

## ECHO SOUNDING. — XII

---

### A. — REPORT ON SEA TRIALS OF DEEP WATER ECHO SOUNDING GEAR IN H. M. S. CHALLENGER AND ORMONDE

(in April, July and October, 1932.)

by

J. H. HAYES, A.M.I.E.E.

---

#### 1. INTRODUCTION.

This report is the outcome of three separate sea trials conducted in H.M. Survey Ships *Challenger* and *Ormonde* in the course of the year 1932.

The development of deep water echo-sounding apparatus had hitherto been governed largely by laboratory observations, the only deep sea trials available being necessarily of short duration, and consequently limited in scope.

The Atlantic passage of H.M.S. *Challenger*, bound for Labrador, presented a good opportunity for prolonged trials of the latest (experimental) type of deep-water echo-sounding apparatus, with which the ship was fitted.

Arrangements were therefore made for a representative of the Anti-Submarine Establishment to accompany H.M.S. *Challenger* as far as St. Johns, Newfoundland, with the object of experimenting with the apparatus, observing its reliability and obtaining as much practical data as possible on echo-sounding problems.

This trip was preceded by a preliminary trial of 12 hours duration in 100 - 1,200 fathoms, off Ushant, in April 1932.

The Atlantic passage occupied eleven days (from June 24th to July 5th), for eight of which the depth lay between 1,000 and 2,500 fathoms, and during which the apparatus was run continuously for about four watches each day.

The third trial was conducted in H.M.S. *Ormonde*, prior to sailing for the Persian Gulf, in October 1932. As in *Challenger's* preliminary trial, this took place off Ushant, in 100 - 2,000 fathoms, and was of some 12 hours duration. The apparatus in this case was a modified form of the *Challenger* equipment, and similar to installations supplied commercially by Messrs. Henry HUGHES & Son, under Admiralty licence. The *Challenger* installation was supplied by the same firm to Admiralty specification, subsequent modifications being in this case carried out at the Anti-Submarine Establishment. The *Ormonde* trial furnished much comparative data between the two installations, which is dealt with in the text of the report.

#### 2. DESCRIPTION OF GEAR.

The echo-sounding installations in the two ships are identical in general principle, but differ slightly in certain particulars. as described below :-

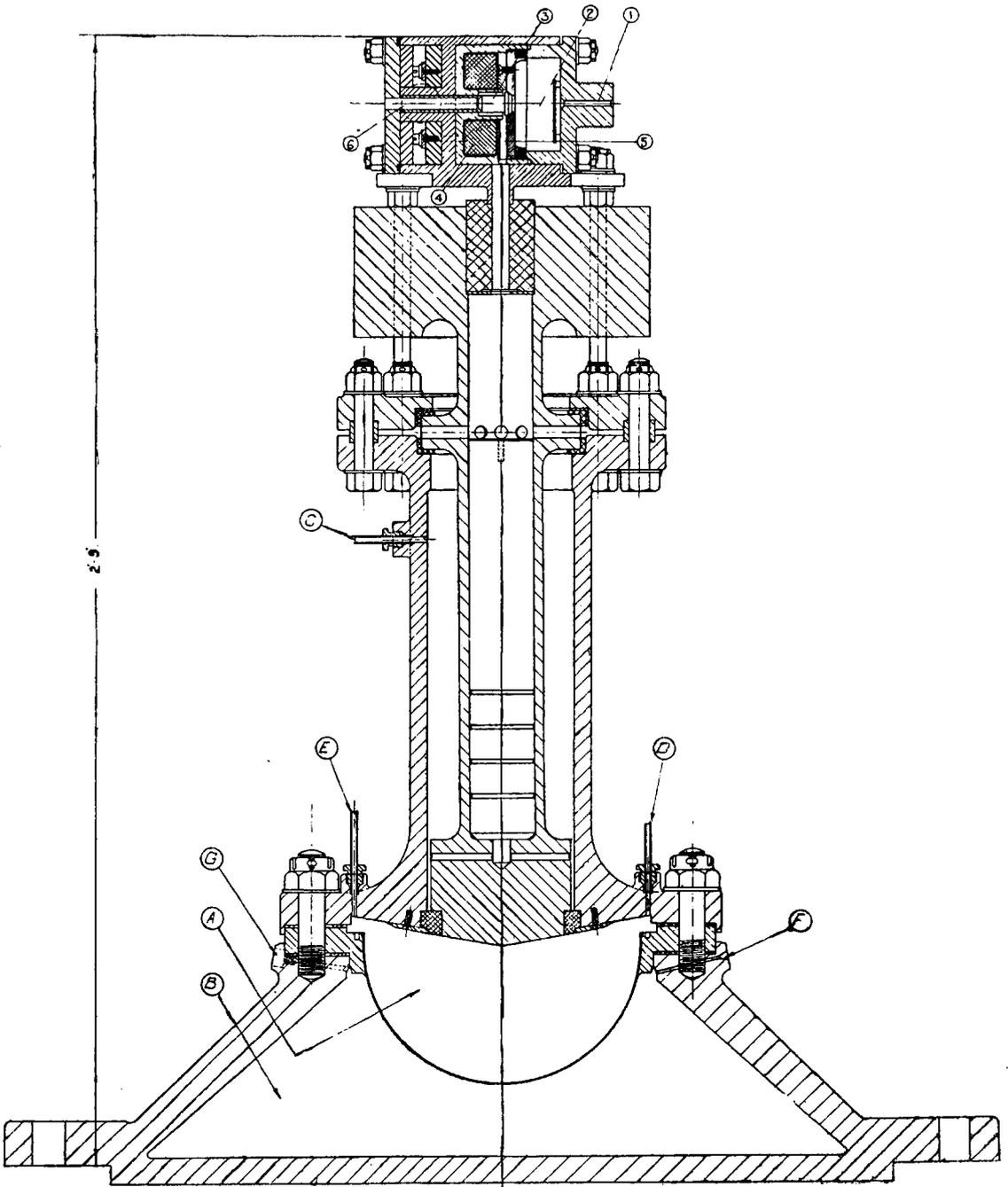


FIG. 1

*Deep sea Balanced Transmitter (H.M.S. Challenger).*

(I) TRANSMITTERS.

(a) *Balancing.* — These are shown in Figs. 1 and 2 respectively, from which it will be seen that *Challenger's* instrument carries a steel acoustic balance mass, which is absent in the *Ormonde* pattern.

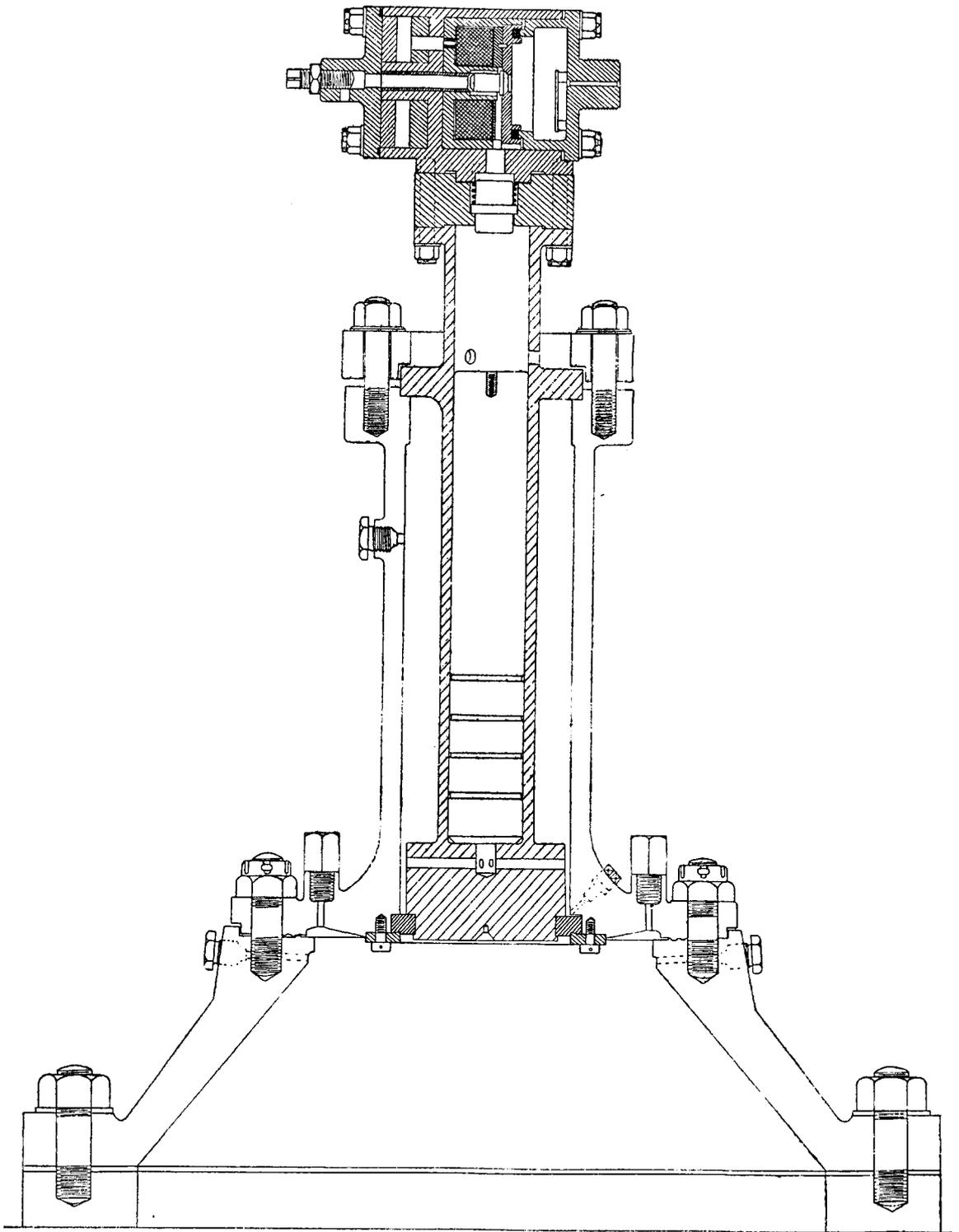


FIG. 2.

*Deep sea Unbalanced Transmitter (H.M.S. Ormonde).*

The relative sound outputs of the two units are shown in Fig. 3. The balanced type, though considerably improving the sound output at 2,000 cycles, developed a fracture at the top of the cylinder after some use, on both the occasions when it has been tried, viz., *Ormonde* November 1931, *Challenger* July 1932.

Pending investigation into the cause of this fracture, it was decided to provide *Ormonde* with an unbalanced type of hammer, and to ascertain from trials whether this, combined with improvements in the receiving equipment, would meet the requirements of the ship.

(b) *Water Tanks (Transmitter)*. — In early models the water in contact with the transmitter diaphragm was maintained at a pressure of 250 lbs/sq.in. and an outer chamber contained water at 50 lbs/sq.in. in contact with the hull plates, both in order to overcome cavitation. Laboratory tests showed that the inner pressure could be reduced considerably without affecting the output, and giving, if anything, a slight improvement at 25-50 lbs/sq.in. Reduction from 100 to 50 lbs/sq.in. during the last *Challenger* trials produced no observable loss of echo strength.

In the *Ormonde* transmitter the hemispherical inner chamber or bowl ring (A) was therefore removed, and the pillar casting adapted to fit direct on to the outer tank. Thus only one water chamber is employed, the pressure being maintained at the 50 lbs/sq.in.

(c) *Magnetic Valve-head*. — The method of mounting this unit differs in the two cases: *Challenger's* being supported on steel pillars, and communicating with the cylinder through a rubber bung. The units themselves are identical except that in *Ormonde's* the magnetising coil is encased in a copper box, to obviate electrical breakdown due to moisture, cases of which had been experienced on previous occasions.

Also the design of the joint for the valve seating cover is modified in the *Ormonde* pattern, to facilitate removal, in which difficulty had previously been experienced.

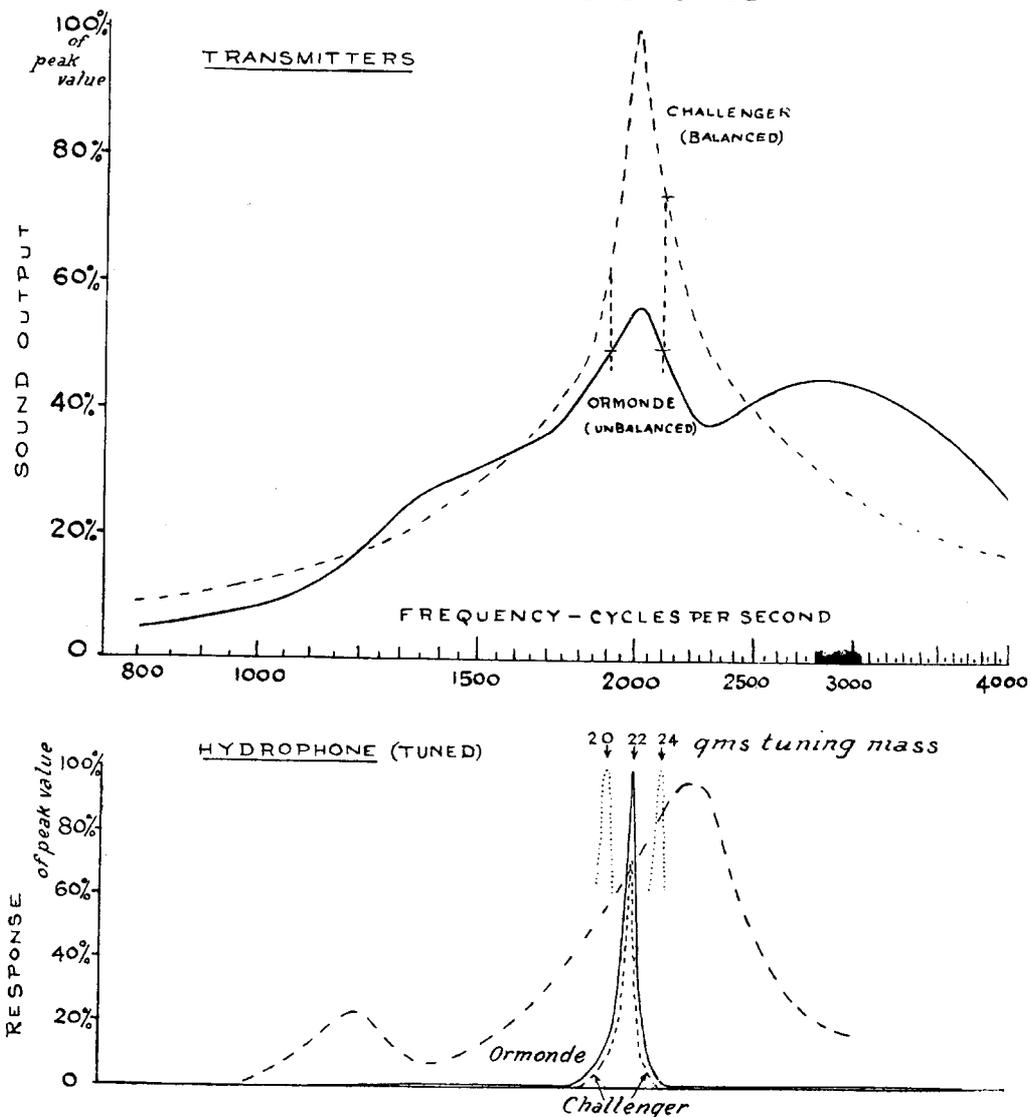
(d) *Air-supply Check Valve*. — An additional refinement was fitted to the *Ormonde* transmitter in the form of a spring-loaded check valve in the air delivery pipe, which can be adjusted to cut off the air supply to the transmitter when the pressure falls below a predetermined value.

Without this valve the air in the reservoir escapes when the recorder is switched off, and some time is required to recharge the reservoir when soundings are required.

(e) *Reducer Valves* for supplying low-pressure air to the under-side of the transmitter-pistons are the same in each ship.

(f) *The Air Compressors* are both electrically driven and water-cooled but whereas *Ormonde's* compressor is operated from a starter in the engine-room, *Challenger's* is controlled from the wheel-house by means of a contactor

DEEP-WATER ECHO-SOUNDING  
FREQUENCY CHARACTERISTICS



FIGS. 3 & 4

Frequency characteristics. — Transmitters and Hydrophones.

relay. A second contactor is caused to insert resistance in the armature of the compressor motor when full air pressure is reached, thus reducing speed and consequent wear and tear. This is effected by an *automatic pressure switch* in which contacts are separated by a spring-loaded plunger operated by the main air pressure.

(II) HYDROPHONES.

The type 752 hydrophone has been replaced in both ships by a small 3-inch tuned diaphragm fitted on a type 752 tank. The diaphragm carries

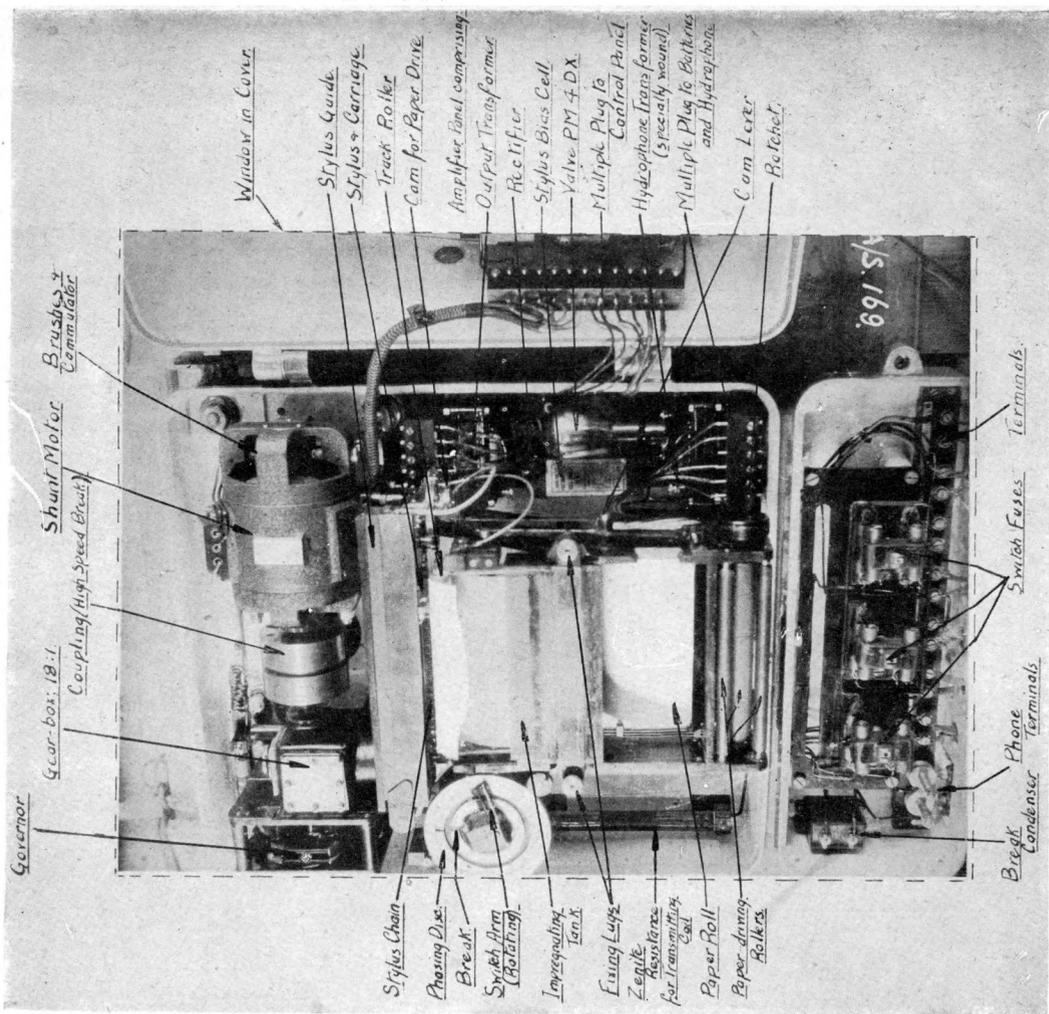


FIG. 6  
 Challenger Recorder. — Inside view.  
 Enregistreur du Challenger. — Vue intérieure.

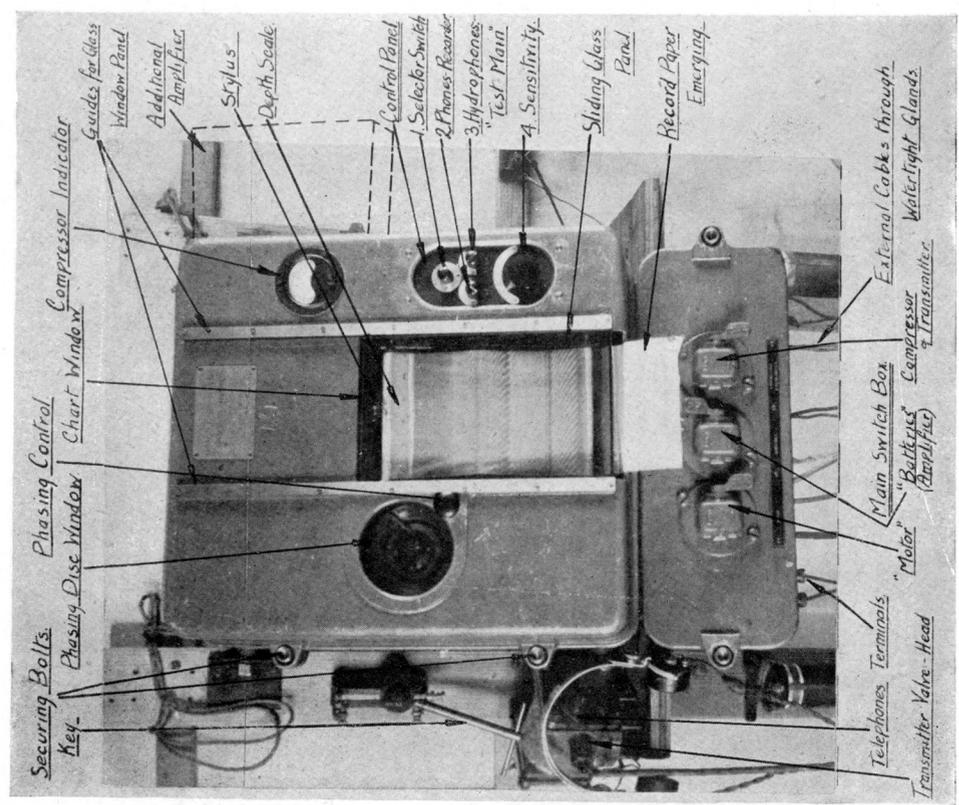


FIG. 5  
 Challenger Recorder. — Outside view.  
 Enregistreur du Challenger. — Vue extérieure.



the usual microphone and adaptor, and is designed to have a natural frequency of 2 kc. when fitted on the ship's hull. Laboratory tests were carried out prior to sea trials to investigate the frequency response of this unit and steps were taken to confine the response peak to 2 kc. and eliminate peaks at other frequencies. To effect this it was found necessary to employ microphones with thicker mica diaphragms (to raise their natural frequency) and to modify the adaptor. A small adjustable mass was interposed to facilitate tuning between the adapter and the hydrophone diaphragm. The resultant peak frequency of the unit is controlled by the weight of this mass which can be varied by trial to give a peak frequency coinciding with that of the transmitter output (see Fig. 4). Thus the hydrophone should respond strongly to echoes from a tuned transmitter, and repress extraneous interference at other frequencies.

### (III) RECORDER BOXES.

In addition to the recorder, these contain transmitter control mechanism and phasing gear, the stylus and paper driving gear, and the hydrophone-amplifying circuit.

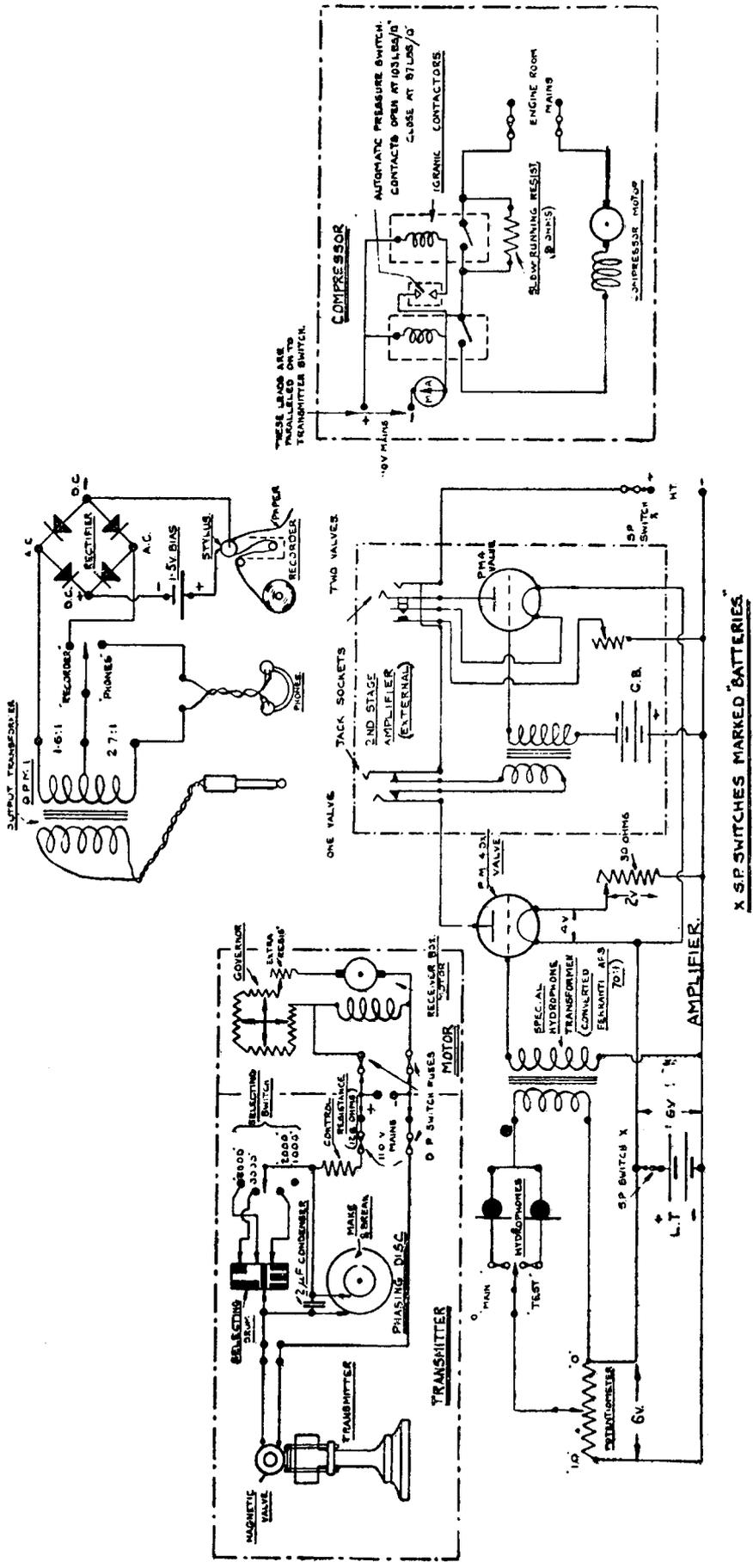
(a) *Challenger Box*. — Figs. 5 and 6 show photographs of the outside and inside of the receiver, the salient features being indicated in the margins. This is essentially an experimental instrument, in which additions and alterations have been carried out as occasion arose. A single stage valve amplifier is mounted on a panel and housed inside the case on the right hand side. Flexible connections with plugs and sockets connect it to batteries and hydrophone leads in the lower (switch) compartment of the box, and also to a control panel in the lid (see photographs). Control (1) on this panel, labelled "selector switch", permits the interval of transmission to be altered from  $2\frac{1}{2}$  to 5,  $7\frac{1}{2}$  or 15 seconds, thus enabling echoes to be recorded in the 1,000 fathom zones, where they would otherwise be masked by a subsequent transmission. (The normal interval of transmission ( $2\frac{1}{2}$  sec.) corresponds to an echo time of 1,000 fathoms). Control (2) inserts either the recorder or telephone in the output circuit (the latter for locating echoes from unknown depths), and Control (3) inserts either the main or "test" hydrophone in the input circuit. The test hydrophone is an auxiliary microphone suspended close to the transmitter and is used for the purpose of setting the zero of the recorder scale. Control (4) varies the sensitivity of the hydrophone.

The lower compartment carries three double-pole switch-fuses and also houses the terminal board for the various external connections.

Fig. 7 shows the theoretical diagram of all the electrical circuits associated with this box, including their control switches.

The milliammeter mounted in the lid of the box measures the current taken by the compressor contactors, indicating whether one or both are energised, and hence whether the air pressure is "full" or "low".

The central portion of the box is occupied by the recording apparatus which will be dealt with in detail later.



**X SP SWITCHES MARKED BATTERIES**

FIG. 7  
Challenger Deep water Echo Sounding gear. - Diagram of Electrical Circuits.

(b) The mechanism of the *Ormonde* recorder box is shown in the photographs of Figs. 8 and 9. This instrument is based upon the design of the original *Challenger* box, to which it is similar in general principle, but embodies in addition a circular telephone scale with short-circuiting contacts, similar to the type 752 receiver, but graduated 0-200 fm. and subject to phasing. The telephones are connected direct in the hydrophone circuit without any amplification.

The recorder amplifier embodies *three* transformer-coupled stages, and is constructed on the cubicle principle, the whole sliding into a separate compartment below the main case, where external connections are effected by finger-spring contacts. H.T. and L.T. batteries of service pattern are housed in a cupboard below the receiver box as in H.M.S. *Challenger*. In addition to the hydrophone potentiometer control a 5-point switch is provided for varying the grid bias of the second valve. The "Phones-Recorder" switch has an intermediate "batteries off" position, operating in conjunction with a red pilot lamp. In place of the selector switch the interval of transmission is controlled automatically by the phasing disc. When passing from the 700 to 900 fathom phase, a projection on this wheel actuates a star-wheel and contact drum, causing alternate breaks of the valve-current to be short-circuited, resulting in a 5 second interval of transmission for the subsequent 1,000 fathoms, for which intermediate phasing positions are provided and marked. A second revolution of the phasing disc causes a reversion to the 2- $\frac{1}{2}$  second interval (the instrument being designed for use up to 2,000 fathoms only). An indicator disc is attached to the selector drum shaft, with red and black sectors so arranged that on the 2- $\frac{1}{2}$  second interval a black sector is visible through the phasing-wheel window in the lid of the case, the 5 second interval being indicated by red. Depth values are engraved on the phasing disc in corresponding colours.

(c) *Sensitising of Record Paper.* — On the *Challenger* recorder plain untreated paper is drawn over rollers immersed in a celastoid tank containing a quantity of starch-iodide impregnating solution. The moist impregnated paper emerges to pass over the track roller where it receives and records the signal from the stylus. Due to the heat dissipated by resistance units in the box, the paper is partially dried on its way out of the box, whence it emerges through the driving rollers at the bottom of the box, which are ratchet-operated by cam and lever from the stylus chain sprocket.

*Ormonde's* recorder employs a roll of ready-impregnated paper, which is moistened by being drawn over a roller carrying a wick, the lower end of which is immersed in a water tank. The wick roller is of *D*-section to enable it to be turned below the level of the top of the tank and so out of contact with the paper when wetting is not required. A heating element is incorporated in the front of the tank which dries the paper as it passes over it. The driving rollers are in this case actuated by a step-by-step cam and ratchet-wheel, operated through worm gearing from the stylus chain sprocket.

An additional refinement is provided on this recorder in the form of zero and time-marking. Contact drums are suitably geared to provide an electrical

impulse to the stylus as it passes the zero mark of the scale (thus providing a continuous zero line, which can be adjusted); and a longer stroke at intervals of one minute (1,800 motor revolutions).

An electrical stylus pen for noting times etc. on the record is provided on both recorder boxes.

NOTE. — As no "test hydrophone" is provided in *Ormonde* the zero line must be set to give a lag of about 17 fathoms (transmitter lag) beyond the point of "break" and final adjustments made by check soundings in about 50 fathoms.

*Challenger's* recorder box is situated in the wheel-house; *Ormonde's* is in the Navigator's chart house immediately abaft the wheel-house. Both recorders are thus under cover and protected from the weather.

### 3. RESULTS OF TRIALS.

#### (I) PERFORMANCE.

The most obvious and tangible measure of the performance of an echo-sounding recorder is the maximum depth at which it is capable of recording echoes consistently, and the type of record it is capable of producing under various external conditions.

As a general guide in this direction, an approximate table is appended herewith giving maximum depths at which consistent records may be expected for the two ships under various working conditions.

#### (II) EFFECT OF TUNED HYDROPHONE.

(a) *Challenger* mechanical tuning and the use of specially designed microphones considerably improved the range and selectivity of the set and showed a definite reduction in interference. The tuning is critical and would repay further investigation. Best results appear to be obtained when both hydrophone and microphone have individual response peaks at the transmitter frequency and less amplification is required if the microphone has a high inherent sensitivity. Microphones show considerable variation in this respect, the granules appearing to have a tendency to pack, causing a falling off in sensitivity after a few hours continuous use. A small "Brown" type microphone gave the greatest reliability in this respect, and as it had a response peak very near that of the transmitter, it gave very satisfactory results. A special intervalve transformer designed to have a maximum response at 2 kc. had only a very slight effect on the interference, indicating that the received interference was almost entirely confined to this frequency — a fact confirmed by telephone listening.

(b) *Ormonde*. A typical response curve of the tuned type of hydrophone now employed is shown in Fig. 4. From this it will be seen that the hydrophone is only seriously affected by water noises of the frequency to which it is tuned. Altering this tuning by some 50 cycles either way had no appreciable effect on the strength of received echo (at 2,100 fathoms). This result indicates that the output of the unbalanced type of transmitter is not concen-

TABLE I.

## RANGES FOR CONSISTENT ECHOES UNDER VARIOUS CONDITIONS.

TYPE OF INSTRUMENT AND AMPLIFIER.	MAXIMUM DEPTH FOR CONTINUOUS RECORDS ON FLAT OR GENTLY SHELVING BOTTOM. — FATHOMS.										
	Ship stopped	Steaming 3 Knots.				Steaming 10 Knots.			Clean Background.		CO <sub>2</sub> Plant running.
		Sea 3.	Sea 2.	Sea 3.	Sea 4.	Sea 2.	Sea 3.	Sea 4.	10 Knots	Stop.	
<i>Challenger</i> , Single Valve.....	1,500	1,250	1,000	750	1,000	750	500	800	1,200	700	
<i>Challenger</i> , 2 Valves	5,000*	4,000*	3,000*	2,500*	3,000*	2,500	2,250	700	2,000	1,200	
<i>Ormonde</i> (3 Valves)	3,500*	2,500*	2,250	2,000	2,250	2,000	1,750	500	1,800	2,000	
<i>Ormonde</i> , range as percentage of <i>Challenger</i> .....	70 %	62½ %	75 %	80 %	75 %	80 %	78 %	71½ %	90 %	Mean 75 %	

(\*) Predicted.

## NOTES.

1. Ranges for *rough seas* are not given as these were not encountered during trials.
2. The *third columns* (Sea 4) are intended to include an aerated condition, *i. e.* a featherwhite windblown surface causing pitching of ship and breaking water on bows.
3. *Aerated water* under the hull near the transmitter or hydrophone reduces echo intensity considerably. This effect is shown in a very marked degree when the ship goes astern. The amount of aeration depends on a number of factors: *e. g.* form of ship; state of sea; direction of wind in relation to course; pitching; and speed.
4. For ranges on *gradients* over 1 in 10, see "Nature of Bottom".
5. "Clean background" indicates intensity of interference below recording value.

trated at one frequency. To an observer in the ship the sound of the transmission appeared muffled and unmusical, whereas in *Challenger* it was heard as a high-pitched musical ring. It is evident that in the present case the exact frequency to which the hydrophone is tuned is comparatively unimportant. The microphones employed during these trials were of a higher degree of sensitivity than those used in the last *Challenger* trials (by about 50%) which would compensate to some extent for the reduced output of the transmitter at 2 kc.

## (III) MAXIMUM RANGE.

The greatest depth encountered on H. M. S. *Challenger's* Atlantic Passage was 2,580 fathoms which was recorded with ease at 10 knots and sea 2-3. With the ship stationary ("Bottling Stations"), double echoes were recorded at 1,852 (3,704) and 2,240 (4,480) fathoms. These figures are considered to justify the predicted values in Table I. On getting under way the echoes were always observed to weaken, in addition to the increase in interference.

During H.M.S. *Ormonde's* trials the echo became weak at 2,250 fm. with ship under way, though this is attributed in part to uneven bottom. On stopping for a check sounding, remarkably good records were obtained at 2160 fathoms, despite an irregular bottom.

#### (IV) INTERFERENCE.

Although microphone tuning does much to eliminate interference from water-noise and machinery in H.M.S. *Challenger*, it is unable to suppress the strong vibrations set up by the *CO<sub>2</sub> refrigerating plant*, which is situated in an adjacent compartment to the hydrophone, and shocks the microphone at its natural frequency. This plant causes interference, when running, on all but the lowest hydrophone sensitivities when employing two stages of amplification, but it is possible to distinguish echo-records up to 2,000 fm. when stationary. On applying more than one quarter of full voltage to the microphone, however, the record becomes completely dark, rendering echoes indistinguishable with any degree of certainty. With one valve this interference does not seriously affect the range, but only the clarity of the records, the stylus current being in this case well below the saturation point of marking.

Slight interference was also observed in this ship from an automatic water pump, an exhaust fan in the canteen store and the ship's wireless transmitter. None of these was intense or continuous enough to be serious.

*Ormonde's* *CO<sub>2</sub>* plant is situated in the after part of the ship and creates little or no interference.

*Water Noise* is always present to some degree, and causes very considerable interference at the higher hydrophone sensitivities when the ship is under way. With ship stationary in a calm sea this type of interference is practically absent. Its effect increases with speed of ship, and shocks the hydrophone at its own natural frequency. Another probable source of interference is "frying" of the microphone at full sensitivity.

#### (V) AMPLIFIERS.

Records obtained in H.M.S. *Challenger* show that a single stage of amplification, though giving perfectly clear records up to nearly full sensitivity (*i. e.* water noise below recording strength) is quite inadequate for depths of over 800 fathoms. The addition of a second stage of amplification, though raising the water noise above the threshold value, enables the echo-trace to be discerned up to 3,000 fathoms or more, since the density of echo records exceeds that of the interference. It was often found possible to discriminate between echo and interference on the record where this was impossible by telephones.

The 3-valve amplifier supplied to H.M.S. *Ormonde*, while giving excellently contrasted records on low sensitivity, amplifies water noises to such an extent on full sensitivity that the background of the record approaches the maximum density of which the recorder is capable, thus impairing the discernment of echoes by reducing the contrast. It is therefore necessary to reduce amplification by grid biasing until the water noise is reduced to a workable value.

FIGURE 26.  
SECTION OF RECORD  
FOR ANALYSIS

SEE FIG. 16.

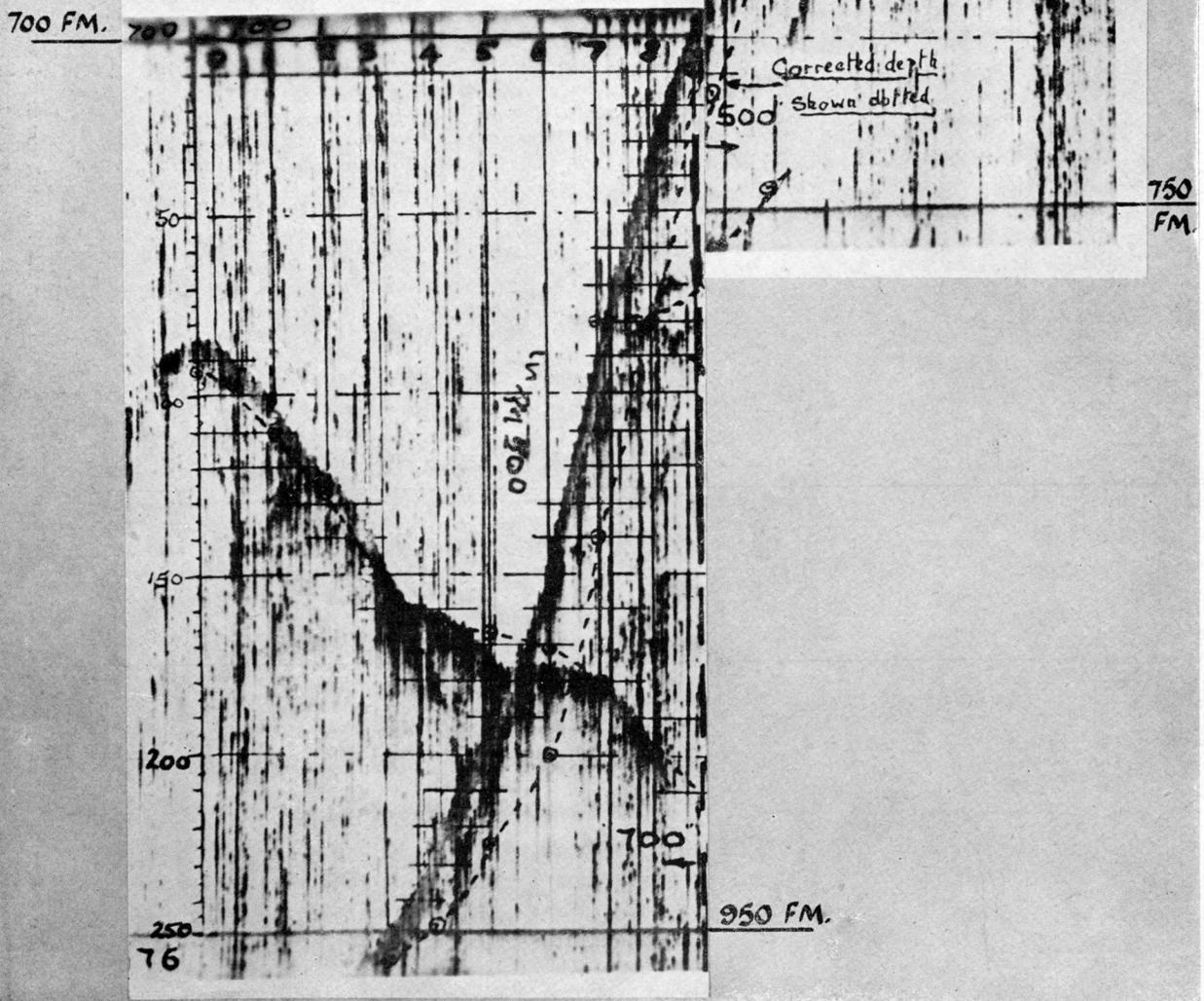


FIG. 26 — Typical section of record. — Fragment typique d'enregistrement.



The excessive blackness of the records on full amplification was at first attributed to instability (L.F. oscillation), which may, however, be a contributory cause.

In practice the strength of echo signal varies with depth through a very wide range of intensity. If constant amplification were used the strong echoes obtained in shallow water would produce unnecessarily strong currents at the stylus and overload the amplifier. This is obviated by reducing the hydrophone volts (D.C.) by means of a potentiometer analogous to a "volume control". By this means it is possible to reduce the sensitivity of the microphone until the level of water noise falls below recordable value. This is possible on both 2- and 3-valve amplifiers and results in the "clean" record referred to in Table I, and shown at the right-hand end of the record section in Fig. 27\*. Another advantage of this reduction in sensitivity lies in the fact that it can be made to remove from the record all trace of direct shock due to transmission near the zero line, thus enabling depths to be recorded to within the draught of the ship. (See also separation correction, page 146).

As depth increases, the strength of echo signal falls off and becomes of the same order as that of the interference. In order to maintain a good echo density of the record it is now necessary to increase hydrophone sensitivity until the interference is amplified above minimum recordable value, and appears as an irregular background to the echo-trace. With further increasing depth the echo trace can be discerned until its signal strength falls below that of the water noise. At this point the hydrophone will be working at high (but not necessarily full) sensitivity.

#### (VI) GRID BIAS CONTROL.

An additional method of output control is provided on the *Ormonde* Amplifier in the form of variable grid bias on the second valve. A tapping-switch gives five alternative values. This enables the valve to be operated on the lower bend of its characteristic, which is effective in reducing interference where the echo signal is comparatively strong, and in accentuating any echo that exceeds the water noise in intensity. This principle, however, introduces a D.C. component into the valve's anode circuit, resulting in transformer losses and consequent inefficiency, which tend to counteract the advantage gained. In practice it is possible to find a mean setting where improvement is obtained, though this would be facilitated by a potentiometer and a valve with a specially sharp anode bend.

#### (VII) RECORDER BOXES.

The *Ormonde* method of sensitising the paper was found cleaner and more satisfactory than that employed in *Challenger*, in which inconsistency of chemical solution was responsible for discolouration of some of the records. These records are also discoloured by bright daylight when damp. The heating element in the *Ormonde* instrument ensures complete drying of the paper under all conditions of humidity.

---

\* Figures 10, 11, 12, 15, 24, 25 and 28 of the original report are not reproduced.

To insert a fresh roll of paper in the *Ormonde* recorder it is necessary to remove the wetting tank, depth scale, and three electrical connections. In the *Challenger* box sufficient clearance is allowed for the insertion of a roll, but removal of the impregnating tank is necessary to permit of reeving the paper on the rollers.

A drawback common to both methods of wetting is the time-lag between switching on and obtaining a record. Normally this amounts to several minutes, but is usually overcome in practice by over-running the paper drive by hand, thus "inching" the moist paper on more rapidly. On the *Ormonde* recorder this lag is reduced somewhat, but there is a possibility of switching off the electrical circuits without turning the wick off from the paper, in which case the impregnating material becomes washed out of the paper for a considerable distance.

The automatic change from 2- $\frac{1}{2}$  to 5 sec. transmission interval above 900 fathoms is a convenient arrangement for permitting records in the 1,000 fathom transmission zone (1,004-1,012 fm.), but results in echoes being recorded only on alternate traces at all depths above 900 fm. This has the effect of halving the apparent density of the echo-contour in a region where good contrast is most needed; for above 1,000 fm. the echo signal is weak, and the high sensitivity required produces a considerable background of water noise. To revert to the 2- $\frac{1}{2}$  second interval it is necessary to rotate the phasing disc through another complete revolution, or alternatively to open the lid and move the selector drum through one sector of the indicator disc (red to black). In *Challenger* the same result was achieved by means of the selector switch on the control panel.

Phasing on rapidly decreasing depths exhibits the same difficulty on both instruments, viz. the necessity of turning the phasing disc back through  $\frac{4}{5}$  ths of a revolution instead of forward by  $\frac{1}{5}$  th — a process entailing the loss of several echoes. Forward motion is prevented by a one-way device intended to safeguard the brushes against being over-run by the break, though this contingency cannot arise while the recorder is running, and with the machine stationary would only be caused by the uninitiated.

In the *Ormonde* receiver the telephones are connected direct in the hydrophone circuit, and are short-circuited except for a short interval once per revolution of the disc, which is adjusted to coincide with the incoming echo arriving once in five revolutions. Using this aural method it was found impossible to obtain reliable readings beyond 500 fathoms. As results of sufficient accuracy are given by the recorder, it was therefore recommended that the telephones be disconnected from the short-circuiting disc and used solely for locating echoes in unknown depths.

With the *Challenger* receiver the use of telephones in unknown depths was of the greatest assistance in locating echoes up to 2,000 fathoms and over, estimation being possible to within 5 fathoms by watching the phasing wheel. In this receiver the telephones are inserted in the output of the amplifier, and are permanently on open circuit. At the greater depths the ear was often unable to distinguish echo from interference although the recorded echo was visible; but it was found possible to hear echoes with the telephone switch to



"recorder", *i. e.* through the capacity (or leak) of the switch contacts (see Fig. 7). Echoes heard thus, though weaker, appeared more free from water noise, and were audible up to the full recording range.

#### (VIII) TRANSMITTERS.

These proved satisfactory in operation in both ships, and gave no trouble during trials apart from initial adjustments. The *automatic pressure switch* of the *Challenger* equipment required frequent attention, and an air leak was caused by a too hard grade of dermatite joint-ring on the valve-head of the *Ormonde* transmitter. *Reduction of water pressure* in the inner chamber of the *Challenger* transmitter from 100 to 50 lbs/sq.in. produced no noticeable effect, as previously stated. *Reduction of air pressure* increased the transmitter lag and produced a marked falling off in signal strength below 75 lbs/sq.in. (normal 100 lbs). The normal lag of the *Challenger* transmitter was sufficiently constant to produce perfectly smooth contours on the records. In *Ormonde*, however, these contours always appear slightly serrated, indicating variations of about 20 % in the transmitter lag. This might be caused by insufficient clearance between piston and cylinder walls, which is indicated by the fact that a high back-pressure was required to return the piston (6 lbs/sq.in. as against 2-1/2 in *Challenger*). The piston, however, appeared perfectly free when tried by hand. Another possible cause is the electrical break on the phasing disc, one of the brushes of which subsequently gave trouble.

#### (IX) ACCURACY OF SOUNDINGS.

(a) The governor of the control motor, though originally set for a sound velocity of 4,800 ft/sec. (1,800 R.P.M.), was altered to give a stylus speed corresponding to a sound velocity of 4,920 ft/sec. or 1,500 metres/sec., for both instruments (1,847 R.P.M.). This is a more convenient mean value as given by Sound Ranging tables (H.D. 282), the maximum deviations being  $\pm 4\%$ , and average  $\pm 1\%$ . The *Challenger* Atlantic trials took place chiefly in the region of N.E. Atlantic Drift, where the above setting should give a correct reading at about 2,000 fm. For other depths and in other regions correction must be applied in accordance with the values given in the tables. For this purpose the curves of Figs. 13 and 14 have been prepared, from which can be read off the fathoms correction for all depths in various regions. The upward trend of these curves at great depths is due to increasing pressure (10-1/2 atmospheres per 100 fm.), the initial downward slope being due to falling temperature.

The correction curves of Figs. 13 and 14 are drawn up for the standard velocity of 4,800 ft/sec. to which all instruments are normally set. As the two instruments of the present report were set for 4,920 ft/sec., a further correction of  $-2.5\%$ , must be applied to the corrections given by these curves.

(b) *Seasonal Temperature variations* at depths over 100 fathoms may be neglected, but in depths less than this the mean temperature in the water column will be influenced by the surface temperature, which will display

TRUE-SCALE BOTTOM-CONTOUR  
 CONSTRUCTED FROM SECTION OF RECORD-CHART

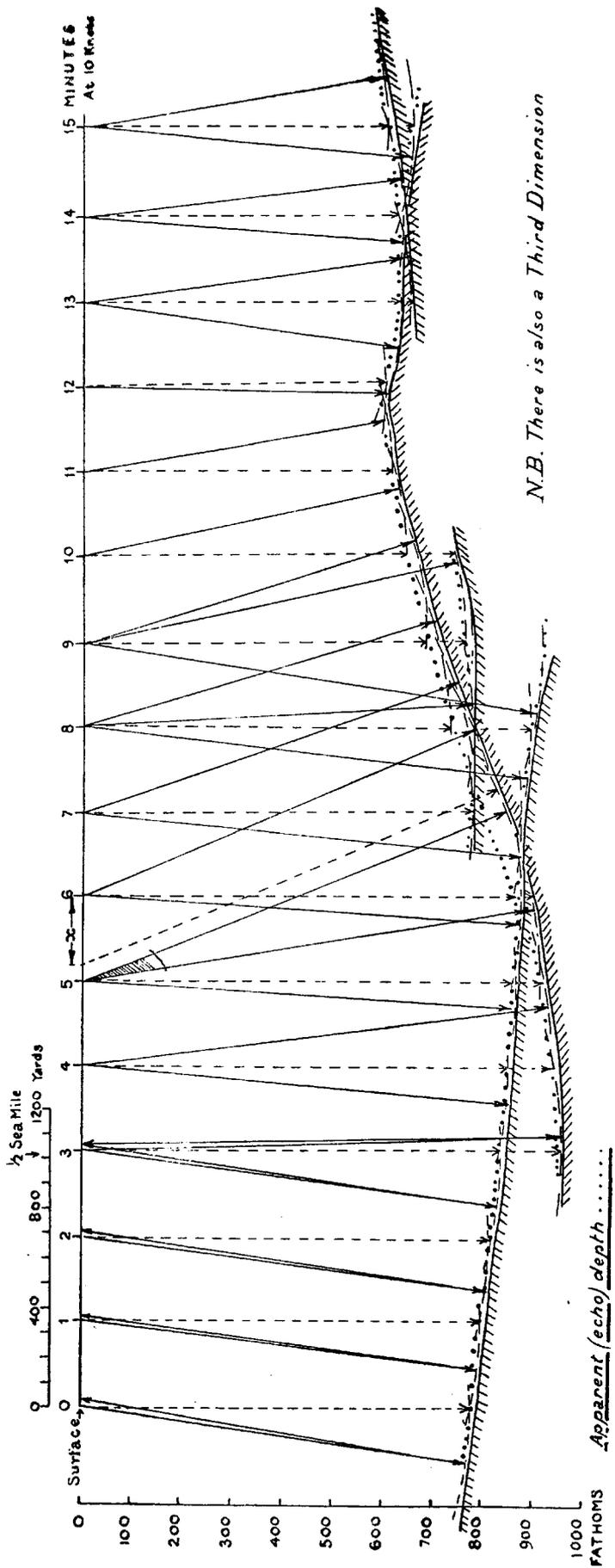


FIG. 16

seasonal variations, thus producing small deviations in sound velocity. These deviations, however, in no case exceed  $\pm \frac{1}{2}$  fathom and can therefore be neglected for the purpose of the present instruments, where the scale only permits of reading to the nearest fathom.

(c) *Correction for separation* is necessary below 50 fathoms, since the depth scale is graduated evenly throughout. This correction was calculated to compensate for the distance separating hydrophone and transmitter in each ship, and supplied to the ship in the form of an enlarged depth scale with corrected scale opposite.

(d) Applying the above corrections to echo soundings taken during H.M.S. *Challenger's* transatlantic passage, the maximum variations from Lucas soundings becomes of the order of  $\pm 0.3$  % or 10 fm. in 2,000 (See Table II). This variation is attributable to governor variation, sounding-wire and correction errors.

*Ormonde's* trials were carried out on the continental shelf off Ushant where the bottom shelves steeply. Application of depth corrections did not here give very close agreement to check (Lucas) wire soundings, being from 1 % to 2 % less than the wire values.

It was suspected that a correction for gradient was necessary and a specimen section of the record (Fig. 26) was therefore analysed, as shown in Fig. 16. This represents a section of the bottom to a proportional scale and shows the diminution in apparent depth due to *gradient*. It also shows that, where the bottom is uneven, echoes may return from points as much as half a mile apart (in 1,000 fm.). (At point 6 in Fig. 26, the two echoes have a horizontal displacement of 750 yds).

For correcting this error due to gradient, two methods present themselves.

(i) Displacement : by moving the point of measurement back or forward by a suitable amount — in terms of the "minute" marks on the chart.

(ii) Direct percentage correction to depth as scaled.

As the gradient is liable to vary, method (i) is the more accurate, though method (ii) is simpler and should give accurate results provided variation in gradient is allowed for. The amount of correction in each case is determined by the bottom gradient, which is proportional to the gradient of the echo trace at a given speed of ship. The calculations leading to the correction formulae are given in the Appendix, and give rise to the correction curves of Figs. 17 and 18. From these it will be seen that the effect of gradient is negligible below 1 in 10, but becomes considerable at the steeper slopes. As gradients are generally steep between the 100 and 1,000 fm. lines, the correction is important.

The above investigation shows that echoes from a falling gradient arrive from astern of the ship's position, and those from a rising shelf, ahead. This accounts for the "cross-over" effect or intersection of echo traces which



always occurs at the trough of a valley (see Fig. 23). Conversely this effect will cause an apparent broadening of peaks (see points 11 and 12 of Fig. 26).

In all cases the echo recorded is that from the *nearest* point on the bottom, and not necessarily the point vertically below the ship. For navigational purposes this is more of an advantage than otherwise, as it gives slight fore-warning of an approaching bank or shoal, or precipitous coast-line. For survey work corrections can be applied.

(e) When applying these gradient corrections, especially where a record displays more than one trace, the presence of a third dimension must be borne in mind, for since the echo is capable of returning from some distance forward or aft, there is also a possibility of lateral deviation.

In both cases the character of the records indicates that the echoes producing definite traces arrive from portions of the bottom that are normal to the direction of propagation. For example the profile constructed in Fig. 16 shows that for an echo to return from a normal surface on a gradient of 1 in 3 (points 6 and 7) requires that the signal can be transmitted and received along a path inclined at  $18^\circ$  to the vertical without appreciable loss of sensitivity.

While there is less likelihood of continuous traces from echoes with lateral displacement, an example of these echoes is seen in Fig. 16, points 7 to 9.

In the case of a ship running at right angles to a gradient however, the normal surface will have a permanent lateral displacement. Correction in this case can only be applied by taking transverse records to investigate the gradient.

TABLE II.

POSITION.	Region (H.D. 282)	Recorded Depth (4920 ft/sec.)	CORRECTIONS. FATHOMS.			Corrected Echo Depth.	Check Lucas Sounding.	Discrepancy %
			Depth. Fig. 13	- 25 % (4920/ 4800)	Gradient Fig. 18			
<i>Challenger</i> , Station 1	7	449	+ 8	- 11	—	446	448	- 0.45 %
» » 2	7	2491	+ 74	- 62	—	2503	2496	+ 0.28 %
» » 8	17	2396	+ 62	- 60	—	2398	2392	+ 0.25 %
» » 11	17	152	+ 1.5	- 4	—	149.5	149	+ 0.33 %
» » 12	17	73	+ 1	- 2	—	72	72	0 %
<i>Ormonde</i> » 1	5	1110	+ 28	- 28	+ 22	1132	1135	- 0.22 %
» » 2	5	2135	+ 68	- 53	+ 17	2167	2165	+ 0.09 %

NOTE. — GRADIENT CORRECTION.

These values are obtained from the following data (with ship under way):

1. Speed 10 knots. Inclination of trace  $65^\circ$ . Correction + 2.0 % in 1110 fm = + 22 fm.
2. Speed 5 Knots. Inclination of trace  $35^\circ$ . Correction + 0.8 % in 2135 fm = + 17 fm.

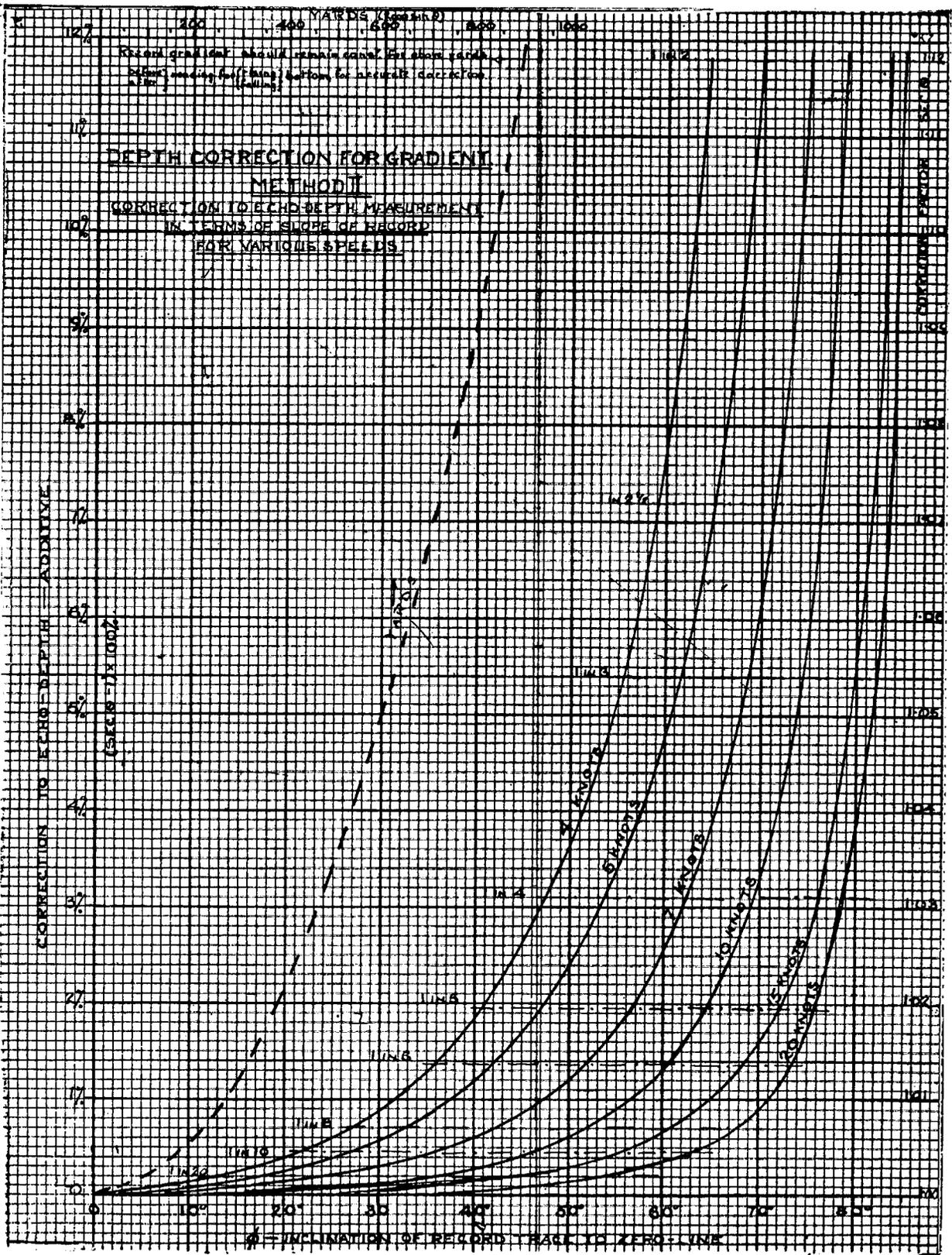


Fig. 18

(f) The gradients at points of check soundings in H.M.S. *Challenger* were not sufficient to warrant gradient correction, but for the two check soundings taken in H.M.S. *Ormonde* (by Lucas machine) gradient correction for echo sounding was applied. A number of these check soundings together with corrections to recorded depth and resulting discrepancies are given in Table II.

The records taken during these trials are preserved in an album at H.M.S. *Osprey*. Those of H.M.S. *Challenger* represent a large proportion of the Atlantic crossing, and from them has been prepared a section profile of the ocean bed.

Typical records obtained in H.M.S. *Ormonde* are reproduced in Figs. 26 and 27, being staggered at the points of phase change to exhibit a continuous trace.

#### (X) NATURE OF BOTTOM.

The depths given in Table I are intended to apply for "flat or gently shelving bottom" only. When steep gradients occur, however, these may seriously impair the clarity of the recorded echoes. At shallow depths the contour is generally faithfully reproduced, the only weakening of echo being an apparent reduction due to the inclination of the trace, or staggering of successive echo marks. At depths greater than 300-500 fm., however, the trace may break up and follow several independent paths (see Fig. 27). This effect is dealt with in a previous paragraph (IX) (e). At still greater depths instances have been experienced of the trace becoming so diversified as to lose its individuality, and in some cases consistent echoes were entirely absent. Figs. 19 and 20 are examples of severe "scattering" encountered during *Challenger's* Atlantic Passage, at 1,400-1,600 fm., in the neighbourhood of a steep shoal near the 30° meridian. Fig. 21 shows a true-scale sectional sketch of this "peak", from which it appears that the gradient of its sides is of the order of 1 in 8. A similar phenomenon was experienced in H.M.S. *Ormonde* on the continental shelf off Ushant, as shown in Fig. 27 (1,200-1,600 fm.). It appears reasonable to suppose that this effect is due to the signal being reflected from a number of surfaces within a fairly wide area on the bottom and at varying distances from the source of the signal. This is borne out by the fact that these points occur only in regions of steep gradient where bottom irregularity is most probable. Fig. 23 shows the "cross-over" effect mentioned in paragraph (IX) (d), while Fig. 22 gives examples of an effect referred to as "layers", probably produced by lateral echoes.

Experience of echo sounding in the North Atlantic indicates a tendency for the bottom to become "difficult" between 1,400 and 1,800 fathoms. To obtain records under such conditions it is necessary to reduce speed until echoes re-appear, and if necessary to bring the ship to a standstill. As these "scattered" echoes are not readily recognisable on telephones, all searching must be done on the recorder, phase by phase, until echoes are observed. In such cases the location of echoes would be greatly facilitated by the provision of a closer depth scale, *i. e.* a slower running speed, so that a greater range is covered by the traverse of the stylus pen. This scheme could be effected



by a change-speed gear, and would provide the following additional advantages :-

- (a) Clearer trace due to greater concentration of echo marks.
- (b) Less supervision for phasing.
- (c) Profiles more readily recognisable for navigation.
- (d) Economy in use of recording paper.
- (e) General reduction of wear and tear.

The open scale could be reverted to for accurate readings when required.

#### 4. CONCLUSIONS.

##### (I) COMPARISON OF TRANSMITTERS.

The maximum ranges obtained in H.M.S. *Challenger* were some 25 % greater than H.M.S. *Ormonde's* in spite of the greater sensitivity of the latter's receiving apparatus. Although possible differences in hull losses make a strict comparison of the two transmitters impossible the results confirm that the greater output of the balanced transmitter increases the maximum range at least 25 %.

##### (II) TUNED HYDROPHONES.

The results obtained in H.M.S. *Ormonde* show a great improvement on those previously obtained with the standard microphones and adaptors. Although the hydrophones used in the earlier trial were tuned to the transmitter's note the adaptor introduced an additional response at a lower frequency and thus increased the strength of the interference shown on the recorder.

##### (III) RECORDERS.

The trials demonstrated the great advantages of the chemical recorder particularly when sounding uneven bottoms and in many cases records were obtained when sounding by telephones was either very difficult or impossible.

##### (IV) "PHASING" OF RECORDS.

The use of the "phasing" system is essential in deep water to provide the required accuracy on a record of limited width, and in *Challenger's* recorder the phasing method provides, in effect, a record 128" wide for depths up to 6,000 fathoms. Telephones (without the short circuiting switch) were used to give a rapid indication of the approximate depth but it appears that a more convenient method would be to record unknown depths on a very closed scale covering say 1,000 fathoms in the width of the paper.

##### (V) AMPLIFICATION.

The recorder entails the use of amplification which is unnecessary with telephone reception. The amount of amplification that can be usefully employed is limited by water noise and ship disturbances. The two stage amplifier in *Challenger* was quite sufficient for normal use with the ship under

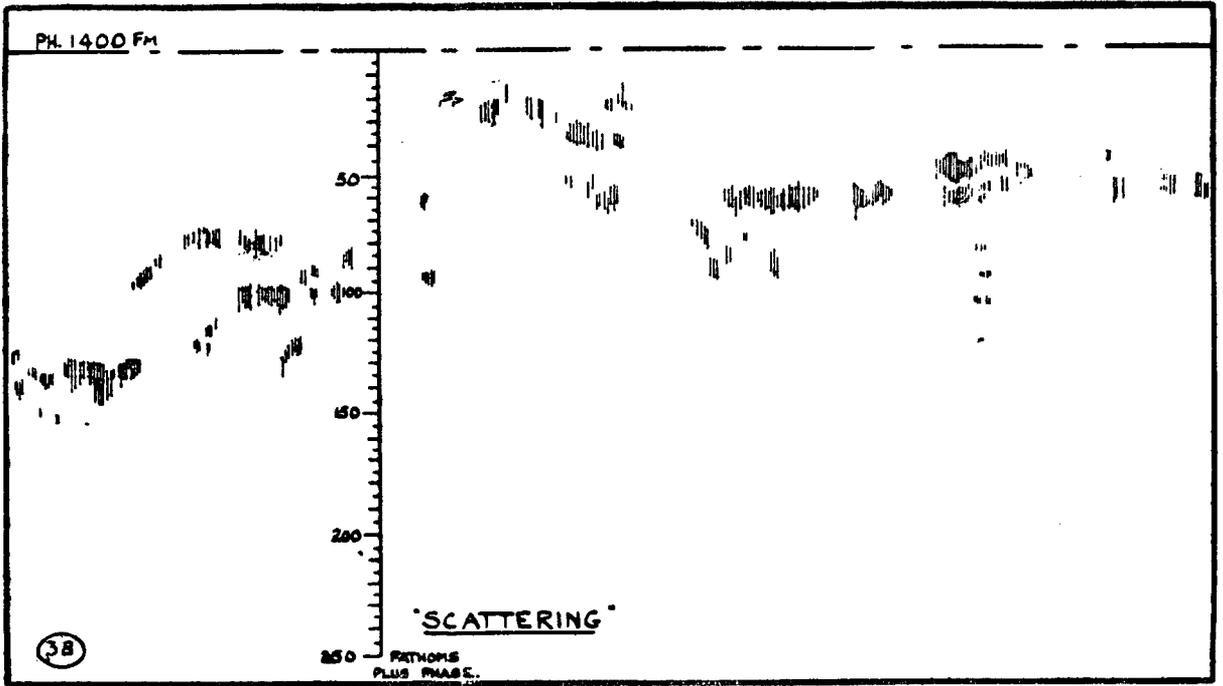


FIG. 19

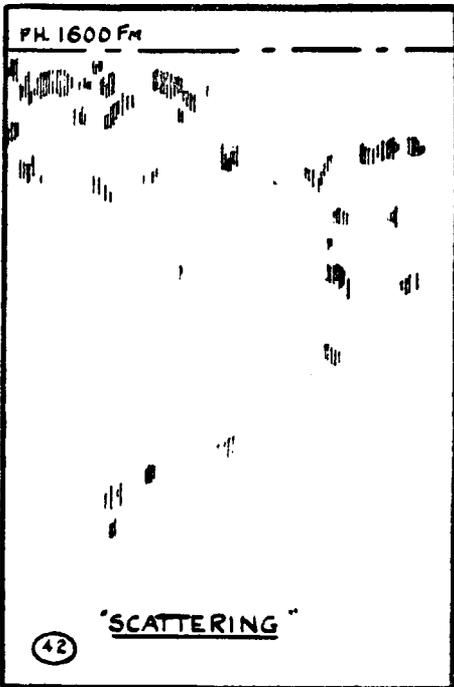


FIG. 20

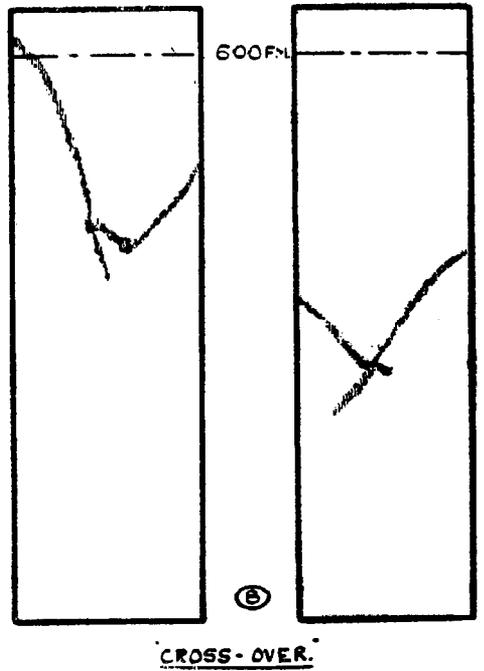


FIG. 23

*Examples of Peculiar Records.*

way but with the ship stopped and under favourable conditions deeper soundings would be possible with a three stage amplifier.

#### (VI) SLOPE CORRECTION.

In deep water the sound from the transmitter covers a large area on the bottom. Even in the case of a concentrated beam from a large high frequency transmitter the beam will spread to a diameter of one mile in a depth of 2,000 fathoms and slope correction is necessary for accurate soundings. For example, the correction for a gradient of 1 in 5 amounts to 2 %.

#### (VII) MAXIMUM DEPTHS.

The trials show very clearly how much the maximum depth at which soundings can be taken depends on ship and weather conditions and on the nature of the bottom and that a large reserve in power is necessary to sound the deepest water under all conditions. Although it has not been possible to check the actual performance of the transmitters with the calculated sound output, measurements show that no greater output can be obtained by alterations in the valve and hammer mechanism. Rough calculations show that the output of the deep-water set is at least one hundred times greater than that of the Type 752 transmitter and further increase in output presents considerable difficulty. These transmitters were designed for use with telephone reception which limited the frequency to about 2 kc., but with recorders the use of a higher frequency would be advantageous.

The intensity of the water noises and ship disturbances fall off rapidly as the frequency of reception is raised and in consequence of the greater amplification that can be employed the output required at a higher frequency is less. For this reason it is considered that any demands for sounding in greater depths can be met by the use of a higher frequency.

---

### APPENDIX.

---

#### DEPTH CORRECTION DUE TO GRADIENT.

---

Where the slope of the sea-bed is appreciable, the shortest and normal echo-path will be less than the vertical path by an amount dependent on the angle of inclination of the bottom to the horizontal.

This is explained by reference to Fig. 17A which illustrates two alternative methods of correction :-

(a) The point of measurement  $X$  may be transferred by a distance  $x$  to a point  $X'$  on the record, such that the echo-depth at  $X'$  ( $d'$ ) is equal to the true depth at  $X$  ( $d$ ). See also Fig. 17B.

TRUE-PROPORTION SKETCH OF MID-ATLANTIC PEAK, LONG. 29°20' W.  
LAT. 51 N. (APPROX)

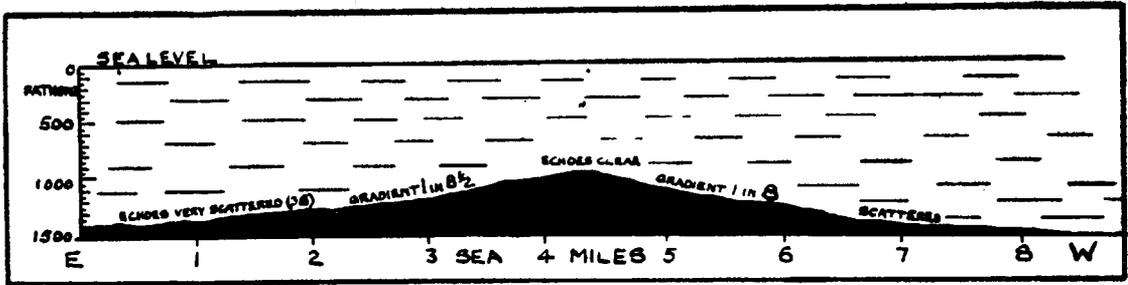
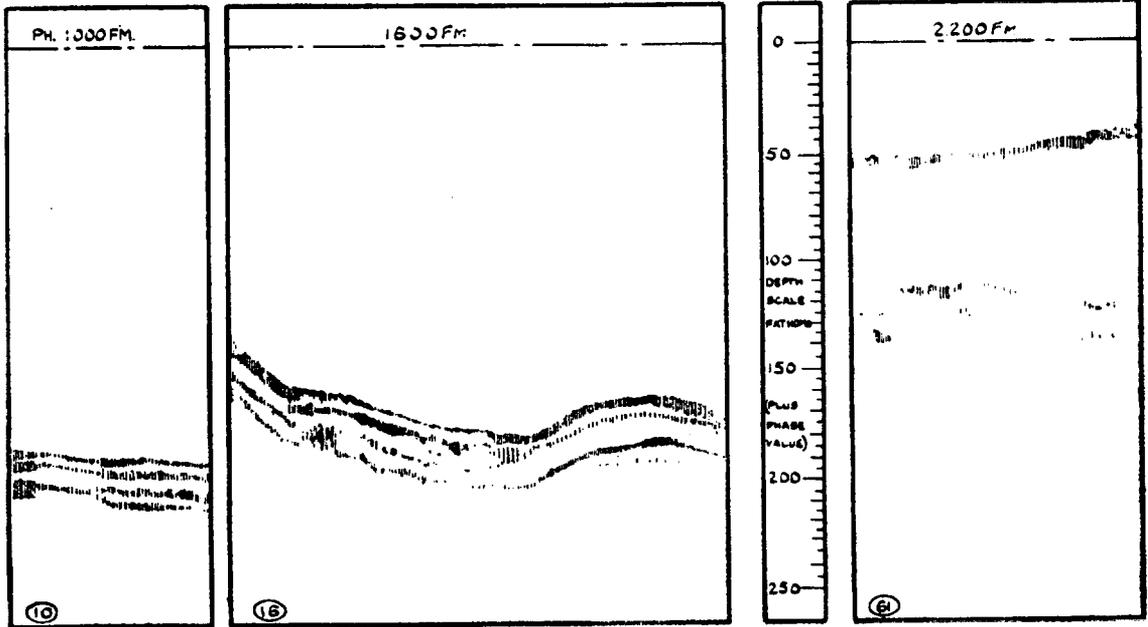


FIG. 21



'LAYERS'

FIG. 22

*Example of Peculiar Records.*

(b) True depth  $XD$  ( $d$ ) may be expressed in terms of echo depth  $XB$  ( $d_e$ ) and bottom inclination ( $\theta$ ), giving a direct percentage correction.

Before investigating either of these methods it is necessary to obtain an expression for the inclination of the bottom. This is found in terms of inclination of echo-trace on the record, and speed of ship, as follows:—

Let  $\varphi$  be inclination of echo trace to zero line of chart (Fig. 17B).

Let  $K$  be speed of ship in knots.

Then distance travelled by ship in one minute =  $\frac{2027.5K}{60} = \underline{33.8K}$  yds.

And by measurement, 200 fm. on depth scale = 13.3 "minute intervals" on paper, *i. e.* 1 minute space =  $\frac{200}{13.3} = 15$  fathoms (= 30 yds) on depth scale.

Now, as mentioned above, section 3 (IX), the speed setting of the *Ormonde* recorder was altered from 1,800 to 1,847 R.P.M. Thus minute marks occur on the paper at intervals of  $\frac{1800}{1847}$  minute = 0.976 minute.

Therefore in one true minute, chart paper moves  $\frac{15}{0.976} = 15.38$  fm. of the depth scale = 30.76 yds.

Therefore ratio of vertical to horizontal scale on chart paper

$$= 33.8K : 30.76 = \underline{1.1K} : 1$$

(For true minutes - 1.12K : 1).

*i. e.* the vertical scale is exaggerated 1.1K times, or nearly times knots made by ship.

So that where  $\theta$  is true inclination of bottom to horizontal

$$\tan \theta = \frac{1}{1.1K} \tan \varphi$$

$$\text{or } \theta = \underline{\tan^{-1} \frac{\tan \varphi}{1.1K}}$$

giving the bottom inclination in terms of inclination of record and speed of ship.

Of the two methods of correction mentioned above, (a) is referred to in the text as Method I and (b) as Method II. Method II is, however, the simpler, and for logical reasons will be dealt with first.

#### Method II.

From the geometrical properties of Fig. 17A :

Angle  $BXD = \theta$ . Hence true depth  $d = d_e \sec \theta$

and correction = 100 ( $\sec \theta - 1$ ) %, where  $\theta = \tan^{-1} \frac{\tan \varphi}{1.1K}$

giving true depth in terms of echo depth, inclination of record trace and speed of ship, as shown in the curves of Fig. 18.

NOTE. — This correction will only be accurate when the inclination of the bottom is constant between the points  $D$  and  $B$  (Fig. 17A). A proviso must, therefore, be added to the above correction, to the effect that the inclination of the record contour must continue uniform for a distance corresponding to  $DB$  on the record.

$$\begin{aligned}
 DB &= d_e \tan \theta \\
 &= 2,000 \tan \theta \text{ yds per 1,000 fm.} \\
 &= \frac{2,000 \tan \theta}{33.8 \times 0.976 \times K} \text{ minute divisions per 1,000 fm.} \\
 &= \frac{60.6 \tan \theta}{K} \\
 &= \frac{60.6 \tan \varphi}{K \times 1.1K} = \frac{55 \tan \varphi}{K^2} \text{ minute divisions per 1,000 fm.}
 \end{aligned}$$

as shown by the dotted curve on Fig. 18.

#### Method I.

This method is to define a point  $X'$  on the record (Figs. 17A & B) at which the echo depth ( $d'_e$ ) will be equal to the true depth at  $X$  ( $d$ ); *i. e.* to find  $XX'$  ( $x$ ) in terms of  $d_e$  and  $\varphi$  such that  $X'B' = XD$ .

It is evident (Fig. 17A) that  $B'$  must lie between  $B$  and  $D$ .

Assume  $B'$  at any intermediate point, and draw  $B'X'$  parallel to  $BX$  to meet the surface at  $X'$ .

Join  $X'D$ .

Then in the right angled triangles  $DXX'$ ,  $DB'X'$ , since  $DX'$  is common, and  $B'X'$  is to be equal to  $DX$ , the triangles are congruent, and  $XX' = DB' = x$ .

$$\text{Now } DB = x + BB' = d_e \tan \theta$$

$$\text{Therefore } BB' = d_e \tan \theta - x.$$

Through  $B'$  draw  $B'Z$  horizontally, to meet  $XB$  produced in  $Z$ .

Then angle  $BB'Z = \theta$ , and, from parallels,  $B'Z = XX' = x$ .

$$\text{Also } BB' = B'Z \cos \theta = x \cos \theta$$

Substituting for  $BB'$  above:

$$x \cos \theta = d_e \tan \theta - x.$$

$$\text{Therefore } x + x \cos \theta = d_e \tan \theta$$

$$\text{or } x = \frac{d_e \tan \theta}{1 + \cos \theta} \text{ (in fathoms)}$$

$$= \frac{2000 \tan \theta}{1 + \cos \theta} \text{ yds per 1,000 fm. } (d_e = 1,000)$$

$$= \frac{2000}{33.8 \times 0.976 K} \cdot \frac{\tan \theta}{1 + \cos \theta} \text{ minute spaces per 1,000 fm.}$$

$$\begin{aligned}
 &= \frac{60.6 \tan \theta}{K(1 + \cos \theta)} \\
 &= \frac{60.6 \tan \varphi}{1.1 K^2 \left[ 1 + \cos \left( \tan^{-1} \frac{\tan \varphi}{1.1 K} \right) \right]} \\
 &= \frac{55 \tan \varphi}{K^2 + K^2 \cos \left( \tan^{-1} \frac{\tan \varphi}{1.1 K} \right)}
 \end{aligned}$$

For small angles (below about  $8^\circ$ ) where  $\cos \theta$  approaches unity, this expression simplifies to

$$\begin{aligned}
 x &= \frac{55 \tan \varphi}{2 K^2} \\
 &\text{or } \frac{27.5 \tan \varphi}{K^2} \text{ minute divisions per 1,000 fm.}
 \end{aligned}$$

The curves of Fig. 18 are plotted to the full formula for the greater angles and speeds.

The requisite extent of uniform gradient in this case is the distance  $B'B$  (Fig. 17A) which is virtually equal to  $x$  and therefore half the distance required by Method II ( $DB$ ). This fact conduces to greater accuracy of correction.

NOTE. — (I) When applying gradient corrections, the corrected depth should always be *greater* than the uncorrected (correction always positive).

(II) These corrections assume that the echo follows the shortest path between ship and bottom, for all values of gradient, and returns from normal surfaces only.

---

#### ADDENDUM.

---

#### *Method III.*

The methods of depth correction described in the above report were both evolved on the assumption that it was desired to convert echo readings to true depth at the point of sounding before transferring to survey chart.

Thus in "Method I" the true depth at a point  $X$  (presumed to correspond to a "fix") is given by the echo-depth reading at the point  $X'$ , on the depth sounding record only. (Only echo-depths can be read on the record).

A third method consists in ascertaining the position of an actual point  $Y$  on the survey chart displaced from the "fix" point  $X$  by a distance  $y$  along the line of soundings, at which the true depth is equal to the echo-depth at the point  $X$ .

The diagram of this method (which may be designated Method III) is shown on Fig. 18a. From it the value of  $y$  is derived in terms of inclination of depth record  $\varphi$  and speed of ship in knots ( $K$ ), as follows:—

$$y = \frac{d_e \tan \varphi}{2.2 K} \text{ giving } y \text{ in fm. where } d_e \text{ is in fm.}$$

or  $y = \frac{d_e \tan \varphi}{1.1 K}$  yds, where  $d_e$  is in fm.

Fig. 18a shows a set of curves plotted to this expression giving in yds. per 1,000 fm. in terms of record slope  $\varphi$ , for various speeds of ship.

This expression is an approximation which will not introduce serious error at normal gradients (9 % at 1 in 2). The full expression in terms of echo-depth and bottom-gradient ( $\theta$ ) is:-

$$y = \frac{d_e \tan \theta}{1 + \sec \theta}$$

The approximation consists in putting  $\sec \theta = 1$  for small values of  $\theta$ .

The full expression is indicated on Fig. 18a by the dotted curves.

The displacement  $y$  will always be in the direction of shoaler water along the line of soundings.

---