METHODS OF ECHO SOUNDING AND THE PRINCIPAL RESULTS OBTAINED.

by

PER COLLINDER.

(Extract from the *Svensk Geografisk Arsbok* 1933 published by the "Sydsvenska Geografiska Sällskapet").

FORMER METHODS OF MEASURING DEPTH.

Actually the idea of using sound to determine distances seems to have been conceived about a century ago, but it is only thanks to the accurate theories developed by the French physicist Jean-François ARAGO at the beginning of the XIX century and by the American seaman and meteorologist Matthew Fontaine MAURY towards the middle of the same century, that it has become possible, in our time, to attain the first practical methods developed by the detailed application of electro-acoustic theory.

It may be as well, perhaps, to recall that the oldest methods of depth measurement known to us are the same as those generally used by our modern vessels. In an admirable narrative of a voyage, to be found in the *Acts of the Apostles*, chapter 27, ST. PAUL clearly mentions the use of sounding in navigation; the historian HERODOTUS, five hundred years earlier, was even more explicit: "When eleven fathoms is found, with mud on the lead, one is a day's run from the coast"; this was his rule for approaching Alexandria.

The sounding appliance used thoughout these two thousand five hundred years was undoubtedly the sounding lead, probably of metal, lowered on the end of a line which was marked beforehand or else measured after the sounding as our fishermen do. The sole important improvement made at the beginning of the present century was the use by the British physicist Lord KELVIN of a tube lowered to the bottom; the tube registered the pressure, from which the depth could afterwards be calculated. This device, called the THOMSON sounding machine, enabled soundings to be taken from the ship at full speed down to about 200 metres (110 fms.), but its use was relatively costly.

A hundred or 150 years before that, seamen had already decided that this depth of about 200 metres roughly marked one of the most important nautical and geophysical limits, namely the limit between the continent and the ocean. Sounding was troublesome at greater depths, owing to the facts that it became harder and harder to detect the instant when the lead touched the bottom, that it was not easy to keep the ship sufficiently stationary, and furthermore that the bottom generally starts to drop sharply towards the depths from beyond this limit. Here begins the "blue water" of the great sailing ships, beyond which it was only possible to navigate by means of the compass and the stars, until they reached the 100-fathom line which is the beginning of the region they called "the soundings", known by modern oceanographers as "the shelf".

The deep blue water was said to be unfathomable but it happened at the beginning and in the middle of the XIX century that some hardy explorers tried to sound the oceans. Thus in 1852 the British warship *Herald*, Captain DENHAM, took a sounding of 7,660 fathoms in lat. 36°49' S., long. 37°6' W., where recent soundings have only given 5,000 metres (2,734 fms.). The discrepancy is due, without a doubt, to a failure to observe the exact instant when the lead touched the bottom, owing to the line continuing to run out under the action of horizontal marine currents. A pioneer in this domain, as already stated, was Matthew Fontaine MAURY, the founder of oceanography and marine meteorology. With his collaborators he developed accurate methods, towards 1850, by means of which it has been possible to verify that the greatest depths of the Atlantic Ocean are, in general, between 5,000 and 6,000 metres (2,700 and 3,300 fms.).

In the latter half of the XIX century, the general depth of the Atlantic Ocean was fairly well known, as was that of certain parts of the other oceans. This was chiefly a result of the efforts necessary for the laying of the great telegraph cables; without this, our knowledge of the great oceanic depths would have remained even more precarious.

An ocean sounding at a depth of 5,000 to 10,000 metres (2,700 to 5,500 fms.) has always been an undertaking, and in bad weather needs a particularly well-trained crew to perform successfully (1). Sometimes also the operation requires long hours, and it is not at all surprising in these conditions that at the beginning of the XIX century well-informed oceanographers gave much attention to finding new aids for the purpose and were inspired, it appears, by the fortunate measurements of depth in the stellar system with which the "organist of Bath", Sir William HERSCHELL, laid the foundation of stellar astronomy.

ORIGIN OF ECHO SOUNDING.

According to the most trustworthy information in our possession, it seems to have been Jean-François ARAGO, whose active genius pervaded the most varied realms of human activity and who was a great friend to the French hydrographic engineers, who in 1807 suggested the use of sound for measuring great depths. The time was not yet ripe; it was only towards the middle of the XIX century that MAURY took up the question anew. In his book, *The Physical Geography of the Sea and its Meteorology*, which went into some twenty editions and which can still be recommended to any geographer interested in the sea, he recounts his unsuccessful attempt as follows:

"By exploding petards, or ringing bells in the deep sea, when the winds were hushed, and all was still, the echo or reverberation from the bottom might, it was held, be heard, and the depth determined from the rate at which sound travels through water. But, though the concussion took place many feet below the surface, echo was silent, and no answer was received from the bottom. ERICSSON and others constructed deep-sea leads having a column of air in them, which, by compression, would show the aqueous pressure... Mr. BAUR, an ingenious mechanician, constructed... a small piece of clockwork for registering the revolutions made by a small propeller during the descent... An old sea-captain proposed a torpedo... One gentleman proposed to use the magnetic telegraph...".

All these attempts failed, but while the question of the geography of the ocean floor was in a fair way to being solved by the use and improvement of the early methods of line sounding, the decade of the Great War saw the technical realisation of the sonic sounding suggested by ARAGO and MAURY.

It is always a delicate matter to make statements on matters of priority, but it seems hardly possible at present to deny that modern sonic sounding was made a practical possibility by the Austro-German physicist, Dr. Alexander BEHM, at Kiel.

Dr. BEHM's investigations in this domain started after the foundering of the *Titanic* on 14th April 1912, as the result of collision with an iceberg. This disaster, which made a great impression in the world, raised the question of assuring communications on the most frequented traffic lanes between Europe and the North of North America against the risks to which the liners are exposed from icebergs coming down from Greenland. These risks are aggravated by the great amount of condensation caused by the bergs when they enter the warm, moist air of the Gulf Stream region off the Newfoundland Banks. While it is possible to avoid these bergs, even at night, in clear weather, there still exists no proved method of ensuring one's safety from them in fog. However, we possess an efficient enough palliative against them in the International Ice Patrol.

If the attempts to determine the approach of an iceberg by means of the submarine echo have failed, they have at least led to the discovery of the acoustic measurement of depths. When in 1912 Dr. BEHM undertook research in this direction, it was not yet known with certainty whether such a thing existed as an echo in water. The reason for this ignorance was very likely due to the fact that over short distances the echo returned too fast to be distinguished from the original sound. It is in this peculiarity that the greatest difficulty resides which remains to be conquered in the method of sounding by echo.

In order to be able to study the translation of sound in water, Dr. BEHM emitted sound in an aquarium, in which he succeeded in photographing the sound waves. He found a well-marked reflection, both from the bottom and sides of the receiver and from the free surface of the water, and even from a much bent metal foil. The size of the

(1) *A description of a sounding of 9,788 m. taken in 1912 by the former research ship* Planet *will be found in Zeitschrift d. Gesellsch. f. Erdkunde, 1927, p. 339.*

aquarium was 27×25×12 cm. (10.64×9.85×4.93 in.), and if we compare these dimensions with the velocity of sound in water (about 1,500 m. — 4,900 ft. — per second), we shall realise the difficulties of the problem Dr. BEHM had to solve. He succeeded in making visible waves which followed each other in the water at an interval of time of 1.5 millionths of a second, and conceived an apparatus for measuring time to this degree of precision.

In echo sounding a lesser degree of precision is sufficient for the measurement of the times. As a rule it is not necessary in sounding for depth that the accuracy should be closer than 1/4 metre. Such a degree of accuracy is only wanted by hydrographers, who, in the course of their survey of the horizontal and vertical co-ordinates of the coastal regions and of the sea, must keep within a limit of error which will not in practice aggravate any error that may be committed in ordinary navigation. They do not, as a rule, carry their precision beyond the point necessary to satisfy the requirements they are working for — but keeping always within the limit of tolerance without which any form of practical-scientific activity would be inconceivable.

For the navigator, as a general rule, an accuracy of one or two metres is sufficient and for a part of echo sounding it is unnecessary to drive things any further than this. We shall look into this question more closely in our examination of types of echo-sounders later on.

Of his pre-war attempts Dr. BEHM himself said, "If I had been able to foresee all these difficulties in their true proportions, I do not believe I should have risked undertaking to solve the problem of sounding by echo. And all the more so if I had known about the numerous fruitless attempts made on the same lines in various parts of the world... To tell the truth, the smoothing out of the difficulties which arose on all sides caused more work than the scientific-technical solution of the problem which forms the foundation of the invention."

When by means of an application with photographic recording, Dr. BEHM had shown in 1912, in Heikendorf Bay near Kiel, that the bottom of the sea could give an echo of sufficient intensity, the road which he had yet to travel was still a long one before the echo sounder became a machine which could be used for geographical, and above all for nautical, needs.

To measure and record the lapses of time with an accuracy of the order of 1/1000 of a second approximately, a choice may be made between various methods. To emit a sound suitable for the object aimed at, three processes are available. Either to use an emitter from which the sound is so piercing that it dominates all the "parasite noises" from the noise of the waves, the engines, and other ship noises; or to use another wave length situated in a different register from the "parasitic sound"; or finally, to introduce the phenomenon of resonance. The latter arises, for instance, when the electric current which sets up the oscillations in the transmitter is of such a frequency that the emitter vibrates with its maximum energy, and that an oscillation has been chosen which will be propagated with as little damping as possible through the layers of water down to a depth of several kilometres. Further, the membrane of the receiver must have its greatest sensitivity in the wave-band intended, and the electric circuit connecting the receiver with the chronograph must have been chosen, within the limits of possibility, for the same frequency. Finally, the element of the chronograph which is sensitive to the pulsations of the echo must be at its maximum sensitivity at the wave-length and for the wave-form intended.

For example, one might take a plank 8 metres long, which would be washed by 2-metre waves. If the plank lies in the direction of propagation of the waves, it will be only slightly affected; while if it is placed parallel to the waves it will rise and fall with each trough or crest of a wave. A plank one metre long would in the first place take up a considerable sea-saw motion for each wave.

By considerations of this nature, the constructor of any echo sounding machine can, up to a point, adapt the properties of the various elements in such a way that they co-operate in the elimination of interfering agencies.

To make the echo usable for navigation, it must have various special peculiarities. It might have been simple enough to take highly accurate measurements in the sacred calm of a scientific observatory. But if the whole observatory were rocked by jerky movements, in a sometimes deafening din; if the observer at times had to use both hands to hold himself in place; and if the existence of the observatory and the life of the observer had to depend in the near future on the results of the observations made; if, further, it happened that important communications reached the observatory from time to time necessitating immediate and weighty decisions of great moment, and if, finally, the endurance of the observer, in such circumstances, gave out and he had to be replaced by someone lacking the instruction necessary for reading the instruments, or whose intelligence was not up to the standard required for the task — one would then approach the conditions in which the echo sounder for navigational use must function without any fatal failure capable of possibly causing the loss of thousands of human lives and an enormous value of goods.

As sound covers an average of 1,500 m. (4,900 ft.) per second — under certain definite conditions a variation of 100 m. (328 ft.) may occur in both directions — the result is that a sound wave emitted at the surface may reach a depth of 750 m. (410 fms.), be reflected from the bottom, return to the surface and be registered as an echo in the space of one second. An error of one metre corresponds to an error of time of 1/750 of a second but, at several hundreds of metres depth, an error even of 10 metres is of no account, at least in the present state of our knowledge of the sea bottom. This represents a tolerance of 1/75 of a second at that depth. A chronographic measurement of this order of magnitude can be effected with a good stop-watch reading hundredths of a second.

In fact — and the author can vouch for this from his own experience — it is possible to obtain perfectly usable oceanic soundings with a stop-watch of this nature, the pair of electro-microphones being immersed in the water and connected by a vacuum-tube amplifier to the head-phones, the source of sound being something like a cartridge ignited by a pocket lamp battery. Anyone wishing to undertake such investigations would be well advised to have a reliable assistant to relieve him during the sounding, for one tires fairly rapidly when manipulating explosives even in relatively small quantities.

There are already a certain number of firms in different countries who manufacture between them more than twenty different types of echo sounders. (1)

THE MOST IMPORTANT ECHO SOUNDING EXPEDITIONS.

Until 1922 it could still be said that echo sounding had not passed the limits of an interesting experiment, though often successful enough. The method of sounding by echo became a practical reality during the summer of 1922, when the U. S. destroyer *Stewart*, having sailed from Newport on 20th June, by way of the Nantucket lightship and the Azores, arrived at Gibraltar on the morning of the 29th, having taken 900 soundings en route at depths varying from 15 to 5,800 metres (8 to 3,171 fms.) (2). Never before had such a dense oceanic profile been made; with the old methods this enterprise would have taken several months and necessitated stops of some days at certain places. On passage the *Stewart* crossed, among others, one of the numerous banks lying off Gibraltar and the North African coast, the Gettysburg Bank. On this bank the U. S. S. *Gettysburg* had found sand and shingle in 1876; the *Stewart's* soundings gave a profile which clearly showed a "coastal" plateau at a depth of about 570 m. (312 fms.).

The astonishment caused in maritime circles by the *Stewart's* performance had hardly died down when, a few months later, one of those well-known "Pilot Charts" appeared (3), representing the first really detailed bathymetrical chart of a region of the continental shelf and continental talus right down to the abyssal depths, made by the destroyers *Hull* and *Corry*.

These echo soundings were intended as a contribution to tectonic geology. They had been taken at the request of the Carnegie Institution of Washington and included the region off San Francisco and the Mexican coast which is very subject to seismological shocks. From the seismological point of view, this bathymetric chart constituted a valuable complement to a chart prepared by the Seismological Society of America of the configuration of the Californian district liable to earthquakes.

---

(1) *The chapter relating to the various types of echo-sounders is not reproduced here.* (I. H. B.).

(2) Hydrographic Review, *Monaco, March* 1923.

(3) Pilot Charts of the North Pacific Ocean. *June* 1923. *Washington, U. S. Hydrographic Office.*

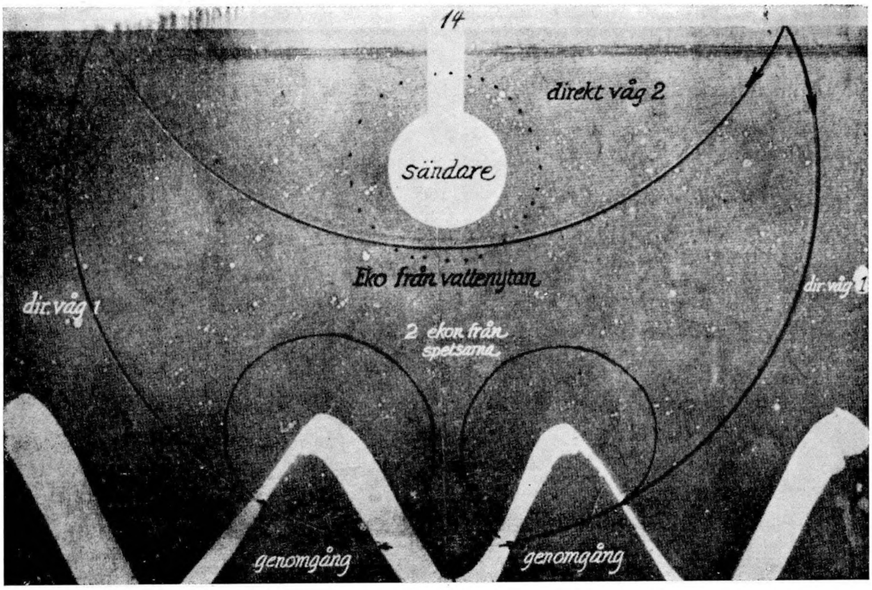

Fig. 1

Dr. Behm's aquarium. Two primary waves concentric with the emitter (sändare), one reflexion downwards from the free surface, and reflexions from two angles of a bent metal foil.

L'aquarium du Dr. Behm. Deux ondes primaires concentriques à l'émetteur (sändare), une réflexion vers le bas provenant de la surface libre, et les réflexions produites par deux angles d'une bande de métal recourbée.

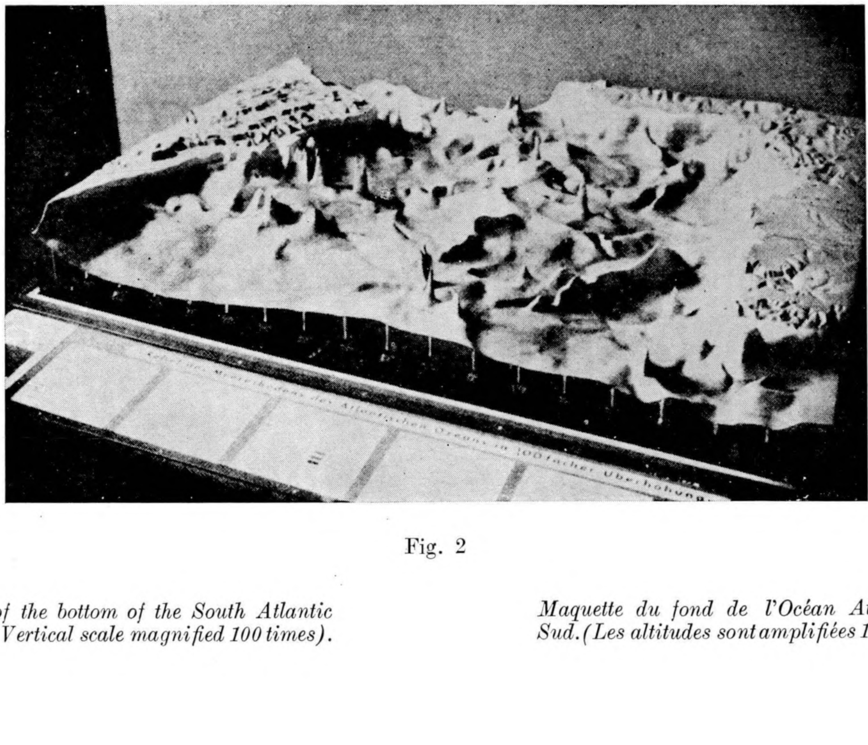

Fig. 2

Model of the bottom of the South Atlantic Ocean. (Vertical scale magnified 100 times).

Maquette du fond de l'Océan Atlantique Sud. (Les altitudes sont amplifiées 100 fois).

Even from the oceanographic point of view, the Californian bathymetric chart was of the greatest interest, for it showed the bottom of the sea to be much more rugged from the coast to the 2,000 fm. line than had previously been shown by the scattered soundings. And this is no peculiarity of that region, as was at first thought. In general the same observation may be made in the various parts of the oceans where close soundings have been taken. This is the case, for example, in the Arctic, where the author has found that the mean gradient, worked out from echo soundings, is directly proportional to the density of the soundings, i. e. the closer the soundings, the more irregular the bottom appears to be. (1)

So far as such conditions prevail, it can be taken as highly probable that the density of the soundings counts for little in providing knowledge of the real configuration.

The machine with which the North American work just described was carried out was made by Dr. H. C. HAYES and is called the SONIC DEPTH-FINDER. It is based on an indirect method of time measurement which reminds one of the British Admiralty Echo Sounder.

The *Meteor* expedition of 1925-27 then came along with its sounding work, the most extensive ever carried out (2). The chief programme of the *Meteor* comprised the study of the South Atlantic from the point of view of the composition of the sea water and the circulation from the surface to the greatest depths. As a matter of fact, the echo sounding was only considered a secondary job. The ship had two echo sounders simultaneously under way during the carrying out of the 14 profiles across the South Atlantic Ocean, and altogether took a total of 67,000 soundings in round numbers.

The results of the *Meteor* soundings generally confirm the results of earlier deep sea soundings. Part of the very important banks and ocean deeps which were already known were thus charted, and it is found, especially from a detailed study of the *Meteor's* profiles and a comparison with older bathymetry, that in the abyssal regions the bottom relief is astonishingly irregular. This is illustrated with particular force by the model of the South Atlantic bottom (Fig. 2) shown at the MUSEUM FÜR MEERESKUNDE at Berlin, which was compiled mainly from the fourteen bottom profiles of the *Meteor*.

Vening MEINESZ, the geophysicist, has for some years been making investigations using a method designed by himself, enabling him to determine the force of gravity near the surface of the oceans by means of a pendulum in a submerged submarine; he has carried out investigations all round the world, but more especially in the Central American zone and in the East Indian Archipelago, where he has also taken echo soundings with an Admiralty machine.

Another important echo sounding expedition was that of the Dutch surveying ship *Willebrord Snellius* which recently carried out a cruise across the East Indian Archipelago and took about 30,000 soundings.

The greatest depth we know of with certainty at the time of writing was accurately taken by means of echo sounding by the German cruiser *Emden*, which in April 1927, when on passage east of the Philippines, sounded the bottom at an unexpected depth, and after zigzagging for some time managed to obtain a depth of 10,790 metres (5,846 fms.) lying in a deep roughly 4 km. (2 ½ miles) square and everywhere more than 10 km. (6 1/4 miles) in depth. (3)

In our immediate neighbourhood there exists one of the greatest enclosed maritime areas which have been completely charted by echo sounding, the Gulf of Bothnia (4). This work was carried out under the direction of Dr. RENQVIST of the Finnish HAVSFORSKNINGSINSTITUT 'Oceanographic Institute), using a British Admiralty machine.

---

(1) Geografiska Annaler, *Stockholm*, 1930, *pp*. 193-214.
Teknisk Tidskrift, *Stockholm*, 1932, *pp*. 57-62.

(2) Die Meteor-Fahrt, Forschungen und Ergebnisse der Deutschen Atlantischen Expedition 1925-1927. *By F. Spiess, Berlin*, 1928.

(3) Die Emden-Tiefe. *By H. Maurer*. Zeitschr. d. Ges. f. Erdk. *Berlin* 1928, *p*. 248.

(4) Bathymetric Chart of the Bothnian Bay and the North Kvark *by Henrik Renqvist*. Fennia 52 *nr*. 6, *Helsingsfors* 1930.

ECHO SOUNDING IN SWEDISH WATERS. THE GREATEST DEPTH IN THE BALTIC.

For hydrographic surveys, echo sounding has been used in Sweden since the summer of 1930; it is the method exclusively used at present for sounding medium and great depths in the waters off our coasts.

The two echo sounders used on board our surveying ships *Falken* and *Svalan* are of the French ultra-sonic type with automatic recording.

The first echo sounding operation of great extent undertaken in our waters was the detailed sounding of the deepest part of the Baltic between Landsort and Gotland, where the old charts showed a maximum depth of 427 metres (233 ½ fms.). This deep region had been designated by the then Hydrographer, Commodore G. Reinius, as the site of an extensive and very detailed survey by the surveying ship *Falken*, Commander Bouveng.

The soundings revealed that the greatest depth in the Baltic is 459 metres (251 fms.) and that this is situated in a triangular deep, about 10 km. (6 1/4 miles) wide and 300 to 400 metres (164 to 219 fms.) deep in the northern part: the deep narrows towards the S. W. and South, but in places its depth exceeds 450 m. (246 fms.). (1)

It is chiefly in the southernmost and deepest parts that the slopes are very steep, and are limited in places on the other side by fairly well defined terraced formations.

Before this comparatively even predominating structure there extends inside towards the Skärgård south of Stockholm, a system of finely cut up formations, as well as decreasing heights, dales and valleys much resembling those which one can see above water on the coast. Later work in the neighbourhood and off Sandhamn channel have shown the same character of bottom, even more marked, perhaps, in the latter region. A particularly striking addition to the general chart is made by a few little valleys some 6 miles long and only a few hundred yards wide, whose beds are only 25 to 50 fathoms below the slightly undulating sandy or clayey bottom. (2)

THE OPENING OF A NEW ERA IN OUR KNOWLEDGE OF THE BOTTOM OF THE OCEANS.

In spite of the fact that the question of certain corrections is not yet resolved, it follows from what has been said that the various methods of echo sounding have already furnished, and are furnishing, an invaluable mass of data on the bottom relief of the oceans, which is helping to solve our problem; the latter in its turn raises new questions of navigation, oceanography, seismology, isostasy, and even perhaps certain branches of geography. The effect of this should be to increase even further our knowledge of the nature of our planet, insomuch as nearly three quarters of its surface were, even up to a few years ago, inaccessible by any other means of investigation, even relatively crude.

The more an improved method of determining the bottom conditions in the high seas spreads throughout the world — in the Indian Ocean, for example, there are vast regions where the soundings are extremely few and far between — the more probable it is that we shall have to revise the conception we have accepted hitherto of the ocean bed being in general an extremely regular surface.

Just within the last few years, a certain number of discoveries have been made which show, for example, that formations comparable with the Hudson and Congo rivers are to be found at several places beneath the surface, forming submarine valleys. The American surveyors have thus found deep canyons on the edge of the continental shelf, some hundreds of miles from the coast (3), and in the spring of 1930 a Spanish fishing boat found a depth of between 80 and 680 m. (44 and 372 fms.) between the Gettysburg

---

(1) *According to the recent account in the* Annales Hydrographiques, *Paris* 1932, *p.* 14, *of the cruise of the research ship* Pourquoi-Pas ? *in* 1930, *Dr. Jean Charcot, with the aid of Swedish soundings, had found an even greater depth,* viz.: 470 *metres* (257 *fms.*) *in* 58°38' N., 18°16' E. *The soundings were checked by line. The salinity at* 400 *metres* (219 *fms.*) *was not less than* 20.23 °/oo.

(2) *The chapter relating to errors of echo-sounding and the possibility of correcting them is not reproduced here.* — (I. H. B.).

(3) Hydrographic Review, *Monaco, November* 1932, *p.* 243.

Bank and Cape St. Vincent in Spain, where the charts showed 2,000 to 3,000 m. (1,094 to 1,640 fms.). Here the surveying vessel *Ormonde* recently found bottom at only 50 m. (27 fms.), and it may be that other similar rises occur in this irregular bottom region.

It is to be expected that the next ten or twenty years will add much to our knowledge of the configuration of the ocean beds. It is not impossible that depths may be discovered several thousand metres deeper than the greatest now known. From the technical point of view, echo soundings could reach these depths; only there does not at present exist any ultra-sonic machine capable of doing so, observing that the high-frequency oscillations are damped out much more quickly during their passage through sea-water than are sonic waves. By using explosive charges, the French Navy succeeded in verifying not long ago that sound is propagated under the surface of the Mediterranean and can be heard at a distance of not less than 740 km. (460 miles). (1).

These facts about the bottom conditions are recorded by the INTERNATIONAL HYDROGRAPHIC BUREAU at Monaco, which has undertaken the keeping up to date of the GENERAL BATHYMETRIC CHART OF THE OCEANS of the late Prince ALBERT I of Monaco. Perhaps from certain points of view it may be regretted that the new edition of this work had already started to appear before our knowledge of the bed of certain oceans was more detailed, but maybe this can be remedied before the whole chart has been republished. In any case, all those who take an interest in oceanography have reason to rejoice sincerely that an institution has taken the risk of burdening itself with this undertaking which is worthy of recognition but is associated with ever increasing difficulties.

(1) Hydrographic Review, *Monaco, May* 1932, *p.* 183.