EXPLORING THE BED OF THE OCEAN*

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THE earth has, for very good reasons, been called the water planet. About 140 million square miles, or more than 70 per cent of the globe, are covered with water, and more than 90 million square miles of water has a depth exceeding 2,000 fathoms. No part of the earth's solid crust is less accessible to scientific investigations than the floor of the ocean. No part, on the other hand, offers a greater variety of unsolved problems. In our days, when both the north and the south poles have been reached, the deserts of central Asia, the primeval forests of Africa and of South America, and the barren ice-fields of Greenland and the antarctic continent have been explored, the last remaining white area on the world map is the ocean floor.

Over its abyssal area, an incessant although very slow fall of minute particles settles from the sea surface. There are remnants of plankton organisms, windblown dust from the great deserts, occasionally mingled with fine volcanic ash from great eruptions and, added to these, as very rare components, are tiny pellets of meteoritic iron scattered from the incandescent surface of shooting stars. In this manner the deep-sea deposits are built up through millions or hundreds of millions of years. They represent an unrivalled archive of the past history of our planet. Probing into them by means of tubular corers, sediment columns can be raised which contain the records from tectonic, volcanic, and climatic catastrophes of a remote past. On the other hand, the great ocean depths are not the lifeless 'azoic' region which they were supposed to be only a century ago. They are, in fact, inhabited by an abyssal fauna of fantastic creatures, capable of sustaining the terrific water pressure and the ice-cold temperature prevailing in great depths, without the faintest glimmer of daylight reaching down into the eternal night.

To science this fascinating field of study was thrown open by the famous *Challenger* Expedition of 1872-76, which marked the birth of deep-sea oceanography. During the three-quarters of a century which has passed since that pioneer cruise, immense progress has been made as regards instruments and methods used in marine research. In one particular respect, however, advance has been very slow, namely, in the technique of raising long and undisturbed cores from great depths. During the Second World War, Swedish oceanographers devoted a large part of their efforts to this problem. In 1942, by means of the vacuum core-sampler, constructed by Dr. B. Kullenberg and me, an undisturbed core, 45 ft. long, was raised from the depth of the Gullmar Fiord. Three years later the still more efficient piston core-sampler, invented by Kullenberg, brought up a core nearly 70 ft. long. Another advance, for which credit is due to Prof. W. Weibull, of the Bofors Armament Works, was the development of a method for sounding the thickness of the carpet of sediment over the ocean floor by recording echoes from exploding depth charges, which are reflected, not only against the bottom but also against the 'bottom below the bottom', affording a measure of a hitherto quite unknown quantity.

After the new methods had been successfully tested in considerable depths during a preliminary cruise to the western Mediterranean in 1946, we felt encouraged to start in the following year the first Swedish Deep-Sea Expedition, sponsored by the Royal Society of Göteborg. The expedition ship, the 1,450-ton motor schooner *Albatross*, the new training ship of the Broström Shipping Combine of Göteborg, was lent to us for the purpose, on very generous conditions. The costs of the expedition were defrayed by donations from leaders of Swedish shipping and commerce, mostly citizens of Göteborg. Before the start on July 4, 1947, the *Albatross* was converted into a floating laboratory with accommodation for a scientific staff of ten to twelve, in air-conditioned cabins and laboratories. With our very heavy gear, including core-samplers weighing up to 1½ tons, carried by steel cables 4,400 fathoms in length and worked from a 140-kilowatt electric deep-sea winch specially constructed for rapid work, it was found advisable to lay our circumnavigating course within or near the fair-weather region of the equatorial calms. Fortunately, we here also encountered problems of special interest, both as regards the deep-sea deposits and the water masses above them.

I think I may summarize the results gained from this cruise of fifteen months duration as, in the main, satisfactory. We brought back a continuous record of the bottom profile along some 20,000 nautical miles of our course, registered by an excellent ultrasonic echograph specially constructed for the expedition by the Marine Instruments Co., of London. This echograph proved extremely valuable for our work in great depths both with the coring tubes and later in our deep-sea trawlings. We further brought back, carefully packed and in cold storage, two hundred long cores taken from depths between 2,000 and more than 4,000 fathoms, the integral core-length exceeding one statute mile. We also had more than four hundred oscillograms from explosions in depths between 300 and 3,500 fathoms and their echoes, and some four thousand samples of sea water from varying depths, some of them of large volume, for uranium- and radium-analyses. Ten thousand temperature records by reversing thermometers or, in the surface layers, by bathythermographs, are included in the oceanographical data, which were mainly concentrated along cross-sections through the equatorial current system. Observations were also made on submarine daylight in different spectral regions, including the ultra-violet, and on the occurrence of light-scattering particles suspended in the deeper water layers. Special attention was given to the very lowest water layers down to about two fathoms from the bottom.

All this material is now being worked upon in different laboratories, both in Sweden and abroad, by specialists in physics, chemistry, mineralogy, radioactivity, biology, etc. It will be several years before all our samples have been analysed and the results made ready for publication. At this stage of our investigations I can only give a brief report on results so far obtained.

Echograms. These display a surprising unevenness of the bottom profile, also in great depths. Sometimes

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it rises or falls by distinct 'steps', from half a nautical mile to several miles in width, with heights varying between tens and hundreds of fathoms, suggesting 'faults' we must have crossed more or less transversely. In other instances, the bottom appears to be strewn with small hills or hummocks, giving two or more intersecting curves. A perfectly level bottom is an exception rather than the rule, a fact which proved a serious complication, both for coring operations and in our sediment measurements, as well as later in deep-sea trawling.

Explosion echoes. These echoes from the 'bottom below the bottom' surprised us by giving considerably greater values for the apparent thickness of the carpet of sediment in the Atlantic Ocean than in the Pacific and Indian Oceans, up to nearly 12,000 ft. and less than 1,000 ft., respectively. A possible explanation of the lower values may be the occurrence of intermediate lava beds, due to submarine eruptions, intercepting or reflecting the explosion waves. That such lava beds actually exist was proved by the coring work, for repeatedly a coring tube was stopped or damaged by hitting 'hard bottom' beneath a more or less superficial 'veneer' of recent sediments. In some cases broken-off fragments found in the bit of the corer showed beyond any doubt that the obstacle was, in fact, a lava bed.

Sediment cores. These very often displayed a distinct and multiple stratification, indicating that conditions of sedimentation have varied considerably during the time represented by the length of the core. Such stratified sediments appear to be specially common near the equator. Shifts in the latitude of the equatorial counter-current with its attendant strip of divergence in the surface, that is, water rising from lower depths rich in nutrient salts and in plankton, appear to give a plausible explanation for this stratification. In some cases stratification may have been caused by changes in the level of the sea bottom itself or else, in the vicinity of submarine slopes, by 'slumping'. Vegetable remains were prominent in cores from the Gulf of Panama, from the Sunda Sea and the Mediterranean, as well as from the western part of the equatorial Atlantic Ocean. On the other hand, mid-ocean cores of red clay, apparently homogeneous, save for their becoming more compact in the lower levels, were also found in lengths exceeding 40 ft., indicating that sedimentation had there proceeded practically undisturbed for at least one, if not two, million years.

Volcanic ash layers or other layers of coarser grain were frequently found intercalated in the ordinary fine-grained sediment, especially in the Mediterranean but also in the Sunda Sea. Both in the Mindanao Deep and in the Romanche Deep, cores with thick layers of fairly coarse mineral fragments were raised from depths exceeding 4,000 fathoms. In the vicinity of extensive desert regions, as in the Red Sea and off the west coast of North Africa, wind-blown sand was a normal component in the cores.

Components of planktonic origin have been looked for in several of the cores, especially shells of pelagic Foraminifera. Both in cores from the Mediterranean and from the Caribbean, Dr. Fred Phleger has found evidence for considerable temperature variations in the water surface, reflected in the varying composition of the calcareous remains. The most plausible explanation is that these temperature variations have been caused by alternations between cold (glacial) and warm (interglacial) periods during the Quaternary Age. Similar results have been found by

W. Schott with cores taken in the open Atlantic. These finds give hopes that submarine chronology may be linked up to the time-scale of continental glaciology. Another possible clue to submarine chronology, at least with cores taken within moderate distances from continental coasts or from forested islands, is derived from a preliminary analysis of the pollen grains found in considerable numbers in cores from the Tyrrhenian Sea. A third possibility is that of radioactive analysis of the upper layers, in which ionium precipitated together with ferric hydroxide from the sea water gives rise to radium, decreasing downwards with the half-period of 82,000 years. Finally, volcanic shards, found in sediment cores and identified from one locality to another, may lead at least to a relative chronology of the different strata, wherever isochronic surfaces can be recognized.

Temperature gradient. In the deep sea bottom, the temperature gradient is one of the outstanding problems of deep-sea geophysics. A special geothermometer, 11 metres long and plunged into the sediment, had been specially constructed for this purpose. Although it worked quite well in other respects, the clockwork used for turning round a tap of the sensitive spirit thermometer it contained generally failed to work at the low temperature of the bottom water. Only two fairly trustworthy values were obtained in the central and the western parts of the Pacific Ocean. Both gave unexpectedly high values for the geothermal gradient, namely, 22 and 26 metres per degree centigrade, so that this particular problem must be left for future deep-sea expeditions to study.

Radium and uranium content. Measurements of the radium and uranium content in large-volume samples of sea water from various localities and depths have confirmed earlier results obtained from a much more limited material. The uranium content, measured in the Institut für Radiumforschung in Vienna, is fairly constant, varying between limits of 1.0 and 1.6 micrograms per litre, with a slight tendency to an increase in great depths. The radium content is always considerably less than the theoretical value in radioactive equilibrium with the uranium (about four units of the thirtieth decimal of a gram per litre), being generally only about one unit of the same decimal place and very often considerably less. Also here a tendency to higher values with increasing depth is manifest. This deficiency in radium already observed in our earlier work supports the hypothesis of a precipitation of the intervening element, ionium, to the sea bottom; this, incidentally, would also explain the generally high content of radium in the red clay and in radiolarian ooze.

Oceanographic studies. Studies of temperature, oxygen and dissolved salts in sea water from different depths were mainly concentrated on sections across the equatorial current system. The analyses, which are now being completed in the laboratory, will afford valuable material for studying the interesting dynamics of the equatorial counter current. The occurrence of light-scattering particles in deep water was also studied, the results indicating that maxima of such particles occur in certain depths.

Biological investigations. Biological work was mainly limited to trawling in great depths in the Atlantic Ocean during the concluding four months of the cruise. Dr. O. Nybelin, director of the Natural History Museum in Göteborg, who conducted these investigations, was greatly helped by Dr. Kullenberg, who worked out the theoretical value of the length

of steel cable required for keeping the trawl on the bottom. Here the deep-sea echograph proved a most valuable asset, since it enabled us to keep the depth in which the trawl was being towed under permanent control and also to pick and choose our trawling ground beforehand, so as to avoid an uneven bottom, dangerous to the gear. Very good catches, both of fishes and of invertebrate organisms, from great depths were made, some of them very rare or even new to science. The deepest haul, made to the north-east of the Virgin Islands, gave conclusive proof that even in depths exceeding 4,200 fathoms (7,600–7,900 metres) bottom-living organisms exist, such as sea-cucumbers and -worms. In all probability even the greatest depths of the ocean are inhabited, although by a sparse and highly specialized fauna.

By means of a large sledge-net towed along the bottom in a depth of about 2,800 fathoms to the south-east of the Bermudas, several hundred manganese nodules, some of them of fairly large size, were obtained. Their rate of radial growth is now being determined by radium measurements in their different layers. Quite near this locality an interesting core was raised by means of a core sampler of specially wide bore. Its uppermost layer was a manganese crust followed by a terracotta-coloured paste rich in iron. But the lower parts of the core also gave a rich display of varying colours.

In general, the results both from the sediment work, the oceanographic series, and the deep-sea trawling lend support to the view that adequate technical resources are now available for extensive research in great ocean depths; such research is of great importance not only for oceanography but also for the almost novel science of submarine geology. A few points which appear to be specially worthy of future study may be mentioned.

(1) The surface layers of the deep-sea deposits in their interrelation with the bottom water. Here water bottles closing at definite heights above the bottom and core-samplers imparting a minimum of disturbance to the semifluid uppermost sediment layer and at the same time giving sufficient material for detailed analysis, centimetre by centimetre, should be used. In connexion with such sampling, the plankton community existing in the upper water layers, especially the foraminifera, should be sampled by means of quantitative plankton catchers.

(2) The raising of long sediment cores has been proved feasible during the expedition, in spite of fairly strong wind and ocean swell. The region we have explored should in future be extended to higher latitudes on both hemispheres. In such long cores reaching well back into the late Tertiary, both the pelagic and the benthonic foraminifera should be studied, with the view of ascertaining by how much the temperatures of the bottom layers were then higher than at present.

(3) The geothermal gradient in the deep-sea bottom should be extensively measured by means of an improved technique. A point of special interest will be to extend these measurements to regions both within and outside areas of pronounced volcanic activity.

(4) Measurements of sediment thickness by means of an improved technique should be carried out in great depths, preferably also by means of depth-charges exploding below the surface of the sediment.

(5) Continuous records of the bottom profile across the oceans should be taken wherever possible. If naval ships on ocean-crossing cruises could be pro-

vided with the supersonic echographs of great range now available at moderate costs, their cruises might afford most valuable material both for bathymetrical and morphological studies of the ocean floor, where hitherto so very little is known.

In the first years of this century an international organisation was set up for co-ordinated systematic work in physical oceanography and in biology over the shelf area and the adjacent continental slope off the coasts of north-west Europe. The International Council for Sea Investigations has carried out invaluable work during the half-century of its existence. The much vaster field offered by the deep ocean now seems to call for a similar co-ordination of efforts on an international scale. Great Britain, where deep-sea oceanography was born, would seem destined to take a leading part, on the European side, of this future work.

507

RESEARCH IN THE COLONIES

WITH its third issue under the title "Colonial Research (1948–1949)"* the collection of annual reports dealing with Colonial research now appears to have taken something like final shape. Under that title the present volume of 134 pages includes the annual report of the Colonial Research Council, the sixth annual report of the Colonial Products Research Council, the fifth annual report of the Colonial Social Science Research Council, the fourth annual reports of the Colonial Medical Research Committee and of the Committee for Colonial Agricultural, Animal Health and Forestry Research, and the second annual reports of the Colonial Insecticides Committee and Colonial Economic Research Committee. That from the Colonial Research Council is the master report covering the whole field, including those of the specialist advisory bodies, and to it are appended a list of schemes approved for research grants under the Colonial Development and Welfare Acts during the period April 1, 1948–March 31, 1949, and of allocations for research under those Acts, 1940–March 31, 1949. Some of the information has already been given in the return of schemes published in July as Colonial 211 and in "The Colonial Territories (1948–1949)" (Cmd. 7715), to which reference has already been made (see *Nature*, August 6, p. 199).

Actual disbursements on research schemes during the year under review amounted to about £750,000 as against £425,760 in 1947–48, and £169,388 in 1946–47. In addition to major schemes already noted as made during the year, this report refers particularly to those for the acquisition and equipment of the Sir Alfred Jones Medical Research Laboratory in Sierra Leone, the preparation of a flora of East Africa, research into the effects of 'Antrycide' injections on cattle in East Africa and provision for the appointments of directors of the projected West African Agriculture and Forestry Research and Veterinary Research Organisations, and for postgraduate training in Great Britain of prospective workers on fisheries and stored products research. A new series of "Colonial Research Publications" was instituted by the Colonial Office for reports by persons engaged on research in the Colonial sphere financed by Government sources, and three reports in this series appeared during the year.

* Colonial Research, 1948–1949. (Cmd. 7739.) Pp. 134. (London: H.M. Stationery Office, 1949.) 2s. 6d. net.