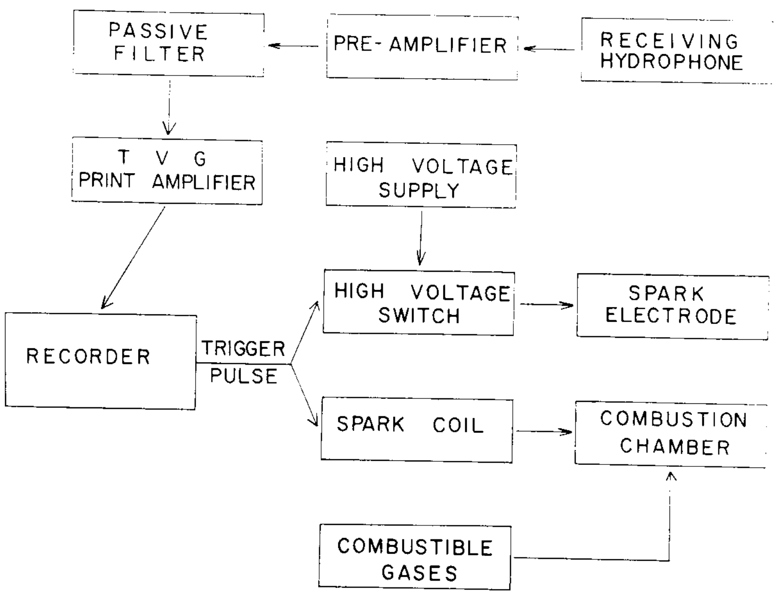

FIG. 3. A block diagram of the SDR equipment. The recorder provides the synchronized trigger pulse which in the case of the Sparker operates a switch which places a charged capacitor across the spark electrode producing the sound, in the case of the RASS the trigger pulse pulses a spark coil which provides the ignition spark in the combustion chamber which is continuously fed propane and oxygen.

The reflected sound is detected by the receiving hydrophone, the signal is then pre-amplified, filtered, amplified, and printed by styli on a moving belt on an electro-chemical recorder.

FIG. 4. The Sparker electrode assembly. The sound-producing spark discharge is between the center electrode and the concentric ring. This replaceable portion of this unit wears out in from 6 to 9 hours and must be replaced.

SDR is equipped so that the change from one sound source to another or from one repetition rate to another requires only a few seconds.

Power consumption for the SDR varies, of course, depending on which sound source is used. The SDR with the Sparker requires about 1,200 w of 110 volts ac power. This power may be unregulated like that produced by a small 2-kw gasoline generator. The SDR with the RASS requires only about 350 of 110 volts ac electrical power plus propane and oxygen supplies. At a repetition rate of one per second the hourly gas consumption is 30 ft^3 of oxygen and about one pound of liquid propane. More simply, a standard 300 ft^3 hand-carried tank of oxygen is required for each 10 hours of continuous operation. A large tank of propane such as that used for home cooking (150–200 lb) will last for 15 tanks of oxygen.

INTERPRETATION OF DATA

The SDR, of course, is capable of a measurement of time only. The depth scale used is based on the velocity of 4,800 ft (800 fathoms) per sec, which is approximately the velocity of sound in water. In order to determine the true depth to a particular reflecting horizon, it is necessary to correct the depths shown by the SDR for the velocity of sound in the water and in the sedimentary column.

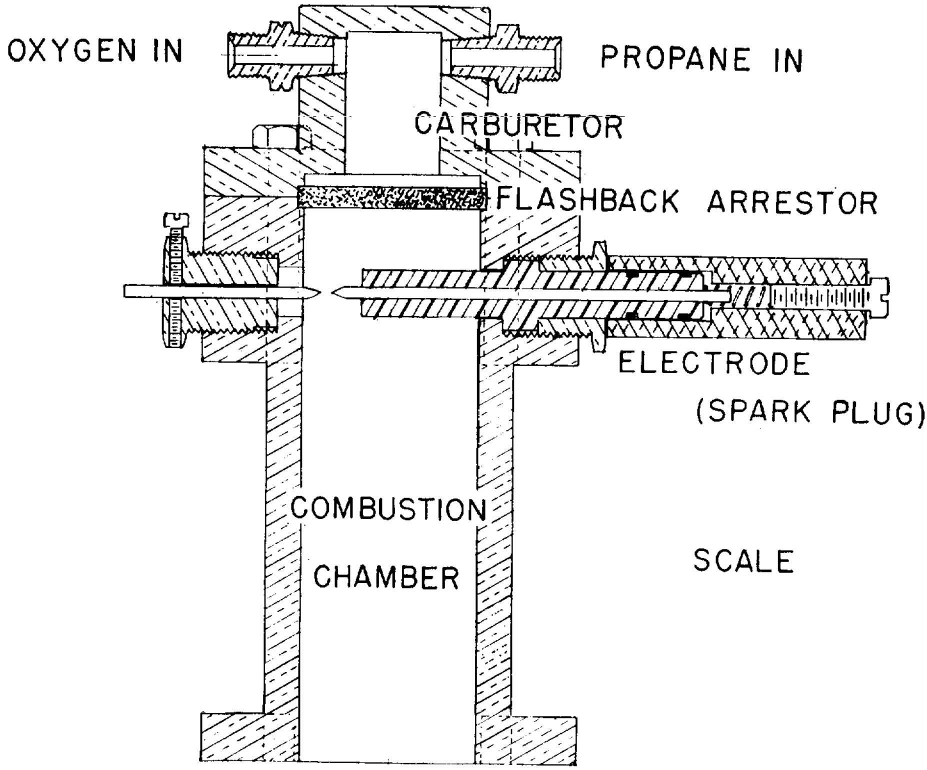

FIG. 5. The RASS combustion chamber. The propane and oxygen are introduced into the carburetor through separate vents. The gasses mix and pass downward where they are ignited by the spark plug. The flashback arrestor prevents continuous burning of the mixture in the carburetor. The resulting explosion exhausts through the bottom of the chamber directly into the water. The unit is contained in a small fish and towed two to five feet below the water surface.

The velocity of the sound in the water can be calculated from a knowledge of the temperature and salinity of the water through application of suitable formulae and tables. For many areas of the world, these values are already known, and it is necessary only to refer to them.

The velocity of sound in the sedimentary column is more complex, however, and one of a number of auxiliary measurements must be made. Of these, seismic refraction profiles, wide-angle reflection profiles, and test borings have been used successfully.

A number of strategically placed seismic refraction profiles, reversed to give true velocity, permit one to correct the depth of the various reflecting horizons as given by the SDR. In addition, they serve to influence one's confidence in the horizontal correlation of the various horizons.

Velocities can likewise be determined through the use of wide-angle reflection

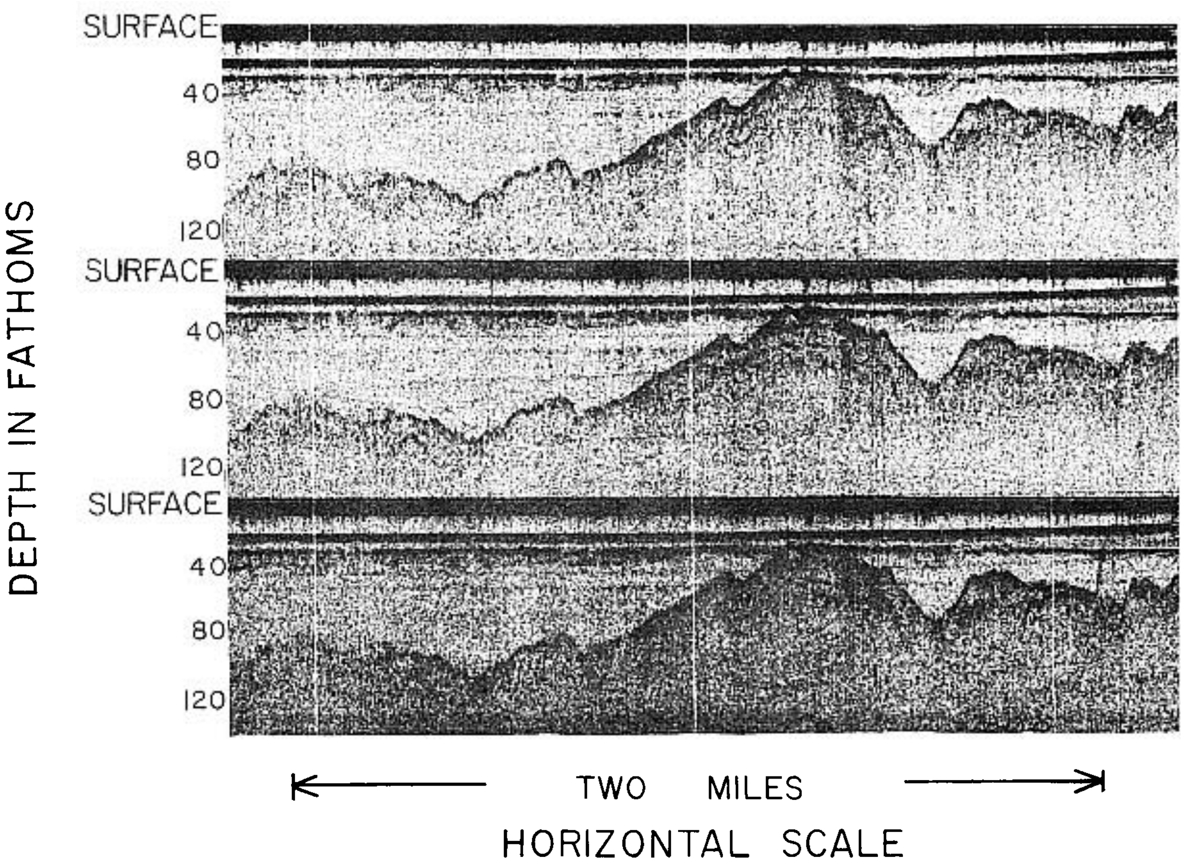

FIG. 6. A portion of a SDR record made in Long Island Sound using the Sparker at a repetition rate of three per second. The Time Variable Gain print amplifier was used to give a clear record of the shallow layers while using higher gain on the deeper bedrock. The repetition rate is varied by an auxiliary keying contact on the recorder.

profiles. In wide-angle reflection profiles the spread between the source and receiver is varied from zero to about four times the depth of the reflecting horizon. These profiles must be made in areas where the layering to be studied is horizontal and relatively free of relief. The SDR lends itself well to making wide-angle reflection profiles, since it is possible by the addition of a longer cable to achieve a varying physical separation between the receiving hydrophone and one of the sound sources. The hydrophone is permitted to drift from the ship, or in some cases it is carried out by a small boat and hauled in. By comparison with data from assumed velocity structures, it is possible to determine the structure in question (Officer, 1955).

Comparison with test borings that are available provide not only true depth

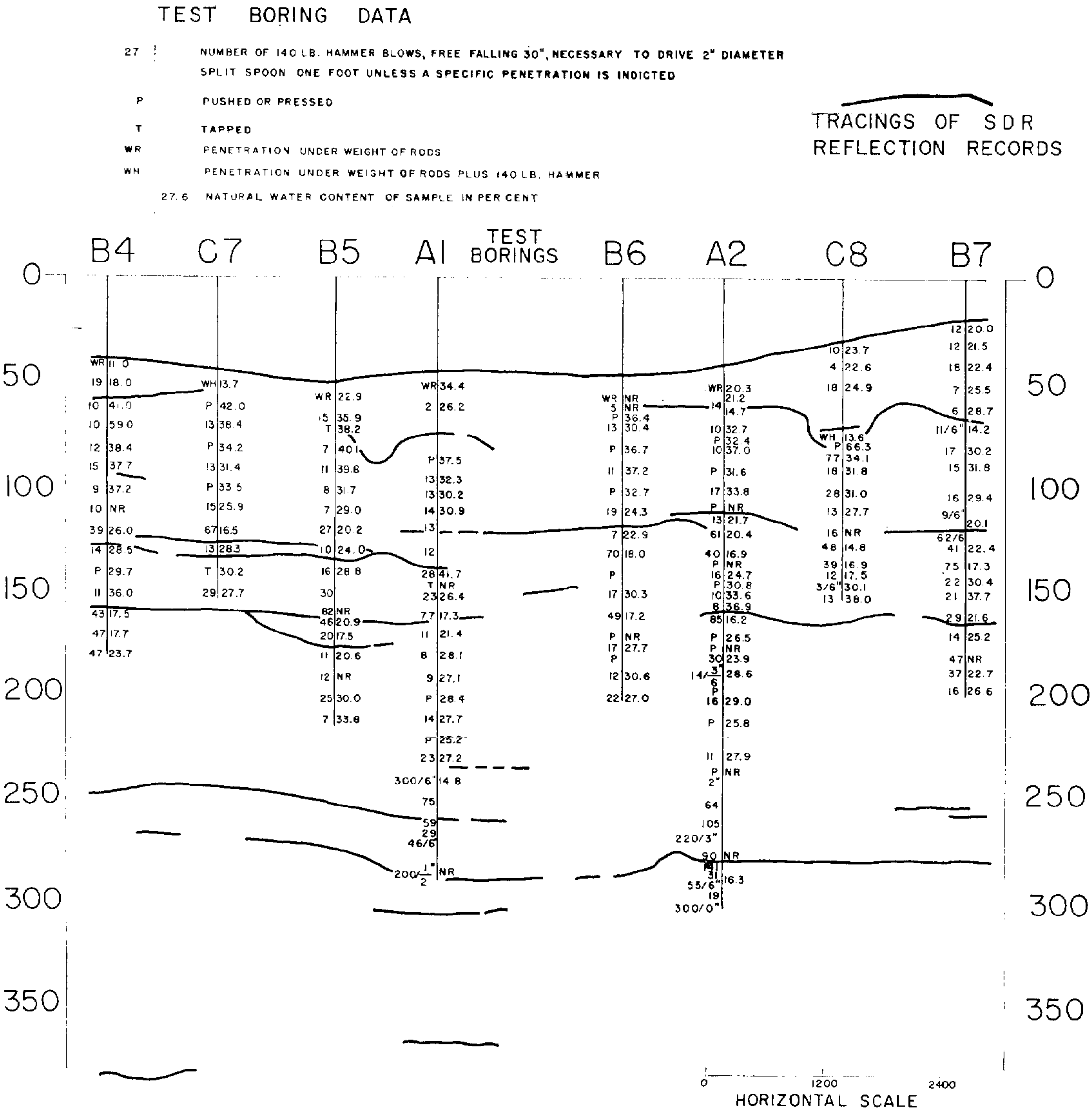

FIG. 7. Tracings of SDR (Sparker) reflections along with test boring data made in Chesapeake Bay for the Chesapeake Bay Highway Crossing. The sub-bottom reflections correlate well with two of the drilling parameters, either with the water content (porosity) of the sediment or with the resistance to mechanical penetration evidenced by the number of 140 pound hammer blows, free falling 30 inches, required to drive a two-inch diameter split spoon one foot.

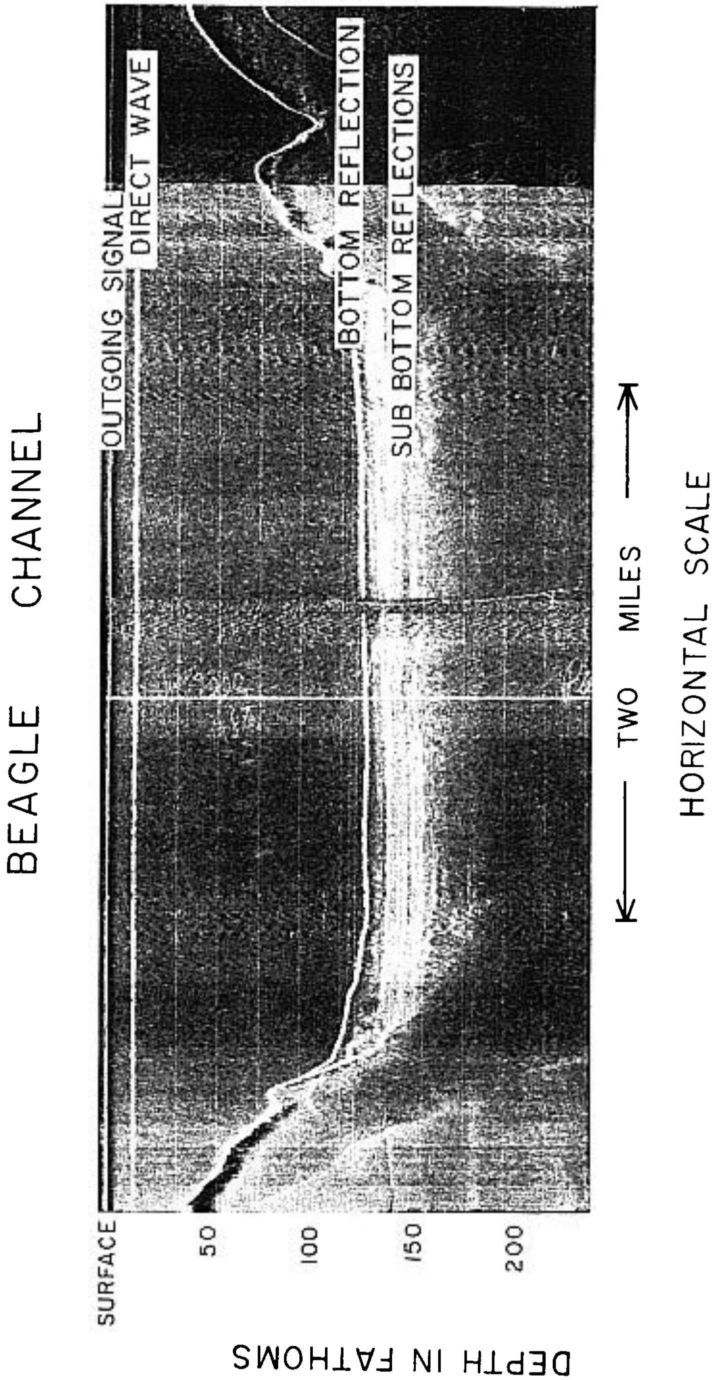

FIG. 8. A portion of a SDR (Sparker) record made in the Beagle Channel (Cape Horn). Visible are at least five sub-bottom horizons presumed to be the result of the Pleistocene history of the area.

to a reflecting horizon but furnish, as well, positive identification of the horizons. It has been found that of the test-boring parameters available in the field, two furnish extremely dependable correlation. These are the porosity (water content) of the sediments and the resistance to mechanical penetration as evidenced by the number of blows required to drive a standard split spoon core sampler. In Figure 7 a series of test borings are shown along with the SDR reflection tracings. These data were collected for the proposed Chesapeake Bay Highway Crossing[1] (1958). It will be noticed in all cases that an SDR reflection horizon correlates with a change in one or the other of the two parameters mentioned. In this particular case the accuracy of depth determinations of both SDR reflections and test boring data is plus or minus 5 ft.

In conjunction with sediment coring and drilling operations, the SDR provides a valuable guide to the selection of sampling sites. An excellent example of this is shown in Figure 8, made in the Beagle Channel (Cape Horn). At least five reflection horizons are visible. It is presumed that each corresponds to a glacial period; hence, in this relatively short vertical section, the Pleistocene history of the area would be preserved.

SUMMARY AND CONCLUSIONS

The Sub-bottom Depth Recorder (SDR) has been developed to study sub-bottom structures in water covered areas. It offers a choice of two sound sources, one using an electrical spark discharge and one a combustible gas explosion. The recording circuit offers selection of passband and time-variable gain. These arrangements give a maximum of versatility to the equipment for use in different areas and sub-bottom conditions.

The SDR has application in the study of geologic structures per se—in the interpretation and correlation of coastal structures. In foundation studies the SDR provides not only a guide toward the placing of strategically located test borings, but it provides an excellent horizontal correlation between borings.

ACKNOWLEDGMENTS

This project was carried out by the Lamont Geological Observatory of Columbia University under contract with the Bureau of Ships and the Office of Naval Research of the United States Navy and with the National Science Foundation Project 11.8, Sea Exploration-Atlantic, as part of the International Geophysical Year 1957–1958.

Dr. W. Maurice Ewing was the Project Director and the authors wish to express their thanks for his advice and assistance throughout the project. The authors wish to thank Dr. J. Brackett Hersey of the Woods Hole Oceanographic Institution for this advice on the construction of the Sparker and to Drs. Charles L. Drake, John E. Nafe, George H. Sutton, J. Lamar Worzel, and Jack E. Oliver

[1] Personal communication with Sverdrup and Parcel, Consulting Engineers, St. Louis 1, Missouri.

for their contributions throughout the project. Mr. Stephen V. Chelminski contributed to the design and construction of the RASS.

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