The Swedish Deep-Sea Expedition

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INTRODUCTION

CUT OFF from active work at sea during the Second World War, Swedish oceanographers devoted their efforts largely to improving the technique of deep-sea oceanography. The raising of long and undisturbed sediment cores from great depths appeared to us to be an especially desirable development. Very little advance had been made in coring methods during the half century which elapsed between the cruises of the "Challenger" and of the "Meteor." In the mid-thirties C. S. Piggot of the Carnegie Institution, Washington, D. C., succeeded in obtaining cores between 1 and 3 meters long from great depths by firing a coring tube vertically downward into the sea bottom with an exploding charge (Piggot, 1936: 207). The chief difficulty in this method was the friction between the column of sediment and the interior wall of the coring tube. Recently an attempt to overcome this difficulty was made by utilizing the high pressure at great depths to operate a "vacuum core sampler" (Pettersson and Kullenberg, 1940, 1941). An undisturbed core 14 meters in length was raised by means of this instrument in the Gullmar Fjord on the west coast of Sweden in 1942. Shortly afterward Kullenberg developed the "piston core sampler," by means of which an undisturbed core 20.3 meters in length was raised from the Gullmar Fjord in 1945 (Kullenberg, 1947). In this device, by trigger action, the entire heavy steel coring tube with attached weights is automatically released on approaching the bottom and sinks down into the sediment. The main wire cable from which the coring tube is suspended is stopped abruptly as the coring tube and weights are released to sink into the sediment. A piston originally at the lower end of the coring tube and attached by an internal wire to the main cable is kept motionless while the coring tube descends around it. Because of the high pressure, the immovable piston immobilizes the column of sediment beneath it as it is cut out by the corer. A view of the piston core sampler suspended alongside the research vessel is shown in Figure 1.

In the spring of 1946 the Swedish government permitted the research vessel "Skagerak" to be used on a trial cruise to the western Mediterranean during which the piston core sampler proved its worth. Cores 8 to 15 meters

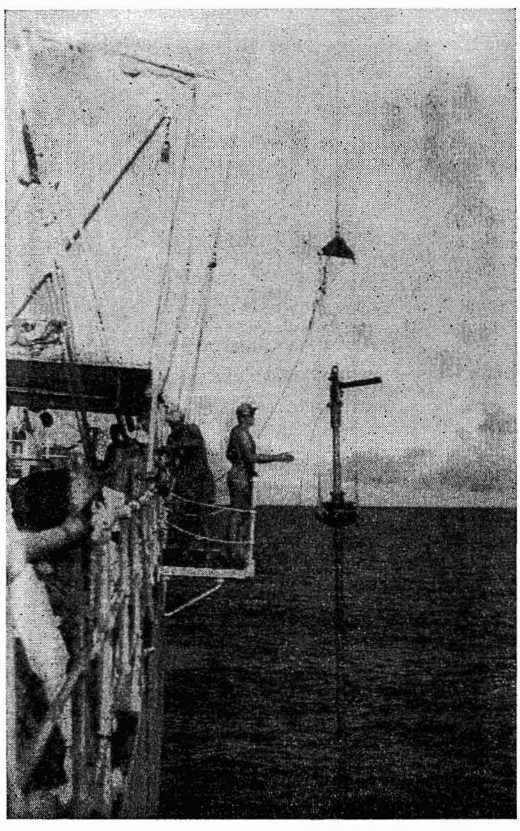

FIG. 1. The Kullenberg piston core sampler about to be hauled aboard the "Albatross."

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in length were raised from depths between 1,600 and 3,600 meters. In many of these cores numerous zones of coarse particles, largely of pyroclastic origin (volcanic ash), were found intercalated in the ordinary sediment, thus giving an unrivaled record of the volcanic activity in the vicinity during historic and prehistoric time (Pettersson, 1946). A few of these cores have since been subjected to various physical, chemical, and biological analyses. In addition to the standard analyses, the cores were examined for pollen and radium content (Pettersson, *et al.*, 1948). Study by Dr. Fred Phleger of the Woods Hole Oceanographic Institution of the Foraminifera contained in different layers of three cores from the Tyrrhenian Sea indicates that considerable change in the temperature of the surface water has occurred, which incidentally makes it highly probable that the span of time required for the deposition of these organisms extends well back into the last glaciation (Phleger, 1947).

Another Swedish invention tested during the same cruise was developed by Professor W. Weibull of the Bofors Armament Works. This device records, by means of hydrophones and an oscillograph on board the ship, the time lag between echoes from the surface of the sediment and from transition layers below this surface. The echoes are initiated by exploding depth charges at depths of 100 meters or less. With this instrument a maximum thickness of the sedimentary carpet was found in the center of the Tyrrhenian Sea where, below a water layer of 3,600 meters, the sediment appears to have a thickness of nearly 3,000 meters (Weibull, 1947).

THE PRESENT EXPEDITION

The interest evoked in our native city of Göteborg by these new tools of deep-sea research, and by the promise they give of a new grip on the unsolved problems of the ocean bed, made it possible for me to obtain, from private donors, the extensive financial backing required for an all-Swedish circumnavigating cruise (Pettersson, 1947: 399). Altogether about 2 million Swedish kroner (more than one-half million dollars) have been given to the Royal Society of Göteborg (Göteborgs Kungl. Vetenskaps och Vitterhetssamhäle), which nominated a committee for planning and organizing the cruise. The great difficulty of finding a ship suitable for the expedition was happily overcome through the generous offer of the great Broström Shipping Combine of Göteborg to lend us their new training ship, the 1,450-ton motor schooner "Albatross," at net running costs for the duration of a 15-month cruise. They also gave permission to install nine laboratories, work shops, refrigeration machinery, and cold storage rooms, besides cabins and a mess room for the scientific and technical staff (air conditioned for work in the tropics) all set up within the space normally used for cargo. The "Albatross" is shown in Figure 2. Thanks to wholehearted co-operation from great Swedish industries, a specially constructed, electric deep-sea winch with an electric power station of 140 kilowatts and other necessary equipment were completed in time. A view of a portion of this winch is shown in Figure 3. The refitting of the ship was carried out at the Lindholmen Shipyard in Göteborg where the "Albatross" had been built. The shipyard work was done at a fraction of the normal cost, thanks to the generosity of the owner of Lindholmen.

The scientific and technical staff is comprised of ten men. Besides the author they are: Dr. Börje Kullenberg, oceanographer and inventor of the piston core sampler; Dr. Nils Jerlow, oceanographer and specialist on submarine light and on the transparency of sea water; Dr. Fritz Koczy, oceanographer and specialist on radioactivity and submarine photography; Leif Bruneau, chemist; Dr. Gustaf Arrhenius, geologist; Viggo Wenzel, depth-charge soundings and short-wave specialist; A. Jonasson, chief mechanic; and K. Pettersson, assistant in the sediment work. Dr. John

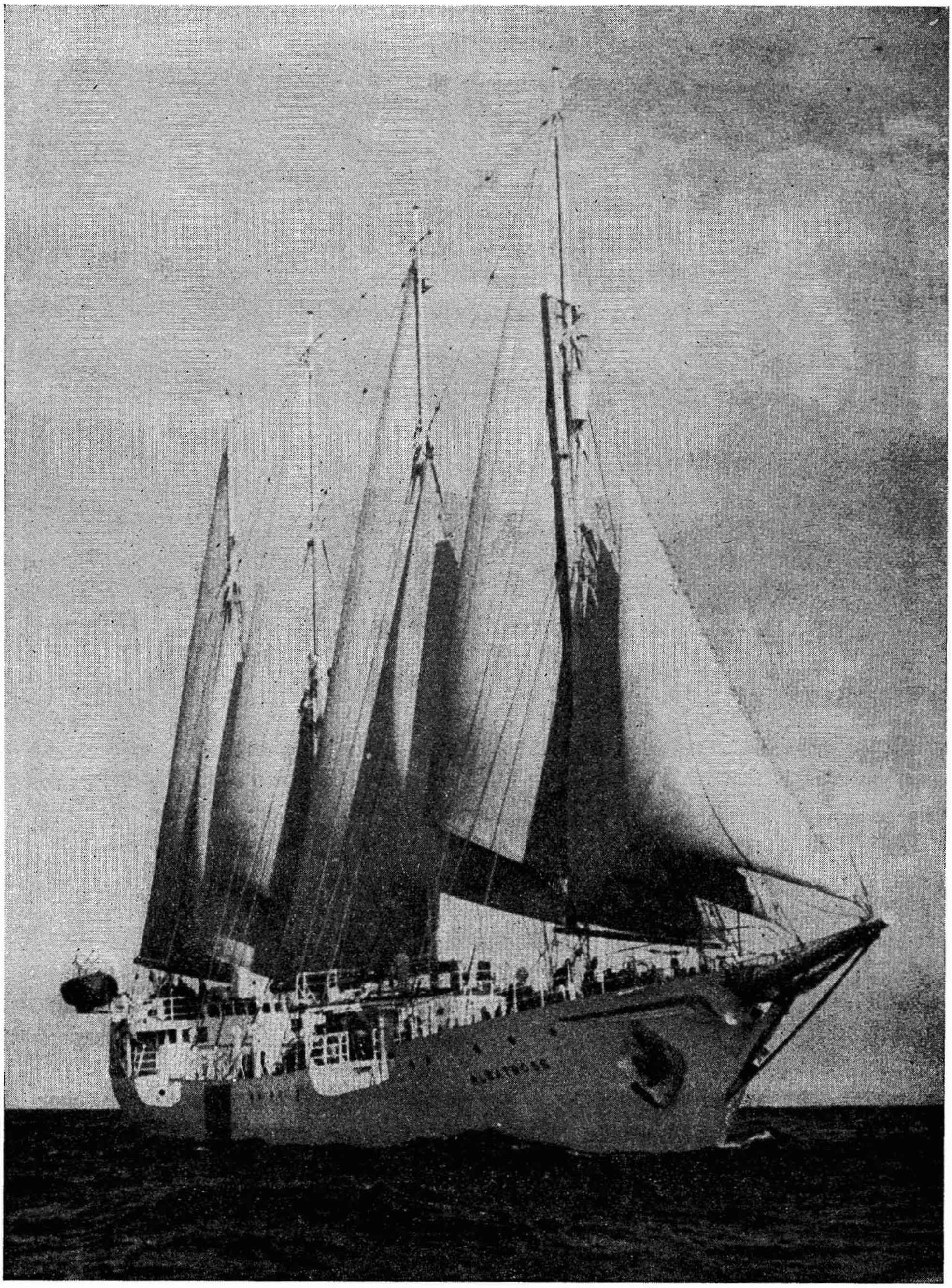


FIG. 2. The "Albatross" under full sail.

Eriksson, surgeon to the expedition, was in charge of the biological work during the first part of the cruise and headed botanical excursions on shore. The ship is most ably commanded by Captain N. Krafft and officers. The total number of non-scientific personnel is 24,

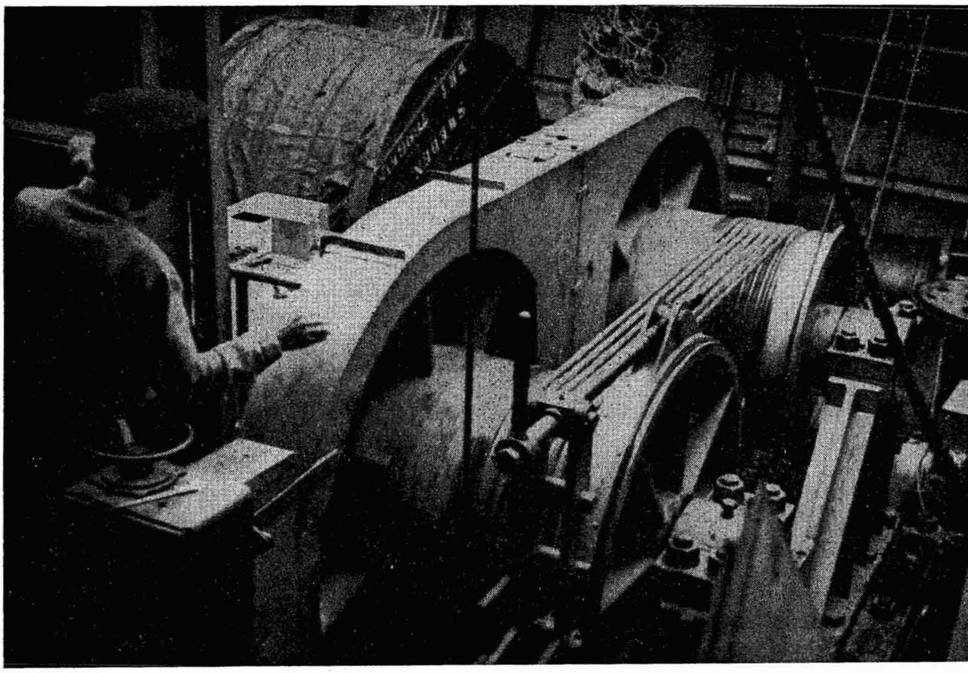


FIG. 3. The deep-sea winch aboard the "Albatross." Only the power drums are shown in the photograph; the 8,000 meters of steel cable are stored on a third great spool which is not shown.

including 12 apprentices between 17 and 21 years of age.

Since our sounding gear is very heavy (approximately 1,500 kilograms), and is carried by a steel-wire cable 8,000 meters in length, a very powerful electric winch capable of raising and lowering a load of over 10 metric tons at a maximum speed of 100 meters a minute was specially built for the cruise. In order to work such heavy gear undisturbed by wind waves and ocean swell, the route to be followed was chosen so as to fall mainly within or near the region of equatorial calms where, fortunately, the sea bottom offers problems of special interest. Our original plan was to begin with a tour of the north Atlantic Ocean down to the equator. Because of unavoidable delay in starting, postponed from the beginning of March to the beginning of July, and the necessity of avoiding the hurricane season in the West Indies and the southwest monsoon in the western Indian Ocean, it was necessary to take a short cut from Madeira to Martinique and from there to Cristobal, where we arrived on August 19. After necessary readjustments had been carried out on our deep-sea winch, in which we were most generously assisted by the Naval Command of the Canal Zone, we passed through the Panama Canal on August 26, and on the following day we left Balboa on a WSW course.

IN THE ATLANTIC

On our way across the Atlantic we had opportunities for testing our gear. Between Madeira and Cristobal eight cores varying in length from 10 to 15 meters were obtained. Most of them consisted of typical red clay, which in the lower levels was considerably tougher than in the upper layers. The greatest depth from which a core was raised was nearly 6,000 meters. As long as we had very calm weather or were running before a moderate sea and swell our deep-sea echo sounder, specially constructed for the cruise by the Marine Instruments of London, gave legible records down to 6,000 meters. The record often became illegible when we moved against head-winds or an adverse swell because of air bubbles interfering with the ultrasonic beam. Even with this limitation, which results largely from the shallow draught of the "Albatross," the echograph was most useful for our coring operations. The bottom profile showed an astonishing ruggedness even at great depths. Perfectly even surfaces extending over greater distances than a few nautical miles were rarely met in the open Atlantic. A curious rise or fall of the bottom profile by "steps," 20 to 50 fathoms and often considerably more in height, suggestive of faults across our course is quite frequent in the records. Professor Weibull, who personally followed the cruise to Cristobal, found distinct echoes from a "bottom below the bottom" corresponding to a thickness varying between 300 and 2,500 meters, i.e., values comparable to those found in the Mediterranean from the "Skagerak" in 1946.

IN THE PACIFIC

From Balboa we steered toward the Galapagos group (see map), raising sediment cores and taking a few oceanographic series under way. In the Bight of Panama a few hauls in 750 and 1,500 meters, respectively, were made with our large ring net 2 meters in diameter in which catches of weird-looking bathypelagic fishes and invertebrates were brought up.

The cores taken here were greenish-gray and rich in organic remains. In one case there was a distinct smell of sulphuretted hydrogen from the lower parts of the core. Near the Galapagos the sediment was of a light greenish color, was rich in foraminiferal tests, and in one case zones of dark volcanic ash were found in the lower levels.

Our purpose in stopping at the Galapagos was twofold. While the men aboard the ship investigated the cool upwelling water south of the islands, which is rich in plankton, and took sediment cores from the bottom there, five of us went ashore on uninhabited James Island where we spent five unforgettable days collecting plants for our great Swedish authority on the Pacific island flora, Professor Carl Skottsberg of Göteborg.

From James Island the "Albatross" followed a course to the WNW which afforded means for a complete oceanographic section across the Equatorial Countercurrent, where the two lines of divergence (upwelling water) and the line of convergence (descending water) were quite distinct. The oxygen minimum in intermediate water layers was also very conspicuous. An almost total lack of oxygen, less than 0.02 cc. per liter, was found in a depth of 150 meters as far north as latitude 14° 13′ N, longitude 120° 25′ W. Close to the 18th parallel north, the "Albatross" turned south, crossing the Equatorial Current System a second time during which we repeated the observations by water sampling in different depths and raising cores from the sea bottom. The sediment was mainly of the red clay type, but near the equator calcareous sediments appeared which were rich in Foraminifera. Curious signs of stratification were also manifest. A great impediment to our coring operations, even at great depths, was the frequent occurrence of hard bottom which the core samplers could not penetrate. In a couple of cases this led to partial or total loss of the corer. In two cases at least, fragments of basaltic rock caught in the bit of the core sampler proved the obstacle to have been a lava bed covered by a thin veneer of sediment. Similar difficulties occurred also near Nukuhiva in the Marquesas. A botanical excursion was made to the high Tovii Plateau of Nukuhiva where bore kernels were taken from one of the rare peat bogs known in the tropics for future analytical examination for pollen. Between Nukuhiva and Tahiti, where we arrived on October 24, our crop of sediment cores was very meager because of the hard bottom.

The sounding of sediment thickness by depth charges gave results different from those found previously in the open Atlantic Ocean, in the Mediterranean, and in the Caribbean Sea. Virtually no definite signs of reflecting layers situated at more than 200 meters below the surface of the sediment were obtained. On the other hand, distinct reflexes from depths varying between 60 and 180 meters were repeatedly obtained. In one case where the corer had been stopped by a superficial layer of lava, distinct reflexes from depths similar to those mentioned in the sentence above were obtained, which indicates that the superficial layer of lava is evidently not impenetrable to the acoustic waves recorded by our hydrophones.

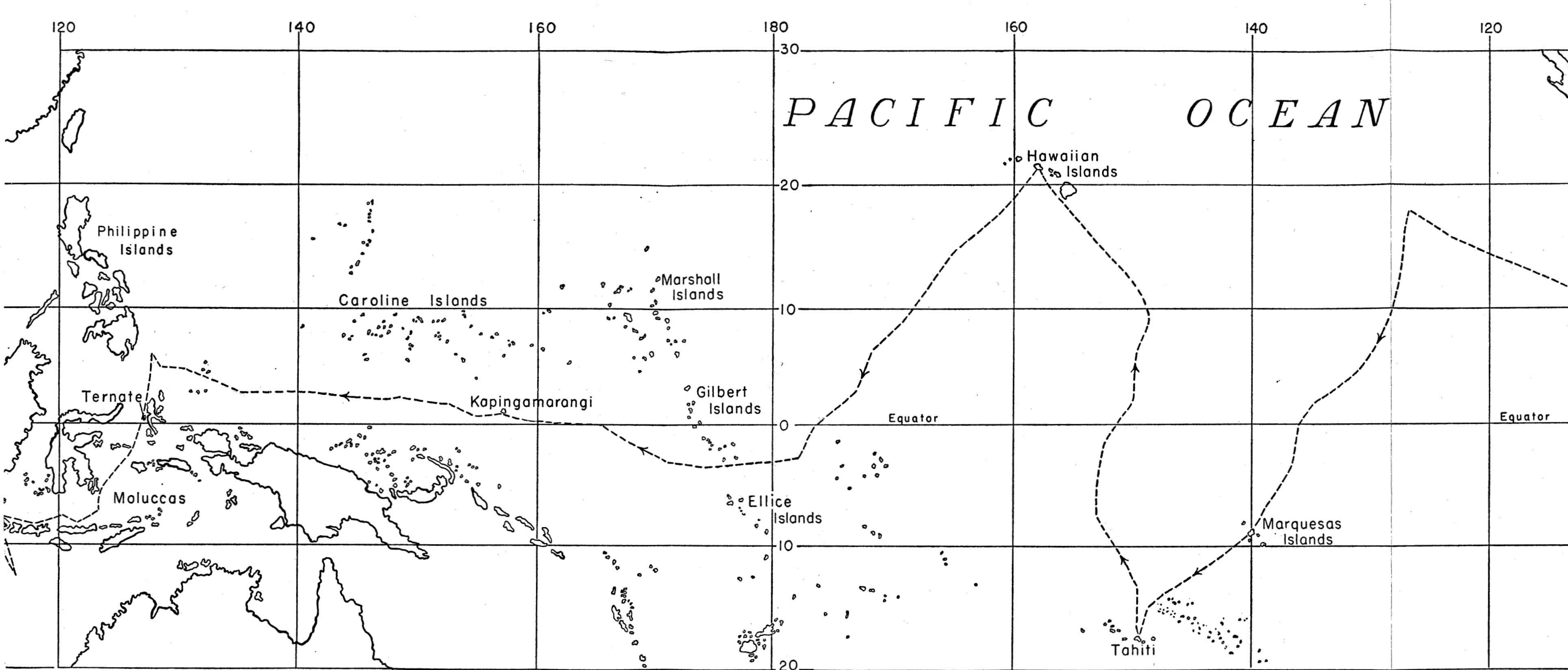
After a pause of 10 days in Papeete the "Albatross" set out on November 2 on a northerly course for Hawaii. Oceanographic series across the Equatorial Current System were made here also, with results very similar to those made previously. While under way we had occasion to repeat several of the stations made over 70 years earlier by the famous "Challenger" Expedition, with results corroborating theirs but with a technique of coring which afforded a depth of penetration more than 20 times as great. The cores, varying from nearly pure radiolarian ooze to nearly pure globigerina ooze, displayed highly interesting stratificatons, with white calcareous sediment alternating with a dark brown or a red clay type. It is tempting to ascribe these variations in the composition of the sediment to climatic fluctuations, acting either directly on the surface temperature of the water and its plankton, or possibly causing a displacement of the whole current system as the polar ice caps grew and varied with inevitable effects on the atmospheric circulation. Here also, especially near the Hawaiian Islands, hard bottom interfered with coring operations and led to loss of instruments.

In Honolulu, when we arrived on November 28, we were most cordially received by municipal authorities, by our colleagues at the Bernice P. Bishop Museum and at the University of Hawaii, and also by the Scandinavian colony represented by the Swe-Nor-Den Society making our stay an unmitigated pleasure. We had occasion to lay our results before our colleagues at a round-table conference at the University of Hawaii, and profited greatly from discussions there and from most stimulating suggestions and advice from Dr. T. A. Jaggar, the greatest volcanologist of our time.

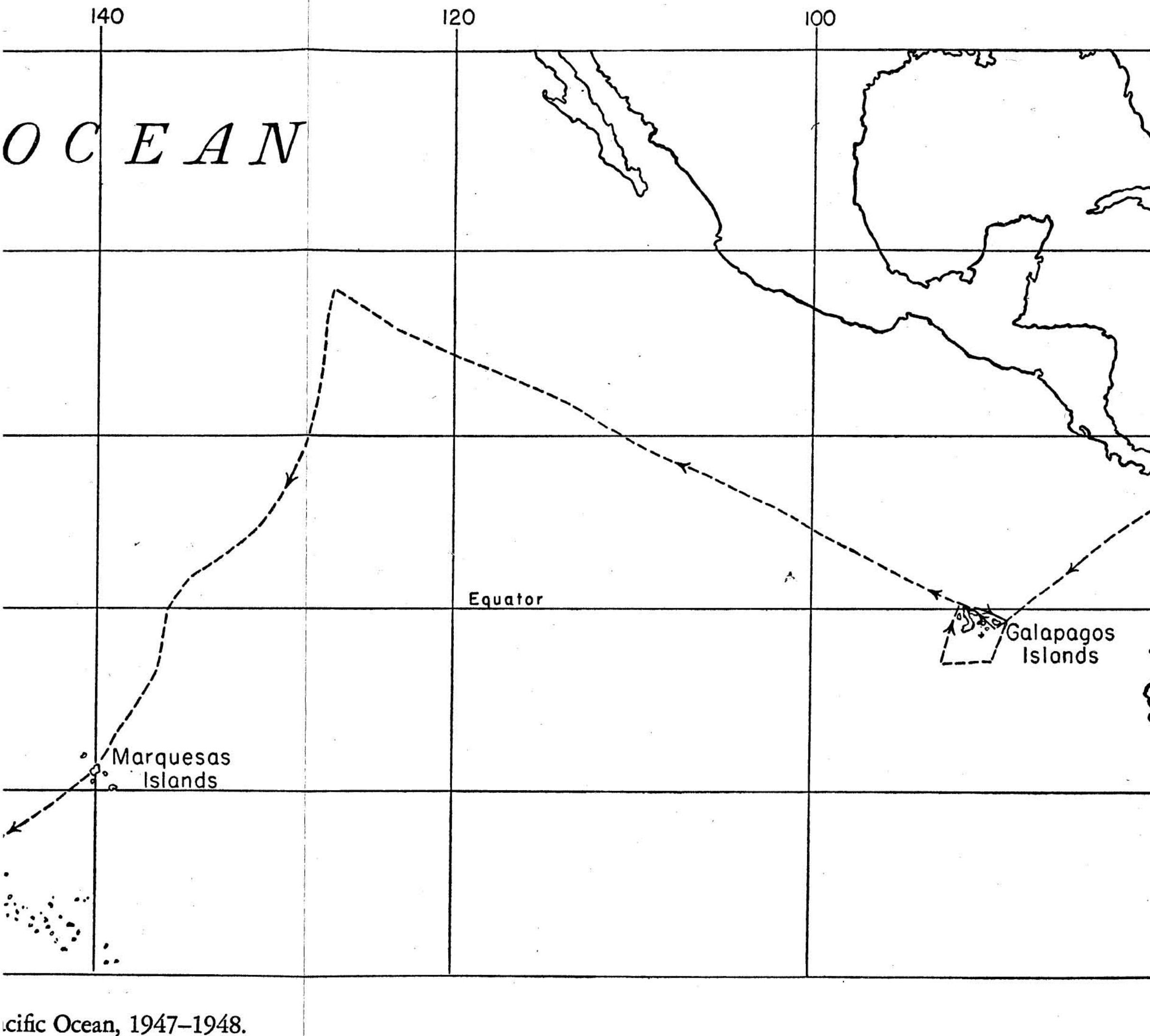
From Honolulu we cruised SW until the equator was crossed, changed our course to WNW, crossed the equator again, and stopped at Kapingamarangi Atoll where submarine light measurements were carried out in the sheltered waters of the lagoon. At the beginning of this segment of our cruise the occurrence of hard bottom again made coring operations difficult, and the bottom profile presented the same rugged and hummocky features as in the eastern and central Pacific. Farther west the bottom became more even and more amenable to both coring and to sediment soundings by depth charges. However, adverse winds, to which the "Albatross" is rather susceptible because of her low-powered auxiliary Diesel engine, made our progress slower than we expected.

In general, the cores taken along our westerly course near the equator were of calcareous sediment, frequently stratified with brownish-gray clay alternating with whitish-gray sediment. Still farther west a greenish color alternated with gray or brown tones. Our last days in the Pacific Ocean were devoted to hydrographic series and soundings in the southernmost part of the Mindanao trench. Here a core raised from the maximum depth of 7,700 meters had a length of only 4 meters, the core sampler having been stopped by a layer of coarse sand rich in volcanic particles! An attempt to raise a core from a still greater depth with an extra wire cable attached to the lower end of our 8,000 meter steel cable failed when the extra wire snapped after the corer was on its way up. The instrument and its precious content were lost.

Faint but legible echograms were taken at cross sections over the trench in latitude 5° 20′ N. The results prove that the depths given in the Snellius charts are several hundred meters too great. Attempts to measure the sediment thickness in the trench failed because the ruggedness of the bottom profile produced spurious echoes which obscured any deeper



Route of the Swedish Deep-Sea Expedition research ship "Albatross," in the Pacific Ocean, 1947–1948.



acific Ocean, 1947–1948.

echoes from transition layers below the surface of the sediment.

Steering south from the Mindanao Deep we finally reached the idyllic harbor of Ternate on January 26, 5 months less a day after our start from Balboa. Our cruise across the Pacific was finished.

SUMMARY OF RESULTS

During our Pacific cruise 57 cores with an integral length of nearly 500 meters have been taken, most of which display more or less distinct stratification. In most, but not in all, cases, the sediment profiles raised by means of the long piston core sampler have been supplemented by cores from the surface layers taken by means of a short core sampler of Dr. Phleger's construction and kindly loaned by him for the duration of the cruise.

According to the technique developed by Dr. Kullenberg, the cores are extricated from thin lining tubes 70 centimeters in length inside the steel coring tube and, after a cursory examination on board, are wrapped first in briophane and then in pergament paper. These wrapped cores are introduced into aluminum tubes filled with molten paraffin wax and stoppered, after which they are placed in cool storage, between 5° and 8° C., pending analysis after our return to Sweden. Experience shows that cores preserved in this manner remain practically unchanged indefinitely.

Sediment soundings by depth charges have been carried out at 75 different positions, where in most cases, two depth charges were set to explode at different depths (500 and 2,500, 4,500, or 6,500 meters). Only between Balboa and the Galapagos were reflexes recorded from depths below the surface of the sediment sensibly deeper than 300 meters. For this striking difference between our results in the Atlantic and in the Pacific, no explanation can yet be offered.

Four complete hydrographic sections have been made across the Equatorial Countercurrent System, yielding results similar to those indicated above. When worked up from the dynamic point of view these sections, supplemented by frequent bathythermograph soundings between the stations, will afford valuable material for the study of the Equatorial Countercurrent and the accompanying strips of convergence and divergence.

At a few deep stations large-volume water samples of 25 liters were taken from different depths for analysis for radium (by the $BaSO_4$ Mitreissreaktion) and uranium (by fluorescence). Such analyses are necessary for confirmation of the ionium precipitation hypothesis set forth by the author in 1936 (Pettersson, 1937), and subsequently substantiated through the work of C. S. Piggot and W. D. Urry (1939: 405; 1941), and also in order to utilize measurements of radium in the sediment for determining the rate of sedimentation in the upper layers (Pettersson, 1943, 1945).

Optical studies on sea water were carried out, partly by direct measurements of submarine daylight in different spectral ranges down to depths of 100 meters, and partly by photographic methods down to greater depths by means of a pressure-tight submarine camera. In addition ultraviolet components have for the first time been measured near the surface in the open sea by means of a special technique (Johnson, 1946). Finally, the amount of suspended particles at different depths was measured by means of the Tyndall method, using samples obtained with specially prepared water bottles. Interesting results which show the occurrence of distinct maxima of such particles at certain depths were found by these measurements.

The records from our echo sounder have already been referred to. When worked up systematically, results of value both from a bathymetrical and from a morphological viewpoint may be expected. An interesting observation made repeatedly when crossing the bands of convergence bordering the Equatorial Countercurrent was extra reflections on the echogram in depths between 80 and 150 fathoms. These reflections indicate densely packed organic matter, presumably shoals of fish or other bathypelagic organisms. It is possible that a kind of intermediate fishing grounds along the equator may be made accessible to exploitation along commercial lines through a future development of the midwater trawling net.

Preliminary measurements of the geothermal gradient in deep-sea deposits were made by means of a geothermometer of special construction. The conditions on the bottom as well as those prevailing at the surface, i.e., wind, waves, swell, and currents, necessarily severely restrict the use of this instrument for it has to be plunged down into the deposit to a depth of about 12 meters and remain there until equilibrium with the surrounding temperature has been attained. Only two successful shots could be made in the Pacific Ocean, both giving unexpectedly high values for the geothermal gradient there (between 20 and 30 meters per degree centigrade). A discussion of these results, which indicate a more intense flow of geothermal heat upwards through the ocean bed than one has, for general reasons, been inclined to assume, must be postponed until more data have been obtained.

In summary it may be said that the new technique developed in Sweden for investigating the deep-ocean bed and its sediments has been found to work well in oceanic depths, and it promises a new and fruitful field of work on the border line between oceanography and submarine geology. When our cores have been examined by different kinds of analyses, a task which will require several years to accomplish, new light will be thrown on problems regarding the deep-sea bottom, its morphology, and its sediments and their chronology. For the latter study both foraminiferal analysis and radioactive age determinations are available.

The investigation of the deep-ocean bed, its stratigraphy, and its fauna manifestly calls for co-ordinated efforts on an international scale. In this future work Honolulu, with its famous Bishop Museum and its University of Hawaii, appears destined to become the foremost center of research in the central Pacific Ocean.

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