BATHYMETRIC FEATURES OF THE PHILIPPINE TRENCH

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INTRODUCTION

The Danish Deep Sea Expedition round the World in 1950-1952 worked in the deepest part of the Philippine Trench from July 12th to August 15th, 1951, interrupted only by four very short visits ashore. Although the principal object of the expedition was to investigate animal life on the bottom of the sea and in the deepest strata of water, it was necessary before each haul or sampling of the bottom to make a thorough examination of the topography of the seabed, not least because the actual bottom of a trench may be quite narrow and the jagged sides are absolutely destructive to the fishing gear. It was therefore necessary to crisscross the area to be examined, often for many hours, before the biological and hydrographical investigations could start, and in this manner an exceedingly great quantity of observations was collected, distributed over several hundred echo sections in all directions.

The manuscript was translated from the Danish by Mr P. Prom.

ECHO SOUNDINGS

The Echo Sounder

The echo sounder especially constructed for the "GALATHEA" was delivered by Kelvin-Hughes Ltd, of London, (MS-21, Type J & K with scale up to 9,000 m uncorrected). As the absorption of the sound waves in water increases with increasing oscillation, the frequency of 15 kc or upwards as used in most other ships would be inappropriate at these great depths, although high frequencies do give the best possibilities for a determination of the directions of the sound waves. The "GALATHEA"'s echo sounder was therefore designed for 10 kc, which combines good penetration through the water with an adequate determination of the direction of the beam.

The transmitter was of extra large type consisting of a 13,35 cm core of nickel rings in front of an air-filled reflector in a 58,40 cm tank (Fig. 1). It was located one-third of the length of the ship from the stem, about 2 m below the surface (draught of the ship 3 m), and the iron plating of the bottom was at this place replaced by a 6 mm thick, unpainted

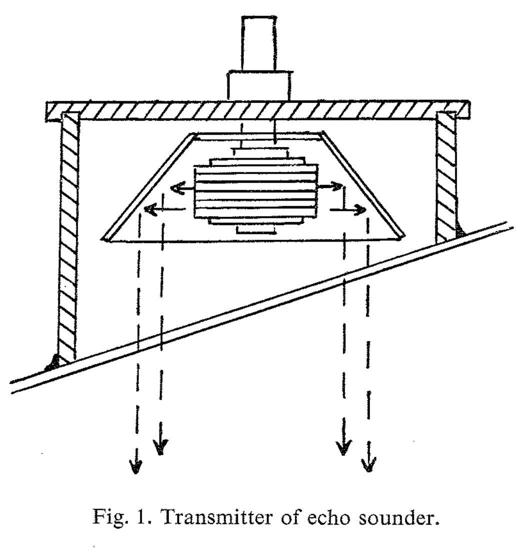


Fig. 1. Transmitter of echo sounder.

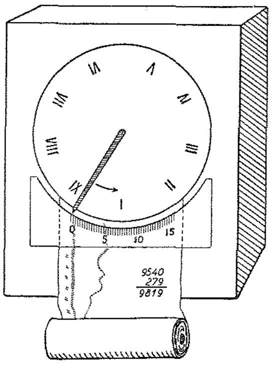


Fig. 2.
Recorder of echo sounder.

plate of stainless steel. The sound waves from the core of the transmitter are focused by the reflector into a beam which through the stainless steelplate passes vertically down into the water. Sounds of two different volumes may be transmitted, the minor volume combined with a short impulse, the major one with a long impulse. It appeared, however, that the minor volume was sufficient at all times and even to be preferred.

The receiver is exactly similar to the transmitter and located in the other side of the ship's bottom.

The echo received, and thus the depth, was recorded on the bridge by means of the apparatus shown in Fig. 2. As a rule the echo sounder was adjusted to transmit sound impulses 5 times a minute, and the recording arm would then rotate at a constant speed of 5 times a minute. By this adjustment the depth will be recorded on the paper sliding slowly past the scale by one mark every 12 seconds, which at a cruising speed of 8 knots corresponds to one recorded sounding for each 50 m. On passages between working areas a speed of 8 knots was frequently maintained, but during sounding operations the speed of the ship was generally lower, often only 3-4 knots.

When work was done in shallow water or it was desired to make a detailed examination of the bottom, the sounder was adjusted to 50 impulses per minute, but at that rate the scale, of course, ranges over only one-tenth of the usual depth interval.

At the 'normal' rate of transmission = 5 times a minute, the width of the paper corresponds to a depth of 1,500 m, but the transmission of sound may be moved ahead outside the paper, so that zero on the scale at the lefthand edge of the paper will correspond to the reception of echoes from depths of 1,000, 2,000, 3,000 m etc. up to 9,000 m, in which last case the adjustment will be equal to the first zero adjustment. When soundings are taken at adjustments 0-1,500 m and 9,000-10,500 m, the hand will at the instant of transmission make a small mark abreast of zero on the scale, but at high-power transmission the arm may, due to overshoot in the apparatus draw a short line extending to a depth of up to 200 m, and the recording of echoes from depths of 0-200 m and 9,000-9,200 m (uncorrected) may thus be more or less concealed by the next transmission mark. In case of the interval between 9,000 and 9,200 m this difficulty may, however, be overcome, if for every second transmission the adjustment is set in such a manner that the transmission mark will fall outside the paper and thereby be prevented from spoiling the reception of the echo of the preceding transmission. At depths of 0-200 m this difficulty may be obviated by the use of 50 transmissions per minute.

The recording of the hand on the paper is caused by an electric current which at the moment of reception will pass from the hand through the paper, which is constantly kept moist, to the base on which it rests, and as the paper is impregnated with sodium iodide a dot of free iodine will be deposited at each impulse. On a scale fastened to the apparatus the uncorrected depth may be read direct and noted at suitable intervals on the paper by means of an electric pencil. Supplementary readings during the subsequent compilation of the data may be made by means of a loose scale shortened in length corresponding to the normal contraction of the paper after drying. As, however, paper of different brands cannot be expected to contract equally, and as furthermore the amount of contraction will vary with the rate of drying, the original readings must always be regarded as the correct ones and subsequent readings be corrected accordingly. On board the "GALATHEA" the paper contracted somewhat more than had been calculated when the 'dry' scale was manufactured; so all subsequent readings have been corrected accordingly.

The principle of having the electric current release a dot of iodine possesses the great advantage that the rotating indicator arm will not have to make any movement to and from the paper at the moment of recording. The iodine deposited will, however, gradually evaporate so that the marks become weaker. If the paper is kept tightly rolled up on a central rod and stored in tight cases, the marks may, however, be kept fresh for several years. To be on the safe side, we did, however, immediately at the first cursory preparation of the observation data draw up all curves with a fine pencil line and at the same time photographed all important parts of the curves.

Accuracy of the Soundings

The "GALATHEA"'s echo sounder functioned to our full satisfaction. It was frequently inspected by the ship's Chief Electrical Artificer and its rate of rotation was checked several times a day and adjusted as required. The apparatus was so designed that the rate of revolution might be so accurately adjusted as to give an error of maximum 0,2 %, and as the error in readings did not exceed 10 m, the total error of the uncorrected soundings might even at the greatest depth be kept at less than ± 30 m. To this must be added possible errors in the correction for deviations in the velocity of the sound due to changes in temperature, salinity and pressure at great depths. The apparatus was tuned to a speed of sound through the water of 1,500 m/sec. (820 fms./sec.), and the calculation of the correction mentioned was made according to D. J. Matthew's tables, 2nd ed., 1939, but for the purpose of control we ourselves tried to calculate the correction on the basis of our own hydrographic observations in the Philippine Trench and found our calculations to be in close conformity with the values given in the tables. As in this area temperature and salinity vary but little with the seasons, the error in the correction can only be a small one, so the total error in the deepest soundings in the areas worked will be less than ± 45 m, and outside the working areas, when the rate of rotation was controlled less frequently, at most ± 75 m.

By way of comparison it may be stated that Maurer (1937) estimates the inaccuracy in the soundings taken by the "EMDEN" in the Philippine Trench in 1927 at ± 140 m, whereas van Huystee (1944) gives ± 100 m as the probable inaccuracy of the "SNELLIUS"' soundings in 1930, while according to Hess and Buell (1950) the inaccuracy of the "CAPE JOHNSON"'s observations in 1945 is ± 91 m. The three research vessels here mentioned used low frequency tones and the echo was picked up by earphone and not as in the "GALATHEA" automatically recorded. When in October, 1951, the "CHALLENGER" measured the great depths in the Marianas Deep – 10,863 m – an echo sounder of the same type as that of the "GALATHEA" was used, but nevertheless as far as the greatest depths were concerned an earphone was used, and by reckoning on a listening-in error of up to 37 m (Carruthers and Lawford, 1952), the total inaccuracy was fixed at ± 110 m (Wüst, 1952).

Spread of the Sound Beam

In most freighters and passengerships equipped with echo sounders for navigational purposes frequencies of 15-40 kc are used, and as it is practical to have the sounder register not only the vertical depths directly below the ship but also irregularities at some distance, it is so constructed that the apex of the conical beam transmitted has an angle of spread of up to 20° with the perpendicular. In survey work the beam should, however, be as narrow as possible, and the "GALATHEA"'s sounder was therefore designed to give a spread of only 8° with the perpendicular, or rather in such a way that the energy emitted which is greatest along the axis of the cone already at an angular distance of 8° from the axis decreases to such extent (up to 50 %) that echoes from more remote positions will not be registered.

In the course of our work, we learned, however, that so long as the ship was in relatively shallow waters the echo was returned from the entire base

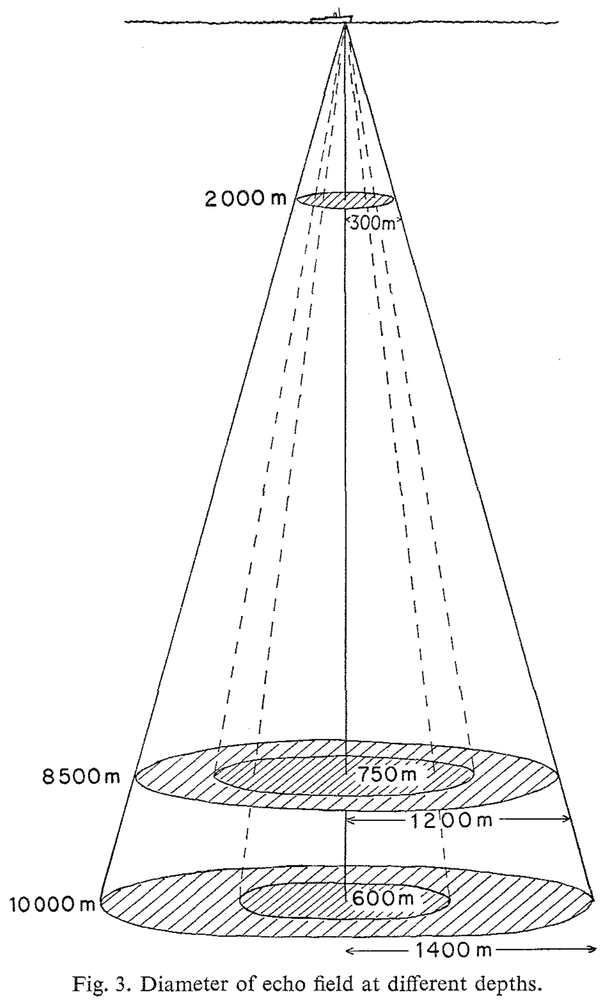


Fig. 3. Diameter of echo field at different depths.

on the bottom of this cone, so that at depths of, say, 2,000 m higher parts of the bottom out to about 600 m from the position of the ship were recorded. At greater depths, however, the part of the cone giving an echo was diminished until at a depth of 8,500 the apex angle was only 2 × 4.5° and at 10,000 m depth only 2 × 3.5° which corresponds to radii of the echo base of 750 m and 600 m, respectively. (Fig. 3). This is in close correspondence with the theoretical exposition by Hodgson and Fridriksson (1955) according to which the field that may be examined with an echo sounder is pear-shaped rather than conical.

The maximum spread can, however, be observed only under ideal reception conditions and when the echoing surfaces are of suitable size. Very frequently the echo will be received only with considerably less spread, mostly because the seabed is not sufficiently regular or because the horizontal surfaces are too small in extent.

A beam sea or swell may cause the ship to heel so much that a beam transmitted will strike the bottom at some distance from the side and at such an angle that the echo will not return to the receiver, or alternatively, a beam transmitted vertically towards the bottom may be thrown back just when the ship is heeling so much that the receiver will be unable to catch it. These problems were very much to the fore in the "DISCOVERY" in 1950 (Herdman, 1955), but we were only little troubled with these difficulties as the sea was calm during the greater part of our stay in the Philippine Trench and the "GALATHEA" was very stable in a seaway.

If the aim is to plot with the greatest possible exactitude the course of the depth curves particularly in the Philippine Trench where the deepest channel at places is exceedingly narrow, a spread of somewhat less than 600 m would be desirable. The spread is, however, not so great as to necessitate a calculation of the correction of the depths due to the greater distance from the circumference of the echo field. The difference between the vertical line to the centre of the field and the oblique line to the circumference will at depths of 10,000 m amount to only 0,2 %, or considerably less than the inaccuracy in measuring technique.

Echoes from Slopes

During the work of the expedition, in connection with hydrography as well as with sampling of the bottom or trawling, it happened quite frequently

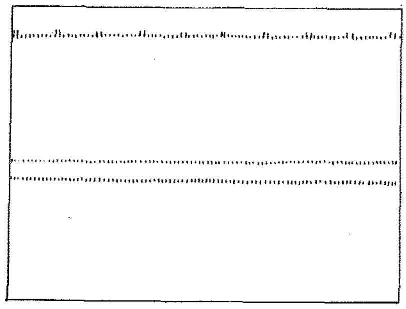


Fig. 4. Recording of echoes from two levels.

that at the beginning of the work we obtained a pure echo from the flat bottom of the deep channel at a depth of about 10,000 m, while during the next few hours another echo very gradually emerged from a level situated 100 or 150 m above the bottom without indication from intermediate depths (Fig. 4). This was due to the fact that during the work the ship was by the current carried in over the western side of the trench, where the bottom rises stepwise and very frequently has so steep slopes that they cannot return an echo to the ship, while at the same time two levels may come within the echo field (Fig. 5). If, on the other hand, the bottom rises without terraces but with a steep slope extending over so long a distance that the next horizontal level will not come within the echo field (Fig. 6) until the preceding level has disappeared, the registration of that level will gradually vanish, the marks spreading slightly beforehand. As this was often a characteristic of the eastern side of the trench, while the stepwise rise was more character-

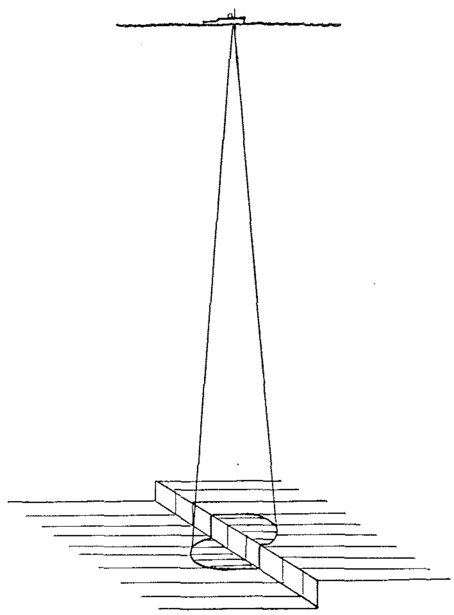


Fig. 5. Echo field distributed on two levels.

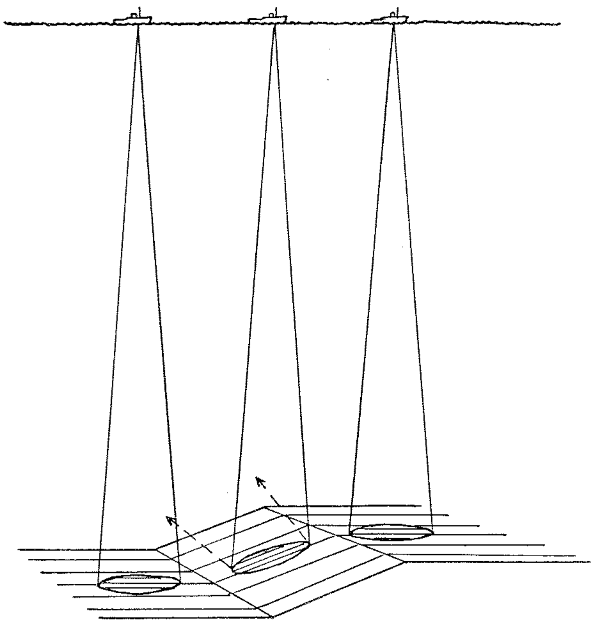


Fig. 6. The echo vanishes between the two horizontal levels.

istic of the western side, the spread of the sound beam was often an aid to us in keeping the ship in place over the middle of the trench during the 10-15 hours a series of operations might last.

A plane seabed need only slope very little in order to throw the echo so much to the side that it cannot be caught by the ship. In the course of our work we learned that as soon as the gradient exceeded 1 : 5 or 1 : 6 (about 10°) the echoes could not be recorded as one continuous curve – and as a rule not at all – even if all other conditions were ideal. In the U.S. Navy vessel "CAPE JOHNSON", which during World War II was stationed in these waters, they frequently experienced this missing echo, just as we did. When, however, it is stated on the part of that ship that in such cases they had to make up to 10 sound transmissions before receiving an echo from certain areas of great depth, and they conclude from this fact that the seabed of the trench in such places must consist of too soft a material to reflect the sound, we must say, that according to our experiences the explanation must rather be that the ship for a time must have been over too steep a gradient of the bottom, and only received another echo when she again encountered a more horizontal bottom (Hess and Buell, 1950).

Air Bubbles in the Water

That air bubbles in the water in boisterous weather or if the ship is moving at high speed in a seaway will spoil the echo is a fact known in all ships, air being a substance which is particularly effective in reflecting sound. In this respect the "GALATHEA" may have been especially troubled due to her shallow draught, more particularly when both oil and freshwater tanks were almost empty after long stays at sea, and the ship was extra high in the water. Lacunae will therefore be found in our echograms from periods of bad weather and particularly in connection with the passage of two typhoons which even for a time compelled us to leave our working area.

ANALYSIS OF THE ECHOGRAMS FROM THE PHILIPPINE TRENCH

Echoes from two Levels

In the analysis of the echograms with a view to the preparation of a bathymetric chart of the Philippine Trench no difficulties are encountered so long as the sea bottom is horizontal and uniform so that only one echo curve will be drawn. When, however, the abovementioned declivities and slopes intervene, regard will have to be paid to the spread of the sound beam, as will appear from the following examples

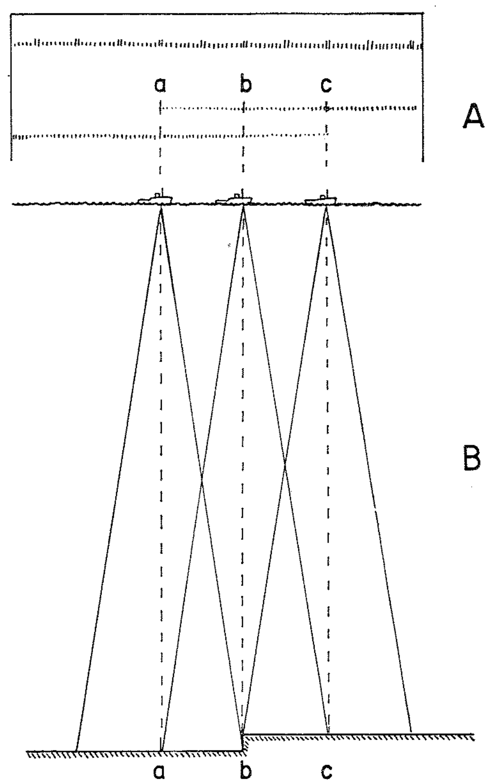


Fig. 7-A. Echogram showing a sharp transition from Level I to Level II of the seabed.
Fig. 7-B. Analysis of the echogram in Fig. 7-A.

in which the ship crossed the deep channel at right angles and constant speed.

The echogram in Fig. 7-A, which is to be read from left to right, shows that the echo from Level I begins to weaken from time a, while at the same position the higher level II manifests itself very slightly. At b the two curves are of equal power, corresponding to the fact that equal parts of the two levels are now within the area covered by the beam. Thereupon Level I disappears entirely at c, whereas Level II is registered at full force. The time marks on the paper and the speed of the ship show that the distance travelled between the positions a and c is 1,200 m over a depth of about 10,000 m, and the echogram must therefore be read in accordance with Fig. 7-B, in which, however, the angle of spread is highly exaggerated.

While the ship is in position a an echo of full power will be received from Level I, but Level II is just beginning to appear although it is still 600 m ahead. Having travelled 600 m (b) the ship must be right above the vertical slope and receives echoes of equal power from I and II, and only when she is 600 m in over the new level (c) the first level will disappear entirely from the recording.

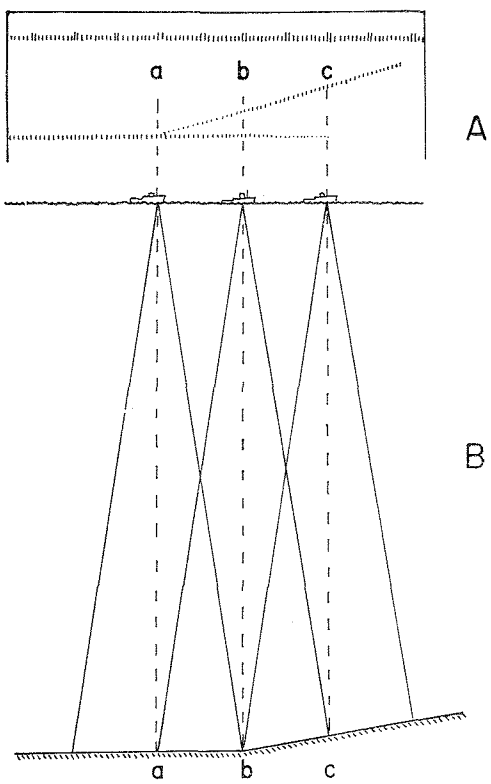


Fig. 8-A. Echogram showing transition from a horizontal level to a gently sloping level.
Fig. 8-B. Analysis of the echogram in Fig. 8-A.

Echo from a gradually sloping Seabed

In the example shown in Fig. 7 the declivity between the two levels is vertical, but in most cases the bottom will slope to some extent, and if the gradient does not exceed 1 : 5 we will have the situation shown in Fig. 8-A-B.

Just when the ship is 600 m from the place where the horizontal bottom (I) adjoins the sloping ground (II), the latter begins to show in the echogram (a) and, similarly Level I will only disappear entirely when the ship has got 600 m in over the sloping bottom. The strongest echo from Level II may not, however, be received from the place right below the ship but from a place a little farther ahead, but as already mentioned this is of very little importance in the measuring of the depths.

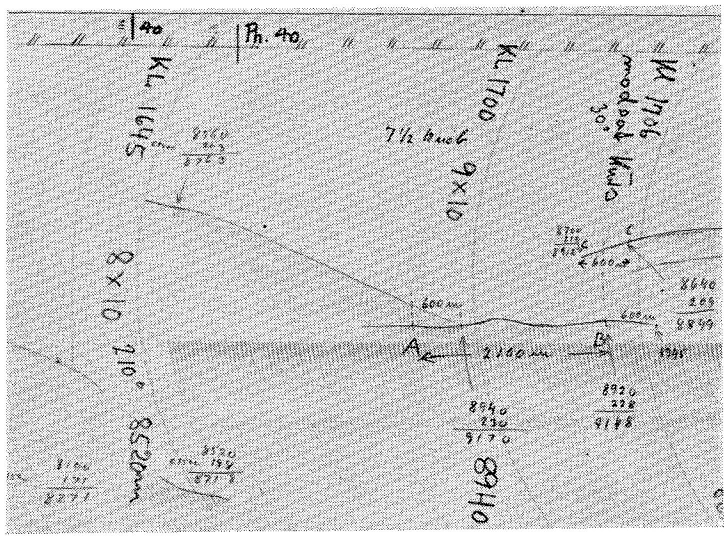
Examples of Echograms from the Philippine Trench

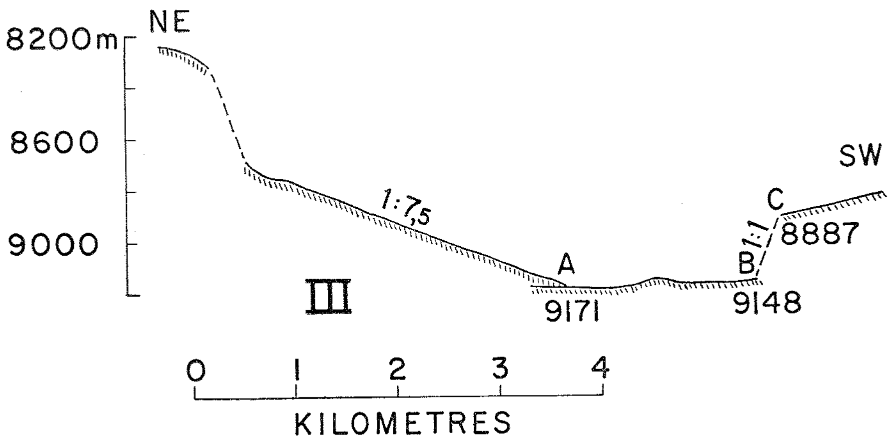
Even if these schematic echograms in actual fact will frequently be more or less distorted by irregularities in the sides of the trench, clear and unambiguous echograms have, however, in many cases been obtained during the many crossings of the deepest channel. An example, Section III in Plate I, is given in detail in Fig. 9-A-B.

The middle of the trench was in this case crossed from NE to SW at a speed of $7\frac{1}{2}$ knots. The eastern side shows a regular gradient of 1 : 7,5 and could thus easily be recorded, while the western side over a horizontal distance of about 240 m rises steeply to a height of 260 m from the bottom, that is at a gradient of somewhat more than 1 :1, and returns no echo. In these and other similar analyses of echograms at great depths (6,000-10,000 m) in the Philippine Trench, a maximum spread from the perpendicular of 600 m has been calculated with, a spread of common occurrence in this area, but in many cases considerably less in other seas. For the plotting of the edge C in Fig. 9-B the weak echo first heard was used, corrected by -25 m for the oblique course of the sound.

The seabed is more irregular at the place where Section II crosses the trench (Fig. 10-A-B). The western side subsides here at an average gradient of 1 : 4.5, but the decline is irregular with several sloping surfaces or clefts towards the bottom of the trench, which incidentally here has a deeper channel along its middle. The eastern side, on the other hand, rises steeply to a small, isolated plateau or N-S ridge more than 1,000 m above the bottom.

Fig. 9-A. Photographic reproduction of echogram from passage across the deepest part of the trench, Section III, Plate I.
Fig. 9-B. Cross-section of the trench prepared on the basis of the echogram in Fig. 9-A. Exaggeration of vertical scale 2.5.



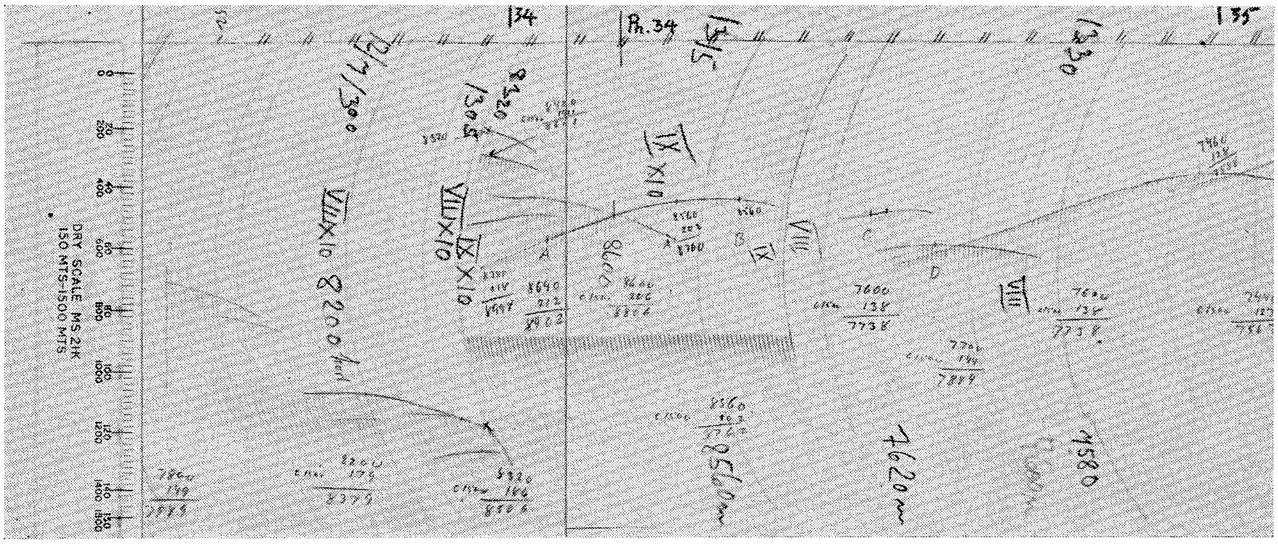


The width of this plateau cannot be determined with exactitude, but it is so narrow that the echo from it was only recorded at most 300-400 m from its edge.

The slopes of the bottom towards A are not too steep to give good echoes, but due to the spread of the beam the curves of the echogram intersect one another until 600 m from the middle of the trench. The lower ends of the intersecting curves were used as a basis for the calculation of the depth at A, and in this case regard was paid to the oblique course of the sound waves and a correction of -25 m was applied. The eastern slope B-A continues to the west of A as a narrow tongue or valley about 600 m into the western side and down to a depth of 86 m below A.

When the gradients of the sides are not too steep for the reception of an echo and the spread of the sound beam is of known and limited size, the profile of the bottom of the cleft may be reconstructed in the manner here used, but if the sides are steeper so that no echo is received, or if a directional sound wave is not used, but for instance sounding by detonation, the bottom of the channel cannot be reconstructed at all, or without any amount of accuracy. Thus, an expedition from Scripp's Institute in 1952-1953 took soundings in the Tonga Trench by detonation and measured a depth of 10,633 m. Fisher is, however, of opinion that the depth may be not less than 10,800 m and that the configuration of the sides may be different from that calculated (Fisher, 1954).

An echo section along the sides of the Philippine Trench may over short distances in many cases show a regular, continuous slope. The most common feature seems, however, to be that the slopes down towards the trench are irregular and heavily incised, as will be seen from Fig. 11 which shows part of the echogram recorded during the southward voyage along the western slope of the trench some distance to the south of the San Bernadino Strait. An exact analysis of the many curves would not be feasible,



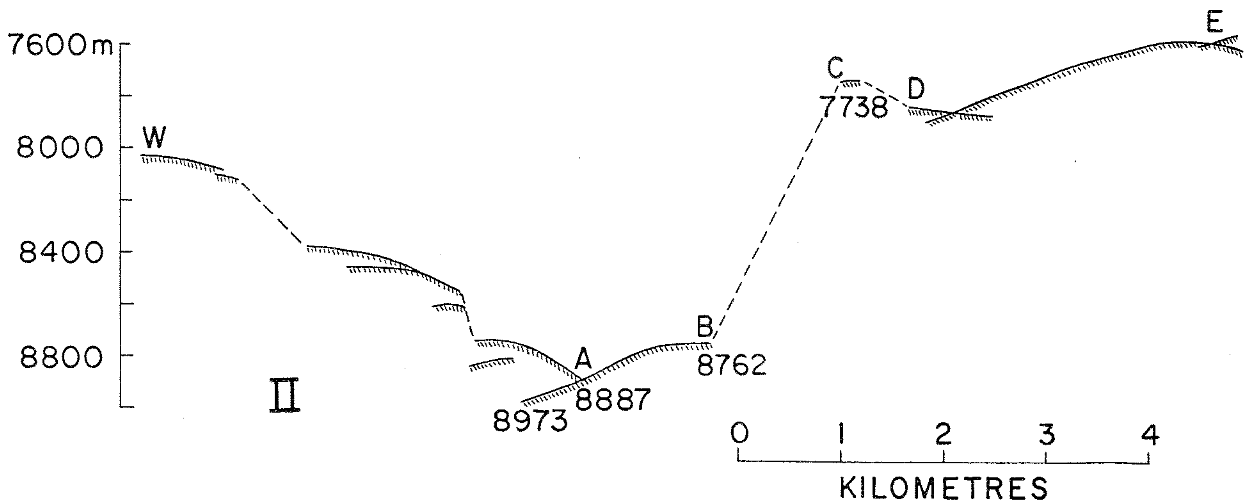


Fig. 10-A. Photographic reproduction of echogram from passage of the deepest part of the trench, Section II, Plate I.
Fig. 10-B. Cross-section of the trench prepared on the basis of the echogram in Fig. 10-A. Exaggeration of vertical scale 2.5.

nor would it serve any practical purpose. The echogram does, however, give some notion of the average depth and in particular a good picture of the jagged character of the slope.

ACCURACY OF POSITIONS OF OBSERVATIONS

The greatest difficulty in connection with an exact survey and plotting will no doubt always be encountered in the determination of the position of the ship and thus also of the sections. The distance from the middle of the trench to the shore averages about 40 nautical miles (75 km), so that in clear weather the highest points of the archipelago may be seen although they cannot be used for the purpose of fixing the position. There was no DECCA chain in the Philippines and the LORAN stations were so remote that they could not be used for a determination of the position with sufficient accuracy. Astronomical fixes must therefore be used as a basis for all positions, and as a consequence observations were taken on board the "GALATHEA" as frequently as possible and with the maximum care. While in most cases we may reckon that the inaccuracy in the determination of positions does not exceed $\frac{1}{2}$-1 nautical mile, certain optical irregularities at times caused, particularly the determination of longitude to be difficult, so that subsequently the longitudes of the sections had to be corrected by other means. Despite the good weather we generally had the sky was often overcast so that whole days might pass without possibilities of obtaining a fix, and when later on we succeeded in getting an ob-

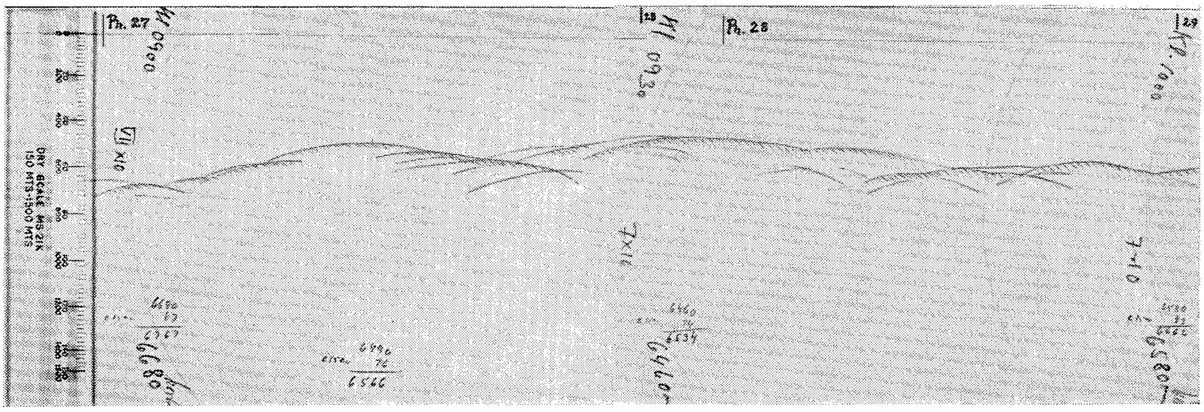


Fig. 11. Photographic reproduction of echogram from jagged slope along the western side of the trench.

servation it frequently appeared that the current had set the ship in a way different from that calculated, so that the intermediate dead-reckoning positions had to be corrected.

The current forms part of the trade drift and therefore mainly comes from the east, but off the Philippine Islands it curves and continues in a southerly direction, but both set and speed vary considerably, and a current of 1-2 knots is a very common phenomenon. Under such circumstances it is difficult to maintain the ship's position during work and also to keep a proper dead reckoning during passages.

Not only in the work on board but also in the preparation of the data collected the greatest possible care and criticism were therefore exercised, and we venture the opinion that although the positions of the sections and charts prepared in this treatise may be subject to correction, such corrections can be made only when new technical aids become available.

When on board the U.S. "CAPE JOHNSON" they measured the maximum depth of the trench (10,497 m), they counted on an inaccuracy in position of 3.5 miles (6.5 km), although the ship had proceeded to the position direct from shore and had radar communication with land until 4 hours before the soundings were taken and again 6 hours later fixed their position both by LORAN and an observation of the sun (Hess and Buell, 1950). Of necessity we must in the "GALATHEA" count on a similar or perhaps even greater inaccuracy on days with poor observation facilities, but now when all the echo sections have been worked out and compared with accurate fixes, we may take it that in general the inaccuracy of the data compiled will not exceed 1½ or 2 miles.

CROSS-SECTIONS OF THE TRENCH

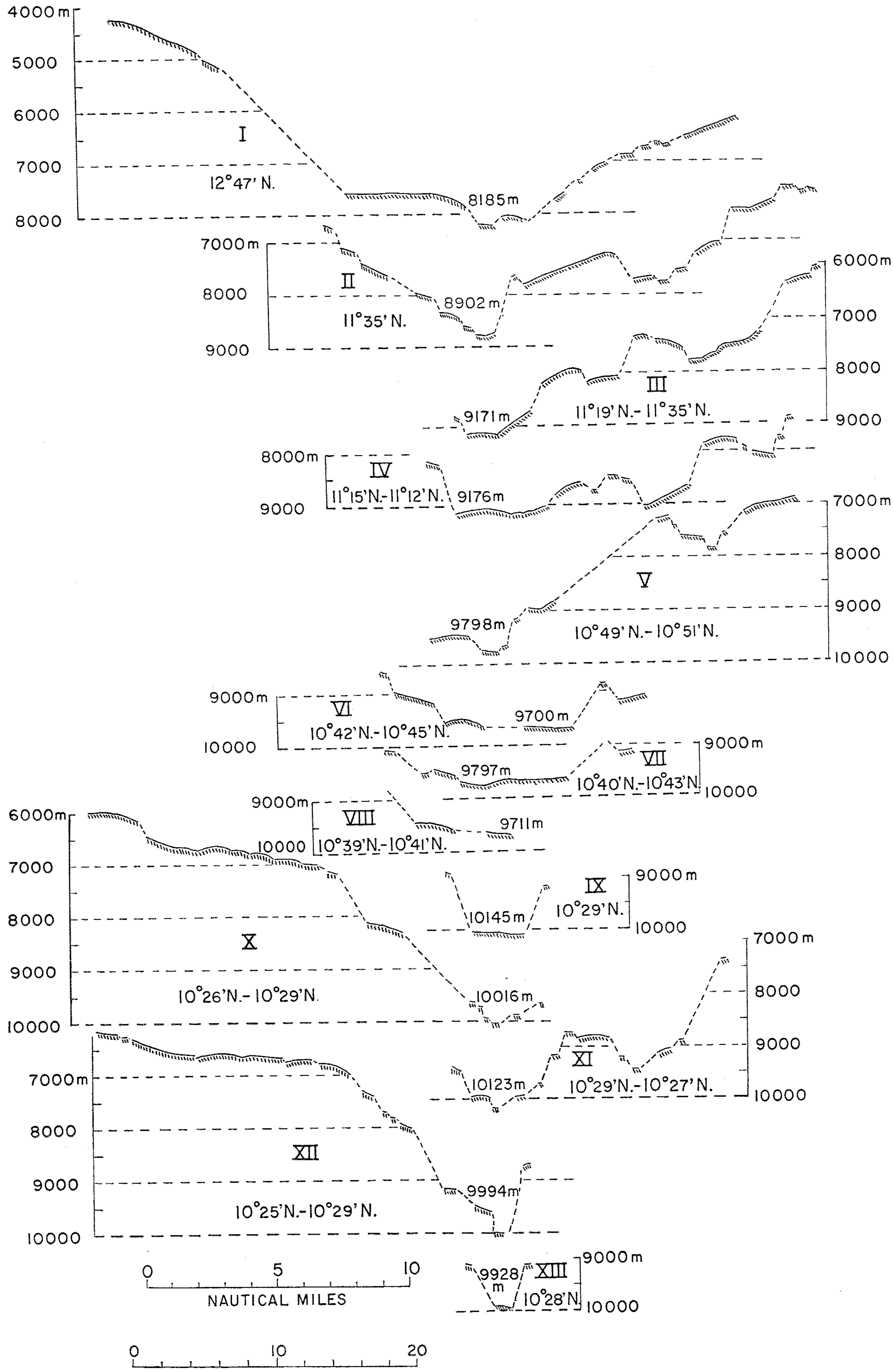
Plates I-II

As the echo sounder was kept going throughout our stay over the Philippine Trench an exceedingly great number of echograms is available, and of these 26 of the best cross-sections are reproduced in Plates I and II. They have all been drawn with a vertical exaggeration of 3.7 (500 m vertically = 1 nautical mile horizontally). The parts of the sections drawn in full line correspond to the distances over which echoes could be received, whereas the stretches from which no echo could be heard are drawn in broken, straight lines.

As a consequence of the abovementioned difficulties in fixing positions, some of the sections were in the work done locally plotted in the charts in a wrong longitude. As, however, it must be presupposed that the deepest channel forms an entity and follows a reasonably regular course, the sections have been displaced in direction east-west, so that the deepest parts of all the sections will be found in a vertical line down across the plates.

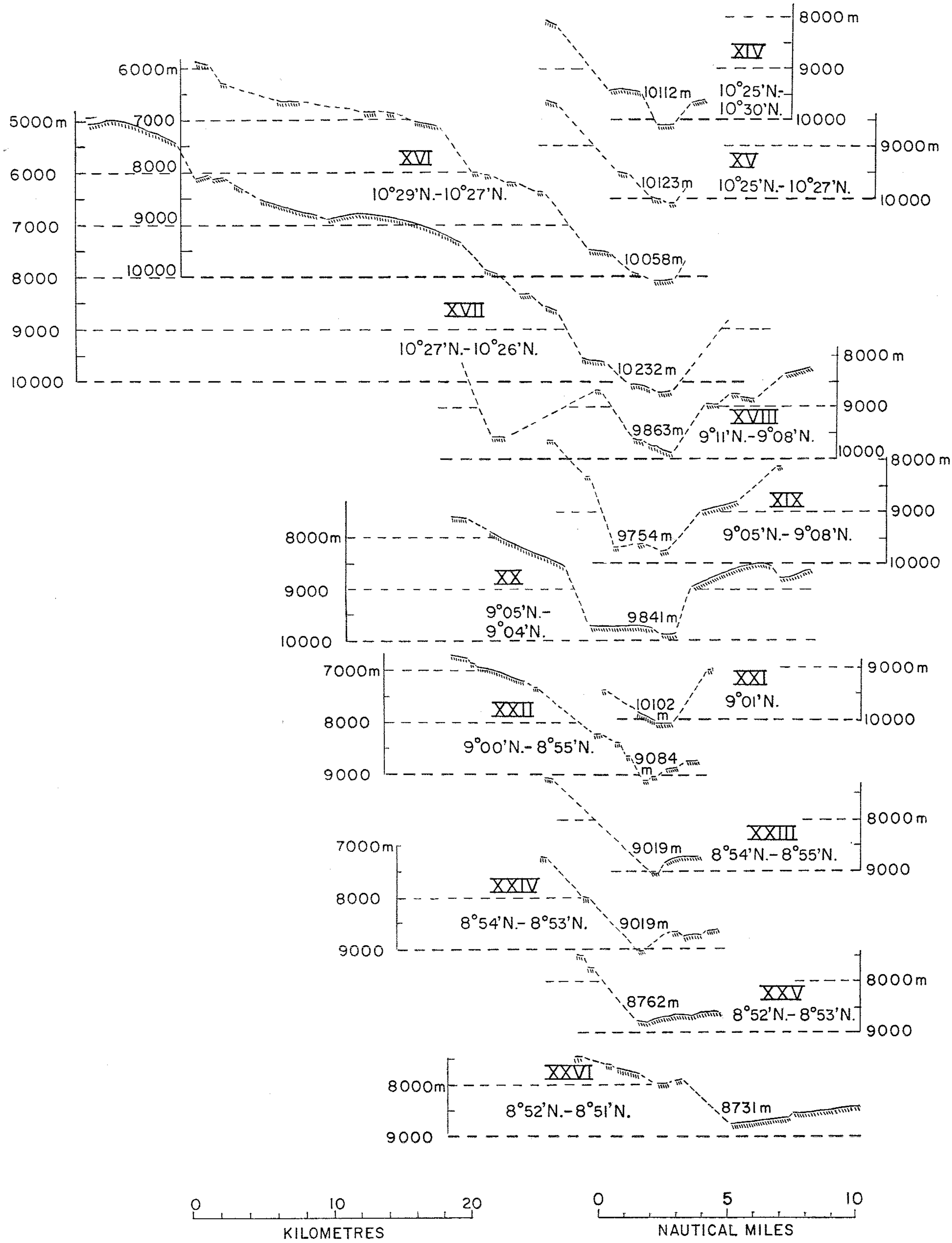
Four of the most perfect sections (I, II, XI-XII and XXVI) have further in Fig. 12 been represented as blocks presumed to be resting on a plane surface at a depth of 10,000 m and spaced 70-95 nautical miles (130-175 km) apart.

Most of the cross-sections show the abovementioned configuration, namely, that the western slope passes down towards the bottom by many, small steps, whereas the eastern side has few but tall steps. Most of the sections between II and XI likewise show subsidence areas in the seabed to the east of the main trench, either branches of the main trench or isolated depressions, or a more or less continuous parallel trench.



4000 m
5000
6000
7000
8000
I
12°47' N.
8185 m
7000 m
8000
9000
II
11°35' N.
8902 m
6000 m
7000
8000
9000
III
11°19' N.-11°35' N.
9171 m
8000 m
9000
IV
11°15'N.-11°12'N.
9176 m
7000 m
8000
9000
10000
V
10°49' N.-10°51' N.
9798 m
9000 m
10000
VI
10°42' N.-10°45' N.
9700 m
9000 m
10000
VII
10°40'N.-10°43'N.
9797 m
9000 m
10000
VIII
10°39'N.-10°41'N.
9711 m
6000 m
7000
8000
9000
10000
X
10°26'N.-10°29'N.
10016 m
9000 m
10000
IX
10°29'N.
10145 m
7000 m
8000
9000
10000
XI
10°29'N.-10°27'N.
10123 m
7000 m
8000
9000
10000
XII
10°25'N.-10°29'N.
9994 m
9000 m
10000
XIII
10°28'N.
9928 m
0
5
10
NAUTICAL MILES
0
10
20
KILOMETRES

Plate I



8000 m
XIV
9000
10112 m
10°25'N.-
10°30'N.
10000
9000 m
XV
10123 m
10°25'N.- 10°27'N.
10000
6000 m
7000
5000 m
8000
XVI
10°29'N.-10°27'N.
6000
9000
7000
10000
10058 m
8000
XVII
9000
10°27'N.-10°26'N.
10232 m
8000 m
10000
9000
XVIII
9863 m
9°11'N.-9°08'N.
10000
8000 m
XIX
9000
9754 m
9°05'N.- 9°08'N.
8000 m
10000
XX
9000
9°05'N.-
9°04'N.
9841 m
10000
7000 m
XXI
9000 m
10102 m
9°01'N.
XXII
8000
10000
9°00'N.- 8°55'N.
9084 m
9000
XXIII
8000 m
9019 m
8°54'N.- 8°55'N.
7000 m
9000
XXIV
8000
8°54'N.- 8°53'N.
9019 m
9000
8000 m
XXV
8762 m
8°52'N.- 8°53'N.
9000
XXVI
8000 m
8°52'N.- 8°51'N.
8731 m
9000
0 10 20
KILOMETRES
0 5 10
NAUTICAL MILES

Plate II

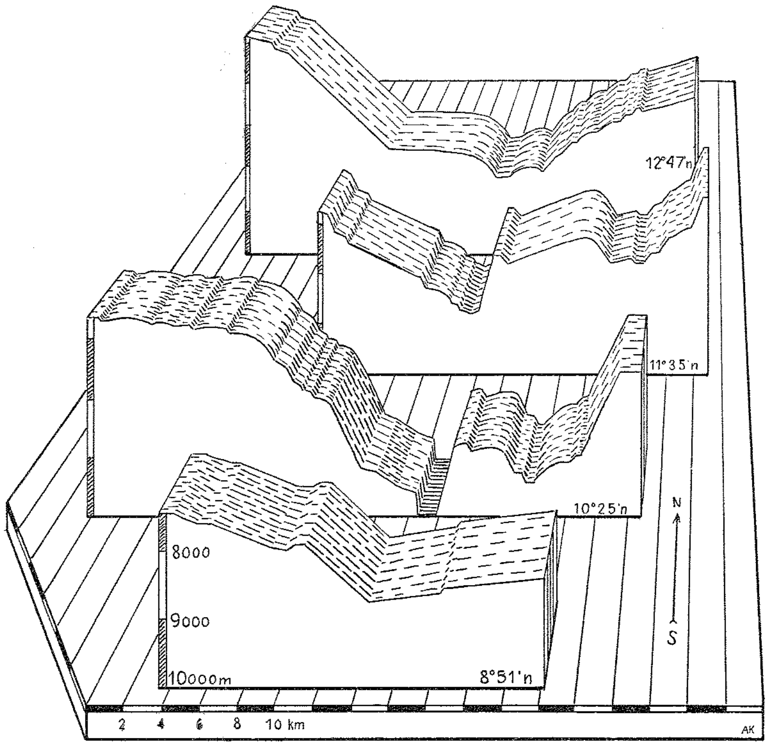


Fig. 12. 4 Sections of the bottom of the Philippine Trench.

BATHYMETRIC CHART OF THE PHILIPPINE TRENCH

Plates III-VI

Already when in 1907 the German survey vessel "PLANET" for the first time ascertained the great depth in the Philippine Trench, so many soundings were taken as to make it possible to draw a depth chart which roughly gave a good idea of the location of the trench (Groll, 1912), and in many places depth curves from this first chart may still be used. To be true, by these first soundings no depths of more than 8,500-8,553 m were found, while already at an earlier time depths of 9,427 m and 9,636 m had been measured in the Kermadec Deep and the Marianas Deep, respectively. In 1912, the "PLANET", however, in several places got soundings of more than 9,000 m, and thereby ascertained a better continuity along the trench. With its 9,788 m the Philippine Trench now assumed the position of the deepest place in the oceans.

During the "EMDEN"'s survey of the Philippine Trench in 1927 the work was concentrated on a rectangle between 9°38′ N, and 9°57′ N, in which 332 echo soundings were taken, 46 of which showed depths of more than 10,000 m. Thereby one of the deepest areas of the trench was localized, even if the deepest soundings (10,790 m and 10,830 m) which soon were recorded in literature were subsequently declared to be erroneous, inasmuch as they must be due to echoes from the sides of the trench (Maurer, 1937, Hess and Buell, 1950, Wüst, 1950-1951). Maurer and Wüst consider 10,400 m a more probable depth.

The soundings taken by the "SNELLIUS" in 1930 (van Huystee, 1944) supplied a number of good soundings within the "EMDEN"'s area and to the south thereof, but no new record depth was found.

In 1944-1945 the "CAPE JOHNSON" laid 4 sections across the trench, partly in the vicinity of the "PLANET" and "EMDEN" deeps and partly somewhat more to the north, and in the northernmost of these sections the greatest depth so far known within this trench was found, – 10,497 ± 90 m, in 10°26.5′ N, 126°39′ E – by means of an echo sounder of a frequency of 18 kc and soundings taken every second mile registered by earphone.

The soundings taken by these expeditions have formed the most important basis of the charts as well as of the Monaco chart and the bathymetric charts published by the U.S. Hydrographic Office in 1946 (No. 5485) and the Japanese Hydrographic Office in 1953 (No. 6901) (Dietz, 1954). Roughly, they show the same picture of the Philippine Trench and none of them attempts to give details thereof.

The bathymetric chart given here (Plates III and IV-VI) has mainly been prepared on the basis of the configurations shown by the 26 cross-sections in

Plates I-II, and the corrected positions of these sections are plotted in the chart. In the drawing of the depth curves these sections have been supplemented by a very great number of other sections which are less perfect and the positions of which have in many cases been adjusted to conform to the 26 basic sections. The depth curves for 7,000 m and downwards are based almost solely on the observation data of the "GALATHEA", whereas the curves for 2,000, 4,000 and 6,000 m are based also on the existing charts.

From the chart as well as from the sections it appears that the trench roughly extends as a continuous subsidence through the entire area examined, i. e. across 4° of latitude, and that in almost the entire southern half of the area depths of about 10,000 m are to be found.

According to our observations, and thus shown in the chart, the northern end of the trench is about 15 nautical miles closer to land than shown in the American chart No. 5485. The position should be rather accurate inasmuch as the "GALATHEA" proceeded there direct from the San Bernadino Strait at a constant speed of 11 knots and obtained good fixes in the evening $5\frac{1}{2}$ hours before the deepest channel was passed and also next morning $3\frac{1}{2}$ hours after the passage. The speed of the current outside the strait may, however, have been wrongly estimated either by us or by the previous expeditions, so it must be left to some future expedition to try to solve this question.

From this northernmost section to section II in 11°35′ N we have only one long section in direction N-S intersecting the trench at a very acute angle, so the curves here have been roughly drawn on the basis of estimates, and no doubt present a more regular picture of the course of the trench than is actually the case. In Fig. 11, which originates from this very section, it was, however, mentioned that the sides in this place are of a very jagged nature.

South of 11°35′ N the trench becomes wider and deeper and seems to take a uniform course to about 10°45′ N. Over this distance the bottom is at a depth exceeding 9,000 m, and the sides show the characteristic features with terraces on the western slope and a secondary valley or depressions along the eastern side separated from the main trench by ridges of up to 500 m.

At 10°50′ N the bottom deepens to somewhat more than 9,700 m, but immediately to the south thereof the trench is wholly or partly interrupted by a crossing ridge projecting from the east and having a depth of less than 7,000 m. In this latitude

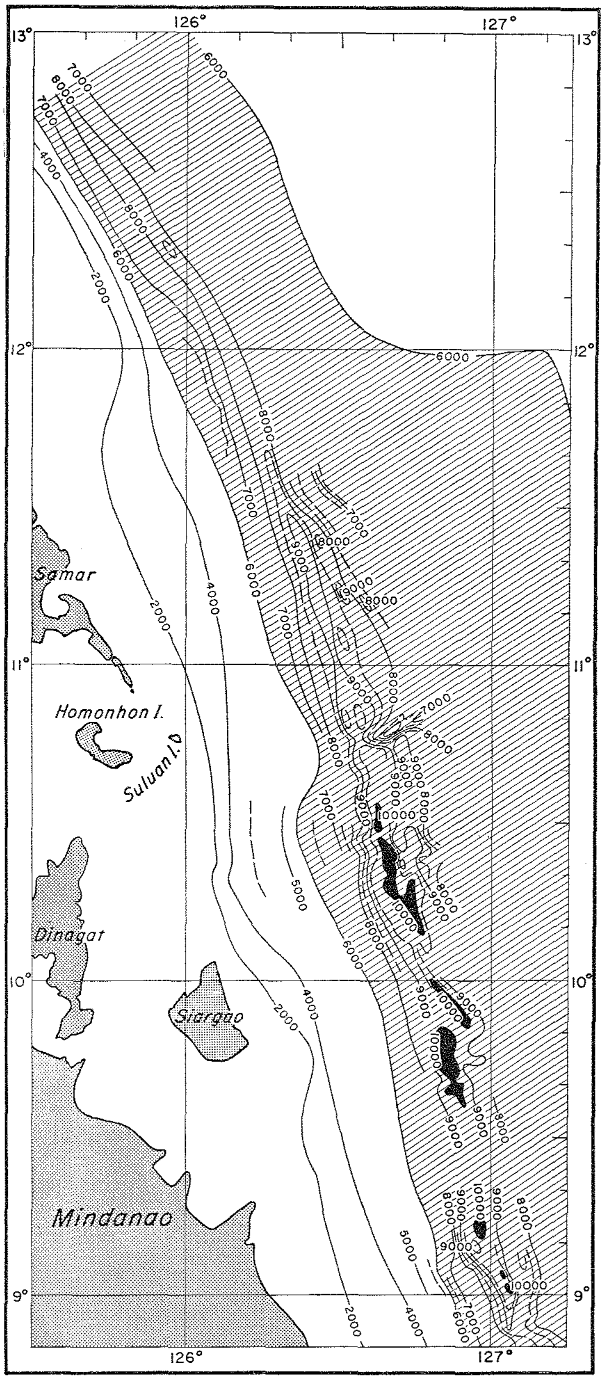


Plate III

several earthquakes have been registered inshore, so the possibility remains that this interruption of the trench is connected with a line of fracture in the crust extending out here from the shore (Repetti, 1931).

Between 10°45′ N and 10°05′ N the central part of the trench is situated. In this place it is wider than in the northern part, and it was here the "CAPE JOHNSON" in July, 1945, obtained a sounding

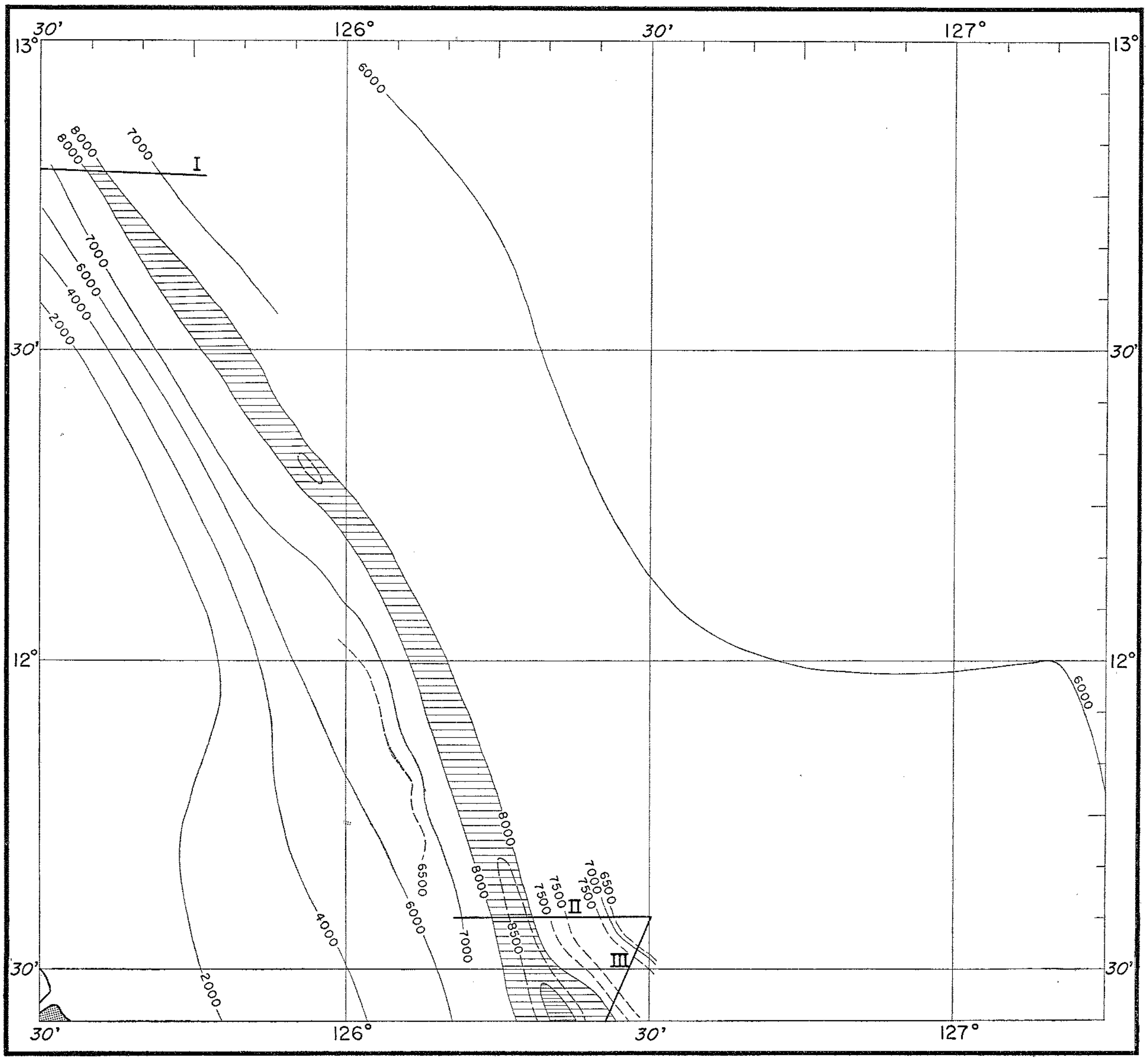


Plate IV

of 10,497 m. As the "GALATHEA" just about this position given by the "CAPE JOHNSON" found particularly good conditions for trawling, we made this our main working area and crossed it time and again. During such a crossing on July 23rd, 1951, in 10°23.8′ N, 126°40.5′ E we found the expedition's greatest depth, 10,265 m ± 45 m, i. e. in a position 3½ miles south of that of the "CAPE JOHNSON". The area containing depths of more than 10,000 m has here at places a width of 2-3 miles, but in most places the deepest channel is quite narrow with widths of less than ½ nautical mile. The bottom of the trench is amazingly flat and over long stretches shows uniform depths of 10,000–10,150 m, but the soft clay ground is amply strewn with gravel and stones which must have come from the sides and possibly have been carried out there by mud slides released by earthquakes. (Bruun & Kiilerich 1955).

As we crossed this area so many times, we must assume that we have also crossed the position given by the "CAPE JOHNSON". We did not, however, find the same great depth, but the possibility cannot be rejected that the 10,497 m sounding has been taken a short distance from the position given or in a depression of so small an extent that we have not happened to encounter it during any of our passages. There is thus no basis for either a confirmation or a rejection of the sounding taken by the "CAPE JOHNSON", and the possibility therefore remains that within or in the immediate vicinity of the area preferred by us for trawling a very restricted deep of 10,497 m may exist, and thus still must be re-

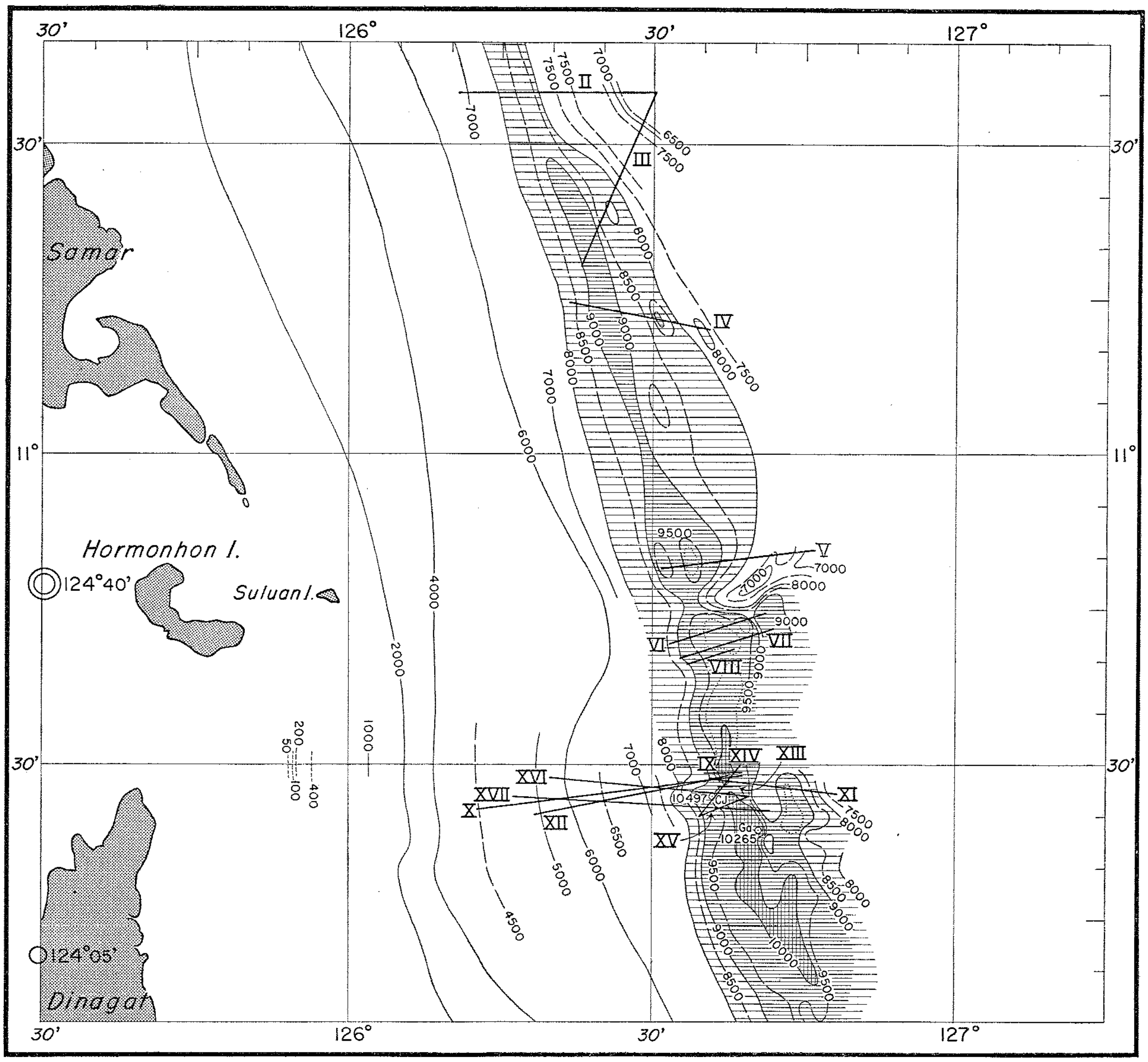


Plate V

cognized as the greatest depth of the Philippine Trench.

Slightly to the north of 10° N the trench again narrows and only a very narrow channel of a depth of about 9,500 m leads – possibly with minor interruptions – to the next section immediately to the south of 10°. It is here the "PLANET" and the "EMDEN" deeps are to be found, and here the "SNELLIUS" and the "CAPE JOHNSON" as also now the "GALATHEA" have searched for the great depth found by the "EMDEN" and concordantly found the greatest depths in this area slightly deeper than 10,100 m. The positions of these expeditions seem to be accurate and consistent, and consequently these soundings have been used extensively in the preparation of this part of the chart.

On the stretch from 9°40′ N to 9°12′ N we encountered so bad weather that the determination of the ship's position was very uncertain, and over long distances no echo could be registered. The latter feature would seem to indicate that the configuration of the bottom here is highly irregular, but as at several places echoes of short duration were received from depths of up to 10,150 m we may take it that by and large the trench continues also through this area and is connected with the deeps at about 9° N even if the data are insufficient to be plotted in the chart.

Within the southernmost area of the chart we found several minor areas with depths of about 10,000 m. Here the trench is of a different character from that farther to the north, there being no evident

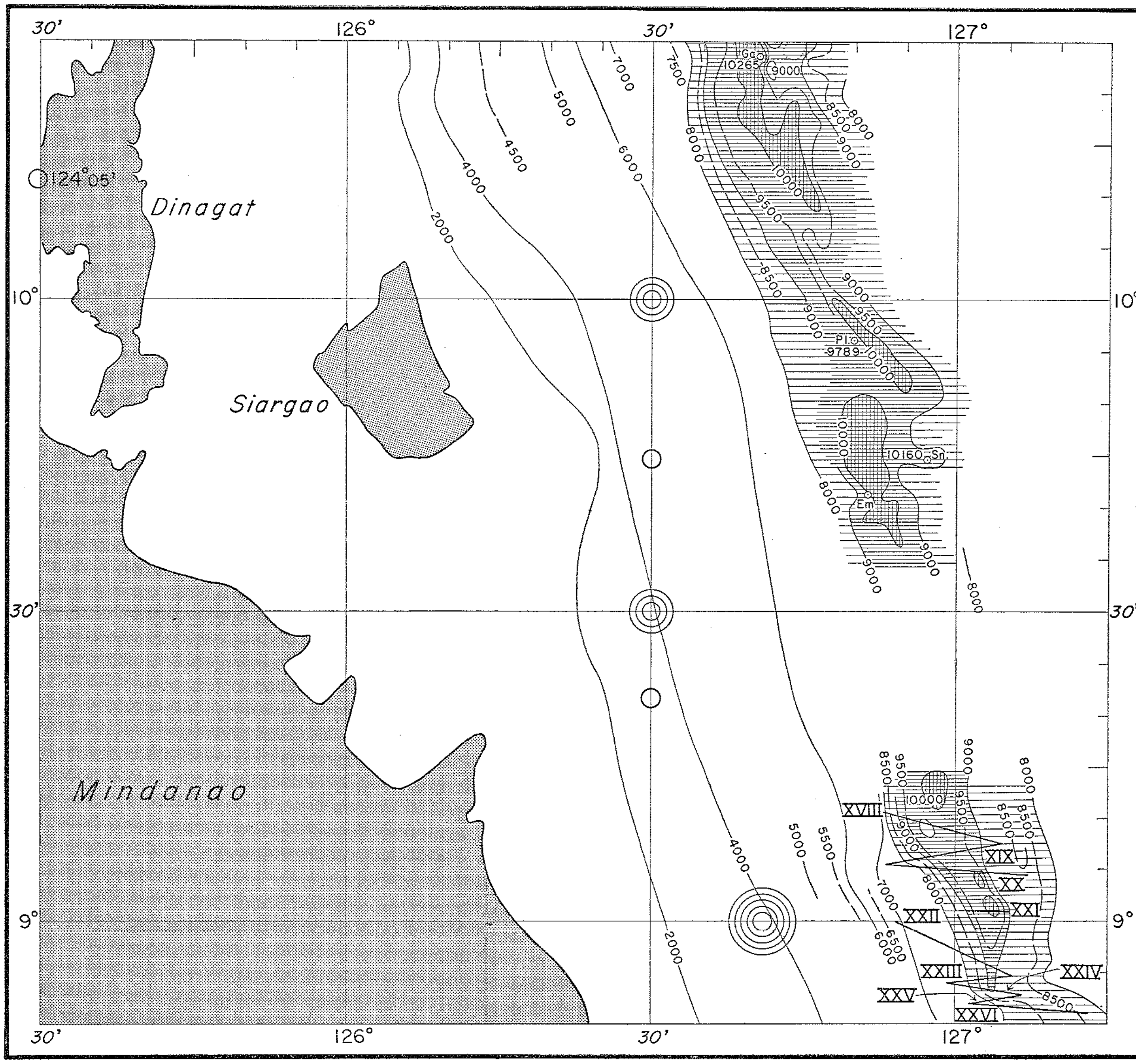


Plate VI

demarcation to the east. To the south of 9° N the trench flattens and in our southernmost section in 8°51′ N no depths of more than 8,750 m were sounded.

EARTHQUAKE CENTRES ALONG THE PHILIPPINE TRENCH

The many earthquakes which occur in the Philippine Archipelago have in most cases their epicentres on the slopes leading down to the surrounding deeps. The epicentres of the 15 earthquakes which in the decade 1920-1929 occurred on the western slope of the part of the trench dealt with in this treatise, have been indicated in the chart by circles (according to Repetti, 1931). More than one epicentre in the same position is indicated by several circles inside each other. The possibility exists that there is a certain relation between the many earthquakes along southern part of the trench and the irregular topography of this part.

By this chart we have endeavoured to compile and publish as much as possible of the great material of observations to be found in the many hundred metres of echograms from the Philippine Trench collected by the "GALATHEA". Many deficiencies may be found in the chart and, no doubt, also errors, but we entertain the hope that it may form the basis for the work of later expeditions within this area and that some of the experiences gathered by us and mentioned in this treatise may benefit others.

REFERENCES

ANONYMOUS, 1912: Die Planet-Tiefe. – Ann. d. Hydr. und mar. Met. Berlin. 1912: 610.

– 1912: Die Planet-Tiefe. – Zeit. Gesell. f. Erdkunde zu Berlin: 471.

BRUNEAU, L., N. G. JERLOV, and F. KOCZY, 1955: Physical and chemical Methods. – Rep. of the Swedish Deep-Sea Exped., **3**. Physics and Chemistry. No. 4. Göteborg.

BRUUN, A. and A. KIILERICH, 1955: Characteristics of the water-masses of the Philippine, Kermadec and Tonga Trenches. – Papers in Mar. Biol. and Oceanogr., Suppl. to **3** of Deep-Sea Res.: 418-425. London.

BUREAU HYDROGRAPHIQUE INTERNATIONAL: Carte Générale Bathymétrique des Océans. Monaco.

CARRUTHERS, J. N. and A. L. LAWFORD, 1952: The deepest Oceanic Sounding. – Nature, **169**, N. 4302: 601-603. London.

DIETZ, ROBERT S., 1954: Marine Geology of northwestern Pacific: Description of Japanese bathymetric Chart 6901. – Bull. Geol. Soc. of Amer., **65**: 1199-1224.

FISHER, ROBERT L., 1954: On the sounding of trenches. – Deep-Sea Res., **2**, No. 1: 48-58. London.

GROLL, 1912: Die neue Tiefenlotungen des »Planet« im Stillen Ozean. – Zeit. Gesell. f. Erdkunde zu Berlin, 1912: 629-631.

HERDMAN, H. F. P., 1955: Directional echo sounding. – Deep-Sea Res., **2**, No. 4: 264-268. London.

– 1953: Soundings taken during the Discovery Investigations 1932-39. – Discovery Rep., **25**. London.

HESS, H. H. and M. W. BUELL, 1950: The greatest depth in the oceans. – Trans. Am. Geophys. Union., **31**, No. 3: 401-405. Washington.

HODGSON, W. C. and A. FRIDRIKSSON, 1955: Report on Echo-Sounding and Asdic for Fishing Purposes. – Cons. perm. intern. pour l'explor. de la mer: Rapp. et proc.-verb. des réunions., **149**. København.

HUYSTEE, TH. VAN, 1944: Echo Soundings. – The Snellius Exped., **2**, Part 2, Ch. 3. Leiden.

KOCZY, F., 1949: Ekolodet, dess princip, utveckling och användning. – Sjöfartsmuseets Årsbok, Göteborg: 17-37.

MATTHEWS, D. J., 1939: Tables of the velocity of sound in pure water and sea water. 2.ed. London.

MAURER, H., 1928: Die Emden-Tiefe. – Zeit. Gesell. f. Erdkunde zu Berlin, 1928: 248-249.

– 1937: Eine Nachprüfung der Emden-Tiefe. – Ann. d. Hydr. und mar. Met., Berlin. 1937: 104-109.

REPETTI, WM. C., 1931: Philippine Earthquakes. Marine Epicentres 1920-1929. – Publ. of the Manila Observatory., **3**, No. 9: 199-203.

RIEL, P. M. VAN H. C. HAMAKER and L. VAN EYCK, 1950: Oceanographic Results. Part 6. Tables. Serial and Bottom Observat. Temperature, Salinity, and Density. – The Snellius-Exped., **2**, part 6. Leiden.

U. S. NAVY, HYDROGRAPHIC OFFICE, 1946: Bathymetric Chart, Korea to New Guinea including the Philippine Sea. No. 5485. Washington.

WÜST, G., 1951: Die grössten Tiefen des Weltmeeres in kritischer Betrachtung. – Die Erde, Zeit. Gesell. f. Erdkunde zu Berlin, 1950-51, H. 3-4: 203-314.

– 1952: Neue Rekordtiefen des Weltmeeres im Marianen-Graben. – Ibid., **4**: 114-115.

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