LIMITS OF ACCURACY OF ECHO SOUNDINGS IN OCEAN REGIONS

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SUMMARY

With the aim of determining the limits of accuracy of echo soundings in ocean regions, we are studying here the following factors : attribution by ocean region of a mean value of sound velocity, directional diagrams of acoustic radiators, measurement of the echo running time, accuracy of the recording of sound impulses. According to observations made at an oceanographic station, the relationship between the depth and the temperature of sea water could be defined approximately, with sufficient accuracy, as being an exponential function. Thus, using an analytic formula, it was possible to carry out rigorously the integrations necessary for calculating the mean sound velocities. The results obtained allowed the determination of sounding errors which could occur at this station owing to the adoption of mean values for ocean regions. At a depth of 5 000 metres the error amounts to about 25 metres. There may occur much greater errors, caused by the directivity of sound vibrators, when echo soundings are carried out over rugged ocean beds. The reasons for the occurrence of faulty soundings are studied. The quantitative investigations made on the accuracy of the echo running time, and the accuracy of the recording of sound impulses, finally led to the conclusion that in numerous cases it is not necessary to use sounding recorders of such a high degree of technical perfection as are available nowadays. The considerable advance in the accuracy of reading sounding records does not justify claiming for the soundings a precision which does not correspond to reality. Certain statements concerning the sounding accuracy have often seemed doubtful because of the inevitable errors already associated with the mere application of the echo sounding method.

Preface

The oceanographic programmes of the International Geophysical Year provided, amongst other important things, for obtaining the best possible results in the exploration of the topography of the ocean bed of navigated sea regions.

Since it is possible to overestimate the efficiency of the echo sounding method, and there is a tendency to seek incompatible precision with this method, the limits of accuracy obtainable with the help of echo sounders in ocean depths are to be more thoroughly investigated, the considerations below being the basis : we exclude from these considerations the study of the influence of the accuracy of the station position on the sounding precision [1] (*).

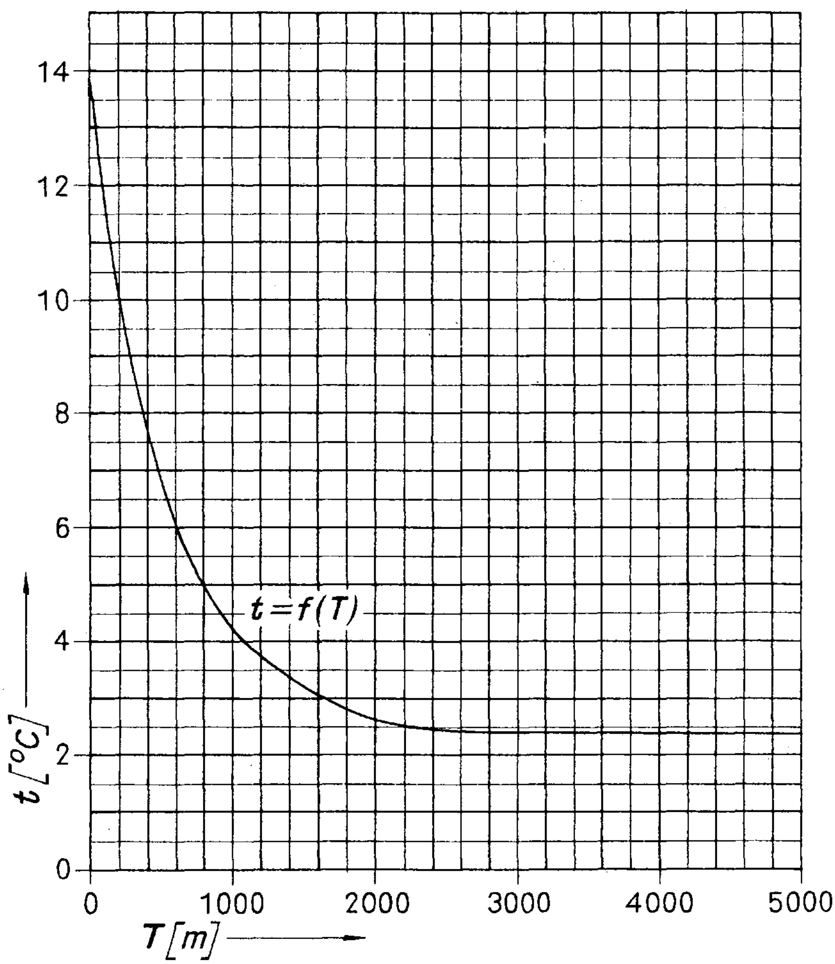

FIG. 1

(*) The figures between square brackets refer to the bibliography at the end of the article.

Influence of the regional generalization of the mean values of sound velocity

In applying echo soundings to oceanic depths, it is of first importance to be able to use the exact mean values of sound velocity in sea water as a basis for the determination of depths. In order to find out the mean values, we calculated them for a definite ship position, and we chose for that purpose an oceanographic observation station north-west of the Azores at 44° 27′ N, 40° 57′ W, carried out by the survey and research vessel *Gauss* of the German Hydrographic Institute. We thus obtained the relationship between the temperature t[°C] and the depth T[m] (figure 1). The curve of the test points could be approximated with sufficient accuracy by an exponential function. According to this curve, the temperatures decrease from about 14°C at the ocean surface to 2.32° at a depth of 4 700 metres. Figure 2 represents, as obtained from the exact measurements [2],

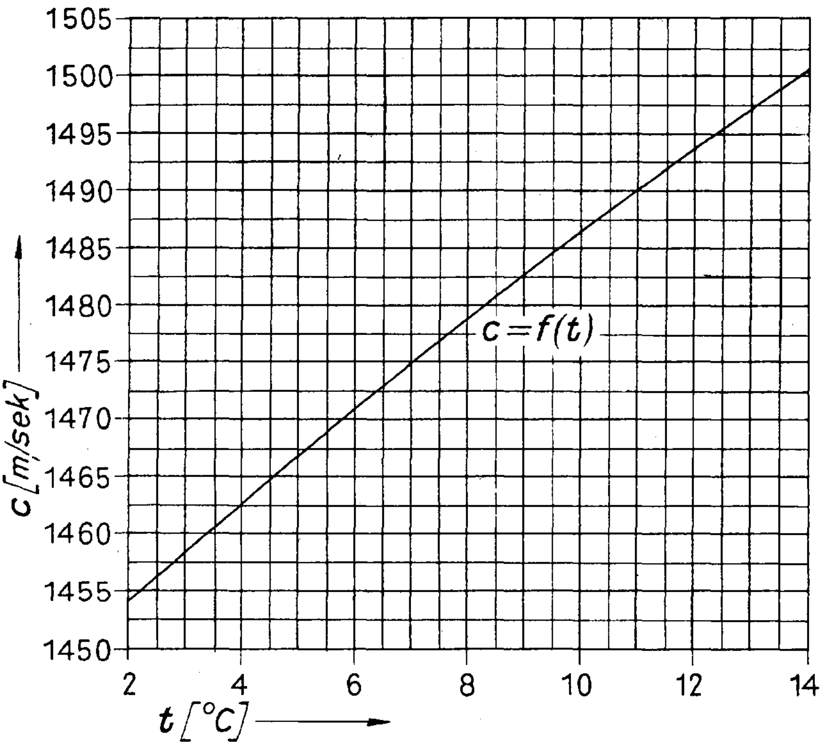

FIG. 2. — Relationship between sound velocity c in sea water ($\sigma = 35\ ^0/_{00}$) and the water temperature.

the relationship existing between sound velocity c (water salinity $\sigma = 35\ ^0/_{00}$) and the water temperature t, and shows that c increases proportionally with the temperature. If it is eliminated in the two equations represented by the curves in figures 1 and 2, we obtain the expression of the sound velocity c_t as a function of depth T. The curve of this expression is given in figure 3. We also see that the temperature and the sound velocity decrease when the depth increases. The relation $c_t = f(T)$ is an exponential function

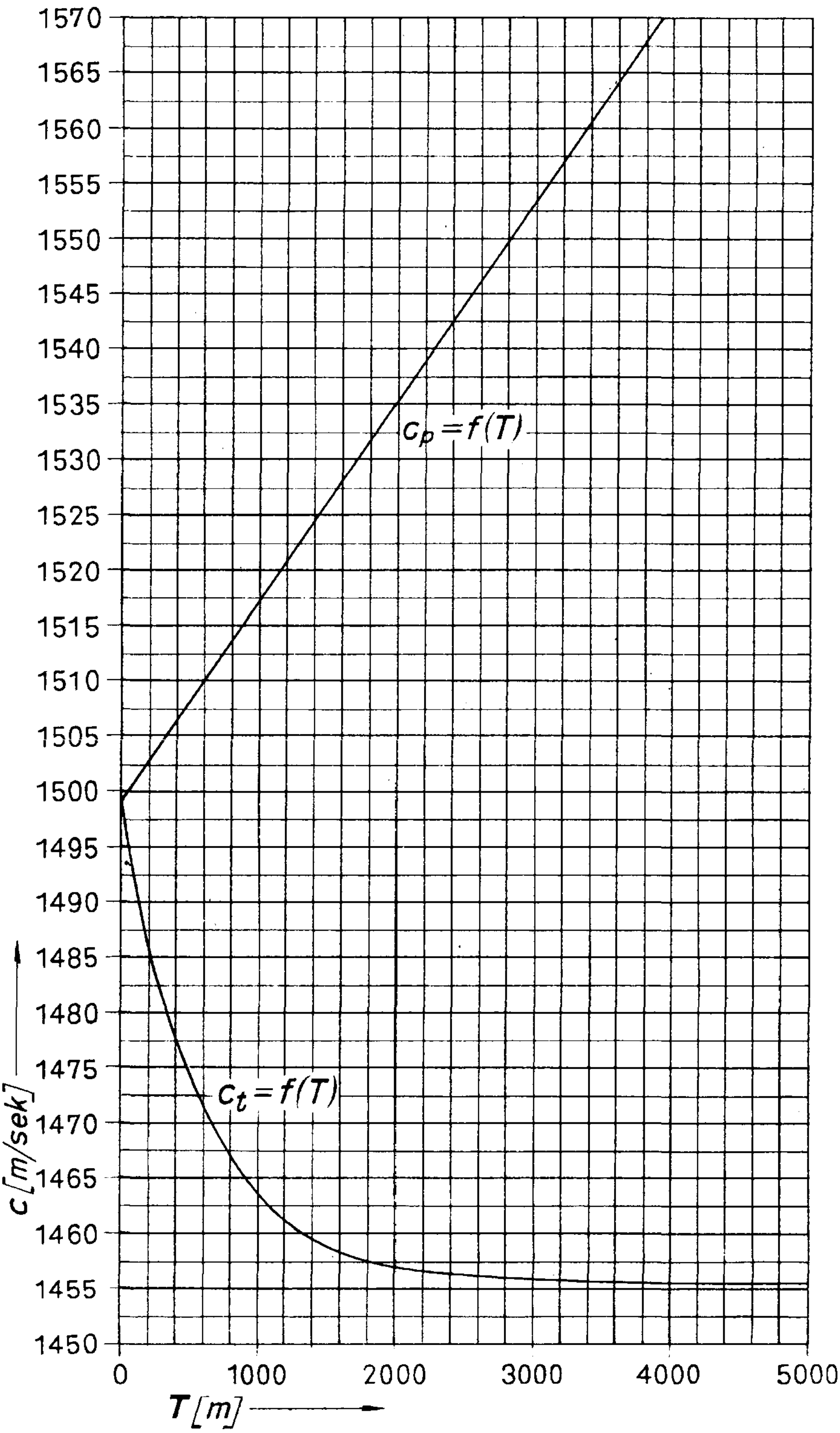

FIG. 3. — Course of components c_t and c_p of sound velocity as a function of depth T.

of the form $c_t = a + b \cdot e^{-nT}$. With the limit conditions $T = 0$ and $T = \infty$ (to which the value $T = 5\,000$ already coresponds) and $c_t = a + \frac{b}{e}$ for $T = \frac{1}{n}$, we get the numerical values of the constants a, b, n and the expression becomes :

$$c_t = 1\,455.6 + 43.4 \cdot e^{-1.67\,.\,10^{-3} \cdot T} \tag{1}$$

It will be noticed at the same time that the depth increases, the component c_t of the sound velocity decreases as a result of the temperature decrease, commencing rapidly but continuing more slowly, and finally reaching a lower limit value.

A second component c_p of the sound velocity results from the effect of pressure p which increases proportionately with the water depth. Its influence on the variation of sound velocity is also known exactly [2].

The function $c_p = g(T)$ has the simple form $c_p = u + v^T$; hence the sound velocity c_p increases proportionately with the water depth. After obtaining the numerical values for the constants u and v, the formula becomes :

$$c_p = 1499 + 1.8 \cdot 10^{-2} \cdot T \tag{2}$$

The course of (2) is also demonstrated in figure 3. The influence of the salinity on the sound velocity is very small at the station where observations were taken. The individual values observed only deviate insignificantly : the mean value of 15 test points amounts to $\sigma = 35.07\ ^0/_{00}$. We can therefore ignore the effect of the third component c_σ of the sound velocity in the case in question.

To determine the mean values (figure 3) each of the functions $c_t = f(T)$ and $c_p = g(T)$ should be integrated and divided by T in the interval of the limits 0 and T, which gives :

$$\begin{aligned} M_{c_t} &= \frac{1}{T} \int_0^T (a + b \cdot e^{-nT})\, dT \\ M_{c_p} &= \frac{1}{T} \int_0^T (u + vT)\, dT \end{aligned} \tag{3}$$

Then the mean value M_c of the sound velocity for a depth T must be formed from mean values M_{c_t} and M_{c_p}, which gives :

$$M_c = \frac{1}{2}(M_{c_t} + M_{c_p}) = \frac{1}{2T} \int_0^T \frac{1}{2} (u + vT + a + b \cdot e^{-nT})\, dT \tag{4}$$

The upper integration limit T always corresponds to that depth for which the mean value M_c of the sound velocity must be calculated. The result of the integration is :

$$\begin{aligned} M_c &= \frac{1}{2T} \left[uT + \frac{v}{2} T^2 + aT - \frac{b}{n} \cdot e^{-nT} \right]_0^T \\ &= \frac{a+u}{2} + \frac{v}{4} T + \frac{b}{2n\,T} (1 - e^{-nT}) \\ &= 1477.3 + 4.5 \cdot 10^{-3}\, T + \frac{12994}{T} (1 - e^{-1.67 \cdot 10^{-3} \cdot T}) \end{aligned} \tag{5}$$

The results are given in Table 1 (*). In these tables, the sound velocities have been computed for every 100 m-depth interval up to 5 000 m.

Table 1 : Mean values of the computed sound velocities as a function M_c (m/s) of the depth T (m) for the ship position 44°27′ N, 40°57′ W.

T [m]	M_c [m/sec]	T [m]	M_c [m/sec]	T [m]	M_c [m/sec]
0	1 499.00	1 700	1 492.15	3 400	1 496.41
100	1 497.73	1 800	1 492.26	3 500	1 496.75
200	1 496.65	1 900	1 492.40	3 600	1 497.10
300	1 495.72	2 000	1 492.57	3 700	1 497.45
400	1 494.93	2 100	1 492.75	3 800	1 497.81
500	1 494.26	2 200	1 492.96	3 900	1 498.18
600	1 493.71	2 300	1 493.18	4 000	1 498.54
700	1 493.25	2 400	1 493.42	4 100	1 498.92
800	1 492.87	2 500	1 493.67	4 200	1 499.29
900	1 492.58	2 600	1 493.93	4 300	1 499.67
1 000	1 492.35	2 700	1 494.21	4 400	1 500.05
1 100	1 492.18	2 800	1 494.50	4 500	1 500.44
1 200	1 492.07	2 900	1 494.80	4 600	1 500.82
1 300	1 492.01	3 000	1 495.10	4 700	1 501.21
1 400	1 491.99	3 100	1 495.42	4 800	1 501.61
1 500	1 492.01	3 200	1 495.74	4 900	1 502.00
1 600	1 492.06	3 300	1 496.07	5 000	1 502.40

In figure 4 the composed curve indicates the course of the resulting mean sound velocity M_c given by the table as a function of depth T.

The depth recorded on the echo sounder at the investigated station amounted to 4 770 m and the equipment was adjusted for a sound velocity of 1 500 m/sec. The curve in figure 4 supplies for this depth a mean value $M_c = 1\,501.5$ m/sec. As a result of the small deviation of this value from the calibration velocity, there is a slight depth compensation of 4.8 m, so that the reduced depth value of the station is T = 4 778 m.

Whilst taking a series of echo soundings in ocean regions, it is absolutely impossible to determine before each sounding the mean value of sound velocity corresponding to the ship's position and to the echo depth registered, because of the loss of time. It is therefore necessary to attribute a mean value to each region when correcting the compensating sound values obtained, as was for instance done when using the tables by MATTHEWS [2], which were carefully compiled from numerous test results

(*) I am especially grateful to Dr. K. MUNKELT for the trouble he took in computing the mean values.

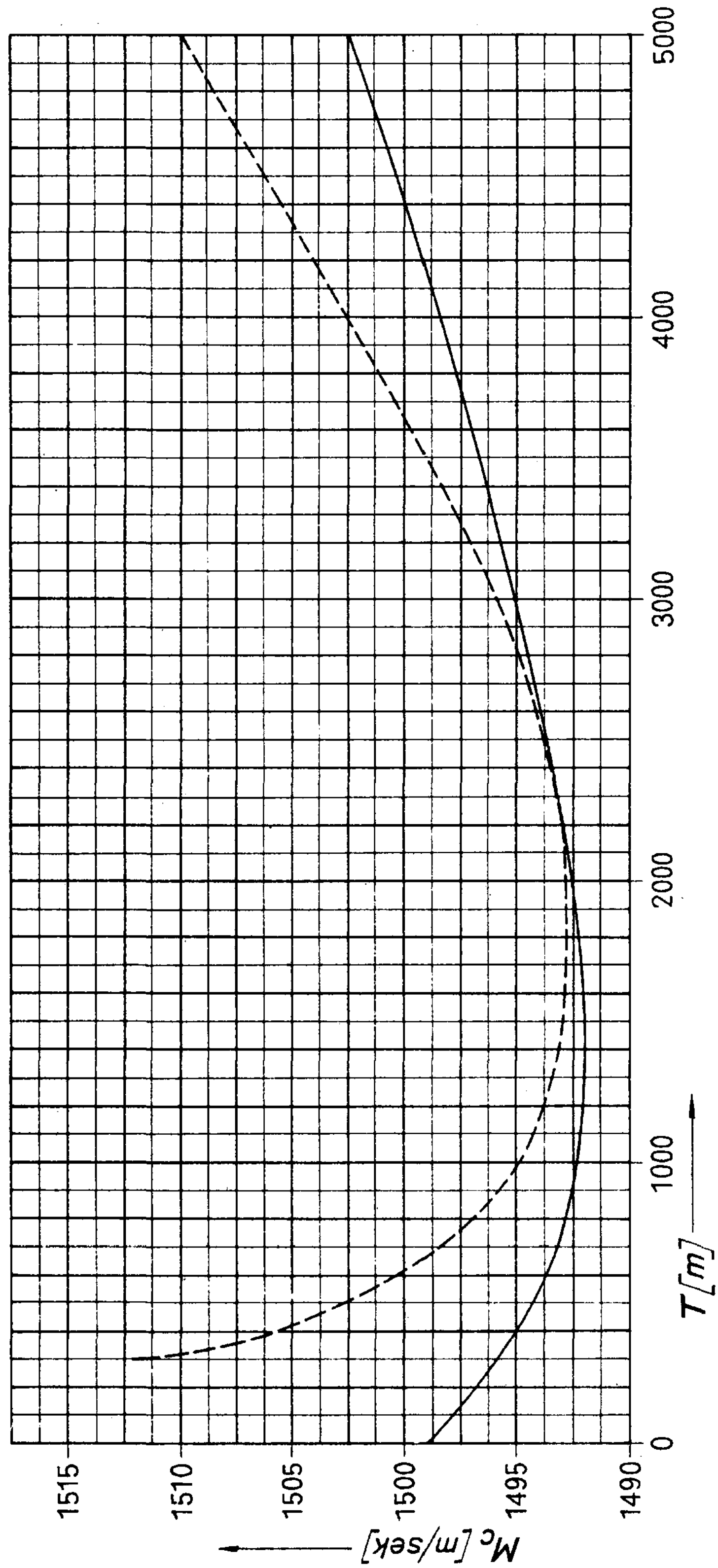

FIG. 4. — Course of mean resulting sound velocity M_c as a function of depth T.

for 52 different ocean sections. There is no doubt that this is the only method, when generally applied, which presents the possibility of obtaining relatively accurate results, i.e. sounding results comparable with each other, which shows its great value to navigation.

If, however, our concern is to obtain the highest possible accuracy for special tasks, it is advantageous to estimate correctly the rate of the errors which must be expected as a result of such regional generalization. The measurements are compared with the curve of the mean values of sound velocity as a function of the depth, as it results from MATTHEWS' tables for which the station where the observations were taken corresponds to region 9. This curve is indicated in figure 4 by a dotted line. It is recognised that in depth zones between 1 200 m and 3 200 m the deviations between the mean values of the sound velocity deduced from MATTHEWS' tables and those determined precisely for individual stations are relatively small, whereas they can reach considerably higher rates in small and larger depths. These differences in the mean sounding velocity Δc and the sounding error ΔT which result are given in table 2 as a function of the depth T :

Table 2 : Differences Δc in mean sound velocities and resulting sound errors ΔT as a function of the depth T.

T [m]	Δc [m/sec]	ΔT [m]	T [m]	Δc [m/sec]	ΔT [m]	T [m]	Δc [m/sec]	ΔT [m]
300	16.28	3.27	1 900	0.45	0.40	3 500	2.25	5.26
400	11.07	2.96	2 000	0.43	0.20	3 600	2.90	6.20
500	8.74	2.92	2 100	0.25	0.20	3 700	2.90	7.17
600	8.29	2.73	2 200	0.04	0.06	3 800	3.19	8.09
700	5.15	2.41	2 300	0.07	0.11	3 900	3.67	9.55
800	4.13	2.21	2 400	0.08	0.13	4 000	4.46	10.80
900	3.27	1.97	2 500	0.08	0.13	4 100	4.38	11.98
1 000	2.65	1.78	2 600	0.27	0.20	4 200	4.81	13.47
1 100	2.12	1.56	2 700	0.29	0.52	4 300	5.13	14.71
1 200	1.93	1.40	2 800	0.50	0.70	4 400	5.35	15.69
1 300	1.49	1.30	2 900	0.50	0.97	4 500	5.71	17.12
1 400	1.01	1.95	3 000	0.90	1.41	4 600	6.18	18.94
1 500	0.99	1.00	3 100	0.93	1.93	4 700	6.44	20.16
1 600	0.94	0.81	3 200	1.26	2.70	4 800	6.79	21.70
1 700	0.70	0.60	3 300	1.53	3.37	4 900	7.15	23.33
1 800	0.74	0.50	3 400	1.59	4.10	5 000	7.50	24.96

In figure 5 are demonstrated the absolute errors (drawn curve and ordinates) obtained between the depths of 300 m and 5 000 m, as well as the course of the error (dotted curve and ordinates). Whilst the relative error is largest in smaller depths (1 %), from 1 $^0/_{00}$ at 1 300 m, zero at 2 200 m and again 1 $^0/_{00}$ at 3 300 m, reaching 5 $^0/_{00}$ at 5 000 m, the absolute

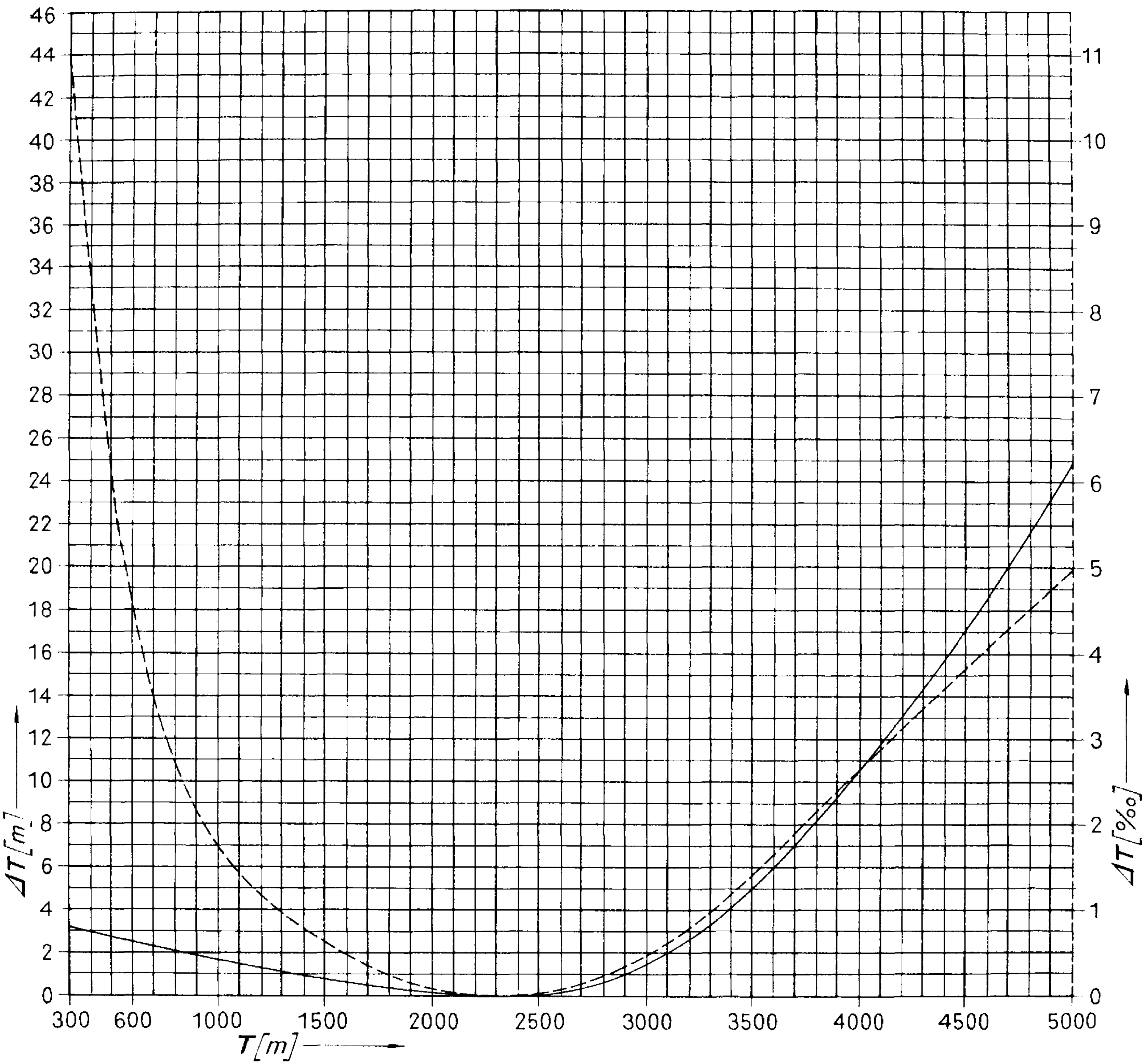

FIG. 5. — Absolute sounding error ΔT(m) (drawn curve and ordinate) and percentage sounding error ΔT[‰] (dotted curve and ordinate) as a function of depth T.

error after decreasing from 3 m to 0 between the depth value 300 and 2 200 m increases slowly at first and then more rapidly, reaching 25 m at a depth of 5 000 m. It will be noticed that the regional generalization of the mean values of sound velocity already leads, at smaller percentage errors, to greater absolute errors in regions of greater depths. These errors could only be discovered if accurate determinations of the mean value of sounding velocity were carried out at the sounding stations. This fact should not be omitted, and therefore too much importance should not be attached to data of an exaggerated accuracy, to which the considerable advance in precision recently achieved with modern recording devices could lead. It should also be noted that more and more authors are critically inspecting the results obtained by taking oceanic echo soundings concerning possible maximal errors [3-6].

Influence of directional diagrams of acoustic radiators and receivers employed for echo sounding

The familiar echo sounding technique is without exception based on the application of audio frequencies (for instance $f = 3$ kc/s, $\lambda = 50$ cm), with which a satisfactory sounding of ocean depths was possible for the first time. Since the dimension of the sound vibrators had to be kept small in comparison with the wave length, it was impossible, for reasons of construction, to achieve a sound directivity. Furthermore, one essential disadvantage had to be accepted : only those echo intervals which gave too small values, as in trenches and on slopes, could be measured. In several cases a useful analysis of the echograms was altogether impossible because any object which was close to the vibrator produced echos. It was therefore of great importance to obtain a method that secured a regular sound projection and reception, when piozo-electric, and later magneto-structive ways of producing vibrations were introduced. The registration then guaranteed a higher approximation in depth measurements. At the same time, reflection regulation led to a concentration of the sound energy by which, on the one hand, the expenses for the sounding recorders could be kept within acceptable limits and, on the other hand, the sounding of greater depths was secured [7]. When selecting the frequency, attention should be paid to the fact that the use of extremely high ultra-sonic frequencies is not possible, as the absorption of the sound energy rapidly increases along with the frequency in ocean water (depth loss) : the absorption is of 5 - 10 db/km for frequencies of 20 to 30 kHz, and of 30 to 40 db/km for frequencies of 100 kHz. It signifies that the sound amplitude decreases to 56 % of its original value at 5 db per kilometre of track. The decrease amounts at 10 db to 32 % per kilometre, at 30 db to 3.2 % and at 40 db to 1 %. Furthermore, another result of the extreme concentration of sound energy would be that because of the ship's rolling in heavy seas, the echoes would frequently not return to the ship at all, due to geometrical reasons.

An extreme concentration of sound energy could also be a disadvantage at abrupt angles of slopes. Since the dimensions of the reflecting surface are large compared with the length of sound waves, quasi-optical reflections take place, so that the sound energy, when reflected, is either weakened considerably and therefore unable to reach the receiving vibrator with sufficient amplitude, or else for geometrical reasons it is not reflected to the receiving vibrator.

Observations of this kind were frequently carried out by the author when taking a series of soundings during the German North-Atlantic Expedition of 1938 in the Azores Archipelago with a 30 kHz sound recorder. In all those cases, depth determinations could only be made with echo sounders.

After revising various cases, we have eventually considered as the most convenient compromise between the price of equipment and the acceptable loss of attenuation for the echo, the use of frequency 12 kHz with a width equal to half the value of the vibrator characteristic of 22°, and a projection capacity of about 1.5 kw supplied by a valve generator [8]. The sounding device thus obtained had secured a reliable registration of bottom echoes of already examined ocean depths (about 5 000 m), and satisfied all conditions to allow the sounding duties to be carried out, with which the research vessel *Gauss* was entrusted on its two cruises in the North Atlantic Ocean during the International Geophysical Year.

We shall now investigate the influence of directional diagrams of sound vibrators on the accuracy of recording. Knowledge of the distribution of sound energy is therefore of great importance. The sounding projection takes place fundamentally within a cone directed downwards [9], its axis forming the vibration area. Its summit is situated at the point of intersection of the diagonals of the sounding diaphragm.

The rate of concentration of the sounding energy is indicated by a directional factor F. For a rectangular diaphragm it is given by the formula :

$$F = \frac{\sin\left(\frac{a\pi}{\lambda}\cos\alpha\right)\sin\left(\frac{b\pi}{\lambda}\cos\beta\right)}{\frac{a\pi}{\lambda}\cos\alpha\,\frac{b\pi}{\lambda}\cos\beta} \qquad (6)$$

The lateral length of our approximately square sounding transducers amounted to : $a = 21.5$ cm and $b = 22.5$ cm; the sounding wave length of 12 kHz was in ocean water : $\lambda = 12.5$ cm. The angles α and β represent the directional angles of a straight line meeting the geometric centre of the vibrator at a point P anywhere within a rectangular coordinating system. The directional diagram computed with these numerical values is equal for both projection and reception vibrators. Since direction characteristics at the projection and the reception take part in producing the sounding record, a directional diagram should be obtained by making for each azimuth the product of the directional curve data for the projection and the reception. Its course is given in figure 6.

Half the maximum intensity which corresponds to an amplitude inclination of 3 db as compared with the maximum value, amounts to 22° while individual characteristics still indicate 30°. As a result of the effect of the vibrator characteristic on the projection and reception side, numerous echoes of the same projection impulses must develop, the transit times of which vary considerably. The shortest transit time is that of an echo of a sounding wave which moves in the direction of the cone axis of the vibration projector, i.e. vertically downwards. The minimum depth registered with this echo corresponds to the genuine depth below the ship on a horizontal ocean bed. There are in addition various echoes with transit times which increase at the same rate as the angle between the departing sound beam and the axis of the vibrator diagram increases. The marginal beams, running along the convex surface of the transducer-projector cone

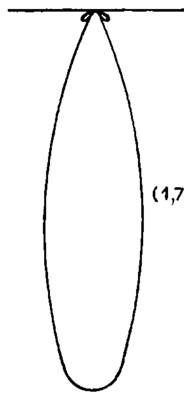

Fig. 6. — Directional diagram of a square magnetostrictive vibrator 22 × 22 cm for the frequency of 12 Kc/s.

correspond to the longest transit time and supply the last echoes. As a result of these considerations, which were proved by quantitative investigations on echo soundings with magnetostrictive transducers, let us keep in mind that a *single* sounding impulse, within a specified interval of time defined by corresponding investigation conditions, continually produces sounding echoes which are joined continuously when registered. The track which corresponds to this interval of time was called by the author *Echolänge* (echo length) [10]. We shall now examine how much importance is to be attached to the *Echolängen* when registering soundings, and which are the precision limits which must be deducted for the evaluation of echograms. Figure 7 illustrates an echogram of one section of the deep sea bottom in the Bay of Biscay.

The horizontal course of the sharply marked depth line is regarded as the upper limit. (The interfering echoes seen occasionally in the figure arise from a second sounding device operating at the same time, and are of no interest to us). In accordance with the slow decrease of intensity of the directional diagram (figure 6), the blackening of the registration below the depth line becomes lighter, then appears in the form of fringes, until eventually it disappears owing to the limitation of the sounding capacity by the actual projector cone. The range of the soundings in figure 7 is from 2 400 to 6 000 m. The sea bed is at a depth of 4 650 m below the ocean surface. The recognizable echo length measured is approximately 100 m. Hence the angle α of the normal and marginal beams is such that cos $\alpha = 4\,650/4\,750 = 0.979$, thus $\alpha = 11°40'$. In the case of our registrations we have to make the calculations with effective cone apertures which practically

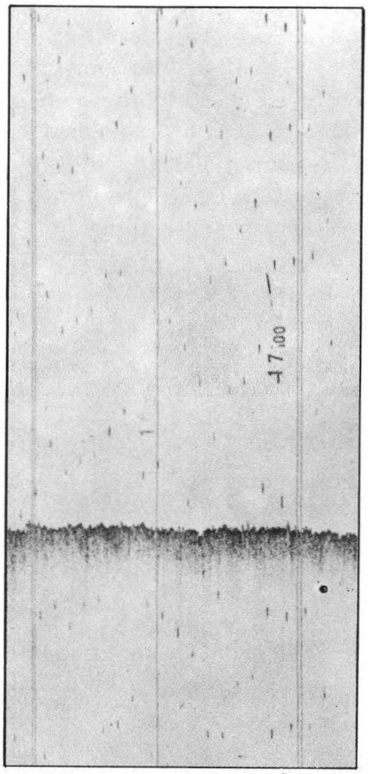

FIG. 7. — Echogram of the deep-sea floor in the Bay of Biscay (4 650 m).

correspond to half the maximum intensity of the diagram experimentally obtained for the transducer.

Since there exists no physical possibility of suppressing the effect of directional diagrams of transducers during soundings, a registration of genuine depths can only be expected if the ocean bottom is horizontal. We can, however, as has been done several times [11-13], investigate schematically the effect of specific, relatively plain configurations of the bottom profile on the variations of echo depths and determine for such cases the resulting deviations. The problem is to know what use such studies will have in practice for the improvement of registered echo soundings. Nothing is known about the possibly manifold topographic conditions at various sounding stations, particularly in the case of deep sea soundings. It would be a vicious circle, to use unknown bottom topography to apply sounding corrections, which are a function of this topography. Furthermore, we have to consider that, because of the three-dimensional extension of the directional diagram when there is an irregular bottom such as trenches, etc., the echo station neither has to be under the ship, nor within the vertical plane of the ship's course, but can be found in any direction inside the effective sounding cone. It is also possible that several echo stations reflect echoes at the same time, which combine and give a sum effect in the registration. The reflection conditions are considerably improved nowadays as compared with the time when sound frequency

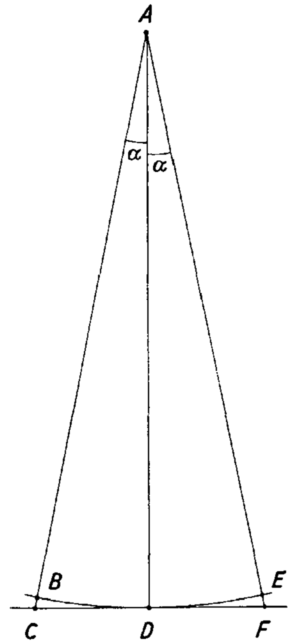

FIG. 8. — Effective area of the directional diagram in the vertical plane of the ship's course for horizontal deep-sea floors, corresponding to figure 7.

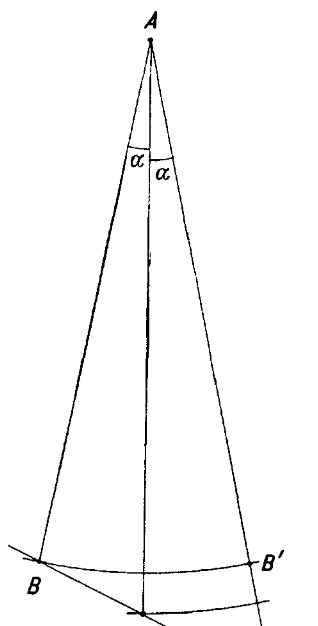

FIG. 9
Influence of a slope on the illustration and echo length.

echo sounders were used. In the case of uncontrolled sounding projection and reception, sounding beams could only be reflected if the reflection were genuine, i.e. in a vertical direction : only normals of the ocean floor could register themselves [14]. On the other hand, at ultra-sonic frequencies, the concentration of sound energy achieved by the directional effect of the transducers can already accomplish a sound recording as a result of a *diffuse* reflection. The registration of soundings has now become a problem with many more aspects.

In order to arrive at a conclusion as to which criterium exists for producing errors in echo soundings in the case of rugged ocean floors, let us go back to the conditions in figure 7 which are indicated schematically in the vertical plane of the ship's course. A represents the ship's position on the ocean surface; the aperture angle 2 α shows the area covered by the cone of sound rays ($\alpha = 11°40'$), AD = AB corresponds to the genuine depth T = 4 650 m and BC = 100 m is the length of the echo obtained, which illustrates the differences between the lengths of marginal beam AC, running along the convex surface, and centre beam AD running along the cone axis. As tg α = CD/AD, radius CD of the circle having point D as centre is equal to 963 m. From this it follows that, in the case in question, an area of about 3 km^2 is struck by the sound energy.

If the intersection is rotated, as it is in figure 8 around the cone axis, the circular arc BDE which touches the ocean floor at point D produces a spherical cup. All the bottom peaks which are inside this spherical cup give rise to incorrect soundings.

The maximum peak produces the minimum sounding. It should be noted that, within a range of about 1 km around the sounding point, bottom peaks smaller than the echo length, i.e. 100 m, can produce incorrect soundings. Bottom slopes of less than 10 % are already sufficient for this purpose.

In figure 9 the effect of a greater slope (slope angle 30°), which is assumed to be on the ship's course, can be seen. In this case too small a depth is obtained on account of the marginal beam AB, while the genuine depth AD is hidden in the region of the echo length B' C.

The considerable increase in the length of the echo produced by the steep slope should be noted, as when it is compared with one coming from a horizontal ocean floor (figure 8), it is nine times greater. An increase in the echo length in the course of registering depth profiles, therefore, always indicates faulty soundings.

The rate of the sounding error thus produced will be more thoroughly investigated by means of an echogram (see figure 10). This echogram represents a section of the North Atlantic Ridge with depths up to 4 650 m and a maximum point rising up to a depth of 2 900 m. The increase (ordinate) indicated on the right-hand side of the figure corresponds to the track of the ship of 15.3 km (abscissa). The maximum slope increase reaches from 2 320 to 2 900 m. Hence we have $r = 481$ m and $l = 50$ m (referring to a horizontal floor). An elementary geometric construction, analogous to the one in figure 9, and made with the help of the data from the foot of the marginal beam, gives for an increase of 31.2 % of radius r an ordinate 150 m long. From the end point of the latter, and from the

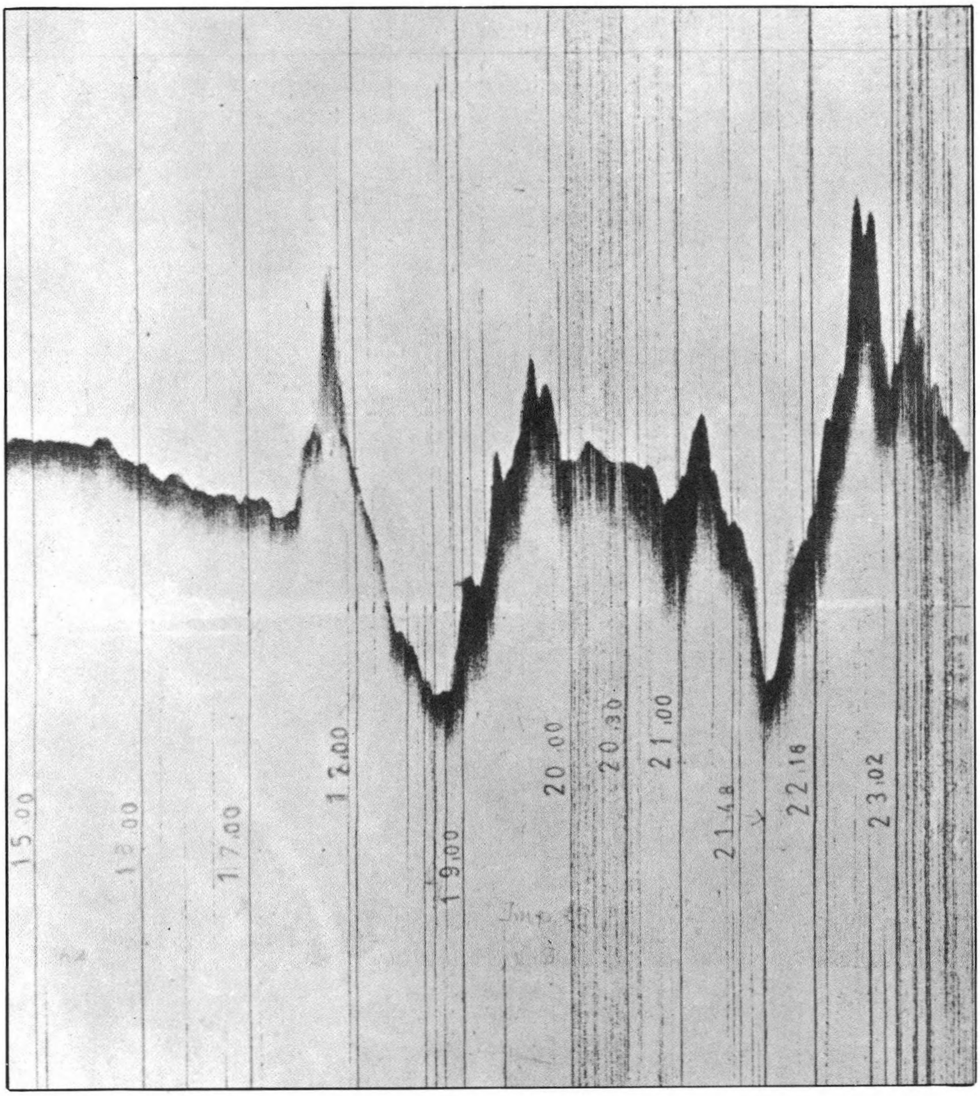

Fig. 10. — Section of echogram of the North Atlantic Ridge with depths of 4 650 m and a maximum peak of 2 900 m.

lowest point of the axis beam, is determined the direction of the slope line. Knowing the slope enables the numerical determination of the echo length which is six times greater ($l = 300$ m) and hence the depth value which is about 100 m too small. Thus it follows that errors of several per cent of the depth (approximately 4 % in our case) can occur for larger slope angles. The accuracy obtained for the error is confirmed by the echo length which corresponds satisfactorily to the value obtained $l = 300$ m given in figure 10 for a depth of 2 320 m. In the case in question, the estimation of the correction is fairly reliable because the depth profile is distinct enough. When the bottom characteristics vary considerably, it frequently happens that the profiles fade from the echogram by overlapping, so that estimations of error are no longer possible. Figure 11 represents an example of this in a section of the continental slope in the Bay of Biscay. Since within the area to be investigated, in the case of sufficient reflection conditions, longitudinal and lateral cracks and remote peaks are included numerically in the measurements, it is not possible to separate these peaks or to place them in direction or position.

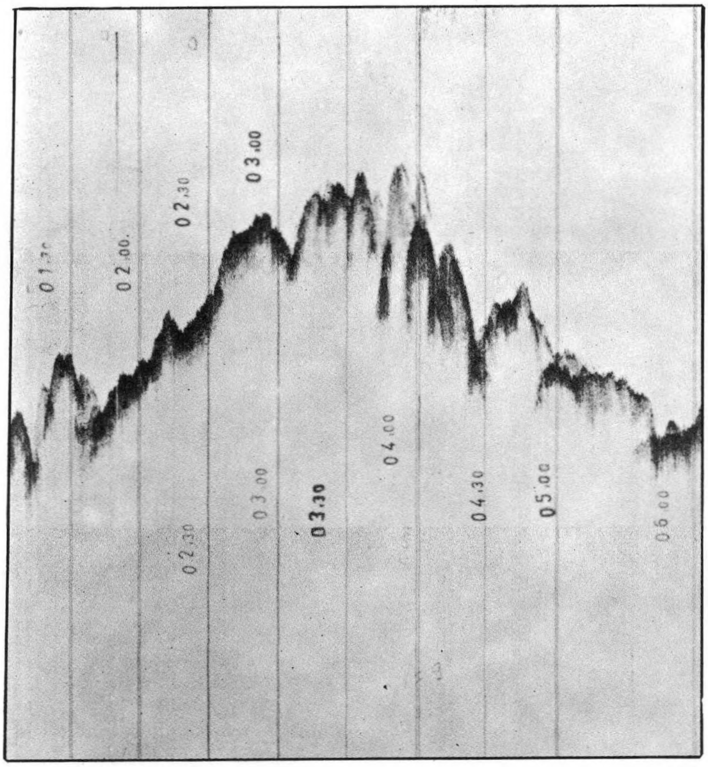

FIG. 11. — Section of echogram of the continental slope in the Bay of Biscay.

The apparent resulting accuracy given by the whole of the equipment is greater than the reading accuracy of the echograms obtained which can be estimated at 0.5 mm. Concerning the accuracy of the registration obtained with the instrument manufactured by Electroacustic of Kiel, it may be noted that : the sounding recorder possesses the following eight ranges which overlap each other : 0/900 m, 600/1 500 m, 0/1 800 m, 1 200/3 000 m, 2 400/6 000 m, 0/7 200 m and 4 800/12 000 m. The paper width available for the registration is 180 mm. For the range of 0 to 900 m a depth of 2.5 m corresponds therefore to a paper width of 0.5 mm. For the range of 2 400/6 000 m for the same width is obtained a depth of 10 m, a value which should be regarded as completely sufficient, considering the rate of the sounding errors. There are, of course, no technical difficulties when decreasing uniformly all depths to ranges of 730 m (400 *fathoms*) for example, and when increasing at the same time the paper width of the recording instrument to 480 mm, as it was done with the Precision Depth

Recorder 16 of the Times Facsimile Corporation, New York. It is merely a question of expense. In any case, it would be necessary to examine the very high registration accuracy of ± 1 *fathom*, being ± 1.83 m, thus obtained (it is obtained from a synchronometer fed by a tuning-fork generator which guides the recorder) can be useful, knowing the errors which develop from the application of the sounding method. If, in addition, we take into account the error in the determination of the sounding position, as well as the influence of swells and heavy seas, it is deceptive to try and obtain an accuracy of ± 1 *fathom* in the registration of soundings.

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