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SACLANT ASW
RESEARCH CENTRE

AN ACOUSTIC, HIGH-RESOLUTION, SEDIMENT PROFILER

by

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TABLE OF CONTENTS

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ABSTRACT

An acoustic sediment profiler is described that utilizes short 50 kHz pulses to achieve a high range resolution. In trials in shallow water, penetration depths of about 9 m and resolution of about 25 cm were obtained.

Suggestions for improvements and for its adaptation to a deep water version are included.

INTRODUCTION

Studies of the sea floor and the layers beneath it have for many reasons become increasingly important during recent years. One reason is the influence of the upper sediment layers upon the propagation of sound in the oceans. It has been shown that, in many cases, most of the sound energy hitting the sea floor is reflected from, or absorbed in, these layers.

To carry out sound-propagation studies at the Centre it became necessary to construct a tool that could produce an accurate record of the sediment layer structure just below the sea floor. The shallow-water version of this tool — the Sediment Profiler — is described in this report.

1. BASIC REQUIREMENTS AND DESIGN CONSIDERATIONS

A Sediment Profiler with the following specifications was required:

a) The resolution should be 0.25 m or better.

b) The penetration into the sea floor should be in the range 10 - 15 m.

c) It should be possible to tow the Profiler at all depths in the Mediterranean; that means a maximum depth of around 2500 fm.

It was decided to construct the sediment profiler on the same principles as an echo sounder, and to equip it with a precision recorder.

High resolution requires a short pulse length and a narrow transducer beam; a pulse length of 0.1 ms and a beam width of about ± 4° were considered appropriate for the purpose. As the profiler was to be a towed vehicle it had not to be too large, and consequently the transducer had also to be physically small. This could be achieved by using a high working frequency, but because the attenuation of sound in the sediments increases rapidly with frequency, it could not be too high. A compromise frequency of 50 kHz was chosen — requiring a transducer of about 20 x 20 cm to give a beam width of ± 4°. As no accurate data of the attenuation losses in sediments were available, the maximum penetration depth could not be predicted.

However, although the profiler to be described here was designed for shallow-water work, provisions were also made for its future adaptation to a deep-water version. For this purpose the transducer used was one that could withstand high pressures, and the physical size and current consumption of the electronics were kept to the minimum. Other aspects of this future adaptation are discussed in the "Conclusions and Recommendations".

The processing of the echo signal presented a problem, because the echo from the sea floor would obviously be much stronger than those from the sediment layers. To reduce the dynamic range to a level where it could be handled by a graphic recorder suggested the use of non-linear amplifiers. Most of the sea-floor echo could be clipped off by a clipper amplifier. However, the amplitudes of echoes from shallow layers and those from layers a little deeper might differ significantly. To counteract this, either an automatic-gain-control could be incorporated, or an amplifier with time-variable-gain could be used.

The shallow-water version of the sediment profiler has been designed in accordance with the above requirements and considerations.

2. GENERAL DESCRIPTION

The sediment profiler consists of three main parts: a transducer, a transceiver, and a recorder. The principle of operation is indicated in the block diagram of Fig. 1.

A keying pulse from the recorder passes the switching circuit and triggers the one-shot multivibrator, which in turn generates a pulse that is normally 0.1 ms long (but may be varied between 0.05 and 0.5 ms). This pulse releases the 50 kHz oscillator, which is normally blocked (inhibited), and which will now oscillate for 0.1 ms. The pulse thus generated is amplified, fed to the transducer, and transmitted into the water.

A little later, the echoes from the bottom and the sediment layers below it are received and, after having passed a pre-amplifier, are fed to the clipper amplifier. Here the signal is amplified and that part of it having a peak value of more than approximately 0.6 V is clipped off.

The clipped signal is fed to an amplifier with time-variable gain controlled in the following way: when the one-shot giving the pulse length fires, it triggers the variable-delay circuit. The latter is usually set manually so that it gives an output pulse contemporaneously with the return of the echo from the sea floor. Another one-shot — having a 25-ms-long pulse — is thereby triggered. During these 25 ms the waveform generator produces a voltage that increases linearly with time. This voltage is fed to the TVG amplifier, slowly increasing the gain of the latter up to a maximum of approximately five times at the end of the 25 ms period. As the input signal is large, some saturation also takes place in this amplifier.

The output signal of the TVG amplifier is rectified, filtered, and fed to a differentiator circuit. The output of the latter is fed to the input of a precision graphic recorder.

A 0,5 Hz oscillator has been added to generate repetition-rate pulses for test purposes.

3. COMPONENT PARTS

3.1 The Transducer

This is of the magnetostrictive type. It is built up of nickel stampings baked together into packs, of small permanent magnets for pre-magnetizing the nickel packs, and of a winding for driving these packs. A single-conductor, rubber-coated cable is used for the winding. The parts are mounted together in a free-flooding bronze housing (Fig. 2) which in turn is mounted on a towed "fish" (Fig. 3).

The size of the transducer face is 20 cm by 17.5 cm. The corresponding theoretical half-value angles of the Transducer directivity patterns become

$$\alpha_1 = 25 \frac{\lambda}{d_1} = 25 \times \frac{3}{20} = 3.8°$$

$$\alpha_2 = 25 \frac{\lambda}{d_2} = 25 \times \frac{3}{17.5} = 4.3°$$

where λ = wavelength of sound in water (in cm)

α_1 and α_2 = dimension of transducer (in cm)

Measurements carried out on the transducer have given the following results:

Resonant frequency	50.6 kHz
Impedance (tuned)	131 Ω
Transmitting sensitivity at 1 m.	73 mbar/A
Directivity (half value angles)	±3.5° and ±4.3°
Acoustic Q	18
Weight	18.5 kg

The directivity diagrams in two planes are given in Figs. 4 & 5.

3.2 The Transceiver

A complete wiring diagram of the transceiver is given in Fig. 6.

The unijunction transistor T1 – together with the capacitors and resistors shown – forms an oscillator with a working frequency of 0.5 Hz. With switch S1 in position INT, the output pulses from this oscillator trigger the following one-shot multivibrator. The one-shot may also be triggered by an external source (as, for example, the moving contacts of a graphic recorder) by means of the switching transistor T9. In this case S1 should be in position EXT.

The output pulse from the one-shot, the duration of which may be adjusted between 0.05 and 0.5 ms by means of the potentiometer P1, is fed to the diode D1, thereby blocking the latter by reversing the voltage across it. The unijunction transistor T3 — which together with C5, P2, R5, R6 and R7 forms a 50 kHz oscillator — is thereby unblocked and oscillates until the pulse (from the one-shot) is ended. Normally this pulse is set to last for 0.1 ms.

The 50 kHz, 0.1-ms-long pulse thereby created is fed to the RC-coupled voltage amplifier T3 and then to the current amplifiers T4 and T5. The pulse amplitude is controlled by the potentiometer P3. T6 is a transformer-coupled amplifier stage that drives the push-pull coupled output amplifier T7, T8. The latter is matched to the transducer by means of the output transformer TR2. C12 serves as tuning capacitor for the transducer. Diodes D2 and D3 short-circuit the receiver input during transmission.

The received signals, after passing the step-up transformer TR5 and the pre-amplifier T17, are fed to the tuned clipper amplifier T16. The diodes D5 and D6 at the output of this band-pass amplifier limit the peak output level for a maximum of approximately ±0.6 V. The signal then passes on to the TVG amplifier T15 via the volume control P5.

The gain of T15 is controlled by T14, which in turn is controlled by the waveform generator. The operation is as follows: The output pulse from the one-shot that controls the pulse length is connected to another one-shot whose pulse length is manually variable (by means of P4) between 5 and 40 ms, thus creating a variable delay. The trailing edge of the output pulse from this one-shot then triggers the next one-shot, which has a fixed pulse length of 25 ms. The first transistor, T10, of the waveform generator is normally conducting, thus short-circuiting C25. When the 25-ms-long pulse arrives, T10 becomes non-conducting, causing C25 to be charged through R25, T11, and P6. The voltage at the collector of T11 therefore increases linearly until the 25-ms pulse is ended. Then T10 starts conducting again, thus discharging C15 and bringing the voltage at the collector of T11 back to its original level. The voltage-changes at the collector of T11 are amplified in T12 and T13, and fed to the base of T14, thereby changing the gain of T15.

In this way the gain can be set to start increasing when the echo from the sea floor arrives, and the rate of increase may be changed by varying C25.

After having passed the TVG amplifier the signal is rectified and filtered by means of D4, C15, and R32. Thereafter, it is differentiated (C14, R28) to get rid of the large dc-component. The output of the differentiator is fed to the input of the graphic recorder.

The transceiver electronics are distributed on four printed-circuit cards. A photograph of one of these cards, which contains the 300 V output amplifier, is shown in Fig. 7.

The output pulse, as measured across transmitter output terminals with the transducer connected, was found to be 570 V peak-to-peak. This corresponds to an electrical output power of about 300 W.

Figure 8 shows some waveforms that demonstrate how the echo signals are processed in the receiver. (The five photographs are not taken simultaneously, nor even taken in the same location, so they are not be related directly to each other.) The waveform of the received echo is shown (A) at the receiver input, (B) at the output of the clipper amplifier, (C) at the output of the TVG amplifier, (D) after rectification and filtering, and (E) after differentiation. It is clearly seen how the weak signals are favoured during the processing.

The transceiver is battery-powered. The three following voltages have been used:

-50 V,	average current consumption (with rep. rate:10/sec)				6 mA
-24	"	"	"	"	2 mA
+12	"	"	"	"	34.5 mA

Of the +12V battery the three one-shots (Phillips building blocks) consume about 25 mA.

These blocks were used to save time, but lower-consumption components should be found for the deep-sea version of the profiler.

3.3 The Recorder

A standard precision graphic recorder made by the Alden Manufacturing Company was used for the recording of the return signals. This is a well-known helix recorder and no further description will be given here.

It should however be mentioned that this recorder is quite difficult to handle. The humidity of the paper must be absolutely right in order to make a good recording; recording-paper fibres also stick to the helix, so that it needs cleaning quite frequently.

With the present, shallow-water version of the profiler, the direct electrical connection through the cable permits the transceiver to be triggered by the sweep generator. If, however, the deep-water version has to be made without direct electrical connection (because no suitable cable can be obtained) it will be better for the sweep generator to be triggered or synchronized acoustically by the transceiver. This is not possible with the PGR, and another type of recorder must be used.

4. PERFORMANCE

4.1 Recordings

The sediment profiler was installed on board the Centre's workboat and tested in the Gulf of La Spezia during the late spring and early summer of 1966. The transducer was mounted on the "fish" shown in Fig. 3 and towed over the side at a depth of about 1 metre. The towing speed was approximately 3 knots.

The trials were concentrated on finding the best way of processing the echo signals, and for this purpose several ways of increasing the gain of the TVG amplifier were tried. These included letting the gain build up

a) as a step-function at different times after the arrival of the sea-floor echo;

b) exponentially with different time constants at variable times before and after the arrival of the sea-floor echo;

c) linearly with different rates of increase at variable times around the arrival of the sea-floor echo.

It was found that the clearest record was combined with the largest penetration when a linear "build-up" was used. In this case, the increase in gain should start when the sea-floor echo arrives. The best result occurred when the gain was increased about five times during the 25 ms mentioned in para. 3.2.

Automatic gain control was tried instead of time-variable gain, but the latter method gave better results.

Figures 9, 10, 11, 12 and 13 are examples of records taken with the final instrument in the Gulf of La Spezia. They are scaled down by a factor of approximately four. The vertical scale is given on the photographs. Horizontally each trace covers about 2.5 km. The line marked S is the surface of the sea (the transducer), and B1 and B2 are the bottom and the "second bottom" respectively.

The multiple Shallow Layers seen in Figs. 9 and 10 give an indication of the resolution of the sediment profiler. The original recording show the two lower layers to be 23 cm apart and 12 cm thick. Thus a resolution somewhat better than the required 25 cm has been achieved.

The maximum penetration, however, seems to be of the order of 8 to 9 m, which is less than the 10-15 m specified.

The relation between cores taken in the Gulf of La Spezia (Ref. 1 and personal communication) and the sediment profiler records is shown in Table 1.

TABLE 1

Sediment Profiler	Core
Multiple or single Shallow Layer	Could not be found. Sometimes shell particles were seen
Intermediate Layer	Same as for Shallow Layer
Deep Layer	Sand and gravel
Light Hills	Coral reefs

Both the Deep Layer and the Light Hills are very good reflectors. No penetration below them seems possible with the present equipment.

The fact that the Shallow and Intermediate Layers cannot readily be found by coring demonstrates the possibilities of the Sediment Profiler. (These layers have also been found with the 12 kHz Mud Penetrator, as described in Ref. 1). Beside the fact that a great area can be explored in a relatively short time, the profiler is able to find reflecting layers that do not show up in a core analysis but which may be of great importance for sound propagation studies.

It should also be noted that scatterers show up very well on the records. Consequently, the profiler might be a useful tool in studies of the scattering layers.

CONCLUSIONS AND RECOMMENDATIONS

An Acoustic Sediment Profiler for shallow water applications has been designed, built, and tried out at sea. It has demonstrated that it is capable of detecting reflecting layers that cannot be found by taking cores. The maximum penetration into the sediments is about 9 metres and the resolution is of the order of 10 to 15 cm. As scatterers show up well on the records, it may also be a useful tool for studying the fine structure of scattering layers.

It is recommended that a better recorder than the PGR be used with the deep-sea version of the profiler. The new recorder should preferably have a sweep generator that could be triggered by an external signal. This could, for example, be done by modifying a Visicorder. The galvanometer mirror could be driven by a normal, triggerable, saw-tooth sweep generator, thus having the light-spot sweep the photographic paper of the Visicorder from left to right.

Between the light source and the galvanometer mirror could be placed a light modulator driven by the echo signals. This light modulator could either be a Kerr Cell or some other similar optical device, or it could be a ceramic transducer. In this way, the recording of signals from a deep-towed sediment profiler without electrical connection to the recorder would be much less complicated. This recorder would also be very useful for working with pingers.

If a penetration of 9 m appears too small, it is recommended that the high resolution profiler should be supplemented with another profiler working at a lower frequency, 11-12 kHz for example. This profiler could have a wider beam (to keep the transducer small) and could be used to find the rough structure of deeper layers. Both profilers could be mounted on the same towed fish and operated simultaneously.

REFERENCES

1. L.R. Breslau and H.E. Edgerton, "The Sub-bottom Seismic Structure of the Gulf of La Spezia", Ext. Rapp. Proc-verb. C.I.E.S.M.M., vol. XVIII, fasc 3, October 1964.

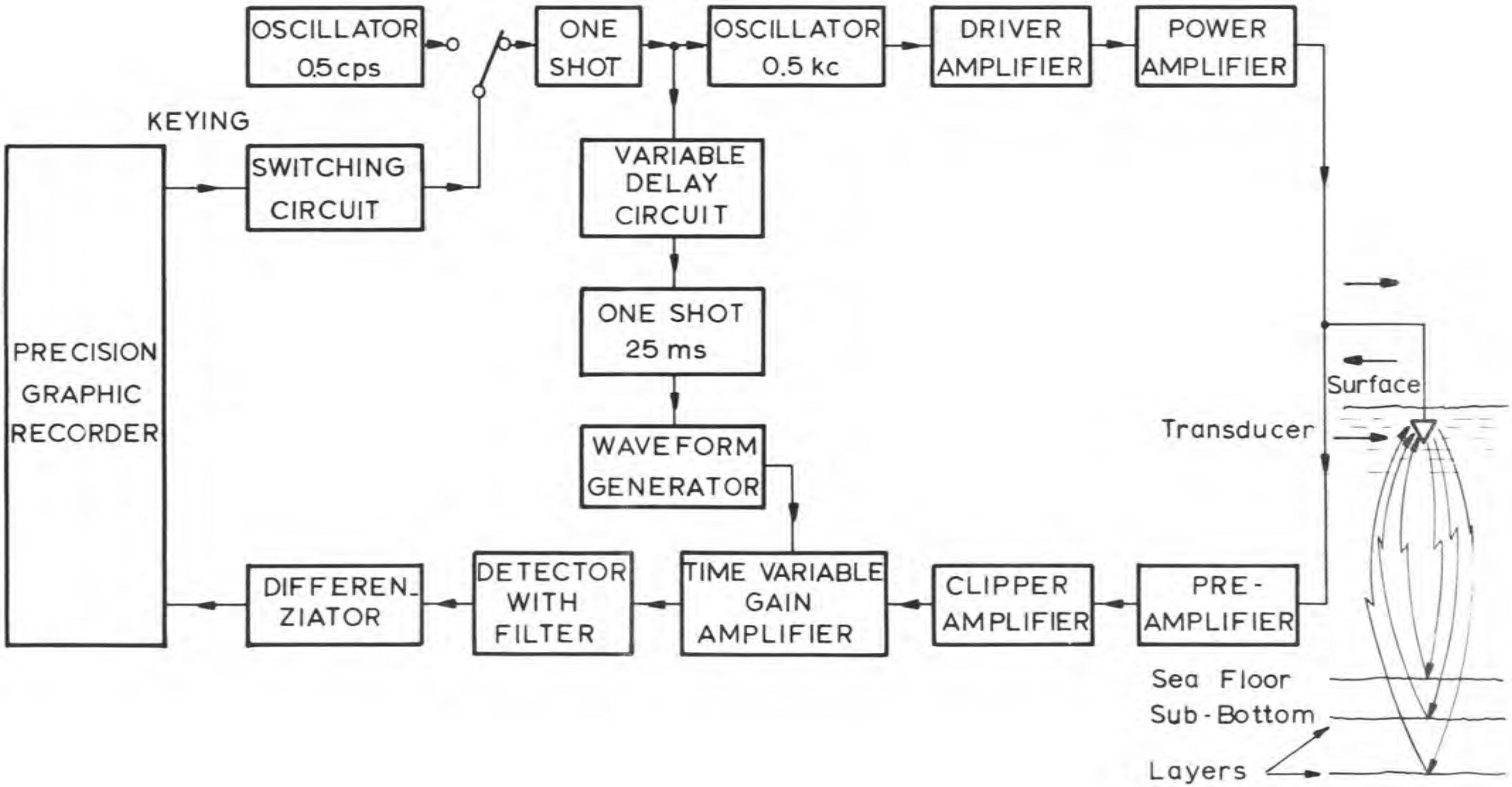


FIG. I BLOCK DIAGRAM OF THE SEDIMENT PROFILER

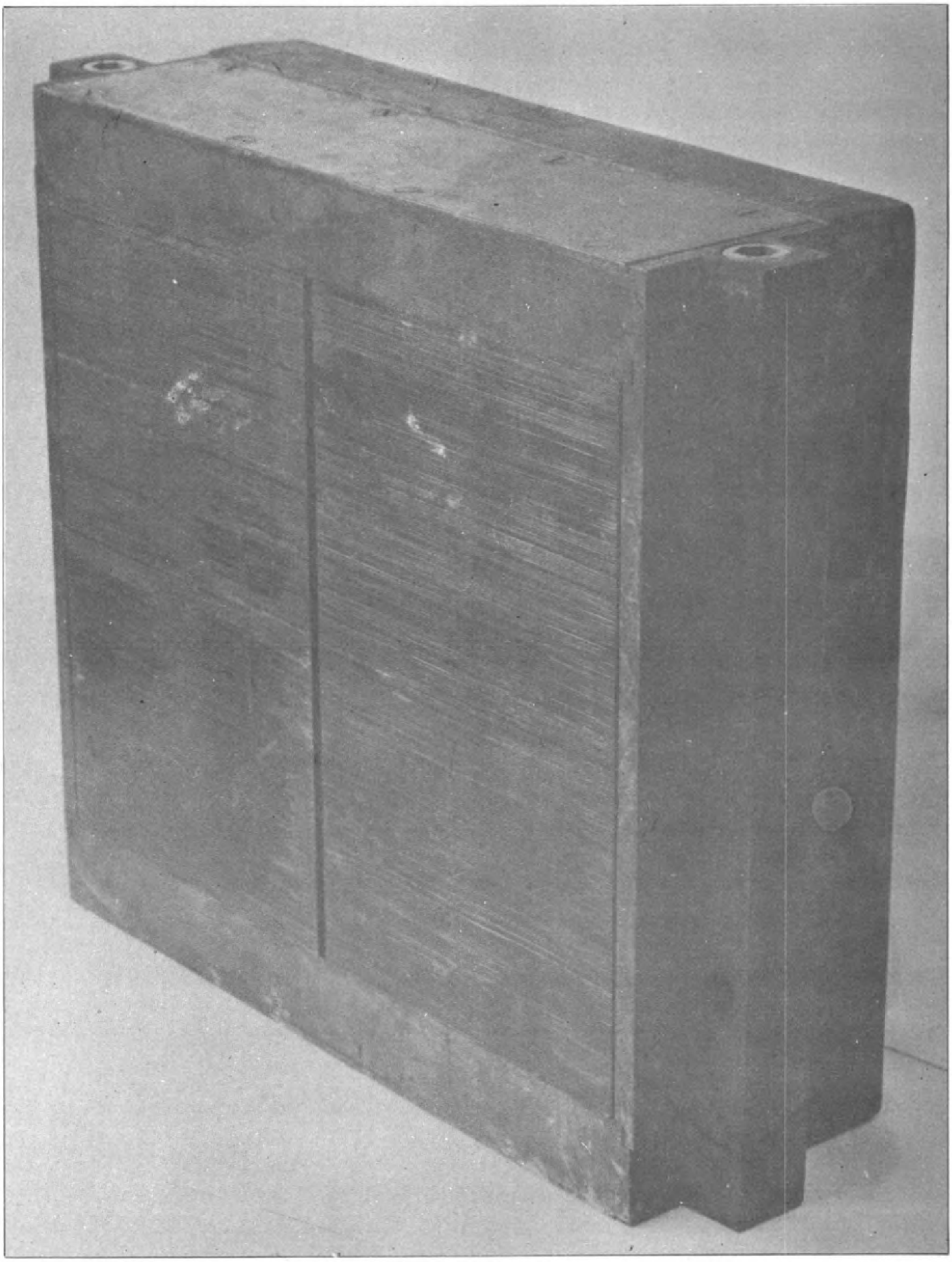


FIG. 2 TRANSDUCER IN ITS HOUSING

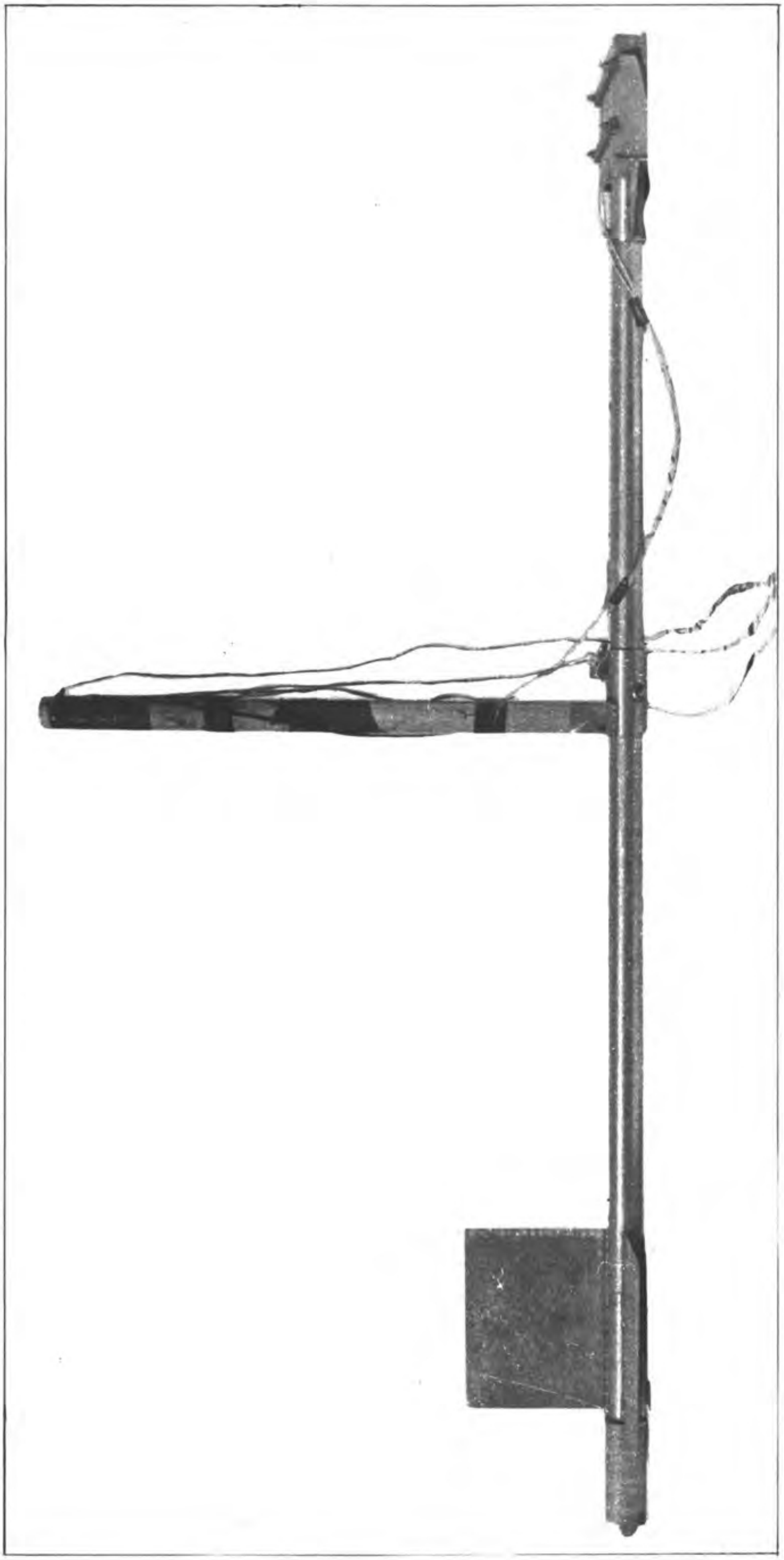


FIG. 3 TRANSDUCER MOUNTED ON A "FISH" FOR TOWING

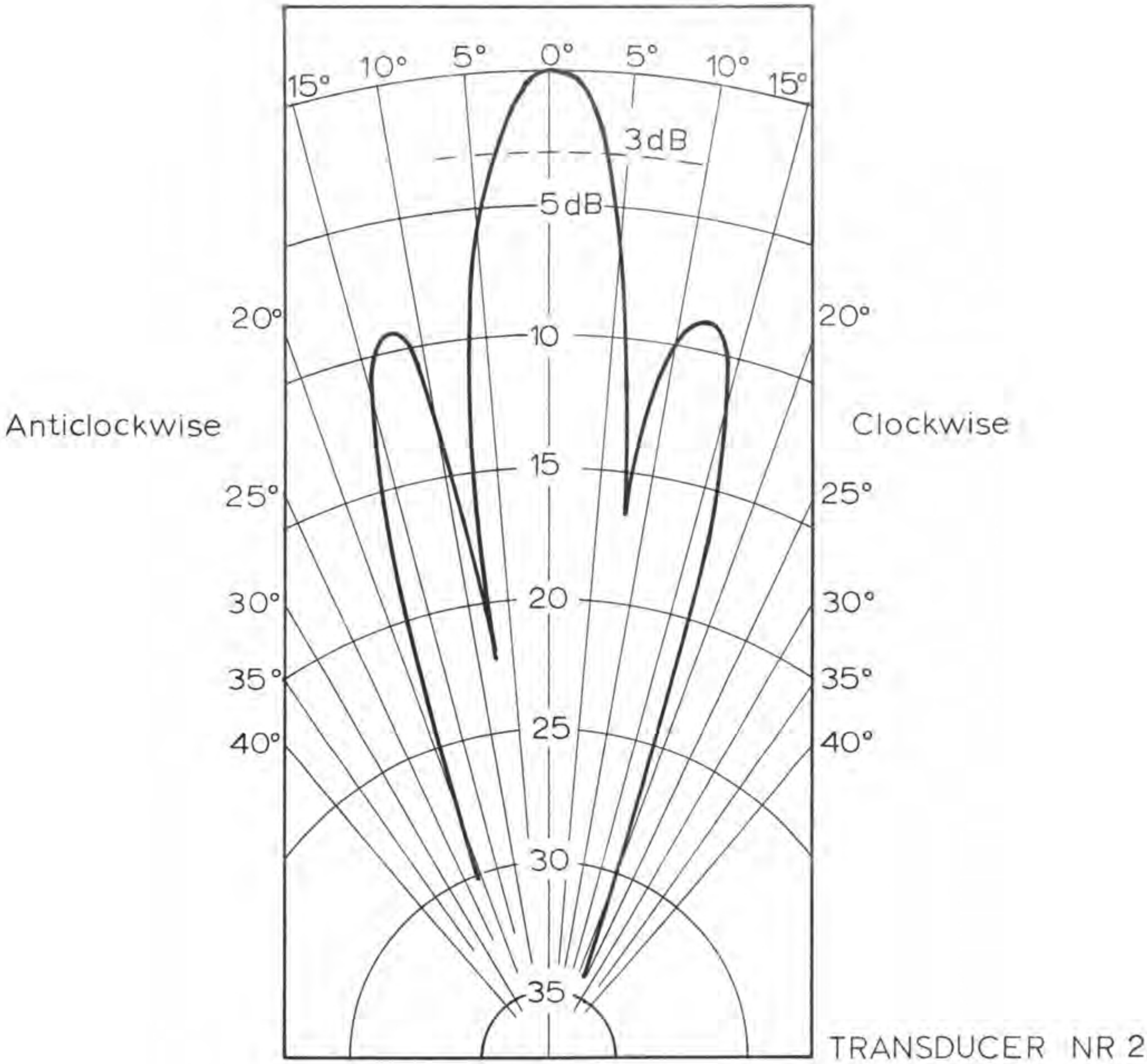


FIG. 4 DIRECTIVITY DIAGRAM IN THE VERTICAL PLANE

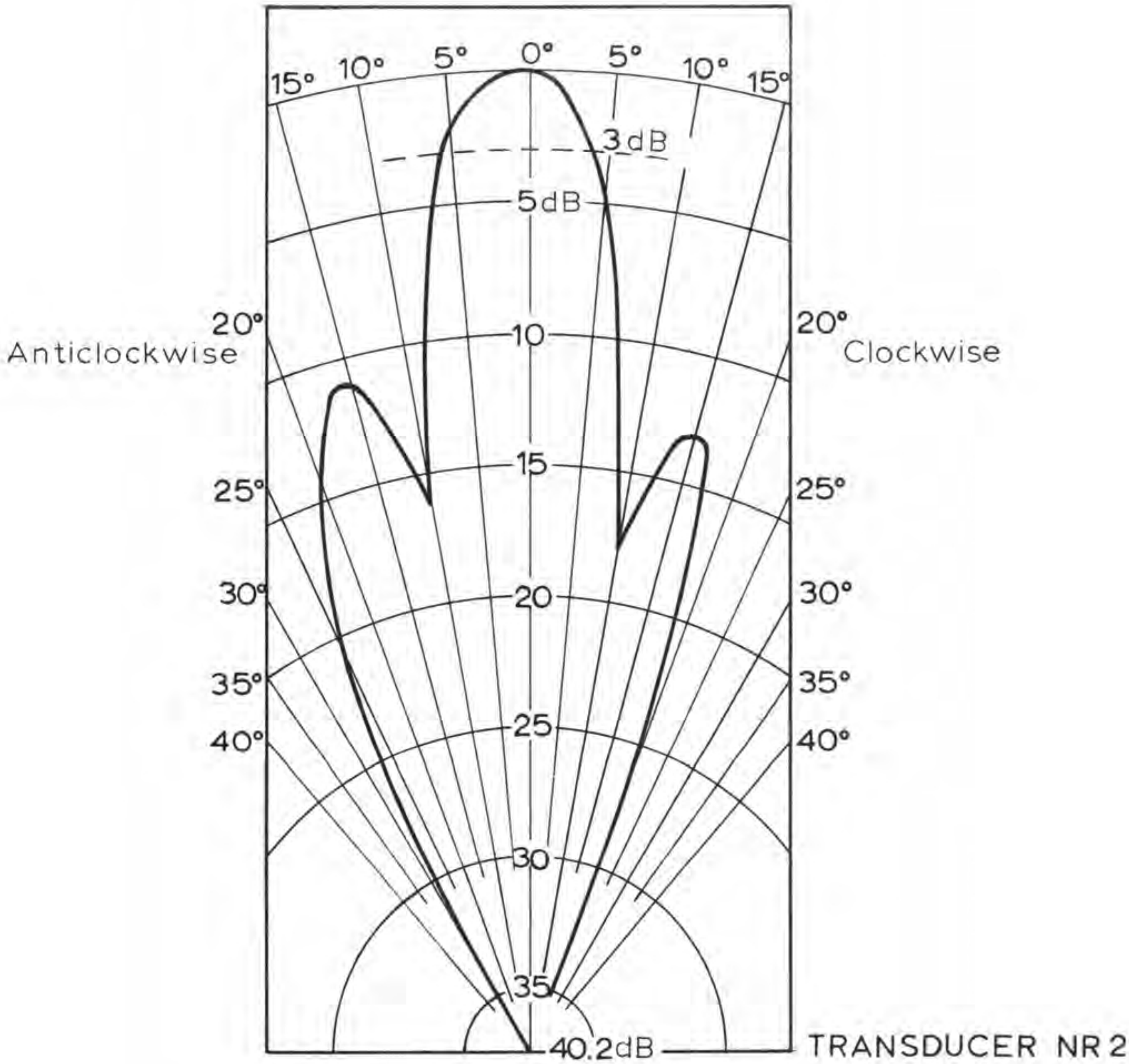


FIG. 5 DIRECTIVITY DIAGRAM IN THE HORIZONTAL PLANE

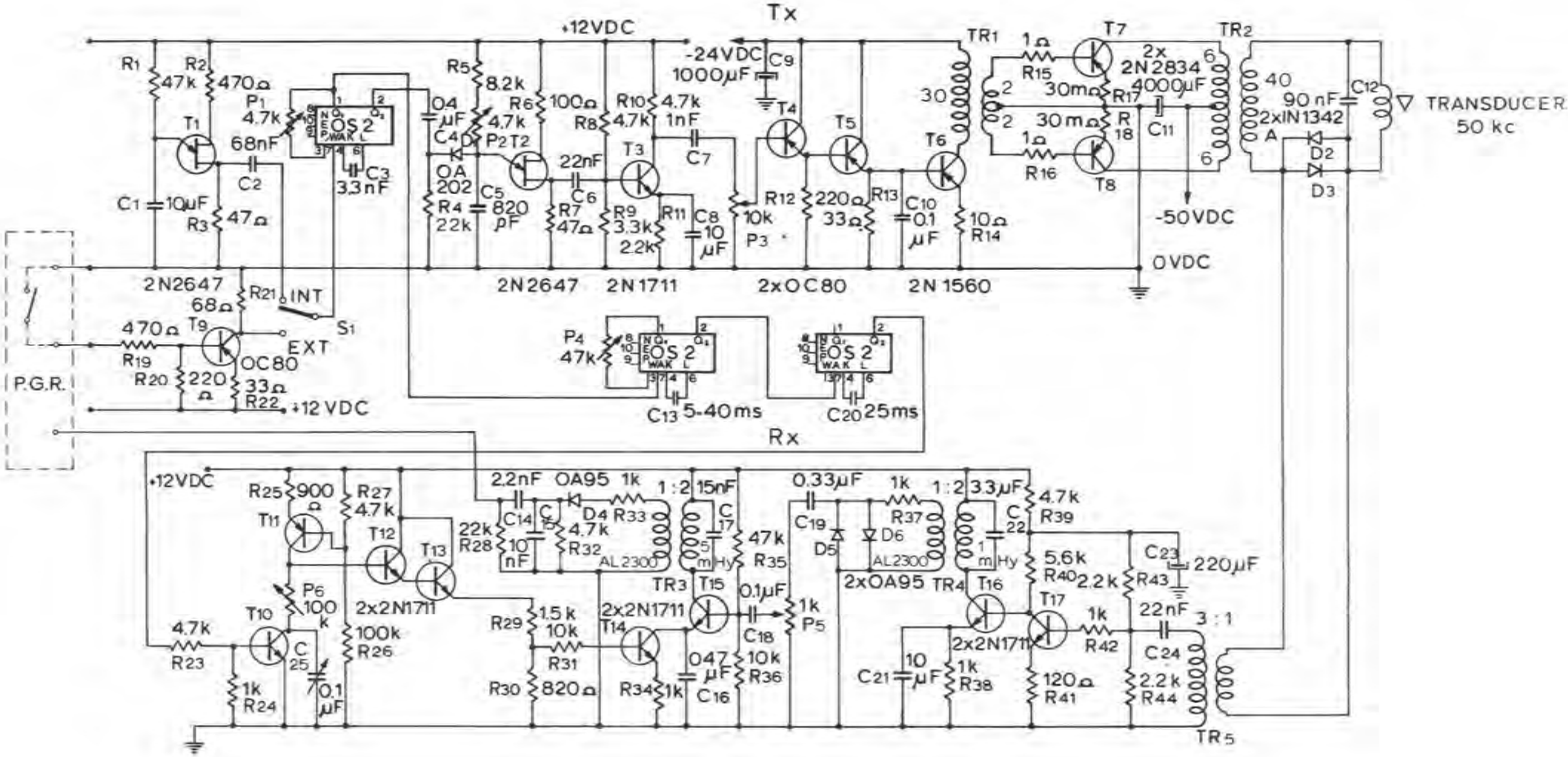


FIG. 6 CIRCUIT DIAGRAM OF THE TRANSCEIVER

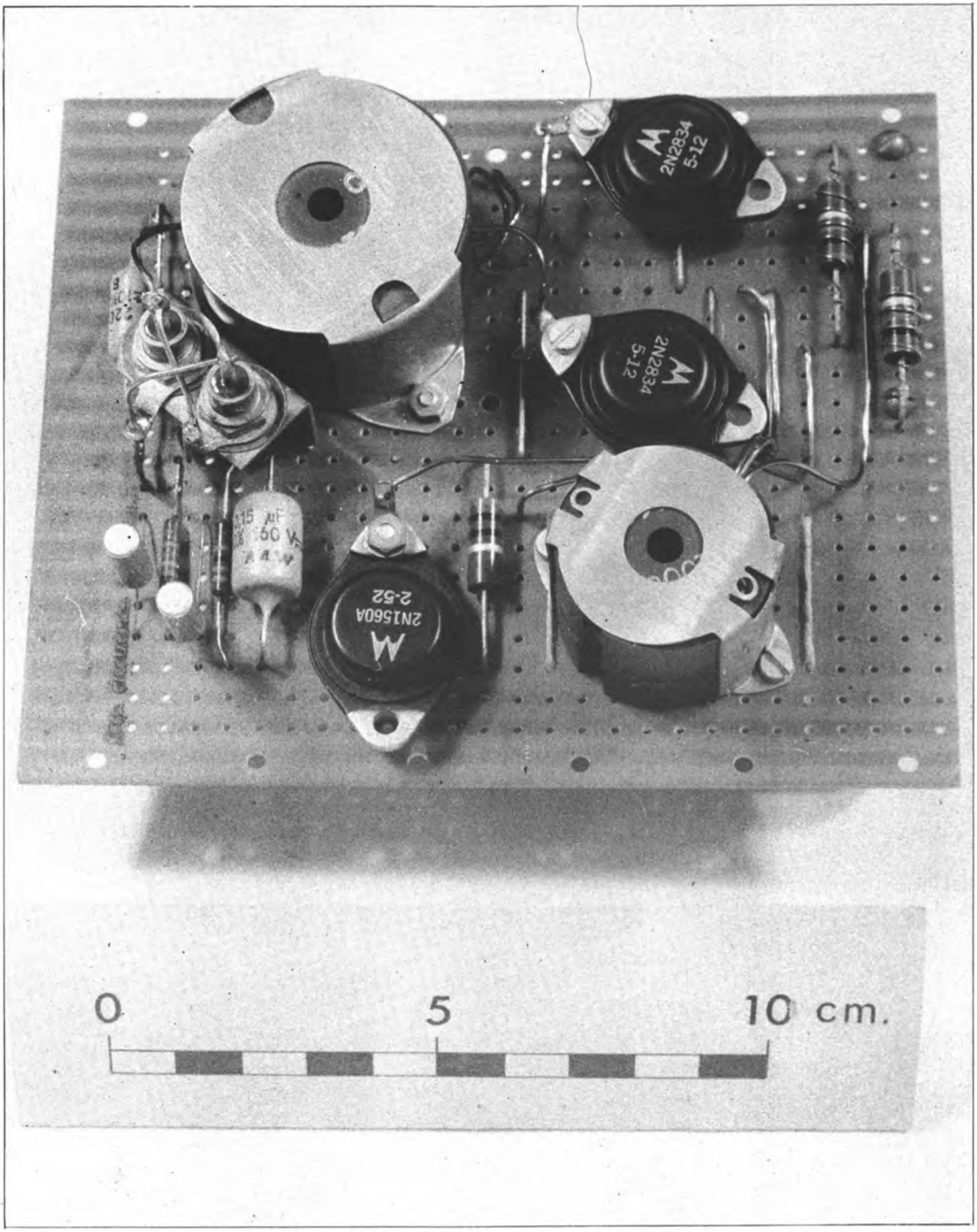


FIG. 7 ONE OF FOUR PRINTED-CIRCUIT CARDS IN THE TRANSCEIVER

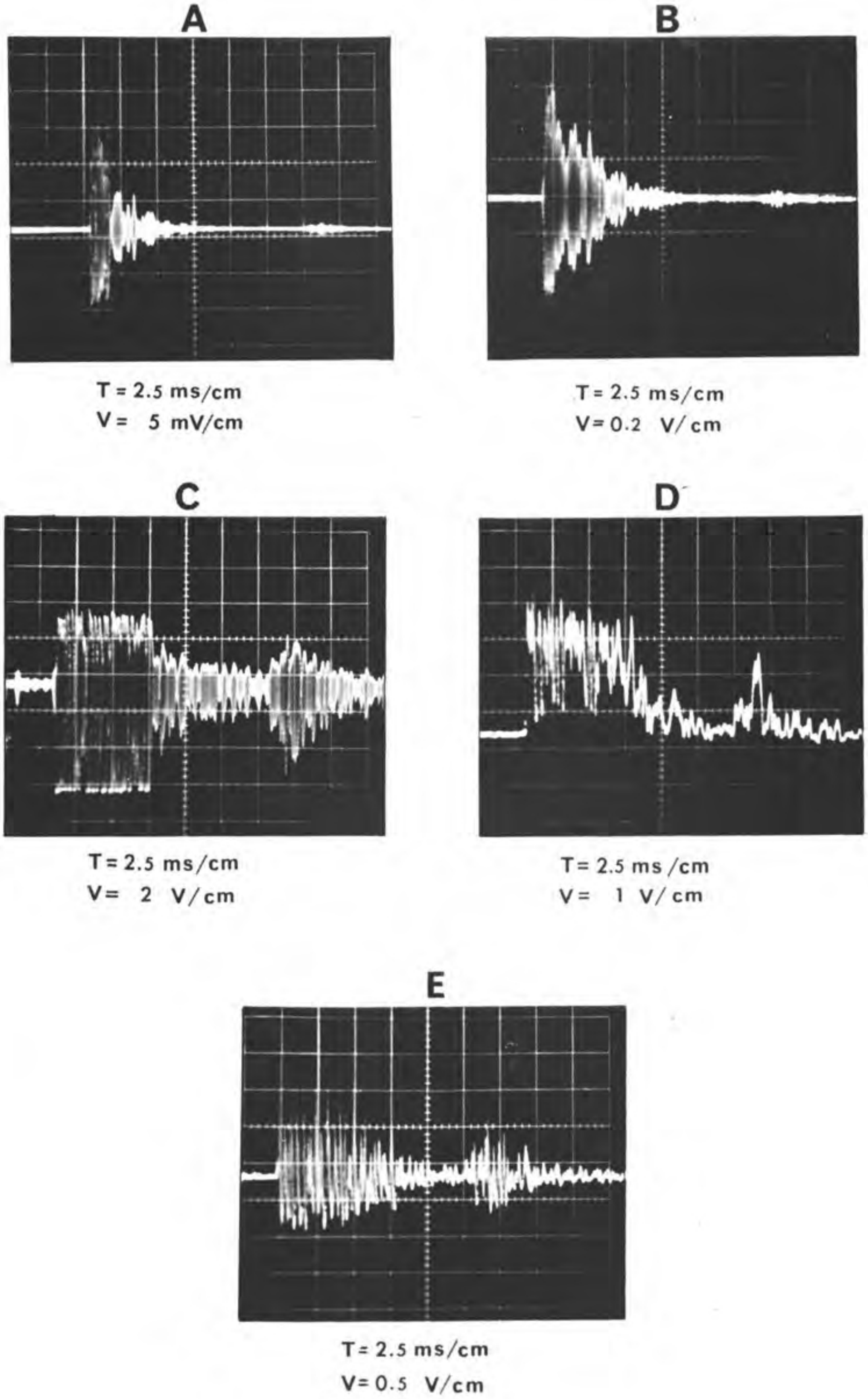
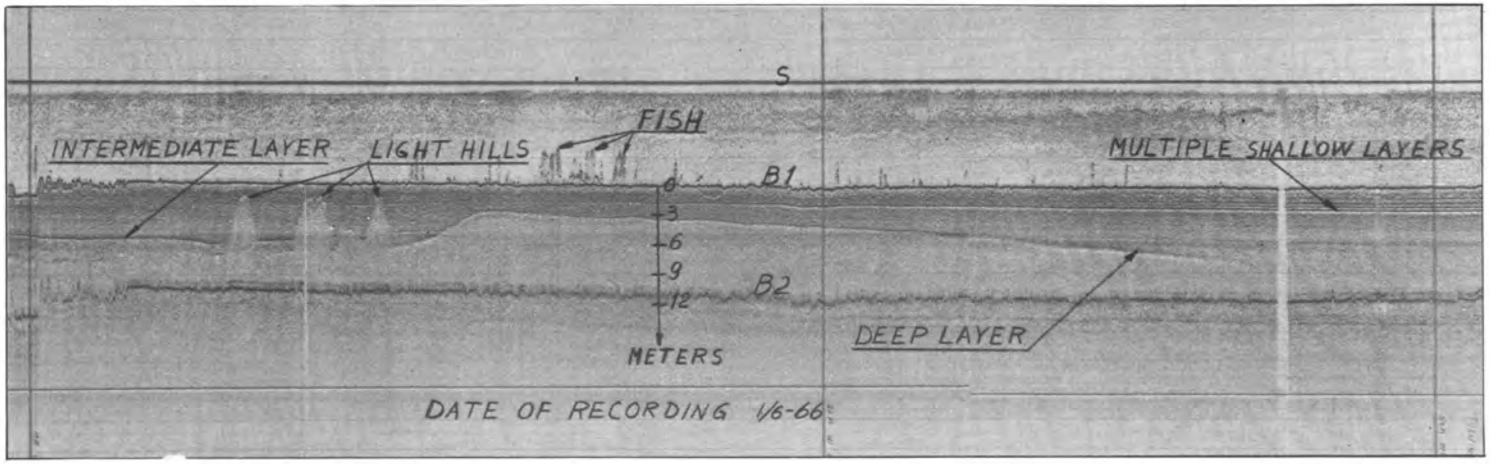
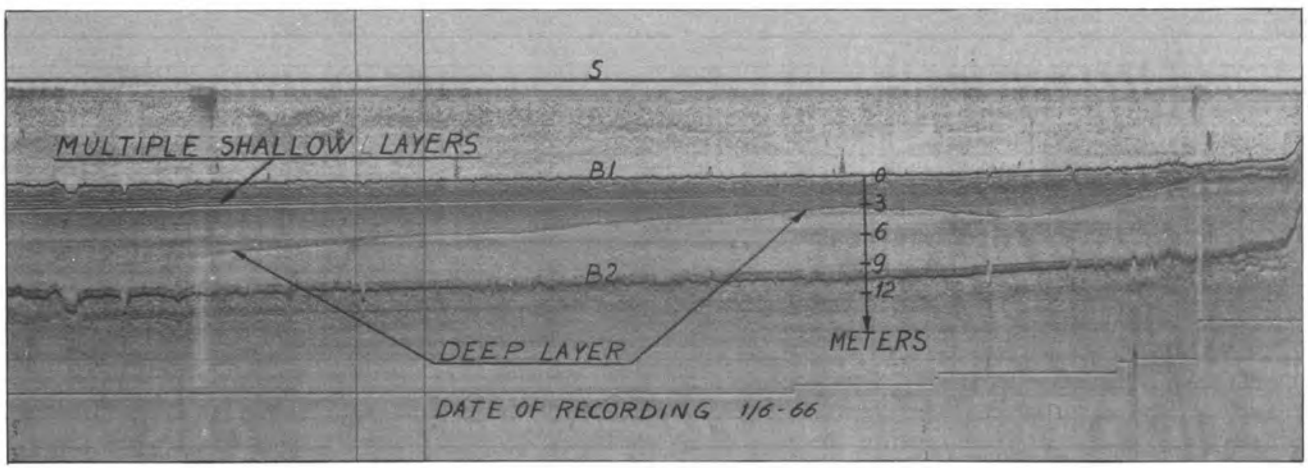


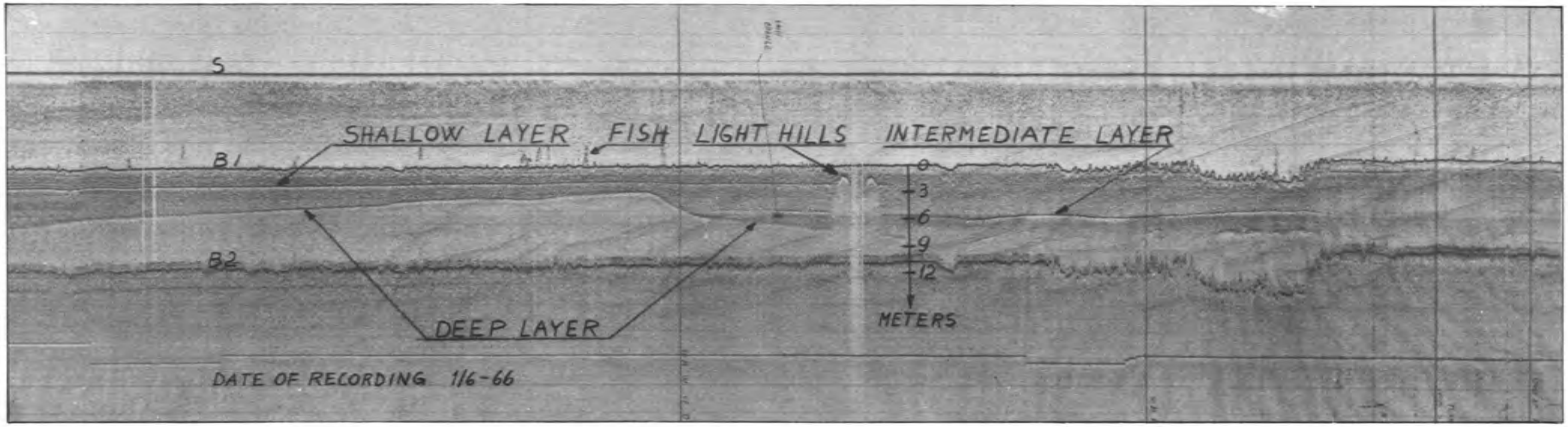
FIG. 8 PROCESSING OF THE ECHO SIGNALS IN THE RECEIVER
(PHOTOGRAPHS TAKEN ON DIFFERENT OCCASIONS):

(A) RECEIVER INPUT
(B) CLIPPER AMPLIFIER OUTPUT
(C) TVG AMPLIFIER OUTPUT
(D) AFTER RECTIFICATION & FILTERING
(E) AFTER DIFFERENTIATION





FIGS. 9 & 10 EXAMPLES OF RECORDS MADE IN THE GULF OF LA SPEZIA (approx. 12 m depth)



FIGS. 11 & 12 EXAMPLES OF RECORDS MADE IN THE GULF OF LA SPEZIA (approx. 12 m depth)

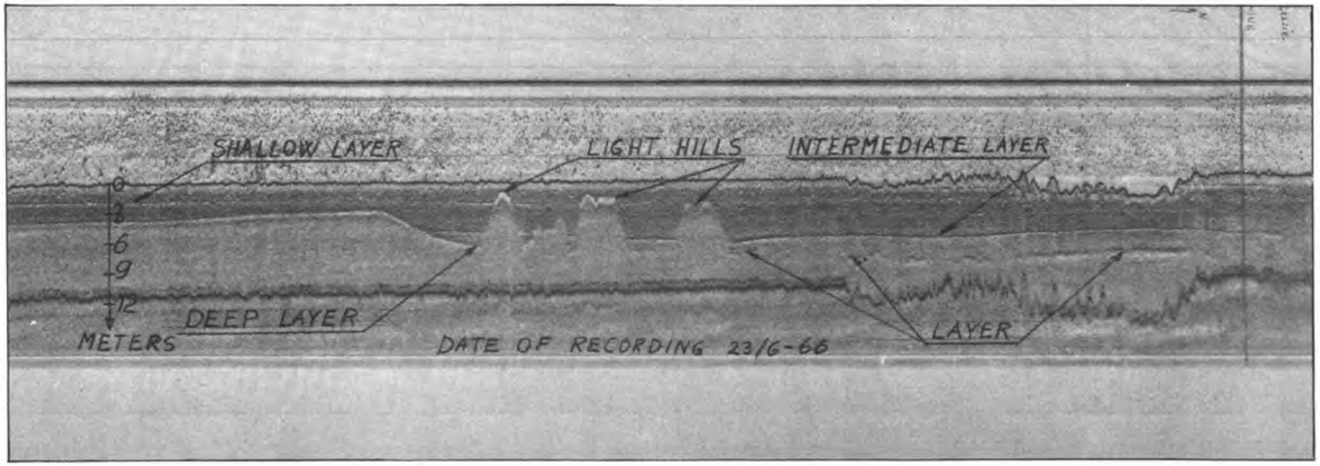


FIG. 13 EXAMPLE OF RECORDS MADE IN THE GULF OF LA SPEZIA (approx. 12 m depth)

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