SOUNDING THE DEPTHS OF THE OCEAN FOR MAPPING THE CONFORMATION AND TOPOGRAPHY OF THE BOTTOM

(Extract from an article by Dr G. W. LITTLEHALES. See *Reports and Papers of the American Geophysical Union*, Thirteenth Annual Meeting — Washington, D. C., April, 1932, p. 33).

In former communications to the American Geophysical Union, I have referred to the bathymetrical chart of the Hydrographic Office, but to-day I have brought the sheets of the Monaco *Carte Générale Bathymétrique des Océans* because the sounding that are registered upon them have been counted, and it is the result of this count that I wish to relate in order to convey the impression that, while the state of knowledge that is necessary for the analysis of details has not yet been attained, oceanographers have been diligent in the careful consideration of the accumulations of soundings, but have been obliged to confine themselves to attempts to delineate those broad features of the general orography of the ocean-basins concerning which alone conclusions may at present be reached.

The total number of soundings greater than 1,000 metres in depth registered in these sheets is 14,900. Of these 6,100 are in the Atlantic Ocean, 2,500 in the Indian Ocean, and 6,300 in the Pacific Ocean. If they were evenly distributed throughout the several basins, there would be in the Atlantic one sounding to each area of 5,367 square miles, in the Indian one sounding to each area of 10,736 square miles, and in the Pacific one sounding to each 10,039 square miles. *There are regions of the ocean as large as the continental United States where not a single authentic sounding is recorded.*

While it must be remembered that not all the known soundings could be entered in some parts of these chart-sheets, yet where none is laid down, none has ever been measured; and in regions where soundings are represented, if all the reported soundings could be included instead of the selection which is given where the room does not allow more to be shown, there would yet be too few, in general, to serve for the delineation of the details of the contours of configuration of the bottom of the ocean. Nevertheless, there are some parts of the bottom of the ocean where the number and distribution of the measurements have proved sufficient to afford an approach toward a fulfilment of this purpose, notably in the South Atlantic Ocean since the expedition of the German steamer *Meteor* and in the lane extending from California to Hawaii, of which a contoured map and profiles are published in United States Executive Document No 153, Fifty-second Congress, First Session, being the *Report of the results of the Survey for the purpose of determining the practicability of laying a telegraphic cable between the United States and the Hawaiian Islands.* And, recently, the method of measuring the depth of the ocean by means of the sonic depth-finder has been employed in the survey of a tract of the bottom of the Pacific Ocean 34,000 square miles in extent, bordering the coast from San Francisco to San Diego and extending seaward to the depth of 2,000 fathoms. A map of the topography of the ocean-floor resulting from this survey by two vessels of the Navy in the course of 34 days has been published. This map was of great significance to the Advisory Committee in Seismology because it seemed to indicate that the mapping of the oceanic basins had been brought within the range of feasibility.

In the present edition of the *Carte Bathymétrique* the geographical position of each sounding is shown and the isobathic contours are delineated for each interval of 1,000 metres beneath the surface of the ocean and, besides these, isobaths are supplied at 200 and 500 metres. The areas between these contours on the charts are tinted blue in shades that become deeper with the depth of the water. The number of shades of blue thus reaches twelve.

The areas enclosed between the successive isobathic contours are now estimated as in Table I :

TABLE I. — ESTIMATED AREAS ENCLOSED BETWEEN SUCCESSIVE ISOBATHIC CONTOURS.

Contour		Area enclosed.	
From	To		
m.	m.	million sq. km.	per cent.
0	200	30.60	8.4
200	1,000	16.40	4.4
1,000	2,000	18.05	4.9
2,000	3,000	36.45	9.9
3,000	4,000	79.01	21.7
4,000	5,000	112.72	30.8
5,000	6,000	66.88	18.4
Beyond	6,000	5.38	1.5

By these results, it appears that about one-half of the sea-bottom lies at a depth exceeding 4,000 metres. A study of the distribution of these greater depths below 4,000 metres, below 5,000 metres, and below 6,000 metres, in successive 10° zones of latitude, has shown that, whereas the greatest expanse of ocean lies in the southern hemisphere, the areas of the floor of the ocean deeper than these successive isobathic contours are greatest in the northern hemisphere between the parallels of 10° and 40° of latitude, in the same planetary zone in which epeirogeny has attained its greatest manifestation in the continents. It is interesting to note that the area of less depth than 200 metres amounts to 30.60 million square kilometres, whereas the area occupied by the fourfold interval next succeeding, from 200 to 1,000 metres, amounts only to 16.40 million square kilometres. Thus, in proceeding oceanward from the coast, the descent from the emergent tracts into the ocean is marked in one of its earliest stages by one of the great, world-wide characteristics of submarine topography, consisting of a bordering platform dipping gradually under the sea to a boundary which, while it has no sharp definition in point of slope and depth; is commonly, though somewhat arbitrarily, regarded as being marked by the depth-contour of 200 metres, although in fact the depth of the edge, as well as the width of the zone, varies much in different continental regions.

This is the continental shelf and, as indicated by the foregoing measurements, it is adjoined by a zone of increased rate of descent, called the continental slope. Not only is the continental slope the seat of many deposit-slips and seismic disturbances, but evidence has been produced to show that underground rivers sometimes enter the ocean at depths beyond the 200 metre line and there bring about sudden changes in deep water. And, again, the continental shelf and the continental slope are occasionally traversed by gully-like physiographic features, such as the Monterey Gully on the coast of California and those associated with the mouths of the Hudson and the Congo, and other great rivers. The relatively diminishing areas which lie beneath increasing depths receal the presence of the maximum gradient of this slope between 200 and 2,000 metres and, in like manner, the increased areas which lie beneath the succeeding deeper zones mark the transition, between 2,000 and 3,000 metres, to the markedly lessened gradient which characterizes the course of descent prevailing thence throughout the depths ranging down to 5,500 metres.

In order to convey an impression of these gradients, a profile of the Pacific Ocean from California to the Hawaiian Islands has been constructed upon the same scale for the representation both of depths and of horizontal distances. From whatever part of the world they are obtained, such profiles do not support the view that the ocean-floor is in general devoid of features of relief. The present profile above mentioned is derived from a continuous line of homogeneous soundings taken less than 10 miles apart, on the average, and frequently at alternate intervals of 10 and 2 nautical miles, along the arc of a great circle of the Globe passing from Point Concepcion to Hilo. Although gentle gradients prevail, great mountainous formations are present in latitude 32°20' and longitude 128°03' and in latitude 27°25' and in longitude 140°42' and many variations of relief thousands of feet in elevation. Indeed, the diversification found to characterize the tracts about which most has been learned points to the view that the oceanic basins are extensively featured with orographical formations. The details of the subject can not be approached with any real sense of satisfaction until knowledge by observation is extended to provide materials for the delineation of isobathic contours at much closer intervals than 1,000 metres.

By the side of these general deductions may be mentioned the indications ascertained by seeking for the greatest difference in depth in each quadrilateral tract bounded by parallels of latitude 2° apart and by meridians of longitude 2° apart. In the North Atlantic Ocean, between the parallels of 45° and 53° of latitude, changes of relief varying from 800 metres to 1,200 metres were disclosed by this plan of investigation, which points to that which is seen in the topography of the continents.

The gradients at which many islands rise from deep-sea bottom is very steep. At the island of St. Helena there are slopes of 38°30' and 40°; at Tristan da Cunha 33°30'; at St. Paul, in the Atlantic Ocean, 62° on a short stretch. These slopes were found in the upper 300 metres; at greater depths the slopes are more moderate. Thus at St. Thome in the Gulf of Guinea, between 1,750 and 2,530 metres depth, the slope is 15°, while in the upper parts twice as much has been found. The submarine base of Jan Mayen, on the east side between depths of 620 and 1,940 metres, has a slope of 6°45' and thence to a depth of 2,330 metres, a slope of 4°. For the volcanic islands in the Mediterranean Sea, slopes of 15° to 22° are not uncommon. For the great Caldera of Santorin, the slope is over 50°. Molokai of the Hawaiian Islands, on the north side, has a slope of 6°15' to a depth of 3,800 metres. In the case of non-volcanic islands, the slope is often smaller, especially the boggy islands of the Mediterranean Sea, whereas Cuba, at 75° west longitude, on the south coast, slopes to a depth of 2,625 at an angle of 35°30'. In the case of coral islands, which often surround a volcanic core, the slope is also considerable. Thus, the base of the Bermuda Islands slopes down to a depth of 3,840 metres at an angle of 16°30'. The Lucipara Islands in the Banda Sea have slopes which, at a distance of two km. from the edge of the reef, average 34°42', while 50° is reached between depths of 200 and 400 metres; at greater depths the slope is only 16° to 19°. To afford a comparison, it may be stated that Fujiyama in Japan, one of the finest specimens of a volcanic peak, has a slope of 35° at the steepest part, and at the base it is still 12° to 13°.

Steep slopes are occasionally found also on the bases of the continents where the area between the depth levels of 1,000, 2,000, and 3,000 is comparatively small. An example of this is the quick descent of the European continent into the depths of the Atlantic. Westward of the British, French, and Iberian coast-banks, an average angle of 13° to 14° has been found. Several isolated mountains stand separated from the coast-bank at the point where the French telegraph cable from Brest to New York reaches the deep sea on the north side of the Bay of Biscay, in 48°30' north latitude; on the sides of these mountains are slopes from 30° to 41°, corresponding to Alpine conditions. Similar gradients have also been determined along the front of the continental slope of California where 35 profiles between San Diego and Point Concepcion have shown an average inclination of 13°.7 between the general isobathic contours of 2,000 and 4,000 metres.

The future doubtless holds in store the disclosure of many significant details in the configuration of the bottom of the ocean. In its present stage, the bathymetry of the ocean has served in the main to portray the generalities of conformation, consisting of rises and basins which seem to be continuous over enormous tracts of the Earth's crust, exhibiting a scale of structure much larger than that in which orography is usually contemplated. The great rises, such as the Mid-Atlantic Rise and the Easter Island Rise, are as large as whole continents; and the basins which flank these elevations are of continental extent.

The deeps are not, as might sometimes be thought, the pits of the basins, marking the limit of the contracting areas enclosed by successive contours of increasing depth; they are, as a rule, far removed from the middle part of the great oceanic basins and, by contrast, are found near the bordering lands where displacement phenomena have taken place on a large scale. Thus, in the North Atlantic Ocean, the greatest deeps are associated with the Great Antillean arc, in the South Atlantic with the Patagonian arc, in the Indian Ocean with the Java-Sumatra arc, and in the Pacific Ocean the most of them are along the island-studded ridges on the continental borders of the ocean. It is characteristic of them to be attended on the side toward the ocean with a rather low rise ascending by gentle slopes from the neighbouring oceanic basin of 6,000 metres and more in depth, and on the other side descending more steeply into the depths of the trough, from whose bottom the ascent toward the continental or the insular shelf proceeds by comparatively steep gradients. These characteristics may be seen in the contoured chart of the Puerto Rico Deep.