H.M.S. CHALLENGER'S WORLD VOYAGE 1950-52

Part II. Indian Ocean and Mediterranean and Techniques of Measurement.

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A contemplation of the work of naval expeditions since the time of Byron cannot fail to force the conviction that this is legitimate work for the Navy in time of peace. (*The Royal Navy* - A History, Vol. VII, p. 568, by Laird CLOWES).

Challenger spent the winter of 1951-52 around Japan, and in April, 1952 proceeded to the Mediterranean until September, when the sailed for England to arrive at Portsmouth 2 years and 5 months after leaving Plymouth. In addition to the narrative started in Part I of the article, this Part II will contain a description of the techniques used in the various series of scientific observations that were made during the world cruise.

Japan

Kure was the base for the ship during the stay in Japanese waters, and, being one of the British Naval Bases for the Korean war, it provided many opportunities to meet friends from home, and also some from the Dominions whose acquaintance has been made earlier in the expedition. The greater part of the time was spent in the north at the small naval port of Ominato on the north-eastern corner of Mutsu Kaiwan, Honshu. It was here, in agreement with the Japanese that a Fleet Summer Base had been established in 1948, and a detailed survey of the anchorage was required. The weather was inclement, and at many times surveying was stopped by snowstorms. However, it as possible to go ashore to study the customs of the Japanese and the formalities of tea-parties, weddings and saki-drinking were observed. The local judo club ran classes for volunteers from the ship and several of the ship's company took up skiing; excellent duck-shooting was also available. In many ways the life was reminiscent of the visit to the North West Canadian Islands during the previous winter.

Seismic experiments were carried out in Mutsu Kaiwan with the sono-buoys anchored and with charges fired from the ship's motor boat. A layer of sediment in which the velocity of sound was 2.0 km./sec. (6,500 ft./sec.) and whose thickness varied from 1.0 to 2.6 km., was found to cover a basement layer characterised by a sound velocity of 6.5 km./sec. (21,600 ft./sec.).

At the close of one day's seismic experiments an earthquake shock was experienced; in the ship at anchor, it felt as if the engines had suddenly started up, and on the shore the ground shook like a jelly for several seconds. The earthquake centre was several hundred miles out at sea to the north-east, but it caused a seismic wave which did a great deal of damage on the shores of the island of Hokkaido to the north.

A visit was paid to the American Naval Base at Yokosuka, where the Ship was greeted by a troupe of geisha girls dressed in traditional costume, and a fleeting glimpse was obtained of Mt. Fuji. It only needed a dish of sushi to complete the three things that proverbially one must see in Japan.— Fuji, geisha, sushi. The Japanese Hydrographer Dr. K. Suda, was shown round the ship, and in his turn entertained several of the Officers at the Hydrographic Department in Tokyo. Lectures were given at Tokyo University and at Hiroshima describing the experimental work carried out in *Challenger* and the results that had been obtained. Hiroshima still bore traces of the atom bomb, but the greater part of the city had been rebuilt and was thriving.

Challenger left Kure for the homeward journey on April 15th, after a few weeks of the beautiful spring blossom for which Japan is so rightly famous.

Japan to Singapore

The journey to Singapore was made with a short stop at Hong Kong for fuel. During the passage to Hong Kong two reported shoal areas were searched, but no shallow soundings were observed. A sea-mount (1,235 fathoms) was discovered in 21°25' N., 128°30' E., and another (638 fathoms) at 14°58' N., 111°58' E. (22). The ship's course passed about 60 miles to the north of a most interesting phenomena, the volcano Didikas erupting out of the sea. However, by the time a report of the occurrence was received it was too late to turn back to gain first hand knowledge.

Two seismic refraction experiments were carried out in the deep water of the Philippine Sea. At both, a few thousand feet of sediment was lying directly on rock in which the velocity of sound was 5.9 km./sec. (19,500 ft./sec.). This velocity is somewhat less than found in flat deep areas of the Pacific, and it is probable that a different type of rock exists here. The large deep area of the Philippine Sea is peculiar, in that it lies to the continental side of the andesite line, but yet is as deep as the Pacific Ocean proper. It will be necessary to determine the depth of the 8 km./sec. layer in order to tell whether the area is true permanent ocean or continental in type.

Singapore was reached in May, and the ship was re-stored during a week at the Naval Base, in readiness for the long run to the Mediterranean. Eight to ten depth charges were used for each seismic experiment and it was always difficult to carry adequate numbers when moving long distances between Royal Naval Store Depots.

The Indian Ocean

The Indian Ocean as entered via the Sunda Strait, since it was desired to find out something of the submarine geology of the Indian Ocean south of the equator. The route home had been arranged to be through the Mediterranean rather than round the Cape, and so there would be no further opportunity of work in the Southern Hemisphere. Sunda Strait was passed in the night and it was not possible to see the remains of Krakatoa, where the great earthquake of the last century blew up part of an island with an explosion equivalent to about a million tons of dynamite.

Although the Indian Ocean was calm, there was a long swell running, and this was a hindrance to seismic measurements that had not been met before, or expected at this stage. After one day experimenting with improved methods of supporting the hydrophones, a technique was evolved which allowed fair results to be obtained at five stations in five days. This was not most concentrated set of experiments of the whole expedition, and was possible because of fine weather and a keen and experienced crew.

The geological structure at the first station, was very similar to the Type « A » found in the deep flat areas of the Pacific, there being 0.4 Km. of sediment resting on a material in which the velocity of sound was 6.4 Km./sec. North of 5°S the Indian Ocean was shown on the echo sounder to be extraordinarily flat; for hundreds of miles there were no irregularities of more than a few fathoms, and the level sloped gradually up from 2,700 fathoms at 5°S to 2,300 fathoms near Ceylon. The *Albatross* had recorded a long distance of level sea-bed in the Indian Ocean during her 1947 expedition. Two sea-mounts were observed to rise steeply out of the flat ocean bed. One was a very large feature, reaching a height of 7,000 ft. above the sea floor and being at least 40 by 60 miles in size. There was not time to check the extent fully to the South-West, but several good traverses were run across the flat top, and it was considered suitable for a seismic refraction experiment. Apart from the study of coral atoll structure, the seismic work had been directed mainly to the problem of the geological structure in the flat ocean, and this was the first opportunity to determine what kind of rock formed a sea-mount. The results showed that the sea-mount was made of materials with a sound velocity of 4.2 km./sec., indicating that it could be volcanic rock, as in the Pacific at Funafuti and Hawaii. To the South and West of the sea mount the basement is covered with 1.5 Km. of 4.2 - 4.5 Km./sec. rock, together with about 0.5 km. of sediment. The cover material may be volcanic in origin, but it does extend much farther, (about 300-400 miles at least) than did the similar material at Funafuti and Hawaii (about 30-40 miles). It is possible that there were other sea-mount sources of volcanic material that were missed by the ship, since the echo sounder only measures the depth along the track, and there was seldom time to search large areas of deep ocean. The whole area North of 5°S and extending almost to Ceylon may be an enormous flow of volcanic material, similar to the Deccan of India. The flow may be through continental type geological structure, or it may be eruption from the permanent ocean bed as in the Pacific. Longer seismic lines, for which two ships would be necessary, are required to settle this point, by finding the depth of the 8.0 Km./sec. layer, which will only be about 10 Km. deep under permanent ocean but 30-40 Km. deep beneath continents. The appearance of the limited seismic results of *Challenger* is somewhat similar to the large volcanic area around Bermuda.

The call to refuel at Colombo was extended by a few days because of a cracked boiler (*Challenger* was getting old and was overdue for a major refit). This gave an opportunity for a visit to the beauties of Kandy and the ruined cities of Polonnaruwa and Sigiyra, and drives through what is one of the most delightful islands in the world.

The moonson had started and the course was set to take the ship via the Seychelles in order to avoid rough seas, and to see this most interesting group of Islands. The Seychelles are rather off the normal track of shipping, and there are not many visitors, but those there are receive a magnificent welcome, judging by *Challenger*'s experience. A special programme of football, picnics, swimming and diving had been prepared and was greatly enjoyed. While at anchor at Port Victoria a short seismic experiment was carried out in order to determine the velocity of sound in the granite rock of which the island of Mahe is composed. A thin cover of coral rock, with velocity 2.1-2.7 Km./sec. (7,000-9,000 ft./sec.)

was found to be above the granite, in which the velocity of sound was 5.5-6.0 Km./sec. (18,100-19,700 ft./sec.).

It is strange that the two groups of islands that are near the tropics, and are isolated, the Galapagos and the Seychelles, both produce curious fauna and flora. The giant tortoises of the Seychelles are among the largest in the world, and the unique coco-de-mer palm carries the largest fruit that is known.

The granite of the Seychelles may be the remnant of an old land mass running from Africa through Madagascar to Ceylon. It may, on the other hand, be a remnant of material left straggling behind, when the nearly solidified scum which possibly formed the continent was floating on a liquid earth. Unfortunately it was not possible to do any seismic measurements on the run North to the Red Sea; the all-too-familiar bad weather was in attendance, since the monsoon had started.

After a short call at Aden for fuel, and a hot Red Sea passage, it was pleasant to steam through the Suez Canal to arrive in the Mediterranean on July 1st.

The Mediterranean

The Mediterranean is not one of the large oceans of the world, and much better guesses at submarine geology can be made for this comparatively narrow sea, with its many islands, than is possible for the vast areas of deep ocean. However, no seismic experiments had been done in the Mediterranean and any results were therefore of interest, even if only to confirm geological forecasts. The position of seismic stations was planned as far as possible to fit in with areas that were shown to be interesting by the submarine gravity survey, carried out in 1951 by H.M.S. *Talent* and the Cambridge University Department of Geodesy and Geophysics.

Station 27, on a flat 1000 fathoms area about halfway between Port Said and Cyprus did not yield any information about a high velocity basement layer such as was observed in the oceans. A material in which the velocity of sound was 4.4 Km./sec. was covered with about 0.3 Km. of sediment. From the results it was possible to say that, if a 6.3 Km./sec. basement layer did exist, it must be at least 1 Km. below the 4.4 Km./sec. layer. A basement layer was observed in Famagusta bay, to the east of the island of Cyprus and it was about 1.5 Km. below a material of velocity 4.4 Km./sec. It is possible that the structures are similar, and that the basement layer is 2.7 Km. below sea surface east of Cyprus and more than 3.2 Km. to the south. The gravity results suggest that there is a line of extra dense rocks running from Morphon bay to Famagusta through the middle of Cyprus, and extending out to sea eastwards. Cyprus has been interesting for its gravity anomalies ever since it was observed that star transits taken to the north and to the south of the island gave a distance which was different from that from triangulation, by considerably more than the errors of measurement.

An echo-sounding survey to the north east of the Morphon Bay showed that the mountains ran some miles out to the sea before ending quite suddenly. At the west of Cyprus a seismic station in Morphon Bay showed that a layer with velocity 4.1 Km./sec. was some 2 Km. deep, and it is probable that this is caused by a fault which has dropped the volcanic pillow lava, which can be seen on the surface a mile to the east. A similar fault has been noted from a boring to the south of the island and there seems little doubt that Cyprus is an old igneous massif bounded by faults on all sides; this gives an isolated steep sided mass to produce the peculiar gravity results.

The Aegean

After leaving Cyprus *Challenger* went up the Aegean to Salonika. An aera to the south east which the chart described as Venus bank was surveyed. Several weeks were spent in the Aegean visiting the islands in pleasant summer weather. At Mudros where the fleet for the Dardanelles operation was assembled, the old cemeteries were visited and some assitance was given to the local caretaker in minor repairs and in painting the gates. The cemeteries are quite well kept gardens with a gentle peaceful atmosphere. At Skyros a visit was paid to the grave of Rupert Brook in its little grove of olives that was visible from the ship at anchor. The stonework had many initials carved on it and the ironwork is broken in one place; apparently the rather sparsely inhabited island of Skyros is visited by parties of tourists. However the grave is tidy and well preserved.

The sardine fishing boats were a common sight at Mudros and one large vessel with storage space and an engine tows a smaller net carrier and six small light-carrying boats. The latter are dropped off at the fishing grounds so that the light can attract the fish. A signal on a horn when a shoal is indicated by bubbles, calls the parent ship to round up the fish in a net.

A few days were spent visiting monasteries in the Mount Athos Peninsula, where an all male population lives, in varying degrees of strictness, a truly medieval monastic life. The monks were most hospitable, and showed their relics of the early days of the Christian faith to many of the ship's company. The monasteries in many cases are perched high on rugged rock faces. The end of the peninsula is dominated by Mount Athos, at the top of which is a small chapel, 6350 ft. above the sea. The chapel is used once a year and on a clear day it is said that Constantinople is visible to those who have the energy to climb up to the top.

The weather was unkind enough to make seismic experiments to the North and West of Crete impossible, but two short refraction lines were obtained in the South of the Ionian Sea, where the sea-bed is fairly flat at about 2000 fathoms. At both places the picture was similar, and 0.4 Km. of sediment covered material in which the sound velocity was 4.5 Km./sec. This was a similar picture to that at the station in the South-East Mediterranean, and it is unfortunate that the experiments were not able to be extended to observe refracted waves from a deep basement. The 4.5 Km./sec. layer may be limestone or volcanic rock, and further evidence is needed before more can be said. It is interesting that the thickness of sediment is much the same as found in the oceans.

Malta

A visit to Malta to refuel served as a reminder that *Challenger* is not the only ship in the Royal Navy. Since Bermuda the ports of call had been ones to which H.M. Ships were infrequent visitors, or had been Naval Bases belonging to other nations.

A short experiment, in a moderate and very short sea, and using one sono-buoy only, showed that 0.2 Km. of sediment lay on top of material with velocity of 3.5 Km./sec., and that this latter material must extend more than half a

Kilometre downwards. This indicated that the hard Malta corallian limestone, which should be within a few hundred metres of the surface, was missing, and it is probable that the channel between Malta and Sicily rest on a calcareous marl similar to that seen in N.E. Sicily. A second refraction station to the South of Malta showed a high velocity (5.7 Km./sec.) layer near the surface, and this could well be the hard Malta limestone. What proved to be the last seismic experiment of the expedition was carried out between Tripoli and Malta, and the geological structure was very similar to that found at the south of the Ionian Sea, although the sediment was considerably thicker (nearly 1 Km.).

Gibraltar and Home

The journey to Gibraltar was uneventful, apart from an electrical fault which necessitated a short delay in the dockyard. Actually, this was probably a sign that the old ship wanted to be home after her long travels, and in fact home was nearer than anticipated for the extensive series of experiments that had been planned in the Atlantic were prohibited by the bad weather for the first week out of Gibraltar, and where cut short when the main shaft jammed. The propeller was got moving after much valiant effort, but *Challenger* had to go straight home to arrive in Portsmouth on September 27th, just under 2 1/2 years since leaving England.

A final sea-mount (794 fathoms) was discovered after leaving Gibraltar, at 38°00' N., 13°20' W. (22).

Method of Experiment

1. *Sounding.* — Two types of echo sounder were fitted in *Challenger*; the « Shallow Water » 767, and the type A/S 49, specially fitted for deep ocean sounding. The 767 was used for routine observations in deep water, since in fine weather, it gave a record in depths of 3000 fathoms, and even recorded 4100 fms. in the Japan Trench. The 767 had a scale width of 160 fathoms so although it had to be phased at frequent intervals in areas where the topography was rugged, it could show up changes in depth of a few fathoms, and this gave some character to the record, so that sea-bottom of different types could be differentiated. The 767 transmitter was magneto-striction type working at 16 Kc.

The type A/S 49 had a 10 Kc. Quartz transducer and gave a longer and more powerful signal than the 767. The recorder has a scale width of 750 fms. and it was therefore difficult to lose the echo because of incorrect phasing. However, the long pulse, and the smaller scale record together with the slower paper speed, made the picture of the sea-bed less colourful than that of the 767. In practice the 767 was nearly always used; a check for correct phasing was made with the A/S 49 when required, normally by listening.

In very deep water the A/S 49 was used with an operator listening, since an audible signal would not always mark the recorder. The interval between transmission and return of echo was timed, sometimes by a stop-watch, but more readily by noting the position of the recorder stylus when the echo was heard. This method was used in the Mariana Trench when the A/S 49 proved itself capable of measuring the deepest ocean depth. The error of recording by this method is of about the same magnitude as that due to uncertainty in he velocity of sound in sea-water and is $\pm$ 20 fathoms.

Seismic Experiments

In order to probe into the layers that constitute the earth's crust, the sound impulses sent out from explosions are recorded, after they have travelled into the various geological formations below the sea. The simplest method of gaining information is to time the wave that reflects from the interface of two layers, but the velocity of sound in the upper layer is required in order to calculate the depth to the interface and in the oceans the constitution of the various layers is not really well enough known to make a good guess. Furthermore reflections always arrive after the very strong wave that travels through the water, and are generally obscured. There is, however, a wave that can arrive before any others, and its arrival time can be measured accurately. This wave is the refracted wave and if the horizontal range is sufficient it arrives before the direct sea-water wave, because the fast travel in the sea-bed more than compensates for the extra path length down to the sea-bed and back. In a similar way a traveller from Piccadilly Circus to Green Park will find it quicker to walk, but to go to Gloucester Road it is worth while going down the steps to travel by Underground. Refracted waves may travel in deeper layers and, if the velocity of sound in the deeper layer is greater than that in the layer above, waves from the deeper layer will, at sufficient horizontal range, appear as first arrivals. By measuring arrival times at various distances the velocity of sound in each rock layer is determined, together with the thickness of each layer. The rock layers cannot be identified unambiguously by the sound velocity but from extensive measurement on land it is possible to restrict the possibilities considerably. Thus, clays are usually 1.5 - 2.4 Km./sec., and may be consolidated to 3.0 Km./sec.; limestone unfortunately has a wide range from 2.4 to 5.5 Km./sec.; granite rocks are 4.8 to 6.0 Km./sec. and basic rocks such as basalt and gabbro are 6.0 to 6.9 Km./sec. However, although the velocity does not identify the rock, it is possible to be correlate the result from one place to another, geological layers being labelled by their velocities. Furthermore the refraction method does give a true picture of the depths at which discontinuities between the various rock layers occur, even if the geological names of the layers are not certain.

The method of obtaining the arrival times of the waves from explosions at different distances was developed by Hill and Swallow (4) (24). The waves from an explosion initiated by the ship are picked up by a hydrophone suspended from a sono-radio buoy which carries a radio transmitter and sends all hydrophone noises the back to a receiver in the ship. The output from the receiver, together with that from three other similar hydrophones, buoys and receivers, are recorded on moving photographic paper by galvanometers. Time marks are made on the paper every 1/20th second. Figure 1 shows diagramatrically how the waves from the explosion travel to the hydrophones. The sono-buoys are laid from the ship half a mile apart in a straight line and the ship steams off in the same line and drops a depth charge every two miles. The instant at which the charge goes off is recorded on the moving photographic paper by means of a hydrophone in the ship. When the ship has gone 15 to 20 miles from the buoys it returns and fires any shots that appear to require repeating and continues to fire a few shots along the line beyond the buoys. The reason for this is that if the layers of rocks are not level the slope may be determined if refracted wave times are measured both down-dip and up-dip. The sound wave that travels directly from the explosion to the hydrophones is recorded together with the refracted wave through the sea-bed, and is

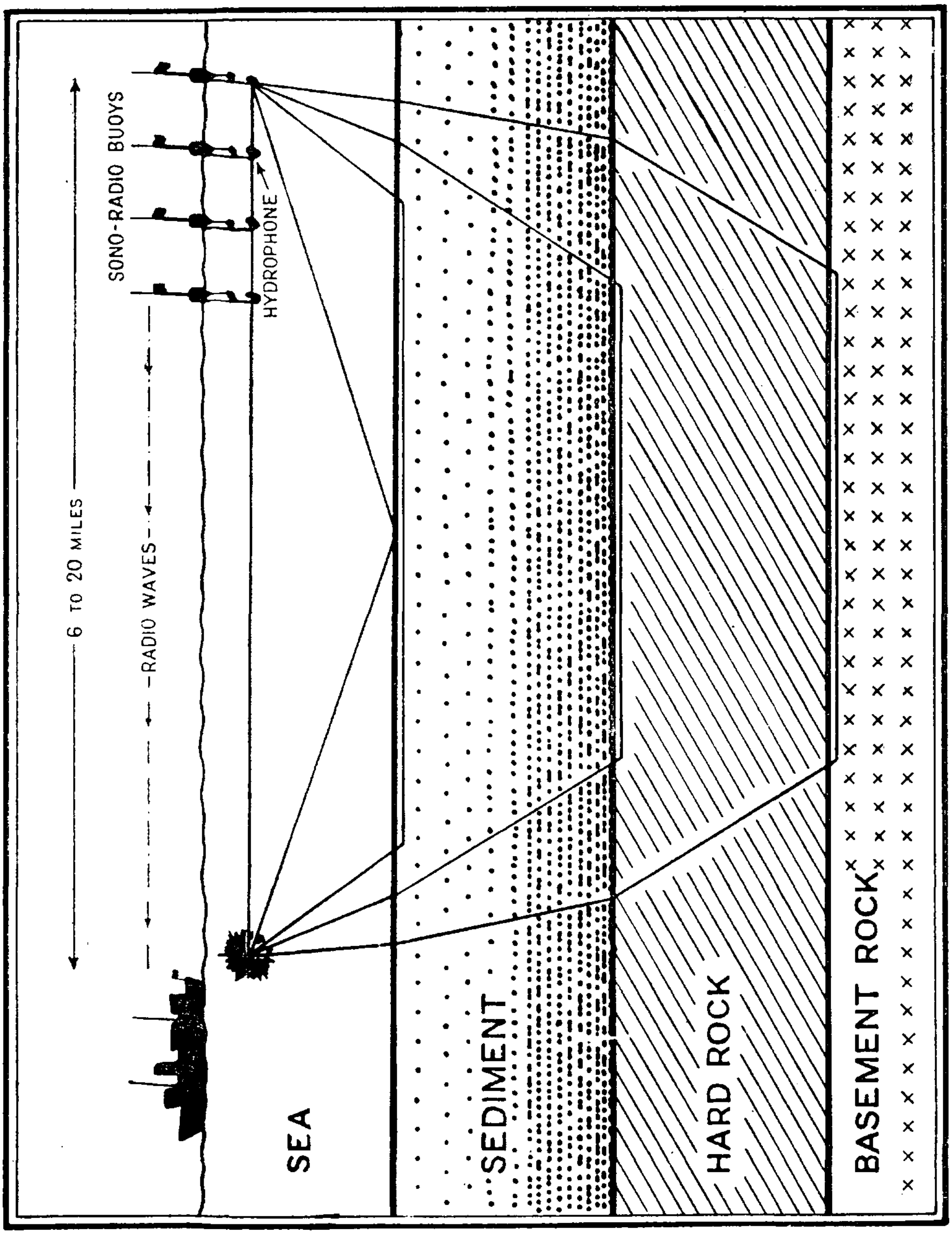

Fig. 1. — Lay-out of seismic refraction experiment, showing the paths by which various waves travel from explosion to the hydrophones.

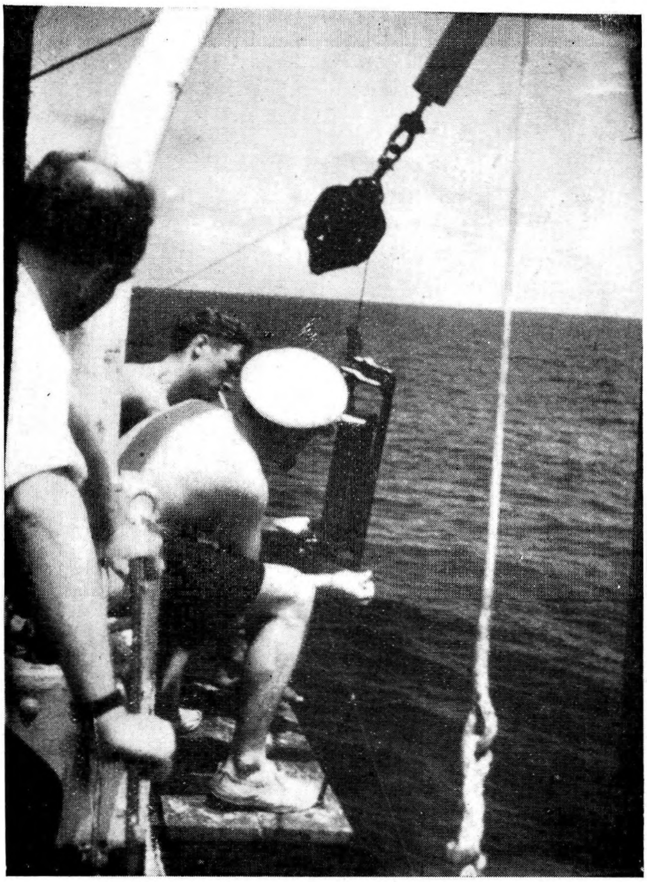

Fig. 2. — Reading reversing water bottle temperatures.

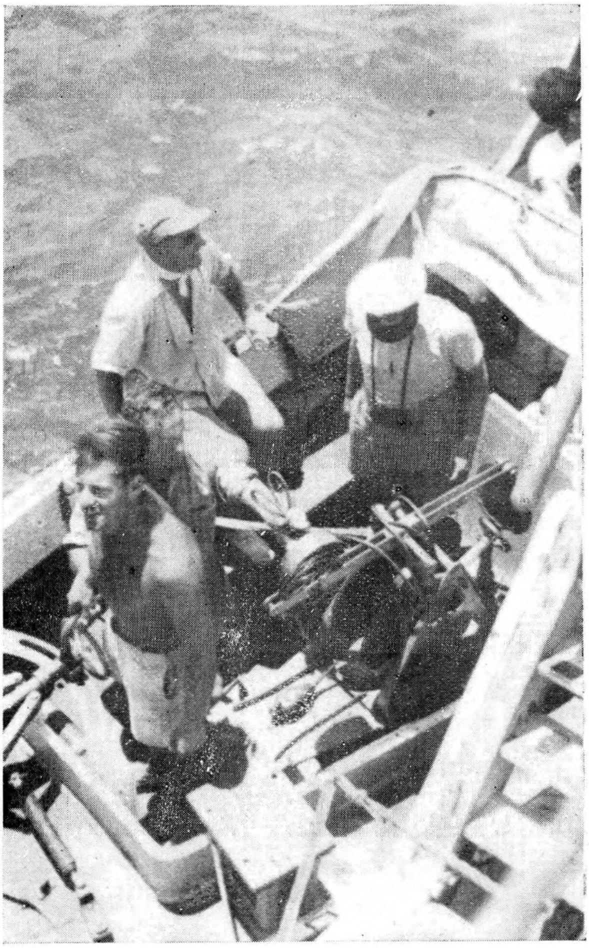

Fig. 3. — The surveying motor boat ready for making taut-wire measurements.

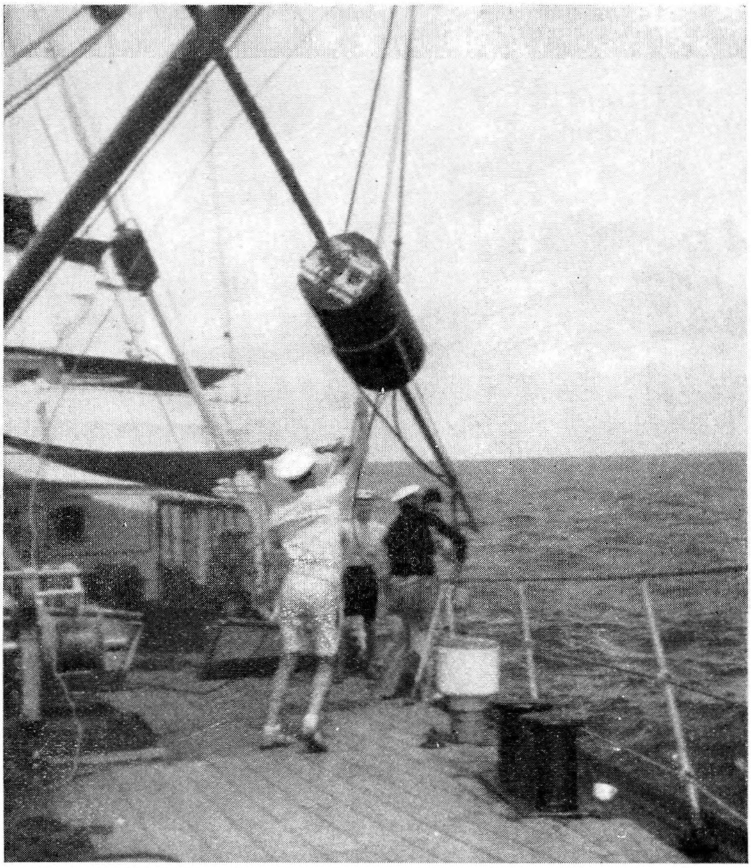

Fig. 4. — Recovering a sono-buoy.

Fig. 5. — Taking the slide from the bathythermograph.

important, because it provides a measure of the horizontal distance, since the velocity of sound in sea water is known sufficiently well in the oceans of the world.

The use of sono-buoys at sea is very much dependent on the weather. When the wind exceeds 10 to 15 miles an hour, the buoys move through the water, and the noise produced at the hydrophone hides the small signal from the depth charge. In the shallow water experiments in the lagoons of coral atolls, the buoys were anchored to the bottom and instead of depth charges, small charges were fired from the ship's motor-boat by electric cable, the instant of firing being transmitted to the ship by radio.

The seismic experiments showed that the geology of the deep oceans is often very simple, with a layer of sediment about 0.4 Km. thick lying on a basement layer which is labelled by the sound velocity of 6.3 - 6.5 Km./sec. This is different from the structure on land and on the fringes of continents, where a much more complex picture, in which 3-4 Km./sec. layers rest on 5-6 Km./sec. material. The *Challenger* experiments were not continued beyond 15 miles, and this was not sufficient to observe refracted waves from the 8.1 Km./sec. layer which lies below the 6.3 Km./sec. one. Other work shows that the 6.3 to 8.1 Km./sec. discontinuity is at 10-15 Km./sec. below the sea surface, while it is 35-40 Km./sec. below the surface on the continents. The continents appear then to be fundamentally different from oceans; they have a much more complicated geological structure, because they have been pushed up and worn down, whereas the oceans have been disturbed only by volcanic erruptions which form isolated bits of land, and perhaps by forces which have formed submarine mountain ranges.

There is still a great deal of work to be done to make sure of these simple generalisations. For example, no measurements have been made in the South Atlantic or in the West part of the Indian Ocean, or in the North and South Polar Regions. Even if the ocean structure is as simple as the few measurements made to data indicate, a great deal of work is required to delineate the boundaries of the true oceans and continents. The form of the junction between continental and ocean structures is not yet certain, and detailed measurements are required in the regions of continental shelves. Seismic work is difficult in such areas because the sea-bed is irregular, and the geological formation may change considerably in the length of a normal seismic refraction experiment. However, useful experiments may be carried out on the edges of continents, using charges at sea and instruments fixed on shore. Such experiments will not entail such expense as a full ocean-going expedition.

The *Challenger* experiments in the vicinity of the Mariana Trench, mentioned in Part I, showed that the geology was somewhat different from that in the true deep ocean. Further experiments in and around the ocean deeps may help to provide the answers to such questions as whether the continents are gradually growing out into the oceans, and how mountain ranges are formed.

Salinity and Temperature Measurement

Standard series of water samples were collected at 17 stations, the locations of which are shown in Fig. 2 of Part I of H.M.S. *Challenger*'s World Voyage (I.H.B. Review. Nov. 1953). The procedure used was as laid down in « The

Oceans » (Sverdrup, Johnson and Fleming), deep temperatures and samples being taken with Eckmann type reversing bottles, and shallow ones with an insulating bottle.

The salinities were not measured on board since space did not allow a chemical laboratory. The Pacific Oceanographic Group, Nanaimo, B.C., and the Dominion Laboratory, Wellington, N.Z., kindly measured the salinities of many samples; the remainder were sent to U.K., to the National Institute of Oceanography. The stations occupied were chosen to fill in gaps in the available data and it was of great interest to find the name of *Challenger*'s worthy predecessor attached to many of the measurements on modern compilations. Regular temperature profiles were obtained with the Bathythermograph, and over 1,000 slides were collected.

Magnetic Variation

The gyro-compass has taken away some of the importance of measurements of magnetic variation, but measurements are always needed to check the values given in navigation charts and in air charts and maps. Frequent opportunities were taken, therefore, to swing the ship to obtain the magnetic variation by reference to the true bearing of heavenly body. Fourteen observations were made at sea and a few readings were obtained on shore using a theodolite with a magnetic needle attachement.

Plankton

Nets were hauled twice daily, usually at dawn and dusk, to sample the plankton in the upper 100 ft. of the sea. The animals were examined by Surgeon Lt. D.O. Haines, and notes were made on type and quantity. Interesting specimens were kept and have been accepted by the British Museum (Natural History).

The results from the expedition are still being worked out, but this report and narrative gives some idea of the scope of the work, and additions to the references at the end of Part I have been made in this Part II.

The discoveries cannot be expected to reach the standard set by *Challenger* in 1872, since the field for study is not virgin, as it was in the last century. However, the results achieved bear some similarity to those of old *Challenger*. The isolated deep ocean soundings have been extended and lines of continuous depth profiles now show the existence of many sea-mounts and of large flat areas of sea-bottom. Just as the 1872 expedition made a survey and comparison of the bottom sediments and animals in all the oceans of the world, so the recent world cruise has made a preliminary survey of submarine geology in many parts of the deep sea. It is probable that seismic work in the near future will be localised, and will be carried out in more detail than by *Challenger*, but the *Challenger* results serve to give continuity between the various localities and to indicate the places in which new and interesting results may be expected.

This account could never have been written the keenness, hard work, and long suffering of the officers and men of H.M.S. *Challenger*. It is they who made the experiments work, although they did not really care how deep the sediment was on the ocean-bed or whether coral atolls were sinking. In the same way, no doubt sailors in the old *Challenger* must haved wondered whatever was the purpose of all the peculiar measurements made in their day. Experimental work at sea is difficult because it takes place from a moving platform, and the sea can be very frustrating indeed in its behaviour. In spite of this, *Challenger*'s crew kept the work going successfully for nearly three years.

The Hydrographer of the Navy, the Ministry of Supply and the Department of Geodesy and Geophysics, Cambridge University, responsible for ship and experimental apparatus, made the expedition possible, and thus maintained the fine tradition in oceanographic research of which England is so rightly proud.

REFERENCES. (This list is a continuation of that at the end of Part I of this article (I. H. R. November, 1953) and many of the references are to work mentioned in both Parts).

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* 19 — 2nd Challenger Expedition. Report by Hydrographic Department, Maritime Safety Agency, Tokyo.

* 20 — Temperature and Salinity Observations. H.M.S. *Challenger,* 1950-52. Hydrographic Department Admiralty H.D. 496.

* 21 — RITCHIE G.S., The Deep Scattering Layer, Institute of Navigation Journal, Vol. VI, n° 4 (1953).

22 — Original tracings of sea-mounts and searched areas are kept at the Hydrographic Office, Admiralty, London, and the numbers of these tracings are given on the chart at the end of Part I of this article.

* 23 — WISEMAN J.D.H. and HENDEY, J.I., Deep Sea Research, Vol. I, n° 1. examination of sample from Mariana trench).

* 24 — An account of the Method is given in an Article « Ocean-bed Prospecting » in *Penguin Science News,* n° 29.
