UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY AND BIOLOGY OF NORTH ATLANTIC DEEP-SEA CORES

Part 5. MOLLUSCA

Part 6. ECHINODERMATA

Part 7. MISCELLANEOUS FOSSILS AND SIGNIFICANCE OF FAUNAL DISTRIBUTION

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Professional Paper 196–D

GEOLOGY AND BIOLOGY OF NORTH ATLANTIC DEEP-SEA CORES BETWEEN NEWFOUNDLAND AND IRELAND

PART 5. MOLLUSCA

By HARALD A. REHDER

PART 6. ECHINODERMATA

By AUSTIN H. CLARK

PART 7. MISCELLANEOUS FOSSILS AND SIGNIFICANCE OF FAUNAL DISTRIBUTION

By LLOYD G. HENBEST

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SUMMARY OF THE REPORT

In May and June 1936 Dr. C. S. Piggot of the Geophysical Laboratory, Carnegie Institution of Washington, took a series of 11 deep-sea cores in the North Atlantic Ocean between the Newfoundland banks and the banks off the Irish coast. These cores were taken from the Western Union Telegraph Co.'s cable ship *Lord Kelvin* with the explosive type of sounding device which Dr. Piggot designed. In the fall of that year he invited a group of geologists of the United States Geological Survey to study the cores and prepare a report. Biologists of the United States National Museum, the University of Buffalo, and chemists of the United States Department of Agriculture cooperated in the investigation and contributed to the report.

The westernmost core of the series (No. 3) was taken in the blue mud zone, but all the others were taken in parts of the ocean where the bottom is blanketed with globigerina ooze. The shortest cores are No. 8, taken on the mid-Atlantic ridge in 1,280 meters of water, and No. 11, taken where the core bit struck volcanic rock. The cores range in length from 0.34 to 2.93 meters and average 2.35 meters. They were taken at depths ranging from 1,280 to 4,820 meters.

Lithology and geologic interpretations.—In about 20 representative samples from each core the percentages of calcium carbonate, clay and silt, and sand were determined and plotted, and the relative abundance of Foraminifera, coccoliths, and diatoms was estimated. Material between these guide samples was examined microscopically, especially in certain critical zones.

Two zones were noted in which silicic volcanic ash (refractive index near 1.51) is common. The upper ash zone was found in all the cores except No. 11, but the lower one was found only in the lower part of cores 4 to 7. In core 3 the upper ash zone is represented by shards scattered very sparsely all through the core, as this core, despite its length of 2.82 meters, apparently did not reach the bottom of the ash zone. The upper ash zone, together with other adjacent lithologic zones, serves to correlate the cores, and the lower ash zone, found west of the mid-Atlantic ridge, helps to confirm the correlation.

Besides the zones of volcanic ash four other zones distinctive in lithologic character were found. These zones are characterized by a relative abundance of sand and pebbles, by a smaller percentage of calcium carbonate, and by a sparsity of Foraminifera and coccoliths. They are distinctive also in texture. The pebbles are subrounded to angular and include a wide variety of rock types—sandstone, gneiss, soft shale, and limestone—of which limestone is the most common. Some of the pebbles are as much as 2 centimeters across. These zones are interpreted as glacial marine deposits formed during the Pleistocene glacial epoch, when continental glaciers were eroding the land. Drift ice from the continental glaciers apparently transported considerable quantities of rock debris far out into the ocean basin.

Between the glacial marine zones found in the North Atlantic cores the sediments consist chiefly of foraminiferal ooze or marl, much like that which is forming today in the same area.

The uppermost glacial marine zone is represented in all the cores except Nos. 3 and 11 and lies just below the upper volcanic ash zone. In cores 4 to 7 the glacial zones are relatively thin and are spaced at approximately equal intervals; between the third and fourth glacial zones (in descending order) is the lower volcanic ash. East of the mid-Atlantic ridge only the uppermost glacial zone has been identified. Other glacial marine deposits are recognizable but their correlation is less certain.

Three interpretations are offered as possible explanations of the four glacial marine zones. The first is that each glacial marine zone represents a distinct glacial stage of the Pleistocene and that each zone of foraminiferal marl separating two glacial marine zones represents an interglacial stage. This interpretation seems least probable of the three. The second interpretation is that the upper two glacial marine zones and the intervening sediment may correspond to the bipartite Wisconsin stage, whereas the lower two represent distinct glacial stages of the Pleistocene separated from each other and from the zone representing the Wisconsin stage by sediments that represent interglacial epochs no greater in length than postglacial time. This interpretation seems to imply too short a time for most of the Pleistocene epoch. The third interpretation, which is favored by the authors, is that each of the four glacial marine zones represents only a substage of the Wisconsin stage. This implies that the North Atlantic at approximately 50° north latitude for comparatively long periods of time alternately contained an abundance of drift ice and then was quite, or nearly free of ice, while on land a continental ice sheet persisted, though it alternately waned and grew.

In the four cores in which the postglacial sediments are thickest the pelagic Foraminifera, according to Cushman and Henbest, reveal an interesting condition. These organisms indicate that during the middle part of the postglacial interval the temperature of the surface water in that part of the North Atlantic was somewhat higher than prevails today.

On the assumptions that the top of the uppermost glacial marine zone represents the beginning of the postglacial epoch as defined by Antevs, and that this was probably as much as 9,000 years ago, the postglacial sediment in these cores accumulated at a rate of about 1 centimeter in 265 years; but, because the sea probably cleared of detritus-laden drift ice long before the land in the same latitude was cleared of the retreating continental ice sheet, the average rate of accumulation may have been as low as 1 centimeter in 500 years.

Coarse-grained sediment on the tops of ridges and fine-grained sediment in the deeper basins indicate that currents move across these ridges with sufficient velocity to winnow out the finer particles and sweep them into deeper basins beyond.

The fact that the glass shards in the volcanic ash zones have been reworked and distributed without any gradation in size through many centimeters of the overlying sediments leads us to believe that mud-feeding animals are continually working over these shards and other particles of sand and silt so that they are redistributed at successively higher levels. The shards and other particles may also be reworked by gentle bottom currents that move the material from mounds and ridges on the sea floor and drift it about over the adjacent flatter areas.

Several layers in the cores are sharply set off by the coarser grain size of the sediment or by a regular gradation in grain size from coarsest at the base to fine at the top. These may be a result of submarine slumping.

The term globigerina ooze is used loosely in this report to designate sediment, half or more than half of which, by weight, consists of Foraminifera. This usage accords more closely with the usage adopted by Correns in the *Meteor* reports than with the usage of Murray and Chumley in the *Challenger* reports, which was based solely on the carbonate content. Limy muds containing a lesser but still conspicuous number of Foraminifera are referred to as foraminiferal marl. The carbonate content of the globigerina ooze in these cores ranges from 46.6 to 90.3 percent and averages 68.2 percent. In 191 samples representing all the lithologic types, the carbonate content ranges from 10.0 to 90.3 percent and averages 41.3 percent. Coccoliths are abundant in many parts of the cores, but by reason of their small size they rarely make up as much as 10 percent of the sediment Pteropods are rather numerous in parts of the cores taken on the mid-Atlantic ridge and on the continental slope off the Irish coast.

Most of the calcium carbonate in these sediments consists of the tests and comminuted fragments of calcareous organisms. The finest particles of carbonate are of indeterminate origin, but their irregular shape and range in size suggest that they are largely the finest debris of the comminuted organisms rather than a chemical precipitate. Clusters or rosettes of calcium carbonate crystals were found in many samples, but they are not abundant. They evidently formed in the mud on the sea floor.

No conclusive evidence of an increase in magnesium carbonate with depth was found, though some of the data suggest it. The magnesium carbonate is somewhat more abundant in the glacial marine zones than elsewhere, but its concentration in those zones is probably accounted for by the presence of clastic grains and pebbles of dolomite.

Diatom frustules, radiolarian skeletons, and sponge spicules are the most common siliceous organic remains found in the cores, and these generally form less than 1 percent of the sediment. One notable exception is the sediment in the middle part of core 9, just east of the mid-Atlantic ridge, which contains 50 percent or more of diatoms.

Ellipsoidal and elongate or cylindrical pellets that appear to be fecal pellets are plentiful in the mud at the tops of cores 10 and 12, taken in the eastern part of the North Atlantic, but were not found elsewhere. No attempt was made to identify them further.

The sand-size material showed no marked variation in the mineral composition of the clastic grains at different horizons within individual cores and no conspicuous lateral variation from core to core. The mineral grains in the sand-size portions were not separated into light and heavy fractions, but simple inspection showed that grains of the heavy minerals are somewhat more common in the glacial marine deposits than elsewhere. Well-rounded sand grains are sparsely scattered through all the cores, but they are rather more plentiful in the glacial marine zones. These grains, which range in diameter from about 0.1 to 1.0 millimeter and average 0.5 millimeter, have more or less frosted surfaces. They may have been derived from the reworking of glacial marine deposits or they may have been rafted by seaweeds. Little was done with the clay minerals other than to note that most of them have the optical properties of the beidellite or hydrous mica groups.

Six samples were tested with a 10-inch spectograph, which revealed the presence of appreciable amounts of barium and somewhat less of boron in each sample. All the samples gave negative tests for antimony, beryllium, bismuth, cadmium, germanium, lead, silver, tin, and zinc.

The original porosity of several samples in core 3 was calculated from the porosity of the dried samples. The original porosity plotted against depth in the core seems to indicate that fine-grained blue muds buried to a depth of 2 or 3 meters in the ocean floor are appreciably compacted.

Partial mechanical analyses of nearly 200 samples were made and plotted, but only four complete mechanical analyses were made. The complete analyses were made by the sedimentation method and include four distinctive types of sediment.

Pumiceous fragments and smaller shards of basaltic volcanic glass (index of refraction near 1.60) are scattered throughout all the cores, but are somewhat more common east of the mid-Atlantic ridge than west of it. Unlike the alkalic volcanic ash it shows no conspicuous concentration in zones. Most of the basaltic glass and pumice has a thin surface alteration film of palagonite. The films are thickest on fragments in cores taken from ridges where oxygen-bearing waters had free access to the sediments. Two varieties of palagonite are recognized.

Core 11 represents only 34 centimeters of the sea floor because the core bit encountered deeply altered olivine basalt. About 15 centimeters of globigerina ooze rests on and within irregular cavities of the upper surface of a mass of clay that is apparently altered basalt. This clay is impregnated with manganese and contains nodular lumps of altered basalt. Part of the basalt near the base of the core is less altered. The clay contains scattered grains of sand and foraminiferal shells in which the original calcium carbonate has been replaced by a zeolite resembling phillipsite. This core may have penetrated the upper, deeply altered part of a submarine lava flow, but the evidence is not conclusive.

Core 10 contains two rather thick beds of distinctive clayey mud. About half of this mud is a beidellite or hydrous mica type of clay and the other half is made up of silt-size particles of basaltic glass, magnetite, augite, and calcic plagioclase. It contains very little common clastic material and exceedingly few Foraminifera. The composition and texture suggest that this mud was derived largely from a submarine volcanic eruption that threw into suspension clay particles perhaps partly from the normal sediment and from deeply altered basalt. A complete chemical analysis of this mud is given.

Foraminifera.—From these cores 184 samples representing every lithologic zone were examined for calcareous fossils. All but five samples contained Foraminifera. As in existing oceans deeper than several hundred meters, pelagic Foraminifera greatly outnumber the bottom-dwelling forms, though in variety of form and in number of genera and species the bottom forms greatly exceed the pelagic. Several zones of relatively pure globigerina ooze were found, and many in which the ooze was clayey or sandy. Though variations in temperature were reflected by faunal changes, the general bathymetric facies of the faunas appear to be rather uniform throughout each core. The bottom faunas are least varied and prolific in cores from the deepest water, whereas in cores from the shallowest water they are by far the most varied and prolific. Cores from intermediate depths contain faunas of intermediate bathymetric facies. These relations to depth are, in general, characteristic also of faunas in the existing oceans. A few scattered specimens of *Elphidium* or *Elphidiella* were found. These genera thrive in shallow water, but in these cores the shells are so rare, so erratically distributed, and in some so poorly preserved that it seems probable they were rafted in by seaweeds or ice and therefore have no significance as indicators of depth. No species peculiar to the Miocene or Pliocene were found. It appears, therefore, that all the sediments penetrated by the cores are younger than Pliocene. Alternation of faunas that are characteristic of the warm and cold climates of the present day indicates great climatic changes during the time represented by these cores. The foraminiferal facies characteristic of cold and warm climates correlate with the alternating sequence of glacial-marine and warmer-water sediments indicated by the lithology. This correlation suggests that all the sediments in these cores are of Recent and Late Pleistocene age.

Diatomaceae.—Fifty-two species and varieties of diatoms were found in these cores. A large percentage of the species are neritic, warm-water forms that are foreign to the region today. Several alternations of warm-water and cold-water diatom floras occur in most of the cores, but their position in the cores is not in accord with the alternations of temperature inferred from lithology and foraminiferal facies. It is suggested that this disagreement may be due to the much longer settling time of the diatoms and that allowance should be made for it. The time equivalent of this difference of phase, as calculated from the vertical displacement necessary for the best approximation to agreement between the foraminiferal and lithologic data on the one hand and the diatom data on the other is of the order of 23, 000 years. This figure appears absurdly high and a figure of several hundred years, based on extrapolation of experimentally timed settling in a relatively small vessel, is considered more reasonable. The action of cold and warm currents, some surficial and some deep seated, is suggested as the possible cause of the apparently erratic distribution of the diatoms. The possibility that the phase difference of 23,000 years mentioned above is related to shifts of ocean currents caused by advances and recessions of drift ice is offered as a speculation. Of 52 species and varieties illustrated, 2 species and 1 variety are described as new.

Ostracoda.—In preparing a series of samples from the cores for the study of the Foraminifera about 175 specimens of Ostracoda were found. These belong to 13 genera and 27 species, all living forms, though 12 of the species are known also as fossils. Most of the ostracodes were found in three cores that were taken in the shallowest water (1,280 to 3,230 meters). One of these cores (No. 8) was from the top of the mid-Atlantic ridge and the other two (Nos. 12 and 13) were from the continental slope southwest of Ireland. In the cores from deeper water (3,250 to 4,820 meters) ostracodes were scattered very sparsely. Like most marine ostracodes, all the species found in the cores are bottom dwellers. Most of the species are decidedly cold-water forms that are found in tropical waters only at great depth, where the temperature is near freezing. Northern forms predominate; only 2 of the species have not previously been known from northern waters, and 10 species are definitely Arctic forms. A few species that have a wider temperature range live not only in cold waters but also in the deep warm water of the Mediterranean.

The predominance of distinctly cold-water ostracodes and the prevalence of Arctic forms suggest that the temperature of the water in this part of the North Atlantic was formerly somewhat lower. But, as might be expected from the fact that all the species in these cores are bottom dwellers, their distribution in the cores shows no evident relationship to the cold and warm zones indicated by the composition and texture of the sediments and by the pelagic Foraminifera.

Mollusca.—The mollusks recovered from these cores can be divided into two groups, the pteropods and the other gastropods and pelecypods. The pteropods are by far the more numerous. All the specimens of the pelecypods and gastropods, other than pteropods, are representatives of deep-water species that are now living in the same boreal or cold-temperate waters. Also, the fragments that could not be identified specifically belong to forms that have congeners now living in these waters. The fauna of these cores, even that taken from the lower parts of the cores, shows no appreciable difference from that now living in the same localities. Among these mollusks no evidence of shallower or considerably deeper water is demonstrable. Molluscan remains, other than those of pteropods, are too scarce to attempt to differentiate cold- and warm-water facies, as was done with the foraminiferal faunas.

The Pteropoda, which are far more abundant in the cores than the other mollusks, belong to two genera and three species. One of the species is new. The geographic distribution of the pteropods is limited more by the temperature of the surface water than by any other factor. Nevertheless, as one species is cosmopolitan, one boreal, and one a new species thought to be the northern analogue of a more southern species and as all three species occur together, they have no significance for differentiating cold- and warm-water facies. These organisms are pelagic and their shells have a rather wide distribution, but, as they are found on the sea floor at depths ranging from 247 to 3,750 meters, they are of little aid as indicators of depth of the ocean at the time these deposits were laid down.

Echinodermata.—The remains of 9 species of Echinodermata were found in the cores. These include 1 ophiuroid, 7 echinoids, and 1 crinoid. No remains of asteroids were found. All the echinoderms found belong to species now living in that part, or adjacent parts, of the North Atlantic. Echinoderm remains are rather uniformly distributed among the cores, but they are most numerous in core 8, which was taken in 1,280 meters of water on the crest of the mid-Atlantic ridge. By far the commonest species is *Pourtalesia miranda*, remains of which were found in nearly two-thirds of the 82 echinoderm-bearing samples and in all the cores except 8 and 11.

Because the association of species in the cores is closely similar to the association of living species in that part of the North Atlantic and because the association of species within each core is independent of the distance below the top of the core it appears that neither the distribution nor the composition of the echinoderm fauna has changed significantly during the interval represented by these cores. No evident relationship was found between the distribution of the various species of echinoderms and the cold- and warm-water facies of the sediments indicated by both the Foraminifera and the lithology.

Miscellaneous fossils and significance of faunal distribution.—The principal fossil groups represented in the cores, listed in order of abundance, are foraminifers, diatoms, echinoids, siliceous sponges, radiolarians, ophiuroids (spines and plates) ostracodes, and pteropods. Remains of barnacles, brachiopods, pelecypods, holothuroids, bryozoans, gastropods, and teleost fishes (otoliths) were also found, but all these are rare. The foraminifers, diatoms, ostracodes, echinoderms, pelecypods, and gastropods were studied separately by specialists. The other groups are briefly noted and illustrated for the sake of the record. The most varied and prolific faunas were found in the three cores that were taken from the shallowest water and the least varied and least prolific were found in those from the deepest water. The bottom-living faunas throughout each core have a broadly similar bathymetric facies, and the bathymetric facies of each core appears to correspond to that of the fauna now inhabiting that locality. Faunas having the characteristics of very shallow-water marine faunas are either absent or, if present, are so rare and erratically distributed that they appear to be foreign in origin rather than indigenous. Ostracodes and pteropods are locally abundant in the cores from the shallower water, but are absent or rare at all horizons in those from the deeper water. The distribution and bathymetric facies of the faunas weigh heavily against the hypothesis of extreme changes in ocean level during the later part of the Pleistocene.

Organic matter content.—The content of organic matter, as determined from 123 samples, ranges from 0.1 to 1.0 percent of the total weight of the sediments, and the average is about 0.5 percent. As in near-shore sediments, it is influenced by the configuration of the sea bottom. It is small on ridges and large in the deeps. It is particularly large in the sediments at the base of the east slopes of ridges, owing in part probably, to material washed from the vicinity of the ridges by eastward-sweeping ocean currents. The organic matter content of the upper layers of the sediments in the abyssal deeps is greater for a few hundred miles east of the mid-Atlantic ridge than it is for a similar distance west of the ridge. The organic content does not vary consistently with depth except in core three, taken at the foot of the continental slope east of the Grand

Banks, where it seems to decrease about 25 percent in the first 1.5 meters. The organic matter content of the sediments tends to be greater in the warm zones, than in the cold zones, and in general it is slightly greater in sediments which, according to Cushman's determination of the Foraminifera, were probably deposited in areas in which the surface water was relatively warm. The organic content is rather closely related to the texture, and increases with increasing fineness of the sediments. The rate of deposition of organic matter is greater east of the mid-Atlantic ridge than west of it, presumably owing in part to a greater supply of plankton and in part to a slower rate of decomposition of the organic matter after it is laid down in the sediments. The slower rate of decomposition within the sediments is inferred from the greater state of reduction of the sediments, which is indicated by the nitrogen-reduction ratio. The nitrogen-reduction ratio suggests a slight increase in state of reduction with increasing depth of burial in the upper part of the deposits, but indicates no significant change in the lower part. The percentage of organic content tends to increase as the percentage of Foraminifera in the sediments decreases, but it shows no relationship to the calcium-carbonate content.

Selenium content and chemical analyses.—As a part of a comprehensive investigation of the distribution of selenium in marine sediments and soils derived from them complete fusion analyses were made of 20 samples from the suite of 11 cores. These samples were taken from the tops of the cores and at intervals of approximately 1 and 2 meters below the top. In addition, 1 core taken on the continental shelf off Ocean City, Md., and 3 cores from the Bartlett Deep were sampled and analyzed, making a total of 31 analyses. The results of the analyses include all the normal analytical data obtained in a so-called complete soil analysis by the fusion method, and, in addition, determinations of organic matter, nitrogen, chlorine (in all but 12 analyses), hygroscopic water, and selenium. All the samples were analyzed with the entrained sea salts. The core from the continental shelf off Ocean City contained the most selenium—at the top 0.6 part per million, at 1 meter 1.0, and at 2 meters 2.0 parts per million. The samples from the North Atlantic cores showed a selenium content ranging from 0.06 to 0.8 part per million. Of the samples from the Bartlett Deep one contained 0.2 part per million of selenium, but all the others contained less than 0.08 part per million. No evidence was found of a relation between the selenium content and volcanic activity.

The silica-sesquioxide and silica-alumina ratios are tabulated and their significance as means of comparing the analyses is discussed.

FOREWORD

By C. S. Piggot[1]

During the last cruise (1927–29) of the nonmagnetic ship *Carnegie* of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington a number of samples of the deep ocean bottom were obtained by means of the telegraph snapper. The Geophysical Laboratory determined the radium content of these samples and found that they contained a concentration of radium[2] as astonishingly high as that reported by Joly[3] and Pettersson[4] from similar samples taken by the *Challenger* and *Princess Alice II*. This high radium concentration in the surface layer of the ocean bottom, which constitutes 72 percent of the surface of the globe, raises questions of great significance to both oceanography and geophysics. An obvious question is whether radium in so high a concentration is present down through all deep-sea sediments or only at the surface.[5] If the first hypothesis is correct it indicates the presence of uranium throughout the sediments, whereas the second indicates the existence of radium itself, presumably separated out from the sea water. The study of this question requires samples of a type analogous to the cores so extensively used in subsurface exploration on land. Inquiries among oceanographic organizations established the fact that although some cores a meter or more in length had been obtained from relatively shallow water, many of them were much distorted by the time they reached the laboratory, and none as long as 1 meter had been obtained from a depth of 4,000 meters or more.[6] Those engaged in such research emphasized the need of apparatus capable of obtaining undistorted cores from great depths. In 1933 the Council of the Geological Society of America approved a grant for the development of such apparatus.[7] Fortunately, cooperation was obtained from several special agencies, particularly the Burnside Laboratory of the E. I. du Pont de Nemours, whose ballistics expert, Dr. B. H. Mackey, offered fundamental suggestions and made many essential calculations and tests; also the United States Bureau of Lighthouses, from whose lightship tender, the *S. S. Orchid*, many experimental soundings were made. Several forms of the apparatus were developed and tested, and in August 1936 14 satisfactory cores were obtained from the canyons in the continental shelf off New Jersey, Delaware, and Maryland, and another from the ocean floor below 2,500 meters of water.[8] This first deep-sea test was made possible by the cooperation of the Woods Hole Oceanographic Institution and was carried out in connection with an investigation of the submarine canyons by H. C. Stetson of that institution. This test demonstrated the feasibility of the apparatus as built but suggested some minor changes in design. These were incorporated in another apparatus, which was put aboard the cable ship *Lord Kelvin* at Halifax, Nova Scotia. Through the courtesy of Mr. Newman Carlton, Chairman of the Board of Directors of the Western Union Telegraph Co., the Carnegie Institution of Washington was invited to have a member of its staff accompany the *Lord Kelvin* while that ship was engaged in making repairs to the North Atlantic cables, in order to test the apparatus in deep water. This offer was gladly accepted, and in May and June of 1936 I was on board the *Lord Kelvin* with the apparatus.

Because of the personal interest and cooperation of the commanding officer, Lt. Comdr. Bredin Delap, Royal Navy, retired, the undertaking was more successful than had been anticipated, and a suite of 11 excellent cores was obtained, extending from the Grand Banks of Newfoundland to the continental shelf southwest of Ireland.

All but two of these cores (Nos. 8 and 11) are more than 2.43 meters (8 feet) long, and all contain ample material for study. Of the two short cores, No. 8 was taken from the top of the Faraday Hills, as that part of the mid-Atlantic ridge is known, where the material is closely packed and more sandy and consequently more resistant; No. 11 came from a locality where the

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[1] Geophysical Laboratory, Carnegie Institution of Washington.

[2] Piggot, C. S., Radium content of ocean-bottom sediments: Am. Jour. Sci., 5th ser., vol. 25, pp. 229–238, 1933.

[3] Joly, J., On the radium content of deep-sea sediments: Philos. Mag., vol. 16, pp. 190–197, 1908.

[4] Pettersson, Hans, Teneur en radium des dépots de mer profonde: Resultats de Campagnes Scientifiques par Albert I^{er} Prince Souverain de Monaco, vol. 81, 1930.

[5] Piggot, C. S., op. cit., p. 233.

[6] Since these inquiries were made D. Wolansky has published her review in the Geologische Rundschau (Band 24, Heft 6, p. 399, 1933), in which she refers to the work of A. D. Archanguelsky in the Black Sea (Soc. Naturalistes Moscow Bull., new ser., vol. 35, pp. 264–281, 1927). Wolansky mentions cores 3 to 4 meters long from depths of 2,237 meters See also Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925–27, Band 3, Teil 2, Lief. 1, pp. 4–28, 1935.

[7] Piggot, C. S., Apparatus to secure core samples from the ocean bottom: Geol. Soc. America Bull., vol. 47, pp. 675–684, 1936.

[8] Cushman, J. A., Henbest, L. G., and Lohman, K. E., Notes on a core sample from the Atlantic Ocean bottom southeast of New York City: Geol. Soc. America Bull., vol. 48, pp. 1297–1306, 1937.

apparatus apparently landed on volcanic rock that may be part of a submarine lava flow. Soundings at the localities where the cores were taken show depths ranging from 1,280 meters at the top of the Faraday Hills to 4,820 meters in the deep water between the mid-Atlantic ridge and the continental shelf.

The thorough test made possible by the interested cooperation of everyone on board the *Lord Kelvin* fully demonstrated the capacity of the apparatus and produced material from strata of oceanic sediments deeper than have ever before been available.

In order that this pioneer material might be examined to the best advantage and an adequate estimate made of the potentialities of cores of this type, a group of investigators representing various fields of science was invited to examine them. Efforts have been made to arrange the sequence of these investigations in such a way that the maximum information may be obtained with the minimum destruction of the samples.

The cores are now at the Geophysical Laboratory of the Carnegie Institution of Washington, where they and others that may be obtained by this laboratory will be held available for further research.

GENERAL INTRODUCTION

By W. H. Bradley

SIGNIFICANCE OF THE INVESTIGATION

The long cores of deep-sea sediment considered in this report represent a longer span of the earth's late geologic history, as recorded in abyssal sediments, than has been heretofore accessible. In a measure, therefore, this study has been exploratory. Because of that exploratory aspect we have not only presented the observations but also have deliberately speculated upon various possible interpretations of the features observed in the cores and upon their relations with one another. Because the cores are few in number and widely spaced, we offer many of the interpretations not as definite conclusions but rather as suggestions to be tested by whatever coring may be done in the future in that part of the North Atlantic.

From this investigation it appears that glacial marine deposits may prove to be sensitive indicators of the climatic changes that caused the growth and decay of continental ice sheets during the Pleistocene. In particular, it seems that the glacial marine record may throw light on the climatic fluctuations that determined substages of the Pleistocene. The marine record was the result of a continuously operating series of causes such that the deposits of each glacial substage were separated from one another by the deposits of the intervening warmer substage. The record of each substage has remained intact and was not obliterated by readvances of the ice. As the equatorward extent of the glacial marine deposits implies a corresponding expansion of continental ice sheets, the extent of the deposits may be used as a measure of the intensity of the climatic changes, and their thickness may be used as a rough indicator of the duration of glacial substages. Similarly, the thickness and poleward extent of tongues of nonglacial sediment—the foraminiferal marl—are measures of deglaciation. The areal extent of these tongues of sediment can be determined by additional cores taken at properly located stations.

When the glacial marine record is more fully known it should provide a basis for correlating the Pleistocene history of Europe and North America.

Cores taken along the meridians in series extending from the Arctic regions into the tropical parts of the Atlantic should make it possible to map the southern limits of pack ice in the sea during successive glacial maxima, at least for the later part of the Pleistocene. As the pelagic Foraminifera in these abyssal sediments are reliable indicators of surface-water temperatures in the Recent and Pleistocene epochs, it should be possible to trace southward into the tropics layers or beds of foraminiferal ooze that are the time equivalents of glacial marine zones. Such layers of foraminiferal ooze could then be correlated with the layer of globigerina ooze in the tropics that Schott [9] identified as a relatively cold-water deposit that probably represents the last glacial epoch of the Pleistocene.

The study of climatology as well as geology may be advanced by the information to be derived from long sea-bottom cores. Significant evidence bearing on postglacial climatic changes may be obtained from minutely detailed study of the Foraminifera in cores taken in parts of the ocean where postglacial sedimentation has been comparatively rapid, as, for example, near the seaward edge of the blue-mud zone. On the assumption that such sediment accumulates at an essentially uniform rate, climatic fluctuations may be located approximately in time within the postglacial interval and may be correlated from place to place along the ocean margins from the Arctic to temperate or even tropical latitudes and perhaps also from continent to continent.

Archeology, also, might profit from the knowledge of a relatively timed and correlated sequence of climatic changes, for such changes may well have made a significant impress on the habits and migrations of peoples, particularly those that dwelt in regions where small changes in either temperature or rainfall were critical. As I have pointed out in an earlier paper,[10] students of archeology and early history, particularly in the Mediterranean region, might profit much from detailed studies of long cores of the sediment in the deep basins of the Mediterranean. In cores from that sea, as elsewhere, changes in the foraminiferal faunas would indicate climatic changes, and the sediments would yield, in addition, evidence of volcanic eruptions and earthquakes. The time when the Sahara became a desert should also be recorded in the Mediterranean sediments by wind-blown sand. Such a change might conceivably be integrated with the wealth of archeo-

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[9] Schott, W., Die Foraminiferen in dem äquatorialen Teil des Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925–27, Band 3, Teil 3, Lief. 1, pp. 120–128, 1935.

[10] Bradley, W. H., Mediterranean sediments and Pleistocene sea levels: Science new ser., vol. 88, pp. 376–379, 1938.

logical records of the region, and the later volcanic eruptions and earthquakes might be correlated with early history.

Some of the problems sketched so briefly here are touched upon in the several chapters of this report, but most of them must be left for future investigators. Nevertheless, methods by which such problems may be attacked are described and discussed at considerable length, particularly in the chapters on "Lithology and geologic interpretations" and "Foraminifera."

LOCATION OF THE CORE STATIONS

The cores were taken along a slightly irregular line between the easternmost part of the Newfoundland Banks and the banks off the southwest coast of Ireland, as shown in plate 1. Each core obtained by the Piggot coring device is numbered to correspond with the station number of the cable ship *Lord Kelvin.* Stations 1 and 2 were trial stations at which preliminary tests were made to familiarize the crew with the apparatus, and no cores were preserved. The 11 cores studied are numbered consecutively, 3 to 13. The relation between the core stations and the submarine topography is shown in figure 1, which is a profile along the dashed line in plate 1 that connects the stations and extends from St. Johns, Newfoundland, to Lands End, England.[11]

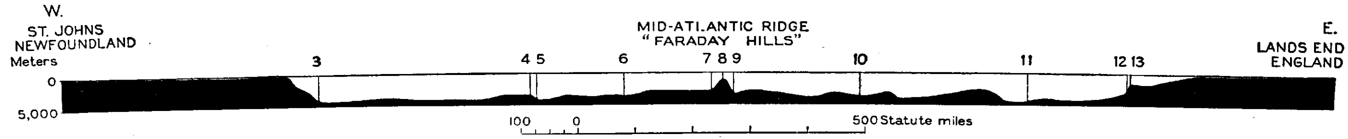

FIGURE 1.—Profile across the North Atlantic Ocean along the line of the numbered core stations shown on plate 1.

TABLE 1.—*Geographic location, length of the cores, and depth of the water from which they were taken*

Core number	Depth of water (meters)	Length of core (meters)	Lat. N.	Long. W.
3	4,700	2.81	46°03′00″	43°23′00″
4	3,955	2.71	48°29′00″	35°54′30″
5	4,820	2.82	48°38′00″	36°01′00″
6	4,125	2.90	49°03′30″	32°44′30″
7	3,250	2.62	49°32′00″	29°21′00″
8	1,280	1.24	49°36′00″	28°54′00″
9	3,745	2.76	49°40′00″	28°29′00″
10	4,190	2.97	49°45′00″	23°30′30″
11	4,820	.34	48°38′00″	17°09′00″
12	3,230	2.43	49°37′00″	13°34′00″
13	1,955	2.21	49°38′00″	13°28′00″

PERSONNEL AND COMPOSITION OF THE REPORT

At the request of Dr. C. S. Piggot, of the Geophysical Laboratory of the Carnegie Institution of Washington, the following six members of the United States Geological Survey undertook a systematic study of the 11 deep-sea cores from the North Atlantic: W. H. Bradley, M. N. Bramlette, J. A. Cushman, L. G. Henbest, K. E Lohman, and P. D. Trask. As the biologic phase of the work progressed it became evident that other organisms than the foraminifers and diatoms should be studied. Accordingly Mr. Henbest invited Dr. Willis L. Tressler, of the University of Buffalo, to examine the ostracodes, Dr. Austin H. Clark of the United States National Msueum, to examine the echinoderms, and Dr. Harald A. Rehder, also of the United States National Museum, to examine the mollusks.

The organic matter content of the sediments was studied by Mr. Trask in collaboration with Messrs. H. Whitman Patnode, Jesse LeRoy Stimson, and John R. Gay, all members of the American Petroleum Institute.

As part of a comprehensive research project on the distribution of selenium in marine sediments and the soils derived from them Dr. H. G. Byers and Mr. Glen Edgington, of the Bureau of Chemistry and Soils, United States Department of Agriculture, made complete chemical analyses of 20 samples from these deep-sea cores. These analyses, together with analyses of samples from several other deep-sea cores and a discussion of the occurrence of selenium, are included in the chapter on "Selenium content and chemical analyses."

METHODS OF SAMPLING AND EXAMINATION

The Piggot coring device [12] takes the cores in brass sampling tubes that have an inside diameter of 4.9 cm. As soon as a core is taken, the tube is cut off at the approximate length of the core and sealed. The cores here discussed were opened under Dr. Piggot's direction at the Geophysical Laboratory of the Carnegie Institution of Washington. A longitudinal cut was made along one side of each brass core barrel by means of a milling cutter so adjusted that it did not cut quite through the wall of the tube. The thin strip remaining was then ripped out without letting brass chips get into the core. After allowing the mud cores to dry somewhat, but not enough to shrink away from the tube walls, the cores and core barrels were cut in half longitudinally with a metal-cutting band saw. In this cutting, the milled slot was held uppermost so that the saw cut only the lower wall of the core barrel and threw the cuttings downward, away from the core.

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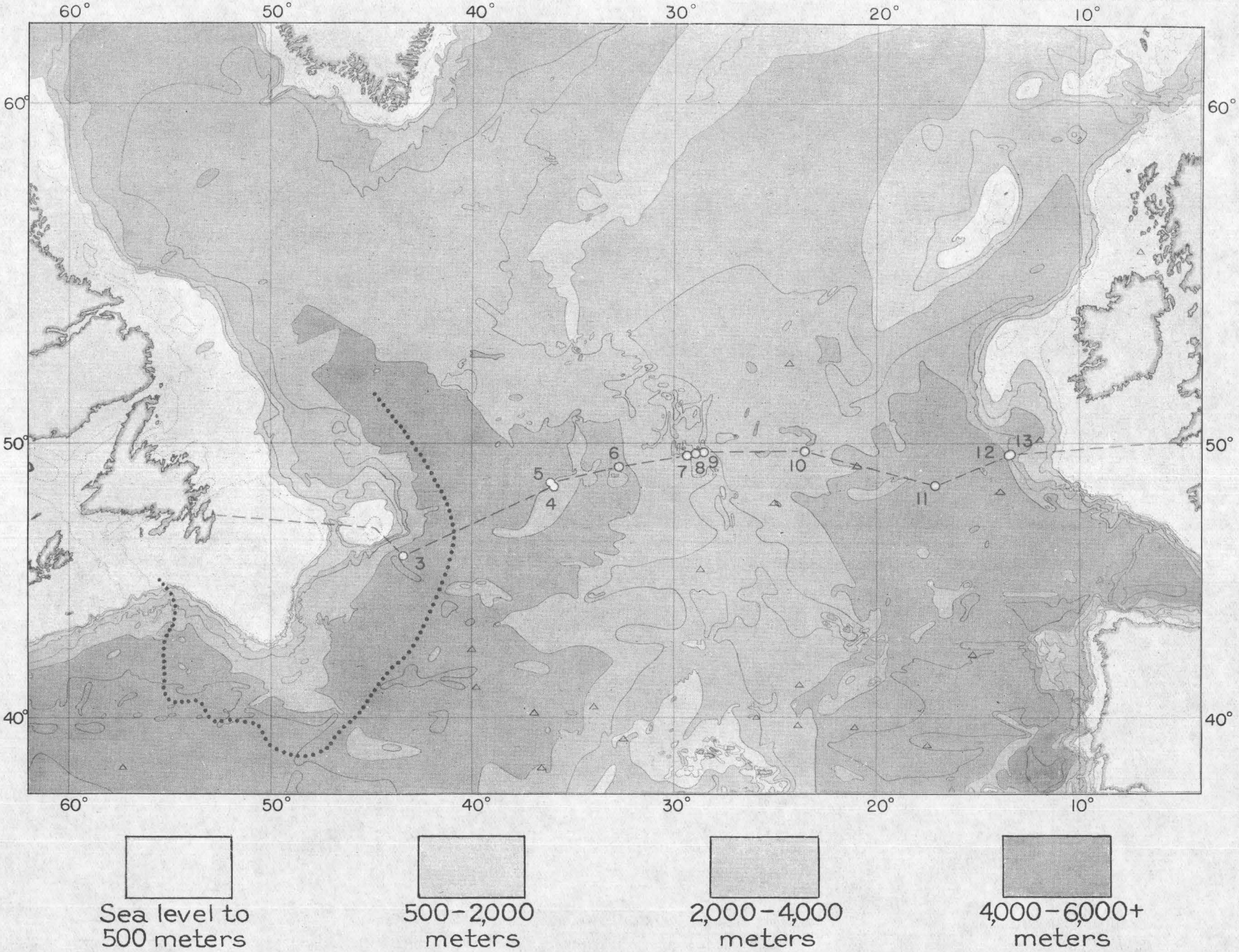
[11] Data for plate 1 and figure 1 were taken from International Hydrographic Bureau, Carte Générale Bathymétrique des Océans, 3d ed., sheets A-1 and B-1, copies of which were furnished by the U. S Hydrographic Office.

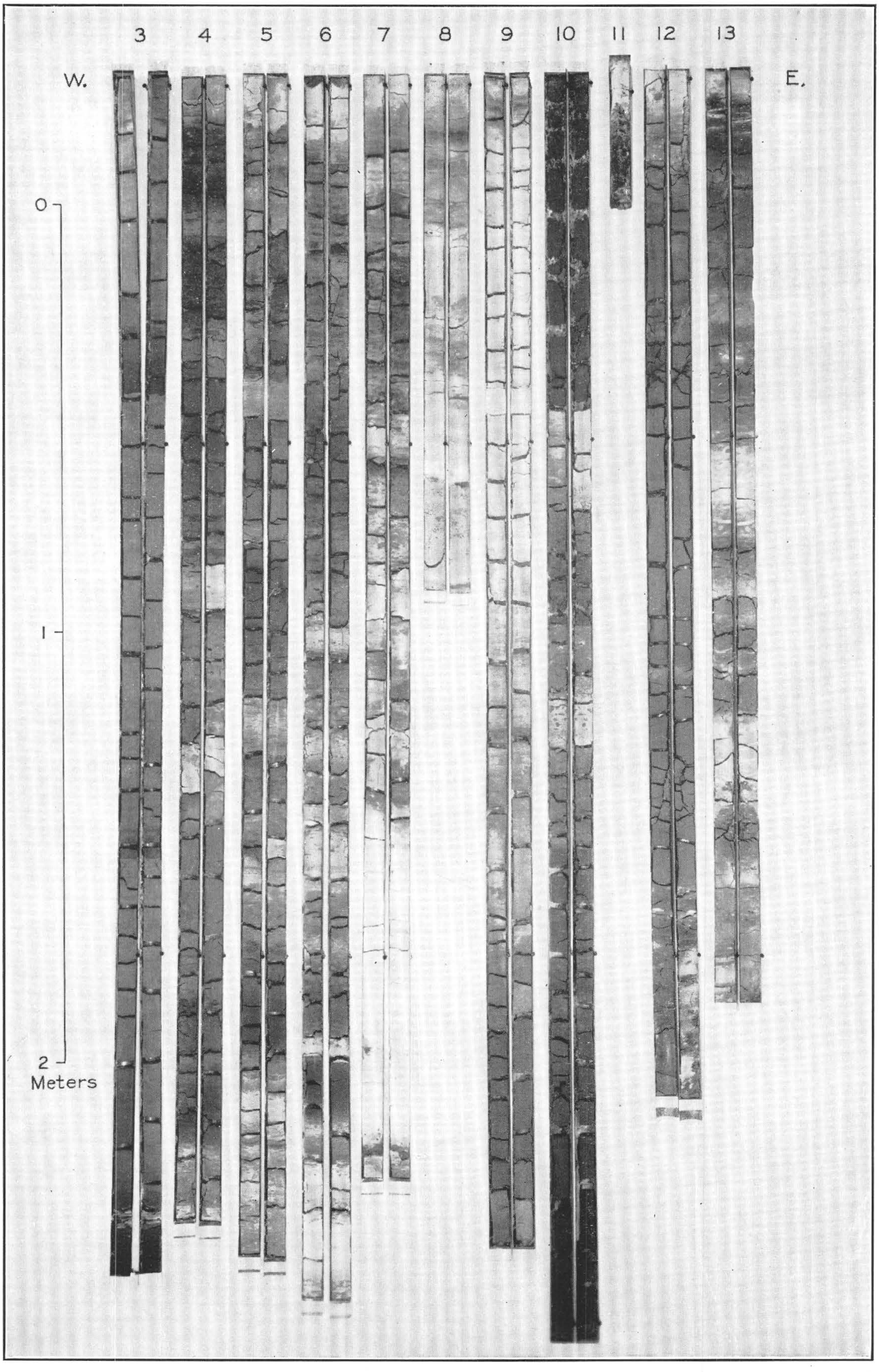
[12] Piggot, C. S., Apparatus to secure core samples from the ocean bottom: Geol. Soc. America Bull., vol. 47, pp. 675-684, 1936.



BATHYMETRIC CHART OF A PART OF THE NORTH ATLANTIC OCEAN.

The numbered circles indicate the core stations. The dashed line connecting them is the line of the profile shown in figure 1. The light dotted line along the coasts is the 200-meter depth contour. The usual limit of drift ice is shown by the heavy dotted line. The small triangles indicate the position of icebergs reported far beyond their normal range during the period January 1900 to July 1916, according to information compiled by J. T. Jenkins (A Textbook of Oceanography, fig. 14, London, Constable & Co., 1921).

U. S. GOVERNMENT PRINTING OFFICE : 1940—O-228324



LONGITUDINAL SECTIONS OF THE AIR-DRIED CORES.

Half of the core barrel was removed from core 11, but the core itself was not cut. Photograph by Geophysical Laboratory, Carnegie Institution of Washington.

Each half core then remained undisturbed in its half cylinder cradle of brass core barrel. (See pl. 2.)

As several months elapsed between the time the cores were opened and the time this investigation began, the mud had dried thoroughly when Mr. K. E. Lohman took a succession of overlapping photographs of each core, about one fifth natural size. These photographs were then assembled as a key chart upon which were marked the parts from which samples for all phases of the investigation were taken. The dried segments of mud shifted somewhat from their original places each time samples were removed, though care was taken to see that during sampling the segments kept their original order and orientation. By reference to this photographic key the findings of all the investigators have been correlated.

Most of the material was hard enough to be sawed into blocks with a hack saw, but a few of the most friable parts were sampled with small channel-shaped scoops of sheet metal after the loose material on the surface had been brushed away.

Samples for all phases of this investigation were taken from only one half of each core, the other half being held intact in the Geophysical Laboratory.

GEOLOGY AND BIOLOGY OF NORTH ATLANTIC DEEP-SEA CORES BETWEEN NEWFOUNDLAND AND IRELAND

PART 5. MOLLUSCA

By HARALD A. REHDER[1]

INTRODUCTION

The species of pelecypods and gastropods described in part 5 were found in the series of deep-sea cores that were collected in 1936 between Newfoundland and the British Isles by C. S. Piggot, of the Carnegie Institution of Washington. The location, physical character, and method of sampling of these cores are described in the introductory chapter of this professional paper.

The specimens of mollusks were obtained from the H series of samples that were originally prepared for the Foraminifera. The sampling and preparatory methods are described in part 2, Foraminifera, by Cushman and Henbest. The location and stratigraphic position of the samples and the general faunal characteristics of the cores are given in part 7, Miscellaneous fossils and significance of faunal distribution, by L. G. Henbest and these data are graphically summarized on plate 21.

The following list is exhaustive for the H series of samples but must not be considered a complete enumeration of the mollusks possibly present in the sediment of that part of the North Atlantic, for only a fraction of each core was available for a study of the invertebrate organisms. This incompleteness is, of course, especially true of the Pelecypoda and of the Gastropoda other than Pteropoda, for each species is represented by only a single specimen whose presence is more or less a matter of chance. The three pteropods, all of which were represented by numerous individuals in the cores, apparently constitute the sole members of this group present.

DESCRIPTION OF SPECIES

PELECYPODA

Yoldiella insculpta Jeffreys, 1879

Plate 23, figures 3, 4

A single valve, of what is apparently this species, was found in core 12, sample H–134, taken in 3,230 meters (1,770 fathoms) of water. This species was originally described from material dredged by the *Porcupine* expedition of 1870, at stations 16, 17, and 17a, about 25 to 30 miles off the coast of central Portugal at depths of 1,350 to 2,000 meters. This locality is considerably east and south of the site of core 12, but the range of a great many of the deep-water mollusks does extend across the Atlantic Ocean. Moreover, the valve was taken from a sample lying in one of the slightly warmer water zones, as determined by Cushman and Henbest from the Foraminifera (pt. 2, fig. 20).

Yoldiella expansa Jeffreys, 1876

Plate 23, figures 1, 2

A minute, glassy, translucent valve, about 1.8 millimeters long, closely resembling this species was found in sample H–133a of core 12. The type locality of *expansa* is station 13, *Valorous* expedition, 1875, in 1,260 meters of water southeast of the tip of Greenland. Other specimens in the Jeffreys collection were found off the tip of Greenland at depths ranging from 2,650 to 3,200 meters. Jeffreys also cites its occurrence at depths of 2,150 to 2,520 meters off the northwest coast of Ireland. The present specimen, coming from a depth of 3,230 meters off the southwest coast of Ireland, fits well into the known geographic and bathymetric range of this species. The type measures about 4.4 millimeters in length, but the other specimens in the Jeffreys collection are considerably smaller and approach the present specimen in size.

Yoldiella sp.

This is a fragment, which, from the nature of what remains of the hinge, seems to belong to this genus. It is being noted merely to record the presence of a mollusk in the middle of core 9 in sample H–85, taken in 3,745 meters of water, southwest of Iceland.

Limatula sp.

Fragments of a thin, translucent species were found in sample H–143 in core 13, which came from a depth of 1,955 meters off the southwest tip of Ireland. A great

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[1] United States National Museum. Published by permission of the Secretary of the Smithsonian Institution.

many species of this genus inhabit depths down to 2,650 meters from Greenland to the Tropics, and these fragments undoubtedly belong to one of those deep-water forms.

GASTROPODA

ARCHAEOGASTROPODA

TROCHIDAE

Genus?

A broken specimen, of a pure white color, that undoubtedly belongs to this family, was found in core 13, sample H–144. It is too imperfect to describe, but judging from the characteristic sculpture and glossy white surface of the shell it undoubtedly is a deep-water form belonging to a hitherto unrecorded group.

PTEROPODA

Spiratella retroversa (Fleming), 1823

Plate 23, figure 8

Numerous specimens of this little boreal pteropod were found in a great many samples. It was found in samples H–62, H–63, and H–64 of core 8, taken at a depth of 1,280 meters and in samples H–132, H–133a, and H–133b of core 12, taken at a depth of 3,230 meters.

Pelseneer,[2] in his treatment of the Pteropoda of the *Challenger* expedition, gives for this species a North Atlantic range extending from the Arctic region to Massachusetts Bay on the American side and to southern England on the European side. These cores, therefore, fall well within the present range of this species.

Spiratella planospira, n. sp.

Plate 23, figures 5–7

The shell is minute, broadly inflated, and thin, with a depressed, flattened spire, which is flatter in young specimens than in adults; the color is white; the surface is glossy and smooth, except for some more or less regular subsutural grooves, which disappear farther down on the whorl; the sutures are well impressed; the aperture is obliquely elongate, limited basally by a straight columella; and the umbilicus is deep and rather narrow.

The type, U.S.N.M. No. 535416, has the following measurements: Height, 1.2 millimeters; greater diameter, 1.5 millimeters; lesser diameter, 1.3 millimeters. It was found in sample H–63 of core 8, collected in 1,280 meters of water in latitude 49°36′ north and longitude 28°54′ west, which is in the middle of the North Atlantic Ocean, about midway on a straight line between England and Cape Race, Newfoundland.

This species was also found in core 8, samples H–61a, H–62, H–63, and H–64 and in core 12, sample H–133a. Most of these specimens are much smaller than the type.

This species is most nearly like *Spiratella lesueurii* d'Orbigny, differing from it in possessing a much flatter spire. Our species may be the northern analog of *S. lesueurii*, as that species, according to Pelseneer, occurs in the warmer waters of the Atlantic, Indian, and Pacific Oceans and is not found in the Atlantic north of the Bay of Biscay. In his check list, Johnson[3] gives latitude 42° north, or approximately Cape Cod, as the northern limit of *S. lesueurii* on this coast.

The specimen figured is not the type, but a smaller, more perfect specimen. These specimens are all rather fragile.

Clio pyramidata Linné, 1767

Plate 23, figure 9

This is a very common species found in core 8, sample H–64, at a depth of 1,280 meters; core 12, samples H–132, H–133a, H–133b, H–133x, and H–134, at a depth of 3,230 meters; and core 13, sample H–135, at a depth of 1,955 meters. It is considered to have a cosmopolitan distribution.

MISCELLANEOUS PELECYPODS AND GASTROPODS

In several samples in cores 8 and 13 traces of pelecypods and gastropods were found, but the remains are too fragmentary for identification and inclusion in this list.

SIGNIFICANCE OF MOLLUSCA

The mollusks recovered from these deep-sea cores can be readily divided into two groups, (1) the pteropods and (2) the other gastropods and the pelecypods. The pteropods are more numerous but less significant as indicators of depth than the other gastropods and the pelecypods.

All the specimens of the more significant group, namely, the pelecypods and the gastropods other than the pteropods, are representatives of deep-water species that are now living in the same boreal or cold-temperate waters. Also the fragments that could not be identified specifically belong to forms that have congeners now living in these waters. The fauna of these cores, even that of samples taken 2.4 meters below the ocean bottom (core 12), shows no appreciable difference from that now living in the same localities. Among the mollusks no evidence of shallower or considerably warmer water in these regions is demonstrable. The paucity of molluscan remains prevents any confirmation of the presence of alternate cold-water and warm-water faunules such as was demonstrated for the Foraminifera in part 2 of this professional paper. The only evidence that the mollusks may agree with such foraminiferal facies is found in the presence of a valve of *Yoldiella*

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[2] Pelseneer, Paul, Report on the Pteropoda—Thecosomata: *Challenger* Rept., Zoology, vol. 23, part 65, p. 28, 1888.

[3] Johnson, C. W., List of marine Mollusca of the Atlantic coast from Labrador to Texas: Boston Soc. Nat. Hist. Proc., vol. 40, no. 1, p. 150, 1934.

insculpta Jeffreys, a species from the waters off the coast of Portugal, in one of the warm-water zones.

By far the greater part of the molluscan fauna of these cores belongs to the other group, the pteropods. The geographic distribution of the pteropods is limited more by the temperature of the surface water than by any other factor. Inasmuch as these organisms are pelagic, the shells have a rather wide distribution, but, as they have drifted down from the upper strata of water and as their shells are found on the bottom at depths ranging from 247 to 3,750 meters (135 to 2,050 fathoms),[4] the presence of these shells in the cores cannot aid us much in determining the depth of the ocean at the time these deposits were laid down. Furthermore, as one species is cosmopolitan, one boreal, and one a new species thought to be the northern analog of a more southern species, and as all three species occur together, they have no significance for differentiating cold-water and warm-water facies.

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[4] Pelseneer, Paul, op. cit., pp. 17-121.

PART 6. ECHINODERMATA

By AUSTIN H. CLARK [1]

INTRODUCTION

The determination of echinoderm remains consisting of dissociated and usually broken plates and spines such as occur in these cores appeared at first to offer insuperable difficulties.

A list was prepared of all the species that might be represented by the remains found in the cores, and cleaned preparations were made of the species of echinoids and of the arm bones, plates, and spines of the ophiurans most likely to be represented in the deposits of the North Atlantic.

After long study it was found that in the irregular echinoids the various types of spines in each genus had characters by which, with a reasonable degree of certainty, they could be distinguished from the corresponding spines in other genera. It was also found that the dissociated arm bones and arm plates of the ophiuran possessed similarly diagnostic characters.

In working out these features in the echinoids Mortensen's memoirs on the Echinoidea of the *Ingolf* expedition proved invaluable, but the following works were consulted also:

CLARK, AUGUSTIN [=AUSTIN] H., The Danish *Ingolf* expedition, vol. 4, pt. 5, Crinoidea, pp. 1–58, figs. 1–58, Copenhagen, 1923.

CLARK, HUBERT LYMAN, Hawaiian and other Pacific Echini, the Pedinidae, Phymosomatidae, Stomopneustidae, Echinidae, Temnopleuridae, Strongylocentrotidae, and Echinometridae: Harvard Coll. Mus. Comp. Zoology Mem., vol. 34, No. 4, pp. 210–383, pls. 90–121, 1912; Hawaiian and other Pacific Echini, the Echinoneidae, Nucleolitidae, Urechinidae, Echinocorythidae, Calymnidae, Pourtalesiidae, Palaeostomatidae, Aëropsidae, Palaeopneustidae, Hemiasteridae, and Spatangidae: Idem, vol. 46, No. 2, pp. 85–283, pls. 144–161, 1917.

KOEHLER, R., Echinodèrmes provenant des campagnes du yacht *Princesse-Alice* (Astéries, Ophiures, Échinides et Crinoïdes): Résultats des campagnes scientifiques accomplies sur son yacht par Albert I, Prince souverain de Monaco, fasc. 34, pp. 1–317, pls. 1–32, Monaco, 1909.

MORTENSEN, TH., The Danish *Ingolf* expedition, vol. 4, pt. 1, Echinoidea pt. 1, pp. 1–193, figs. 1–12, pls. 1–21, Copenhagen, 1903; idem, vol. 4, pt. 2, Echinoidea pt. 2, pp. 1–200, figs. 1–27, pls. 1–19, Copenhagen, 1907; idem, vol. 4, pt. 8, Ophiuroidea, pp. 1–121, figs. 1–52, pls. 1–3, Copenhagen, 1933; Handbook of the Echinoderms of the British Isles, pp. i–ix, 1–471, figs, 1–269, Oxford Univ. Press, 1927.

Most of the genera in the region under consideration are represented by only a single species, so that generic determination is all that is necessary. In the genus *Pourtalesia* the spine fragments agree minutely with corresponding parts of the spines of *P. miranda*, but there is a possibility that some other species may also be represented. The characteristic sculpturing on the side arm plates and the long, slender distal arm bones of *Ophiocten sericeum* leave no doubt regarding the proper identification of that species.

No specimen of any species of *Echinosigra* was at hand for comparison with the fossil material, and therefore it is possible that some of the spines identified as those of *Plexechinus hirsutus* may be from *Echinosigra*, though I believe them all to be correctly identified.

It is rather curious that the Asteroidea are not represented in any of the cores.

SPECIES REPRESENTED IN THE CORES

The following echinoderms are represented in the cores:

- Ophiuroidea.
  - Ophiolepididae.
    - *Ophiocten sericeum* (Forbes).
- Echinoidea.
  - Echinidae.
    - *Echinus affinis* Mortensen.
  - Urechinidae.
    - *Plexechinus hirsutus* Mortensen.
    - *Urechinus naresianus* A. Agassiz.
  - Pourtalesiidae.
    - *Pourtalesia miranda* A. Agassiz.
  - Aëropsidae.
    - *Aëropsis rostrata* (Norman).
    - *Aceste bellidifera* Wyville Thomson.
  - Hemiasteridae.
    - *Hemiaster expergitus* Lovén.
- Crinoidea.
  - Bourgueticrinidae.
    - *Rhizocrinus lofotensis* M. Sars.

ANNOTATED LIST OF SPECIES

The following notes on the geographic and bathymetric distribution of the genera and species represent the information known before the echinoderm fragments found in these cores were studied. Species the bathymetric ranges of which have been extended by their occurrence in these cores are listed under the heading "Bathymetric anomalies" on page 116.

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[1] United States National Museum. Published by permission of the Secretary of the Smithsonian Institution.

Genus OPHIOCTEN Lütken

Geographic range: Cosmopolitan in water of low and moderate temperatures.

Bathymetric range: From about 5 to about 4,700 meters.

Thermal range: From −1.85° to +13° C., chiefly below 4.5° C.

Number of included species: The genus *Ophiocten* includes 15 species, but a few of these undoubtedly are merely local variants of other species.

Ophiocten sericeum (Forbes)

Mortensen[2] has shown that *Ophiocten signata* is a synonym of this species, and believes it likely that the the subantarctic *O. amitinum* as well as *O. hastatum* from Marion Island and *O. pattersoni* from south of Martha's Vineyard will prove to be identical with *O. sericeum.*

Geographic range: From Hudson Bay, the Canadian Arctic Archipelago, Grant Land, and northwestern Greenland eastward to the New Siberian Islands and southward in deep water to Georges Bank, off Massachusetts, south of Iceland, and the Bay of Biscay.

On suitable bottoms in cold water this species frequently occurs in immense numbers.

Bathymetric range: From about 5 to about 4,500 meters.

Thermal range: From −1.1° to +9° C., chiefly between −1.1° and +4°C.

Material: The distribution of the fragments of *O. sericeum* in the cores is shown in table 19.

TABLE 19.—*Distribution of fragments of* Ophiocten sericeum *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
8	H-69	42-52	Side arm plates, upper arm plates, and arm spines.
8	H-71	60-64	An arm bone from the distal part of an arm.
8	H-77	118. 5-121. 5	Arm bone and arm spines.
8	H-78	121. 5-123. 5	Arm bones and side arm plates from near the arm tips.
12	H-133a	216-217. 5	Side arm plates.
12	H-133b	217. 5-223. 5	Side arm plate.
12	H-134	236-243	A basal arm spine from a large individual.
13	H-137	23. 5-27	Side arm plate.

Genus ECHINUS Linné

Geographic range: From Nova Scotia, southeastern Greenland, southern Iceland, the Faeroe Islands, and Finmark southward to the straits of Florida and Puerto Rico, and South Africa; Ascension Island and Tristan da Cunha; southern Patagonia and southern Chile; the Kermadec Islands (north of New Zealand) and southern Australia; and eastern and southern Japan. It is most strongly represented in the northeastern Atlantic, where 7 species occur. In Antarctic and subantarctic regions the genus *Echinus* is replaced by the closely allied genus *Sterechinus.*

Bathymetric range: From between tide marks down to 3,184 meters. Most of the species occur in water of moderate depth. Littoral species are found only in the northeast Atlantic region and in the Mediterranean.

Thermal range: From −1.28° to about +27° C.

Geologic range: Cretaceous to Recent.

Number of included species: The genus *Echinus* includes 16 Recent species.

Echinus affinis Mortensen

Plate 22, figures 29, 34, 36, 39, 40

Geographic range: From Cape Hatteras, N. C., northward to the Grand Banks, southern Iceland, the Faeroe Islands, and the Rockall Bank, and southward in the eastern Atlantic to the Azores.

This species often occurs on the ocean bottom in immense numbers. It is exceedingly abundant from Cape Hatteras northward to Massachusetts.

Bathymetric range: From 99 to 3,184 meters.

Thermal range: From −1.28° (*Albatross* station 3454) to +22.8° C.

Material: The distribution of the fragments of *E. affinus* is shown in table 20.

TABLE 20.—*Distribution of fragments of* Echinus affinis *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
8	H-61	0-1. 5	Spine fragments.
8	H-61a	6-8. 5	Do.
8	H-62	8. 5-10. 5	Do.
8	H-62-63	9-17. 5	Do.
8	H-63	10. 5-17. 5	Do.
8	H-64	17. 5-21	Do.
8	H-66	29-31	Do.
8	H-67	31-35. 5	Do.
8	H-68	35. 5-38	Do.
8	H-69	45-52	Do.
8	H-69a	52-58. 5	Do.
8	H-70	58. 5-60	Do.
8	H-72	71. 5-73. 5	Do.
8	H-73	87-90. 5	Do.
8	H-74	90. 5-94	Do.
8	H-76	111-114. 5	Do.
8	H-77	118. 5-121. 5	Do.
8	H-78	121. 5-123. 5	Do.
9	H-83	79-82	Do.
9	H-89	190-200. 5	Do.
12	H-133	208-213. 5	Do.
12	H-133a	216-217. 5	Ambulacral plate and spine fragments.
12	H-133b	217. 5-223. 5	Two interambulacral plates from the actinal surface, and spine fragments (pl. 22, figs. 29, 34, 36, 39, 40).
12	H-134	236-243	Spine fragments.
13	H-135	0-5. 5	Do.
13	H-138	41-42. 5	Do.
13	H-139	42. 5-47	Do.
13	H-140	53. 5-60. 5	Do.
13	H-144	89-94. 5	Do.
13	H-145	94. 5-100. 5	Do.
13	H-152	169. 5-173	Do.

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[2] Mortensen, Th.. The Danish *Ingolf* expedition, vol. 4, pt. 8, p. 97, Copenhagen, 1933.

Genus PLEXECHINUS A. Agassiz

Geographic range: Southwest of the ridge between Greenland and Iceland, southwest of Iceland, and southwest of The Faeroes; the shores of the Antarctic Continent; and the Gulf of California.

Bathymetric range: From 380 to 2,376 meters.

Thermal range: From about −1.85° to +6.1° C.

Geologic range: Known only from the Recent seas.

Number of included species: The genus *Plexechinus* includes 3 species, which, according to our very meager present information, appear to inhabit widely separated localities.

Plexechinus hirsutus Mortensen

Plate 22, figure 28

Geographic range: From east Greenland to The Faeroes south of the ridges separating the abysses of the North Atlantic from the cold northern deeps.

Bathymetric range: From 887 to 2,376 meters.

Thermal range: From 1.6° to 6.1° C.

Material: The distribution of fragments of *P. hirsutus* in the cores is shown in table 21.

TABLE 21.—*Distribution of fragments of* Plexechinus hirsutus *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
7	H-48	0-7	Spines.
7	H-49	19-23	Do.
7	H-50	49. 5-54	Do.
7	H-51	70. 5-74. 5	Do.
7	H-53	107. 5-112	Do.
7	H-54a	133. 5-139	Do.
7	H-57	183-191	Do.
7	H-58	203-209	Do.
7	H-59	232-240	Do.
8	H-62	8. 5-10. 5	Do.
8	H-63	10. 5-17. 5	Do.
9	H-83	79-82	Do.
9	H-86	161-163. 5	Do.
9	H-89	190-200. 5	Do.
9	H-92	239-242. 5	Do.
12	H-130	183-191	Do.
13	H-140	53. 5-60. 5	Do.
13	H-151	154. 5-159	Do.
13	H-157	218. 5-221	Do.

Genus URECHINUS A. Agassiz

Geographic range: Cosmopolitan at suitable depths and temperatures, except that it is not found north of the ridge across Davis Strait (lat. 67° N.), the ridge between Greenland and Iceland, or the Wyville-Thomson Ridge between Iceland and The Faeroes, or in the Arctic Ocean.

Bathymetric range: From 771 to 4,065 meters.

Thermal range: From about −0.2° to 3.5° C.

Geologic range: Late Tertiary and Recent.

Number of included species: The genus *Urechinus* includes 7 species.

Urechinus naresianus A. Agassiz

Plate 22, figures 35, 37, 38

Geographic range: From the ridges across Davis Strait (lat. 67° N.), between Greenland and Iceland, and between Iceland and The Faeroes southward to the Caribbean Sea and, in the east, to Marion Island off the coast of southern Africa. In the antarctic and subantarctic seas it is replaced by the closely related *U. wyvillii.*

Bathymetric range: From 771 to 3,135 meters.

Thermal range: From 1.4° to 4.1° C.

Material: The distribution of fragments of *U. naresianus* in the cores is shown in table 22.

TABLE 22.—*Distribution of fragments of* Urechinus naresianus *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
7	H-53	107. 5-112	Spine.
9	H-88	168-175. 5	Do.
9	H-89	190-200. 5	Spines.
12	H-133a	216-217. 5	A plate and a spine fragment.
12	H-133b	217. 5-223. 5	Fragments of plates (pl. 22, figs. 35, 37, 38).
13	H-138	41-42. 5	Spine.
13	H-139	42. 5-47	Do.
13	H-152	169. 5-173	Spines.

The plates and plate fragments agree in minute detail with corresponding portions of the test of living specimens at hand. The rather broad, very finely cross-striated borders, the spine bosses, and the numerous much smaller bosses of the pedicellariae are characteristic.

Genus POURTALESIA A. Agassiz

Geographic range: Cosmopolitan in water of suitable depths and temperatures.

Bathymetric range: From 219 to 3,610 meters.

Thermal range: From −1.0° to +13.7° C.

Number of included species: The genus *Pourtalesia* is currently regarded as including 6 species, some of which probably are merely local forms of other species.

Pourtalesia miranda A. Agassiz

Plate 22, figures 26, 31, 32, 33

Geographic range: From the ridges across Davis Strait (lat. 67° N.), between Greenland and Iceland, and between Iceland and The Faeroes southwestward to the southern Caribbean Sea.

Bathymetric range: From 638 to 3,135 meters.

Thermal range: From 1.4° to 3.3° C.

Material: The distribution of the fragments of *P. miranda* in the cores is shown in table 23.

TABLE 23.—*Distribution of fragments of* Pourtalesia miranda *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
3	H-164	91–95. 5	Spine fragments.
4	H-20	74. 5–82	Do.
4	H-21	104–112	Do.
4	H-22	141. 5–145	Do.
4	H-23	153–161	Do.
4	H-24	179–182. 5	Do.
4	H-26	200–204. 5	Do.
4	H-30	258–262	Do.
4	H-31	268–271. 5	Do.
5	H-6	75. 5–84. 5	Do.
5	H-8	110. 5–114	Do.
5	H-9	124. 5–132. 5	Do.
5	H-11	198–205. 5	Do.
5	H-13	259. 5–264. 5	Do.
5	H-14	274–281. 5	Do.
6	H-35	34. 5–42	Do.
6	H-37	88. 5–90	Do.
6	H-38	114–121. 5	Do.
6	H-40	152. 5–158–5	Do.
6	H-42	189. 5–195	Do.
6	H-43	211. 5–217	Do.
6	H-44	235. 5–236	Do.
6	H-46	265. 5–270. 5	Do.
6	H-47	282–290	Do.
7	H-49	19–23	Do.
7	H-49a	32. 5–36. 5	Do.
7	H-53	107. 5–112	Do.
9	H-79	0–2	Do.
9	H-80	2–9. 5	Do.
9	H-83	79–82	Do.
9	H-85	136. 5–140. 5	Do.
9	H-88	168–175. 5	Do.
9	H-89	190–200. 5	Do.
9	H-93	264–268	Do.
10	H-102	136–139. 5	Do.
10	H-104	163–166. 5	Do.
10	H-106	190. 5–196. 5	Do.
12	H-114	15. 5–20	Do.
12	H-115	34–38. 5	Do.
12	H-117	57–60	A primary spine from the actinal plastron (pl. 22, fig. 26).
12	H-118	62–66. 5	Spine fragments.
12	H-128	149–154	Portion of a primary spine.
12	H-133a	216–217. 5	Portion of a primary abactinal spine.
12	H-133b	217. 5–223. 5	Do.
12	H-134	236–243	Spine fragments.
13	H-139	42. 5–47	Do.
13	H-146	105. 5–112	Do.
13	H-147	112–115	Do.
13	H-152	169. 5–173	Primary spine from the upper border of the buccal cavity (pl. 22, figs. 31, 32, 33).
13	H-153	173. 5–180	Spine fragments.

Genus **AËROPSIS** Mortensen

Geographic range: Known from the area between Cape Hatteras and Massachusetts, from Davis Strait, the Bay of Biscay (?), off Portugal (?), off Peru, off the west coast of Central America, central Bering Sea, and from a locality near the Aru Islands. It is probably cosmopolitan under the proper conditions of bottom, depth, and temperature.

Bathymetric range: From 2,148 to 5,200 meters.

Thermal range: From 1.4° to 3.6° C.

Geologic range: Known only from Recent seas.

Number of included species: The genus *Aëropsis* includes 2 species, one from the Pacific Ocean and the Arafura Sea and the other from the North Atlantic. These two species are not very well differentiated.

Aëropsis rostrata (Norman)

Geographic range: From Cape Hatteras to Davis Strait; recorded also from the Bay of Biscay and from the sea off Portugal, but these records require confirmation.

Bathymetric range: From 2,230 to 3,150 meters.

Thermal range: From 1.4° to 3.6° C.

Material: The distribution of the fragments of *A. rostrata* in the cores is given in table 24.

TABLE 24.—*Distribution of fragments of* Aëropsis rostrata *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
4	H-31	268–271. 5	Spine fragments.
5	H-6	75. 5–84. 5	Do.
6	H-38	114–121. 5	Do.
6	H-40	152. 5–158. 5	Do.
6	H-42	189. 5–195	Do.
6	H-47	282–290	Do.
7	H-50	49. 5–54	Do.
7	H-51	70. 5–74. 5	Do.
7	H-58	203–209	Do.
9	H-79	0–2	Do.
9	H-80	2–9. 5	Do.
9	H-81	37. 5–42	Do.
9	H-86	161–163. 5	Do.
9	H-88	168–175. 5	Do.
9	H-89	190–200. 5	Do.
11	H-177	5. 5–12	Do.
12	H-113	0–5	Do.
12	H-115	34–38. 5	Do.
12	H-116	52–57	Do.
12	H-128	149–154	Do
12	H-133a	216–217. 5	Do.
12	H-133b	217. 5–223. 5	Do.
13	H-137	23. 5–27	Do.

Genus **ACESTE** Wyville Thomson

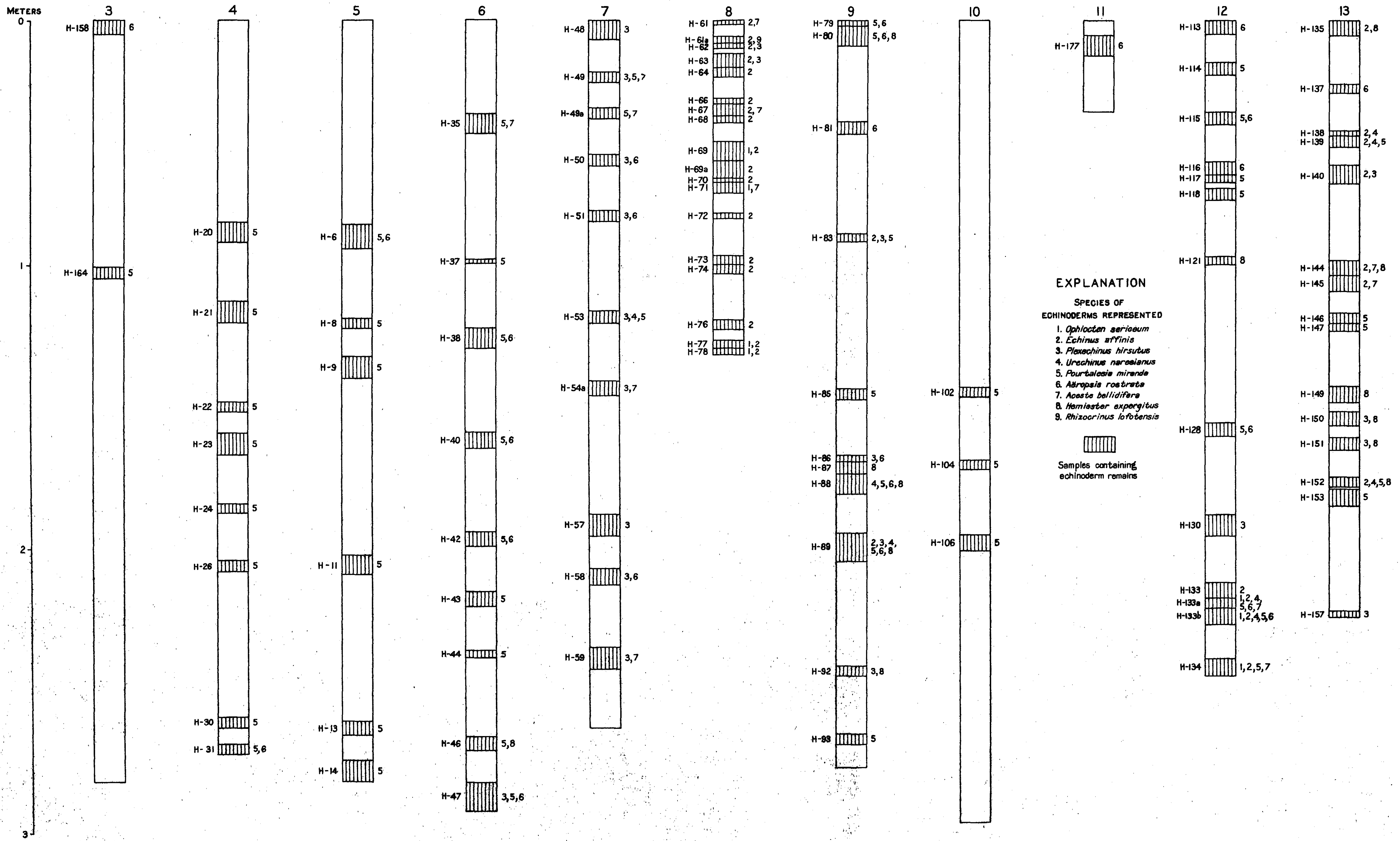
Geographic range: Off southern New England and Virginia, off the Azores, the eastern Atlantic, the Canary Islands, the Caribbean Sea, off Uruguay, off the coast of Peru, northwest of the Marquesas, the Hawaiian Islands, southern Japan, the Lesser Sunda Islands, and the Bay of Bengal. It is probably cosmopolitan on suitable bottoms under the requisite physical conditions.

Bathymetric range: From 435 to 5,200 meters.

Thermal range: From 0.0° to 8.9° C.

Geologic range: Known only from Recent seas.

Number of included species: The genus *Aceste* is currently considered as including 3 species, *A. bellidifera* from the Atlantic, *A. ovata* from the Pacific, and *A. weberi* from the Bay of Bengal and the Lesser Sunda Islands. But the differences between these are slight and unimportant, and they probably represent merely more or less constant local varieties of a single cosmopolitan species.



(Faces p. 114)

CHART SHOWING THE DISTRIBUTION OF THE SPECIES OF ECHINODERMS IN THE CORES.

Each column represents a core. The vertically ruled rectangles represent echinoderm-bearing samples. The numbers at the left of the rectangles are the serial numbers of the samples; the numbers at the right correspond to the numbers of the species of echinoderms listed below the column that represents core 11.

Aceste bellidifera Wyville Thomson

Plate 22, figure 27

Geographic range: Known from off southern New England and Virginia, off the Azores, near the Canary Islands, the eastern Atlantic, the Caribbean Sea, and off Uruguay.

Bathymetric range: From 698 to 3,473 meters.

Thermal range: From 0.0° to 7.6° C.

Material: The distribution of the fragments of *A. bellidifera* in the cores is shown in table 25.

TABLE 25.—*Distribution of fragments of* Aceste bellidifera *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
6	H-35	34. 5-42	Spine (pl. 22, fig. 27).
7	H-49	19-23	Spine fragments.
7	H-49a	32. 5-36. 5	Do.
7	H-54a	133. 5-139	Do.
7	H-59	232-240	Do.
8	H-61	0-1. 5	Do.
8	H-67	31-35. 5	Do.
8	H-71	60-64	Do.
12	H-133a	216-217. 5	Do.
12	H-134	236-243	Do.
13	H-144	89-94. 5	Do.
13	H-145	94-5. 100. 5	Do.

Genus HEMIASTER L. Agassiz and Desor

Geographic range: From the ridges across Davis Strait (lat. 67° N.), between Greenland and Iceland, between Iceland and The Faeroes, and from The Faeroes to Norway southward to the Caribbean Sea and the Canary Islands; Indian Ocean; from the Malay Archipelago northward to southern Japan; and from the west coast of Central America southward to Ecuador.

Bathymetric range: From 139 to 4,062 meters.

Thermal range: From 1.6° to 11.8° C.

Geologic range: Cretaceous to Recent.

Number of included species: The genus *Hemiaster* includes 5 Recent species.

Hemiaster expergitus Lovén

Plate 22, figure 30

Geographic range: From the ridges across Davis Strait (lat. 67° N.), between Greenland and Iceland, between Iceland and The Faeroes, and from The Faeroes to Norway southward to the Caribbean Sea and the Canary Islands; the Malay Archipelago and northward to southern Japan.

Bathymetric range: From 402 to 3,107 meters.

Thermal range: From 2.4° to 7.7° C.

Material: The distribution of the fragments of *H. expergitus* in the cores is shown in table 26.

TABLE 26.—*Distribution of fragments of* Hemiaster expergitus *in the cores*

Core No.	Sample No.	Distance from top of core (centimeters)	Description of fragments
6	H-46	265. 5-270. 5	A typical spatulate spine of intermediate width.
9	H-80	2-9. 5	An anterior primary spine.
9	H-87	163. 5-168	Do.
9	H-88	168-175. 5	Spine.
9	H-89	190-200. 5	An anterior primary spine.
9	H-92	239-242. 5	Spine.
12	H-121	89. 5-90. 5	Fragments of spines.
13	H-135	0-5. 5	Do.
13	H-144	89-94. 5	Tip of a spatulate spine.
13	H-149	135. 5-141. 5	A spatulate spine.
13	H-150	145. 5-150	Spine fragments.
13	H-151	154. 5-159	A spatulate spine.
13	H-152	169. 5-173	One nearly complete spatulate spine, the tip of another, the base of a third, and a fragment (pl. 22, fig. 30).

Genus RHIZOCRINUS M. Sars

Geographic range: From Florida northward to Nova Scotia and Davis Strait (as far as lat. 65°16′ N.), eastward and northeastward to western and southern Iceland, western Ireland, western Scotland, and the Lofoten Islands.

Bathymetric range: From 140 to 3,135 meters.

Thermal range: From 1.4° to 9.3° C.

Geologic range: Eocene to Recent.

Number of included species: The genus *Rhizocrinus* includes only the single Recent species *R. lofotensis*. The form occurring along the North American coast from Florida to Nova Scotia is regarded as a subspecies, *R. lofotensis verrilli.*

Rhizocrinus lofotensis M. Sars

Geographic range: From Florida northward to Nova Scotia, Davis Strait (lat. 65°16′ N.), western and southern Iceland, western Ireland, western Scotland, and the Lofoten Islands.

Bathymetric range: From 140 to 3,135 meters.

Thermal range: From 1.4° to 9.3° C.

Material: Core 8, H-61a, 6-8.5 centimeters below top of core.—Two pinnulars.

OCCURRENCE OF SPECIES BY CORES

The distribution of echinoderm species in each core is shown graphically in plate 20.

RELATIVE FREQUENCY OF THE SPECIES

By far the commonest species represented in the cores is *Pourtalesia miranda*, remains of which were found in 50 samples, from all the cores except core 8 and core 11. The next commonest species was *Echinus* *affinis*, the stout spines or plates of which were found in 32 samples, but these samples were from only 4 cores. Other species frequently encountered were *Aëropsis rostrata*, in 24 samples representing all but 3 cores, and *Plexechinus hirsutus*, in 20 samples from 6 cores. *Aceste bellidifera* was found in 13 samples from 5 cores, and *Hemiaster expergitus* in 13 samples from 4 cores. *Urechinus naresianus* was found in 8 samples from 4 cores, and *Ophiocten sericeum* in 8 samples from 3 cores. *Rhizocrinus lofotensis* was found in only a single sample from the upper part of core 8.

DISTRIBUTION OF SPECIES BY CORES

The distribution of the echinoderm species represented in the cores is shown in table 27.

TABLE 27.—*Distribution of the echinoderm species represented in the cores*

Species	Cores										
	3	4	5	6	7	8	9	10	11	12	13
Ophiocten sericeum	---	---	---	---	---	×	---	---	---	×	×
Echinus affinis	---	---	---	---	---	×	×	---	---	×	×
Plexechinus hirsutus	---	---	---	×	×	×	×	---	---	×	×
Urechinus naresianus	---	---	---	---	×	---	×	---	---	×	×
Pourtalesia miranda	×	×	×	×	×	---	×	×	---	×	×
Aëropsis rostrata	---	×	×	×	×	---	×	---	×	×	×
Aceste bellidifera	---	---	---	×	×	×	---	---	---	×	×
Hemiaster expergitus	---	---	---	×	---	---	×	---	---	×	×
Rhizocrinus lofotensis	---	---	---	---	---	×	---	---	---	---	---
Total number	1	2	2	5	5	5	6	1	1	8	8

Cores 12 and 13 contained the largest number of echinoderm species, 8 each. Core 8 contained remains in the greatest abundance, but these represented only 5 species. Table 28 presents a fairly accurate picture of the relative abundance, although echinoderm fragments were probably more uniformly distributed through the cores than is indicated by the samples examined.

TABLE 28.—*Number of samples containing echinoderm remains and numbers of species represented*

Core	Depth (meters)	Number of samples containing echinoderm remains	Number of species represented
3	4, 700	2	1
4	3, 955	8	2
5	4, 820	6	2
6	4, 125	9	5
7	3, 250	10	5
8	1, 280	18	5
9	3, 745	11	6
10	4, 190	3	1
11	4, 820	1	1
12	3, 230	13	8
13	1, 955	15	8

BATHYMETRIC ANOMALIES

A number of the cores came from water deeper than the maximum at which some or all of the included species are known to live. The species for which the depth range is extended are listed below. Following each species is given the difference between the greatest depth at which it has been found previously and the depth at which the core was taken, also the difference between the maximum depth at which the genus has been found and the depth at which the core was taken.

	Difference, in meters, between depth of core and greatest known depth of—	
	Species	Genus
CORE 4:		
Pourtalesia miranda	825	350
CORE 6:		
Aceste bellidifera	657	0
Hemiaster expergitus	68	68
Plexechinus hirsutus	1, 754	1, 754
Pourtalesia miranda	990	515
CORE 9:		
Aëropsis rostrata	600	0
Urechinus naresianus	615	0
Pourtalesia miranda	610	135
CORE 10:		
Pourtalesia miranda	1, 060	585
CORE 12:		
Pourtalesia miranda	100	0
Aëropsis rostrata	85	0
Urechinus naresianus	100	0
Echinus affinis	51	51

Core 13 was taken at a depth 275 meters shallower than the minimum depth at which one of the contained species, *Aëropsis rostrata*, had previously been found and 193 meters less than the previously known minimum depth of the genus *Aëropsis*.

The apparent discrepancies are probably due to incomplete knowledge of the bathymetric range of the species noted. Comparatively few dredge hauls have been taken in the northeastern Atlantic at depths greater than 3,000 meters, far too few to give us an adequate picture of the true conditions at those depths. The greatest depth at which a core containing the remains of echinoderms was recovered was 4,820 meters (cores 5 and 11). Farther south the *Princesse-Alice* [3] dredged no less than 7 species of echinoderms (exclusive of holothurians) in 4,275 meters at station 1,306, and 3 species in 6,035 meters at station 1,173.

ASSOCIATION OF THE SPECIES ON THE PRESENT OCEAN BOTTOM

The most extensive work in the region under consideration was done by the Danish *Ingolf* expedition in 1895–96, and it is interesting to note the association of the species represented in the cores at the various *Ingolf* stations.

Ingolf station 18; southwest of Iceland (lat. 61°44′ N., long. 30°29′ W.); 2,075 meters; temperature 3.0° C.

Urechinus naresianus.
Pourtalesia miranda.
Rhizocrinus lofotensis.

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[3] Koehler, R., Échinodermes provenant des campagnes du yacht *Princesse-Alice* (Astéries, Ophiures, Échinides et Crinoïdes): Résultats des campagnes scientifiques accomplies sur son yacht par Albert I, Prince Souverain de Monaco, fasc. 34, pp. 292, 293, Monaco, 1909.

Ingolf station 24; Davis Strait (lat. 63°06′ N., long. 56° W.); 2,192 meters; temperature 2.4° C.

Pourtalesia miranda.
Hemiaster expergitus.

Ingolf station 36; Davis Strait (lat. 61°50′ N., long. 56°21′ W.); 2,623 meters; temperature 1.5° C.

Urechinus naresianus.
Pourtalesia miranda.
Aëropsis rostrata.

Ingolf station 37; Davis Strait (lat. 60°17′ N., long. 54°05′ W.); 3,135 meters; temperature 1.4° C.

Urechinus naresianus.
Pourtalesia miranda.
Aëropsis rostrata.
Rhizocrinus lofotensis.

Ingolf station 39; south of Iceland (lat. 62°00′ N., long. 22°38′ W.); 1,581 meters; temperature 2.9° C.

Urechinus naresianus.
Pourtalesia miranda.
Hemiaster expergitus.

Ingolf station 40; south of Iceland (lat. 62°00′ N., long. 21°36′ W.); 1,545 meters; temperature 3.3° C.

Ophiocten sericeum.
Urechinus naresianus.
Pourtalesia miranda.
Hemiaster expergitus.

Ingolf station 67; south of Iceland (lat. 61°30′ N., long. 22°30′ W.); 1,782 meters; temperature 3.0° C.

Pourtalesia miranda.
Hemiaster expergitus.

Ingolf station 76; southwest of Iceland (lat. 60°50′ N., long. 26°50′ W.); 1,473 meters; temperature 4.1° C.

Plexechinus hirsutus.
Urechinus naresianus.

Ingolf station 81; southwest of Iceland (lat. 61°44′ N., long. 27°00′ W.); 887 meters; temperature 6.1° C.

Ophiocten sericeum.
Plexechinus hirsutus.
Rhizocrinis lofotensis.

Ingolf station 83; southwest of Iceland (lat. 62°25′ N., long. 28°30′ W.); 1,667 meters; temperature 3.5° C.

Plexechinus hirsutus.
Urechinus naresianus.
Rhizocrinus lofotensis.

The general similarity between the association of species as represented in the cores and the association on the sea bottom as represented in the *Ingolf* dredgings is rather striking.

At *Ingolf* stations 36 and 38 there were dredged three of the four species represented in core 12, sample H–133b, taken 217.5–223.5 centimeters below the surface, and at stations 39 and 40 there were found three of the four species represented in core 13, sample H–152, taken 169.5–173 centimeters below the surface.

The tendency of *Echinus affinis* to appear alone in sections of the cores, as in cores 8 and 12, is parallel to the incidence of this species in the *Ingolf* dredgings. The *Ingolf* obtained it at eight stations, but at none of these were any of the other species represented in the cores.

Aceste bellidifera, remains of which were rather common in the cores, was not dredged by the *Ingolf*.

RELATION OF SPECIES TO DISTANCE BELOW TOP OF CORE

The relation of the remains of the various echinoderm species represented to the distance below the tops of the cores at which they occur is shown in table 29.

TABLE 29.—*Relation of echinoderm species to distance below top of core*

Species	Distance below top of core (centimeters)					
	0–30	30–75	75–139	139–195	195–240	240–290
Ophiocten sericeum	×	×	×	------	×	×
Echinus affinis	×	×	×	×	×	------
Plexechinus hirsutus	×	×	×	×	×	×
Urechinus naresianus	------	×	×	×	×	------
Pourtalesia miranda	×	×	×	×	×	×
Aëropsis rostrata	×	×	×	×	×	×
Aceste bellidifera	×	×	×	×	×	------
Hemiaster expergitus	×	------	×	×	×	×
Rhizocrinus lofotensis	×	------	------	------	------	------
Total number	8	7	8	7	8	5

The absence of *Ophiocten sericeum* between 139 and 195 centimeters; *Echinus affinis, Urechinus naresianus,* and *Aceste bellidifera* below 240 centimeters; *Urechinus naresianus* above 30 centimeters; *Hemiaster expergitus* between 30 and 75 centimeters; and *Rhizocrinus lofotensis* below 30 centimeters is probably without significance. On the basis of the available evidence it is reasonable to infer that from the time represented by the lowest parts of the cores until the present day all the species represented in the cores have maintained essentially the same relationships on the sea bottom.

It should be noted that in core 4 no echinoderm remains were found higher than 74.5 centimeters below the top, in core 5 above 75.5 centimeters, in core 6 above 34.5 centimeters, and in core 10 above 136 centimeters. Whether or not this is of significance cannot be determined at present.

PART 7. MISCELLANEOUS FOSSILS AND SIGNIFICANCE OF FAUNAL DISTRIBUTION

By LLOYD G. HENBEST

INTRODUCTION

The fossils discussed in this chapter were found in the 11 cores of deep-sea sediment that were collected by C. S. Piggot in 1936 between Newfoundland and the British Isles. Details of location, depth of water, and length of core, beyond the data appearing on plate 21, are presented in the introductory chapter.

The original purpose of this chapter was to furnish a record of the occurrences of organisms that were not studied by the specialists of particular groups. It became evident before I had completed picking out the metazoan fossils from each sample that the distribution of the faunas had a significance that was incompletely represented by any single group except perhaps the Foraminifera. I have attempted to organize the data on the larger aspects of faunal distribution independently and without infringing on the field of the reports on special groups. The chapter on the Ostracoda, by W. L. Tressler, was finished before this chapter was completed, and his work is the source of certain data on the ostracodes. The data on temperature were obtained from the chapter on Foraminifera.

It is a pleasure to acknowledge my indebtedness to W. H. Bradley, of the Geological Survey, and Waldo L. Schmitt, of the United States National Museum, for helpful criticisms of the manuscript.

The following groups of organisms, listed in order of importance as rock-forming agents, were found in these cores: Foraminifera, Diatomaceae, Echinoidea (spines and, rarely, dissociated plates), Silicispongiae, Radiolaria, and Ostracoda. Locally, Pteropoda are in the first rank of lime-precipitating agents. Scattered fossils or recognizable fragments of Brachiopoda, Pelecypoda, Gastropoda, Bryozoa, Echinodermata other than Echinoidea, barnacle plates, and otoliths of teleost fishes were recovered but are rare and are very minor elements in the fauna and sediment.

All the metazoan fossils discussed in this and closely related chapters (pts. 4, 5, and 6) were recovered from the H series of samples, which were originally taken and prepared for studying the Foraminifera. These samples are numbered H–1 to H–177, except several additional samples that were taken during the progress of the work. These additional samples were designated by supplementary lower-case letters, as, for example, H–133a and H–133b. Three samples were also obtained from the B series, making a total of 184 samples that were studied. The locations of all the H samples are shown on plate 21 and of the B samples on plate 3.

METHODS OF PREPARATION AND STUDY

The samples were not removed until after the cores had thoroughly dried. At most horizons the sediment had hardened sufficiently on drying to withstand the cutting out of coherent sectors of the core with a hacksaw. The sectors were trimmed of extraneous material to avoid contamination, or, wherever the sediment was too friable to handle, extraneous material was scraped away before excavating a sample. The average trimmed sample had a volume of 2 to 5 cubic centimeters.

The samples were very carefully washed in 200-mesh bolting silk, precautions being taken to avoid contamination and breakage of specimens. Though most samples required only a prolonged soaking in water before washing, some required boiling or treatment with washing soda. As a result of this method of preparation, minute diatoms and radiolarians, clay, and fine silt were washed through the sieve. Though effective for shells of Foraminifera and larger organisms, this method frequently does not separate small diatoms and radiolarians from a clay matrix. Consequently the estimates of relative abundance of organisms (see pl. 21) based on the washed residues are more or less inaccurate for the small diatoms and radiolarians but not for a few large forms, such as the diatom *Coscinodiscus*, which is clearly recognizable in such washed residues. The diatoms, however, are only treated incidentally in this chapter in connection with certain distributional problems, as they have been treated comprehensively in the chapter by K. E. Lohman, who worked with a different series of samples.

It should be noted that the few samples that were boiled in a solution of washing soda did not originally contain enough silica fossils to characterize the sediment. Therefore, it is unlikely that the possible destructive effect of the washing soda on the silica fossils made a serious difference in the gross estimates of organic silica.

Several of the groups of metazoan fossils were submitted to specialists, who supplied either memoranda that have been incorporated with due acknowledgments in this chapter or reports that appear as separate chapters or parts. (See p. XIV of the introductory chapter). Representatives of the metazoan fossils are illustrated on plates 22 and 23.

In order to show clearly the geographic and stratigraphic distribution of the groups of fossils in these cores, the washed residue of each sample was searched under a low-power stereoscopic microscope, and the occurrence and the relative abundance of the organisms were plotted on a large chart (pl. 21). After recovering the metazoan fossils and incidentally any rare or significant specimens of Foraminifera that came to view, the sample was divided, and about three-fifths was sent to the Cushman Laboratory, where the Foraminifera were systematically picked out and organized for study by Frances L. Parker.

Obviously such a method of determining the proportions of the various groups is applicable only to the microorganisms, because they alone are found in sufficient numbers in these small samples to be representative of their groups. The inclusion of a whole specimen of a large metazoan fossil in a small trimmed sample is more or less accidental. In our sampling, however, we searched the exposed surfaces of each core for large fossils, thus making our record more comprehensive than that afforded by the trimmed samples alone. For these reasons, the large fossils are generally indicated on the chart as present or absent. Locally, fossil pteropods and ostracodes were found in sufficient abundance to be given a numerical rating.

Rough estimates were also made of the ratio of organic (i. e., shell) silica and calcium carbonate to the inorganic sediment in the washed residue of each sample. Wherever the organic calcium carbonate content was large enough to characterize the sediment it was indicated on the chart (pl. 21) by a solid black rectangle. The presence of only subordinate amounts of organic calcium carbonate was indicated by a broad, vertical line, and the absence by a blank space. In an adjacent column the relative amount of organic silica was similarly indicated, It should be emphasized that these estimates reflect the relative abundance of organically produced calcium carbonate and silica in samples of the sediment from which has been washed all the material fine enough to pass through 200-mesh silk bolting cloth. Because considerable quantities of organically produced calcium carbonate and silica, such as coccoliths and minute diatoms and comminuted fragments of foraminiferal shells, pass through the sieve, the relative amounts of these constituents that were in these samples before washing may be considerably different from those shown on plate 21. In some, the relations are almost certainly reversed. For estimates of the percentage of foraminiferal shells and estimates of the relative abundance of coccoliths in unwashed samples of sediment in the cores see plate 3 of the chapter entitled "Lithology and geologic interpretations."

NOTES ON THE GROUPS OF FOSSILS

BARNACLES

Plate 23, figures 20–38

A few dissociated plates of barnacles were found in samples H–61a, H–70 to H–75, H–77, H–78, H–133a, H–133b, and H–134. In all but one of these samples the plates were associated with an abundance of globigerinids. In that one exception (H–75) the number of globigerinids was estimated as common rather than abundant. In samples H–77, H–78, H–133a, H–133b, and H–134 pteropods are associated with the barnacles, and in H–133a, H–133b, and H–134 the pteropods are abundant. All our specimens of barnacles were taken from cores 8, 12, and 13, the three from the shallowest depths. The depths from which these cores were taken range from 1,280 to 3,230 meters (700 to 1,770 fathoms). Because barnacles attach themselves to all sorts of objects, whether fixed, floating, or swimming, the plates of shallow-water barnacles are widely distributed over the ocean bottoms.

BRACHIOPODA

Plate 22, figures 15–18

Six samples in core 8 contained fragments or parts of shells large enough to be definitely recognizable as brachiopods. In core 13 one recognizable fragment was found. In core 12 an identifiable valve was found. The three most nearly complete specimens were submitted to G. A. Cooper, of the United States National Museum, for identification. He reported as follows:

> These specimens belong to two widely different genera of brachipods. The genus *Gryphus* was represented in core 8, sample H–61a, by a poorly preserved dorsal and ventral valve.
>
> The genus *Cryptopora* was represented in core 12, sample H–133b, by a single dorsal valve sufficiently well preserved to be identified as the species *C. gnomon* (Jeffreys). This brachiopod has a range in existing seas of 100 to nearly 1,800 fathoms.

The present depth of water at core station 12 is 3,230 meters (1,770 fathoms).

BRYOZOA

Plate 22, figures 20–24

Specimens recognizable as undoubtedly Bryozoa were found in three samples, H–66 and H–69 in core 8, and H–132 in core 12 (pl. 22, figs. 23, 24). These were submitted to R. S. Bassler, of the United States National Museum, who reports that "they belong to three species of *Entalophora*, a genus of Cyclostomata. They were most likely transported to this locality on floating or swimming supports."

These, along with specimens of the foraminifer *Elphidium* (see p. 47) and a few other erratics, both inorganic and organic, give increasing evidence of the importance of rafts (probably seaweed) and perhaps ice as transporting agents of attached or frozen microorganisms and small invertebrates.

A few fragmentary specimens of problematical, bryozoanlike growths were found in samples H–61, H–61a, and H–63, core 8 (pl. 22, figs. 20–22). Specimens of these were sent to R. C. Osburn, of Ohio State University, and to Elizabeth Deichmann, of the Museum of Comparative Zoology, Harvard College, and both have reported that they are bryozoan. Osburn, besides reporting that they are definitely Bryozoa, adds the following information:

> One of these four [specimens] shows a perfectly good aperture with an avicularian process and chamber, and another specimen shows the same structures less perfectly. I cannot be certain of the genus, but *Jaculina* of Jullien comes pretty close. It occurs down to 500 meters. This species is not *J. blanchardi* (the only one known in the genus) and is probably new.
>
> There is another species on slide 61 [sample H–61, not illustrated], the left-hand specimen. It is imperfect and a small scrap but looks as if it might belong to the Reteporidae.

DIATOMACEAE

The diatoms recorded on the chart represent only species of *Coscinodiscus*, the tests of which are large enough to be retained by the sieves used in washing foraminiferal samples. Diatoms of this genus are sufficiently abundant at places in some cores to be a conspicuous or even a dominant constituent of the sediment. In such proportions the importance of the diatoms as mineral-precipitating agents is evident, and their abundance can readily be estimated, even in samples prepared for Foraminifera. A comprehensive treatment of the diatoms is given in part 3 of this professional paper, by K. E. Lohman, who worked with a separate series of samples.

ECHINODERMATA

Plate 22, figures 25–40

Echinoderm remains other than echinoids are very rare and fragmentary, but the echinoid remains are widely distributed through the cores. They are not sufficiently plentiful in any sample to characterize the sediment but are so widely distributed, even in zones where other groups of organisms are scarce or absent, that they are important limy elements of the sediment. However, echinoids may not contribute as much calcite to the bottom sediment as they destroy or dissolve as a result of ingesting large quantities of bottom sediment that contains an abundance of calcareous shells.

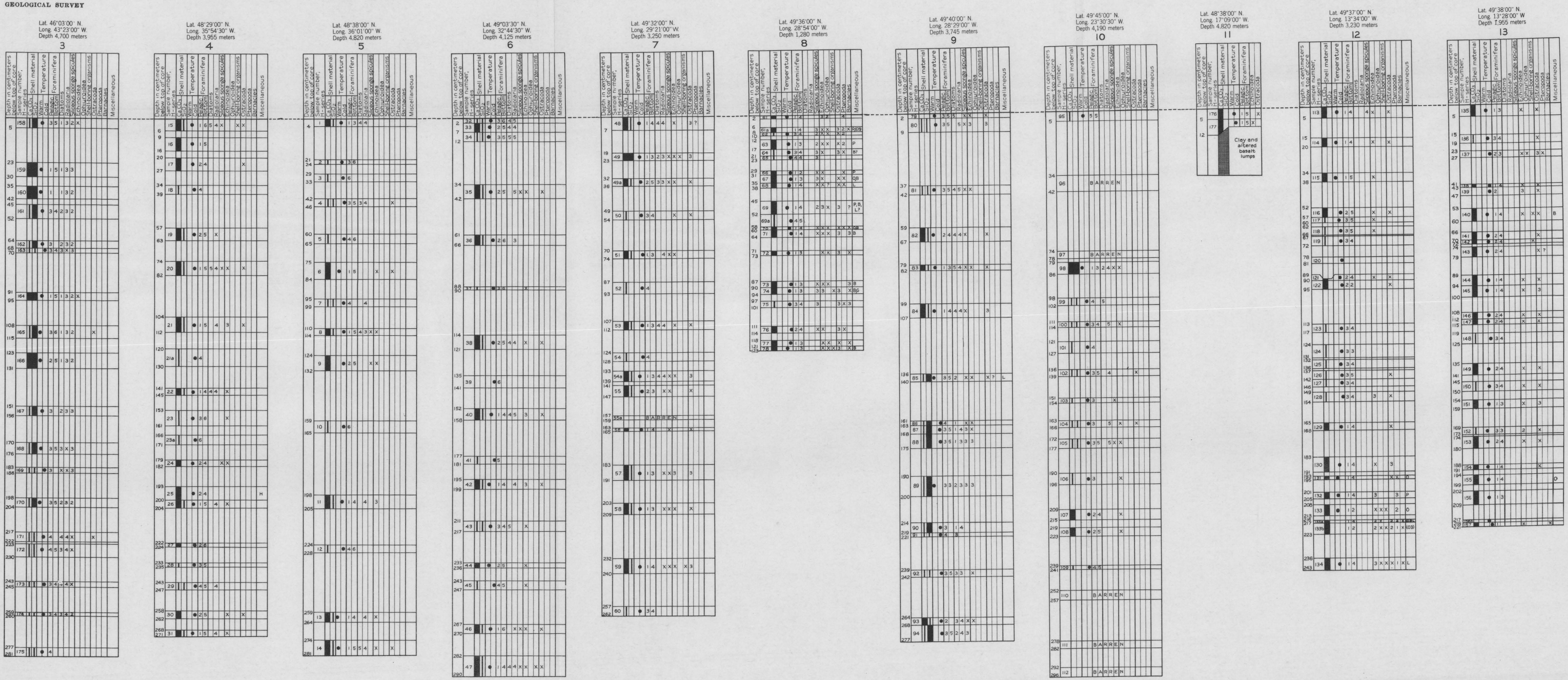
The echinoids are represented chiefly by spines, but in core 12, sample H–133b, a few dissociated interambulacral plates and fragements were found. A number of the samples contained a few ophiuroid spines and marginal or peripheral plates and vertebrals. In number and distribution these are greatly exceeded by the echinoid remains.

The echinoderm fossils were submitted to Austin H. Clark, of the United States National Museum, for study. His report is part 6 (pp. 111–117) of this professional paper and was prepared after this chapter was written. It contains an interesting observation that deserves additional comment here in connection with my discussion of hypotheses of extreme changes in sea level. Clark observes that several species in the cores are found at somewhat greater depths than previously recorded. I have attempted to correlate the occurrences at depths greater than previously known with the time and climatic zones recognized in the cores, but without success. Furthermore, the anomalies do not appear to be systematic within themselves. In view of (1) the widely observed generalization that within the zone of calcite stability in sea water, deep-sea organisms are not closely restricted by small variations in depth; and (2) the apparent lack of a systematic arrangement of the occurrences, these downward extensions of range seem to have no observable significance. The possibility that such forms as *Hemiaster* may have burrowed into sedimentary layers below those representing their life zone and died there makes it unsafe to conclude that the habitats of all the echinoids were as lacking in fine zoning as they appear to be from the sedimentary record of these cores.

FORAMINIFERA

The Foraminifera are the subject of a separate chapter (pt. 2, pp. 35–50), but the preeminent importance of the group as a member of the faunas and as a source of significant information on distribution and ecology makes it appropriate to include in this chapter a brief survey of its faunal distribution. The temperature data on the chart in plate 21 were originally contributed in the chapter on "Foraminifera," figures 11 to 21. The estimates of relative abundance, however, were prepared for the present chapter.

Pelagic foraminifers are present in most samples. Only 5 samples out of 184 were barren of pelagic species, and only 4 were nearly so. Shells of bottom-dwelling forms are less widely distributed. About 32 samples contained no bottom-dwelling forms, and 11 contained only a very few. A wider distribution for pelagic forms is to be expected, because they are generally independent of bottom conditions that may make a locality unfavorable as a dwelling place for bottom-living foraminifers though favorable for preservation of the shells rained down from the zone of light penetration. In 100 samples—four-sevenths of the total number taken from the cores—the pelagic foraminifers constitute a considerable or even a principal part of the washed residues.



(Faces p. 122)

CHART SHOWING THE DISTRIBUTION AND RELATIVE ABUNDANCE OF THE MISCELLANEOUS ORGANISMS IN THE CORES.

Each core is represented by a wide, vertical column that has the core station number at its top. Each sample of the series H-1 to H-177 is indicated by a pair of horizontal lines between which the sample number and other symbols are placed. The position and length of each sample is indicated both by the relative position in the column and by the number of centimeters below the top of each core. The ratio of organic lime and silica to inorganic material in the washed residue of a sample is roughly indicated by a solid black rectangle if the lime or silica constitutes more than approximately 15 percent of the volume or by a wide vertical line if the lime or silica is present in smaller amounts. Relative differences in surface-water temperature as shown by the pelagic foraminifers are indicated by large dots on or near a reference line that represents the present-day surface-water temperature at each core station. The relative abundance of the organisms is shown by the numbers 1 to 6: 1 indicates that the organisms are abundant or a dominant constituent, roughly 25 to nearly 100 percent; 2 indicates that the organisms are plentiful and a conspicuous element of the sample; 3, common; 4, a minor constituent, roughly 1 percent or less by volume; 5, uncommon; and 6, rare. The presence of larger organisms or others whose abundance is not adequately represented by small samples is indicated by ×. Organisms too scarce for a separate column are listed under "Miscellaneous" and indicated as follows: B, Brachiopoda; G, Gastropoda; H, Holothuroidea; L, Pelecypoda; O, otolith of teleost fish; P, Bryozoa.

Pelagic foraminifers and diatoms occur in all degrees of relative abundance in the same deposits. In samples H-159, H-160, and H-164 both pelagic foraminifers and *Coscinodiscus* are so abundant that the washed residue is composed almost wholly of the two kinds of organisms. In sample H-86 (core 9), the pelagic foraminifers are subordinate in volume in a *Coscinodiscus* ooze. In 18 samples, *Coscinodiscus* constitutes either a large or principal part of the volume of the residues.

It is a significant fact that the most varied and prolific faunas of benthonic Foraminifera were found in the cores from shallowest water and the least varied in the cores from deepest water.

OTOLITHS

Plate 23, figures 10-19

Otoliths were found in 8 samples in cores 8, 12, and 13. These were submitted to L. P. Schulz, of the United States National Museum, who informed me that they apparently came from small teleost fishes and that for lack of comparative material they are at present not identifiable.

These otoliths, it will be noted, occur in the three cores from the shallowest depths.

OSTRACODA

The ostracodes were submitted to W. L. Tressler, of the University of Buffalo, for study. He has contributed a separate report, part 4 of this professional paper. A few specimens have been found since his report was completed and have been included in my chart, plate 21, though they have not been added to his records. These additional specimens do not seem to change the general features of distribution as presented by Tressler.

While recording the distribution of the ostracodes it soon became obvious that the most varied faunas and the greatest number of specimens were found in the cores from the shallowest water, whether in cold, normal, or warm zones (as indicated by the Foraminifera). On the contrary, the cores from the deepest water are characterized by a nearly uniform rarity of specimens and lack of variety.

This feature of ostracode distribution in the cores is characteristic of marine ostracode faunas now living.

In his description of the ostracodes from these cores, Tressler indicates that 7 of the 27 species identified have been recorded only from water deeper than Murray's line, that is, the 200-meter line. These 7 species were found in cores 6, 7, 8, 12, and 13, with 11 occurrences in the cold-temperature zone, a similar number in the normal zone, and 9 in the warm zone or normal to warm zone [1] as indicated by the Foraminifera.

All the other species, except *Paracytherois producta* and perhaps *Cytheropteron alatum*, have been recorded from a wide range of depths.

PTEROPODA

Plate 23, figures 5-9

The pteropods from the cores were submitted to H. A. Rehder, of the United States National Museum, whose report is part 5 of this professional paper. Owing to the importance of the pteropods as a source of ecological data, I shall briefly call attention to certain interesting features of their distribution.

Pteropods are more widely distributed in core 8 than in any of the others. They are abundant in three and present in eight other samples. In core 12 they were found in six samples, in four of which they were so abundant that the sediment is a globigerina-pteropod ooze. In core 13 they were found in one sample and were doubtfully present in another. According to inferences based on associated pelagic Foraminifera, nine pteropod-bearing zones were deposited when the water temperature at the respective coring stations was colder than it is today, three or four when like that today, and three when warmer. It is significant that the pteropod shells occur in the cores from the shallowest water, with the possible exception of core 7 (sample H-48), in which a fragment identified with uncertainty as a pteropod was found. The water at core station 7 is 3,250 meters deep, which is only 20 meters deeper than that at core station 12 and not an unusual depth for pteropod shells. The distribution of shells at all places in the cores is in harmony with the bathymetric distribution of ostracode shells in the present oceans at the depth and latitude represented by the cores.

Pteropod oozes are generally restricted to comparatively small areas. They are found most commonly around islands or on submarine ridges far removed from land and in shallow, warm, or temperate water. Pteropod ooze commonly intergrades with globigerina ooze and generally ranges from 800 to 3,000 meters in depth. Pteropod shells are reported to be rare in sediments deposited at a depth greater than 4,000 meters (2,200 fathoms). The absence of pteropod shells from the deeper water of many areas seems to be a result of their high solubility rather than the complete absence of a pteropod fauna from the shallow-water zone above. Though pteropod ooze is comparatively restricted, the organisms are very widely distributed, even in cold regions. For example, *Limacina helicina* (Phipps) and *Clione limacina* are reported from the Arctic region and *L. antarctica* Woodward from the Antarctic by Pelseneer.[2]

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[1] For explanation of these temperature zones see part 2, Foraminifera, p. 48.

[2] Pelseneer, Paul, Report on the Pteropoda; *Challenger* Rept., Zoology, vol. 23, pp. 21, 22, 1888.

RADIOLARIA

Radiolaria are rather generally present in cores 3 to 7 9, and 10, but they are subordinate to the foraminifers, diatoms, and probably siliceous sponges in importance as rock-forming agents. No radiolarian ooze was found. To a considerable extent, the estimates of abundance of the radiolarians as determined from samples prepared for Foraminifera is inaccurate, because the smaller forms may have passed through the sieve, and the ordinary methods of washing a sediment for foraminifera do not always separate a radiolarian skeleton from the matrix.

A peculiarly large type of radiolarian was found in core 6, sample H-42. (See pl. 22, fig. 19.) It agrees closely with the original description and figure of *Oroscena huxleyi* by Haeckel[3] and was reported by him from the North Atlantic (west of Canary Islands) at a depth of 5,000 meters (2,740 fathoms). This and related species were found, as reported by Haeckel, in water of similarly great depth.

SHELL-BORING ORGANISM

Plate 22, figures 41–46

At various places in several of the cores (especially in cores 8, 12, and 13 and rarely in cores 4, 6, and 7) occasional specimens of bottom-dwelling Foraminifera, especially *Pyrgo*, and a few Ostracoda were found to have one or more circular holes bored through the shell. One specimen of the foraminifer *Globorotalia* sp. was found that had each chamber bored. The organism evidently required a hole for each chamber to remove the contents of a shell. The organism that bored this shell, as shown by many other examples, seemed to have been unable to select beforehand the most appropriate place for boring, because a hole was frequently begun over a suture or so near one that after penetrating the outer layer a septal or other buried wall was encountered. When this happened the animal evidently moved over to a new location and bored a new hole.

The identity of the boring organism is uncertain. It was a bottom-dwelling form, because only the bottom-dwelling Foraminifera and Ostracoda are bored. The holes have a diameter of 0.09 to 0.17 millimeter. They are circular and are smaller at the bottom than at the top. They are not conical, however, as the sides curve inward toward the relatively small hole at the bottom. The organism was undoubtedly very small, and the great smoothness and circular shape of the holes strongly suggest enzyme action rather than mechanical excavation by radulae. Only one gastropod specimen (part of the columella) was found, and it was found in a sample containing bored foraminifer shells. Evidence that the boring organism was a gastropod accordingly depends principally on the similarity in form of these bore holes to holes bored by gastropods through shells of larger invertebrates rather than on the occurrence of this one gastropod fragment.

SILICEOUS SPONGE SPICULES

Plate 22, figures 1–14

Tetraxon and monaxon siliceous sponge spicules are widely distributed through all the cores but those from the deepest water. At a few horizons they occur in sufficient numbers to constitute an appreciable proportion of the washed residues of the sediment. It is not at all improbable that some samples fortuitously contained the remains of a single sponge closely assembled at the place of burial and therefore give an exaggerated appearance of abundance. Nevertheless, the distribution is so general through all the cores that the average number of spicules found in these small samples appears to represent the average spicule content of the sediments. If the spicule content of these sediments represents the average content of deep-sea sediments elsewhere, an immense amount of silica is precipitated through the agency of sponges. In these particular sediments, judging by the washed residues, sponge-spicule silica probably exceeds the volume of radiolarian silica.

MISCELLANEOUS

Very few holothurian spicules were found. A single definitely recognizable gastropod specimen, represented by only the columella of a shell, and a few small fragments of shells that might have belonged to gastropods were found. Four fragments definitely recognizable as pelecypod shells and one fragment apparently of a pelecypod were recovered.

Not all benthonic organisms left recognizable fossils, but they recorded their presence in the immense amount of work accomplished. No unaltered soft tissue of any organism or chitinous remains of Crustacea were found. Only siliceous and calcareous or phosphatic shell structures survived destruction by scavengers or saprophytes. It is evident from these fossil-bearing sediments that every bit of organic material available as food has been utilized one or more times until no recognizable structures of soft tissues remain. In this respect these Recent or relatively late sediments resemble the conditions of fossil preservation that are commonly encountered in outcrops of ancient marine sediments.

The sediment at the top of core 10 (sample H-95) was burrowed by an organism of unknown identity. This zone of sediment is discussed by Bramlette and Bradley in part 1, Lithology and geologic interpretations.

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[3] Haeckel, Ernst, Radiolaria: *Challenger Rept.*, Zoology, vol. 18, pt. 40, p. 1599, pl. 12, fig. 1, 1887.

USE OF FOSSILS AS INDICATORS OF DEPTH

The only groups of fossil organisms that are sufficiently well represented in number and morphologic detail to permit a natural classification are the Foraminifera, Diatomaceae, Ostracoda, and perhaps the Radiolaria. The Metazoa, except the Ostracoda, and Echinoidea are represented either by fragments or parts which do not admit of very close classification or by only a few specimens and offer a very meager source of ecological data; for example, sponge spicules are numerous and widely distributed but cannot be classified closely enough to yield much information about their identity or distribution.

The pteropods are locally an exception. Though pelagic and widely distributed in tropical to arctic waters, the distribution of pteropod shells in bottom sediments is limited to a zone of lesser depth than foraminfer shells. The lower limit of depth in which pteropod shells are insoluble is rarely greater than 3,000 to 4,000 meters. Though depth itself is not the immediate factor that limits the downward range of pteropod shell stability, depth is closely correlated with the involved combination of carbon dioxide content, temperature, salinity, and hydrostatic pressure (listed in order of importance), which do determine the solubility of calcium carbonate in sea water. Though it is sometimes stated that pteropods inhabit the warm temperate and tropical waters, they are in fact widely distributed and are found even in arctic waters. Likewise the pteropod shells in the cores are not restricted to the sediment deposited from the warmer waters but occur also in the zones of glacial marine sediment. Some of the cores were taken from bottoms within the existing zone of pteropod shell stability in the North Atlantic and some from bottoms below that zone. The cores collected from this zone of stability contain pteropod shells, whereas those from below contain none. Inasmuch as all the cores, including those from deeper bottoms, contain remains of normal foraminiferal faunas from the pelagic realm, the distribution of pteropod fossils among the cores and within each individual core gives a clue to the past history of sea levels.

All the core stations lie within and some near the base of the zone of stability of foraminifer shells. The shells of Globigerinidae in several of the cores from the deepest water showed the effects of etching.

The sources of evidence on depth just described are not strictly paleontologic, as they are a product of the relationship between the physical and chemical character of the water and the solubility of shells of dead organisms—a matter of preservation. Several of the other groups represented are also largely or entirely pelagic, and as the cores lie well within their more or less extensive bathymetric range of shell stability they give us little information on depth.

The only bottom-dwelling organisms besides the ostracodes and echinoids that, from a taxonomic standpoint, are adequately represented in the cores are the bottom-dwelling Foraminifera, which compose a fauna of greater taxonomic variety than the other fossils. So little systematic collecting or dredging and study has been done with close attention to factors of distribution related to depth and to the problem of possible mixture of existing forms with fossil shells in submarine exposures of pre-Recent beds that even the Foraminifera cannot yet be used for a detailed analysis of ecology. However, several general aspects of marine animal distribution make it possible to use the bottom faunas as indicators of depth within rather broad limits.

It seems to be generally accepted that the variety and population density of marine faunas is by far the greatest in the zone of light or close thereto. The depth of the zone of light penetration varies through a wide range and is controlled by a number of factors, principal of which are turbidity of the water, latitude (or angle of light incidence), and, locally, the density of floral and faunal population. In the Temperate Zone light apparently capable of causing photosynthesis penetrates as much as 100 meters. Below this depth the variety and density of the bottom-living population decreases rapidly, and the changes per unit of depth become less and less marked. The changes in faunal composition between the zone of light and 1,000 meters is far greater than the change between 1,000 and 4,000 meters.

These features of bathymetric distribution are a coarsely graduated yardstick with which the bathymetric distribution of the core faunas can be measured.

In sediments that contain remains of a moderately varied and populous assemblage of bottom-living animals the absence of bottom-living faunas or species (except a few evidently erratic specimens) characteristic of the zone of light or of shallow water, may be considered as evidence that the sediments were deposited in deep water. As the sediments in these cores were deposited under alternately glacial and nonglacial climates, it is difficult to suppose that the absence of shallow-water organisms was caused by any factor except depth or factors depending on depth.

Bottom-dwelling, shallow-water marine invertebrate faunas from the Mesozoic to Recent have been characterized by the predominance of Mollusca. In the core samples, bottom-dwelling Mollusca are conspicuous by their absence. Of the many thousands of fossil specimens found in these cores bottom-dwelling Mollusca are the most poorly represented, and some of these are undoubtedly deep-water forms, as, for example, the shell-boring organism which was possibly a gastropod. Mollusca are not present on all shallow-water bottoms, but they are so common and so widely distributed in a great variety of shallow-bottom environments that the complete absence of their remains in sediments of such variety as those in the cores would be hard to explain had the water at any time been shallow. If it were argued that they were absent because of high salinity at times of reduced ocean level, it would then be necessary to explain why such powerful effects of salinity were not registered in faunal records elsewhere.

Barnacles and bryozoans are also conspicuous by their scarcity. These organisms are extremely abundant in a variety of shallow-water communities.

SIGNIFICANCE OF DISTRIBUTION RELATIVE TO HYPOTHESES OF EXTREME CHANGES IN OCEAN LEVEL

The bathymetric distribution of the organisms represented in these cores has a significant bearing on the hypothesis of fluviatile origin of submarine canyons. Before describing this evidence the hypothesis will be outlined very briefly.

The continental shelves in the middle and low latitudes of the world are notched with deep canyonlike valleys, some of which are obviously continuations of existing major stream valleys, whereas others are short and, though very deep, appear to be strictly local notches in the margin of the shelf. The canyons so far described appear to have either a narrow V-shaped cross section, or, if comparatively wide, they have steep walls. The gradient is steep, at least locally, even in the long canyons. Thus the valley form is distinctly youthful. One feature of the submarine canyons that should be kept in mind during the following discussion is the great depth of the floors of many canyons below existing sea level. The floors of the Georges Banks Canyons, according to Stetson,[4] are 1,200 to 8,000 feet (375 to 2,400 meters) below sea level. The mouth of the submarine Hudson River Canyon is at a depth of approximately 2,000 meters. Others are still deeper.

The origin of these canyons remains an enigma. Several hypotheses of origin have been suggested, but our paleontologic data from the cores seem to be relevant most particularly to the fluviatile hypothesis of Shepard,[5] Veatch,[6] and perhaps also to that of Hess and MacClintock.[7] A comprehensive review of the problem and hypotheses has recently been published by Douglas Johnson.[8]

Though Shepard proposes a number of cooperative but subordinate causes, his hypothesis relies principally on stream erosion during intervals of greatly lowered sea level that were caused by evaporation of water from the seas and temporary storage in the Pleistocene ice sheets. He estimated[9] that the sea level was lowered 3,000 feet or more (approximately 1,000 meters). This figure is to be discussed below.

According to Veatch the lowest level that the sea reached, as measured by the submarine canyons, is represented by the Congo Canyon, off the coast of Africa, which extends to a depth of 3,000 to 3,500 meters below present sea level. Veatch supposes that the cutting of this canyon began in post-Mousterian (Old Stone Age) time, and that the ocean did not finally return to its present level until 5,000 years ago, or after the beginning of written history. The time and extent of the changes of sea level supposed by Veatch make the following discussion regarding Shepard's hypothesis pertinent also to that of Veatch.

The deeper submarine valleys are not reported to change character consistently at or near the 1,000-meter contour but continue without change of shape into depths ranging from 2,000 to 3,000 meters or even more. If, therefore, these particular hypotheses of fluviatile origin are to be consistent, it is necessary to assume that there were one or more changes in sea level of at least 2,000 meters and more likely 3,000 meters. The hypothesis of Hess and MacClintock differs from Shepard's hypothesis principally by supposing a change in sea level caused by deformation of the hydrosphere, but they are not specific as to ultimate causes.

The bearing of paleontologic data from the deep-sea cores will be discussed first in relation to supposed changes in sea level of 2,000 meters during Pleistocene time. The discussion relative to extreme changes of 2,000 meters applies so much more decisively to the hypothesis of Veatch that the reader will be left to make his own deductions for a 3,000-meter change.

Several significant features of the distribution of the fossils in the cores have either been suggested above or are shown in the chart, plate 21. These and additional points may be summarized as follows:

1. The most varied and prolific bottom-dwelling faunas were found in the cores from the shallowest water, and the least varied and least prolific were found in the cores from the deepest water.

2. Though the bottom-dwelling faunas in each core vary somewhat in specific and generic composition from zone to zone, they generally have a similar bathymetric facies throughout.

3. No definitely identifiable very shallow-water or intertidal faunas were found in any of the cores. Very shallow-water and intertidal bottom-living Mollusca are entirely absent. The specimens of shallow-water Foraminifera, such as *Elphidium* and *Elphidiella*, and shallow-water bryozoans are very rare and so erratically distributed that they are evidently not indigenous. During the time represented by the cores, *Elphidium* and *Elphidiella* have been two of the most common or prolific and characteristic bottom-living Foraminifera in very shallow water around the North Atlantic.

4. The bottom-living faunas in each core not only

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[4] Stetson, H. C., Geology and paleontology of the Georges Banks Canyons, Part 1, Geology: Geol. Soc. America Bull., vol. 47, p. 340, 1936.

[5] Shepard, F. P., The underlying causes of submarine canyons: Nat. Acad. Sci. Proc., vol. 22, pp. 496–502, 1936.

[6] See unsigned article, Ice age history of the earth: Science, new ser., vol. 88, supp., p. 7, 1938; and more particularly Veatch, A. C., and Smith, P. A., Atlantic submarine valleys of the United States and the Congo submarine valley: Geol. Soc. America, Special Papers, No. 7, pp. 25–48, 1939.

[7] Hess, H. H., and MacClintock, P., Submerged valleys on continental slopes and changes of sea level: Science, new ser., vol. 83, pp. 332–334, 1936.

[8] Johnson, Douglas, Origin of submarine canyons: Jour. Geomorphology, vol. 1, pp. 111–129, 230–243, 324–339, 1938; vol. 2, pp. 42–58, 133–156, 213–234, 1939.

[9] Shepard, op. cit., p. 501.

have a similar bathymetric facies, but the bathymetric facies of each core is characteristic in a general way of the present depth at which the core was collected.

5. In the present oceans ostracode shells are rarely found at depths greater than 4,000 meters (2,200 fathoms). In the cores from deeper water they are rare or absent, but in those from shallower water they are common. Out of 27 species of ostracodes identified from the cores, 7 species have not been recorded from shallow water. According to the temperatures indicated by associated Foraminifera, 11 out of 31 of the occurrences of these 7 species were in cold, 11 out of 31 in normal, and 9 out of 31 in warm zones. The cores represented are 6, 7, 8, 12, and 13.

6. Pteropods are locally abundant in the three cores from the shallowest water and absent in those from the deepest. Shell fragments uncertainly identified as pteropods were found in one sample from cores 7 and in one from core 9. Pteropods are rather widely distributed in the pelagic zone of warm and temperate regions, but their shells rarely or never accumulate in the abyss at depths greater than 4,000 meters.

7. As discussed more fully elsewhere (see pt. 1), the time interval represented by the core samples evidently extends back through part and perhaps much of the Pleistocene. It therefore includes some of the more important glacial intervals involved in Shepard's hypothesis and all of the time supposed by Veatch.

8. Miscellaneous circumstances of significance in connection with the above points are that the cores were sampled at small intervals, every lithologic zone or change was represented by samples, and only 6 samples out of 184 were nearly or completely barren of calcareous fossils.

If the sea level were lowered 2,000 meters, the areas represented by cores 8 and 13 would be 720 and 45 meters, respectively, above water. The faunas in these cores have a broadly similar facies throughout and contain no bottom-living assemblages that are characteristic of the zone of light and certainly none that are characteristic of very shallow water or the intertidal zone. Furthermore, a reduction of level by 2,000 meters would reduce the depth at the location of core 12 to the present depth of core 8, and cores 7 and 9 to the present depth of core 13, but the population density and faunal variety of these cores reflect no such major shifts. The zones of the most abundant and varied fossils in core 12 (samples H–131 to H–134) were deposited in water of normal or warm temperature, and therefore do not seem to have been introduced by a reduction of sea level during a cold period unless by slight chance the local marine climate were the reverse of the general climatic trends in glacial intervals.

The ostracodes were most varied and common in cores 8, 12, and 13 and were rare or absent from samples in cores from deeper water. A reduction of 2,000 meters or even 1,000 meters in sea level should have introduced zones containing a greater abundance of ostracode shells in the cores from deeper water.

Pteropod shells were found in cores 12 and 13 and abundantly in core 8 in warm, normal, and even some cold zones. Their absence from any part of the cores from deeper water must be due to (1) the former absence of these organisms in the pelagic faunas in the area and time represented (2) solution of the shells before burial, or (3) solution of the shells after burial. A complete absence of pteropods in the pelagic faunas in the vicinity of all cores from deeper water seems improbable, because pteropods have a wide distribution. It also seems unlikely that pteropod shells once buried and protected by surrounding sediments deposited during a low-water interval would be dissolved when the ocean water rose to normal level. Solution of shells before burial, therefore, seems to be the most likely explanation and their absence implies deep water.

In addition to the evidence relating to the continuity of the bathymetric facies of the fossils within each core, no definite evidence of emergence, such as indications of subaerial erosion, weathering, and bedding structures characteristic of very shallow water, were observed in these cores.

It may be proposed that the times of greatest water removal were obviously periods of low temperature and increased salinity and consequently greatly reduced marine faunas, thus producing zones with few or no fossils. The biological record in these cores does not indicate such a conclusion. The cores were sampled closely. Every lithologic or stratigraphic change was represented by the H series of samples. No such marked alternation of zones characterized by prolific warm-water faunas and of zones either barren of fossils or characterized by cold-water or depauperate faunas were found. On the contrary, zones containing *Globigerina pachyderma* or other indicators of cold or cool climatic conditions were well populated for the depth represented, and the assemblage of bottom-dwelling forms contained no definite evidence of shallow-water conditions. As already stated above, only 6 samples out of 184 were found to be nearly or completely barren of calcareous organisms. The absence of shallow-water faunas under such circumstances as these has more than negative significance; furthermore, the location of samples was determined almost entirely by lithologic character, and no zones were left unsampled because they appeared to be barren.

The history of the Foraminifera during late Cenozoic (including Recent) time seems to have considerable bearing on any hypothesis involving enormous, widespread changes in ocean level within any fraction of the Pleistocene epoch. First, it may be noted that the modern fauna of Foraminifera began in Miocene time. The assemblage changes in oceanic areas during and since that time have been as a whole rather gradual or gradational and are related more to local or regional migrations, the advent of variations, or the extinction of a few species, rather than to extensive or abrupt changes in the generic as well as the specific content of the assemblages of the world.

Keeping this fact in mind, we may turn aside to calculate certain pertinent physical implications in the hypothesis of great changes in ocean level. The following figures are based mainly on data assembled by Littlehales.[10]

	Cubic kilometers
Total area of marine water, 365,490,000 square kilometers.	
Total volume of water	1,330,000,000
Between strand and depth of 0.2 kilometers:	
Area, 30,600,000 square kilometers (8.4 percent).	
Volume, $\frac{(0+0.2)}{2}\times 30{,}600{,}000$	3,060,000
Between depths of 0.2 and 1.0 kilometer:	
Area, 16,400,000 square kilometers (4.4 percent).	
Volume, $\frac{(0.2+1.0)}{2}\times 16{,}400{,}000$	9,840,000
Between depths of 1.0 and 2.0 kilometers:	
Area, 18,050,000 square kilometers (4.9 percent).	
Volume, $\frac{(1.0+2.0)}{2}\times 18{,}050{,}000$	27,075,000
Deeper than 2.0 kilometers:	
Area, 300,440,000 square kilometers (82.3 percent).	
Volume of upper 2.0-kilometer layer (in the area where the ocean is more than 2.0 kilometers deep), $2.0\times 300{,}440{,}000$	600,880,000
Total volume of marine water 0.0 to 2.0 kilometers deep (48 percent of total volume of water)	640,855,000

From these approximate data it is evident that a general change in ocean level of 2,000 meters would involve nearly 50 percent of all marine water. A change of such order would profoundly affect marine organisms in two respects. First, it would nearly double the salinity, and second, it would enforce extensive migrations to and from embayments and epicontinental seas, the areas where the great majority of marine organisms live, except the pelagic inhabitants of the open ocean.

It is generally agreed that the removal of water during the Pleistocene would have had to take place principally by evaporation, because freezing of ocean water in place would have a comparatively small effect on ocean level unless marine ice were pushed onto land. Even so, freezing is a fractionating process the efficiency of which varies greatly according to the local or general opportunities for removal of the brine as the water crystallizes from the solution. According to Veatch's hypothesis the water was also removed by evaporation. If half of all ocean water were removed mainly by evaporation it is probable that the salinity would be nearly doubled; furthermore, it is practically certain that such an increase in salinity would be accompanied by a change in proportions of the salt content. The proportion of the more soluble halides would increase because of the precipitation of the less soluble salts though base exchange might affect the proportions.

The effects of extreme change of salinity on marine life remain more or less problematical. Laboratory experiments on the reaction of organisms to changes in salinity have been made and indicate considerable adaptability where the changes are slow, but these experiments are not very impressive from a paleontologic point of view, because a relatively insignificant number of species have been represented by the experiments, and especially because slow-working factors that in time may profoundly affect the history of a species or fauna are hardly possible to evaluate or reproduce in the laboratory.

Ecological animal geography is a source of significant though complicated information on the influence of salinity on the distribution of life in time and area. Comparisons of the distribution of life are likely to be complicated by the presence of ecological or historical factors that vitiate, or at least make doubtful, any conclusions as to simple casual relationships. It may be noted, however, that the Caspian Sea contains a fauna of undoubted marine origin, but it is known to lack the groups of marine invertebrates that are intolerant of marked variations in salinity. The salinity is around 13 parts per thousand, whereas the normal salinity of the oceans is about 35 parts per thousand. The Baltic Sea ranges in salinity from about normal at its junction with the North Sea to 2.5 parts per thousand where it is most diluted by fresh water. The Baltic is accessible to marine organisms, but in the areas of lowest salinity the fauna is reported[11] to be extremely limited in varieties of marine invertebrates. These and similar

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[10] Littlehales, G. W., Configuration of the oceanic basins: Nat. Research Council Bull., vol. 85, pt. 5, pp. 13-46, 1932.

[11] Hesse, Richard, Allee, W. C., and Schmidt, K. P., Ecological animal geography, pp. 283-287, New York, John Wiley and Sons, Inc., 1937.

examples indicate a deletereous effect of low salinity.

Marine areas of very high salinity are unfavorable for marine life, but it is not always certain whether high salinity is the primary cause or is one of several related causes; accordingly such examples do not give a definite, simple answer to our question. It is regarded as significant, nevertheless, that areas of high salinity are inhabited by abnormal faunas.

Indirect but significant evidence on the influence of salinity as a factor in ecology is the long-enduring line of demarcation between marine and fresh-water life. A few forms that are very tolerant of salinity changes can pass freely. Some of them feed and a very few propagate at will in either fresh or saline water, but the number of such forms is exceedingly small in comparison with the less tolerant species, genera, and even major groups that are mostly or even completely restricted to each realm. Although not definitely or simply conclusive, the history and geographic distribution of marine organisms raise serious doubts that extensive changes in salinity could have happened even once, to say nothing of four times, during the Pleistocene without causing large-scale changes in the history of marine life of the time.

Universal or very extensive lowering of sea level, as much as 2,000 meters, would drain the majority of epicontinental seas and isolate the remainder and would result in connecting many islands and larger land masses. The following land connections in the middle and equatorial latitudes would result from such changes of sea level: Florida and Venezuela through the West Indies; Yucatan and Cuba; the East Indies and the Philippines with Asia and probably also with Australia through one or more bridges; and Africa with Eurasia through several very broad connections. A lowering of sea level sufficient to permit subaerial erosion of the Congo submarine canyon as supposed by Veatch would have connected Madagascar and Africa. It may be stated, however, that the faunas of Australia and Madagascar seem to have been isolated for a much longer period than that represented by Pleistocene and Recent time.

It has been suggested that if the present-day influences of elevation on climate were effective during periods of greatly lowered sea level, many mountain areas, such as the middle and perhaps the southern Appalachians, would have stood high enough to have been glaciated at times of widespread glacial climates. Evidence of mountain glaciation is lacking in these Appalachian regions.

The paleontologic record indicates that repeated migrations and intermingling of faunas and floras caused by diastrophism result in rapid changes in life history. Extreme changes in sea level would force the life in epicontinental seas, where the great majority of species of marine organisms live, to migrate and intermingle extensively. Such an extensive recession of the ocean would result in a great complex of changes in biologic barriers, ecologic provinces, temperatures, currents, local balance between evaporation and fresh water supply, and extreme changes in composition of the water. The distance of migration would be very great in many places, and important differences in substrates would be encountered in most regions. Organisms finding temporary haven in isolated seas would likely fare as those in the Black and Caspian Seas did. So, it is probable that extreme changes in sea level would have more drastic effects on marine life than would periods of diastrophism if shore lines and the volume and composition of ocean water remained more or less unchanged. As I have already stated, late Cenozoic history of the Foraminifera does not contain evidence of such radical and universal faunal changes. The evidence then, as recorded in these few cores, gives no support to a hypothesis of a repeated or even a single general lowering of the sea level of as much as 2,000 meters during or since the Pleistocene.

The preceding argument against a 2,000-meter, universal change of sea level during Pleistocene time seems to be supported by fairly reliable evidence for the time represented by the cores. The evidence relative to a general change of 1,000 meters in sea level—aside from the fact that the hypothesis thus restricted fails to explain the parts of typical canyons below the present 1,000-meter contour—is much less definitive, principally because, within the zone habitable by calcareous-shelled animals, the facies of marine faunas changes more gradually with depth in the abyss than it does in shallow water. However, the preceding arguments are relevant, at least in a modified measure, to the supposition of a depth change of 1,000 meters.

A reduction of sea level by 1,000 meters would reduce the depth of the areas represented by cores 7 and 12 to that of the present depth of core 13; core 13 to the present depth of core 8; and core 8 so nearly to the zone of light that variants or even some members of shallow-water faunas should appear in considerable number. Evidence for changes of even 1,000 meters in sea level seems to be lacking in the distribution of the variety, population density, and faunal composition of the fossils in these cores.

The paleontologic evidence from these cores is equally adverse to supposing an extreme change of sea level from any other cause than glacial climate that simultaneously affects the whole earth and accomplishes the removal of the water by evaporation. The hypothesis of Hess and MacClintock shares some but not all of the objections to Shepard's hypothesis. Hess and MacClintock, however, might argue that the depth of the ocean along the line of the core stations did not change much while the hydrosphere was deformed by the motivating force which they postulate. If any of these hypotheses involving extreme changes in ocean level during Pleistocene time are proved to be true, the present general understanding of faunal adapability will have to be changed most drastically.

Murray and Hjort [12] presented evidence, based chiefly on the alternation of sediments that characterize widely different depths of ocean bottom, which they interpreted as indicating great changes in ocean bottom level, but they do not cite specific localities, and it is not possible to decide whether the alternation is a result of changes in ocean level, temperature of sea water, local diastrophism, or other possible causes. The changes in shell accumulation as represented in our cores seem to be caused more by long-period variations in climate than by extreme changes in depth of water. The absence of very fine lamination from these cores is probably due largely to the reworking of sediments by bottom-dwelling organisms, such as echinoids and holothurians. Also the sediment may have accumulated so slowly that microorganisms had ample opportunity to destroy any thin layers of organic matter that accumulated and that would, if buried and preserved, give rise to lamination. Bottom currents, though feeble, may have aided in the destruction of thin, alternating laminae of different substances on the sea floor.

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[12] Murray, John, and Hjort, Johan, The depths of the ocean, pp. 174-75. 1London, Macmillan Co., 1912.

PLATES 22–23

PLATE 22

MISCELLANEOUS FOSSILS

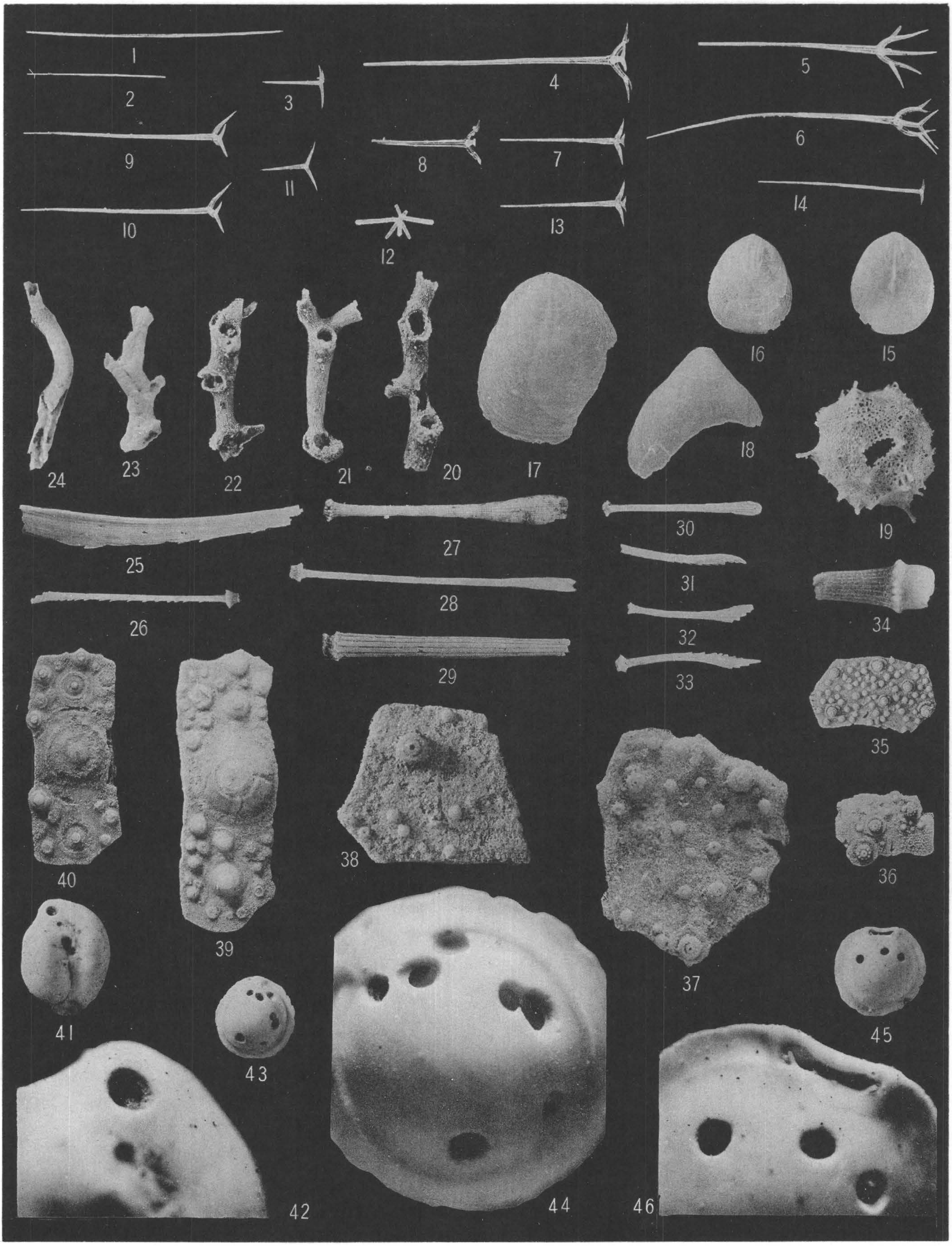
FIGURES 1–14. Siliceous sponge spicules. 1–11 and 13–14, × 10, core 8, H–63; 12, × 15, core 6, H–35.
15–16. Brachiopod. *Cryptopora gnomon* (Jeffreys). × 5. 15, Interior view; 16, exterior view. Core 12, H–133b.
17–18. Brachiopod. *Gryphus* sp. × 15. 17, Exterior view of dorsal valve; 18, exterior view of pedicle valve; both valves belong to the same individual. Core 8, H–61a.
19. Radiolarian. *Oroscena huxleyi* Haeckel. × 15. Core 6, H–42.
20–22. Three specimens of Bryozoa, apparently representing a new species of *Jaculina.* × 15. Core 8, H–61a.
23–24. Two specimens of Bryozoa belonging to the genus *Entalophora.* × 15. Core 8, H–69.

ECHINOIDEA

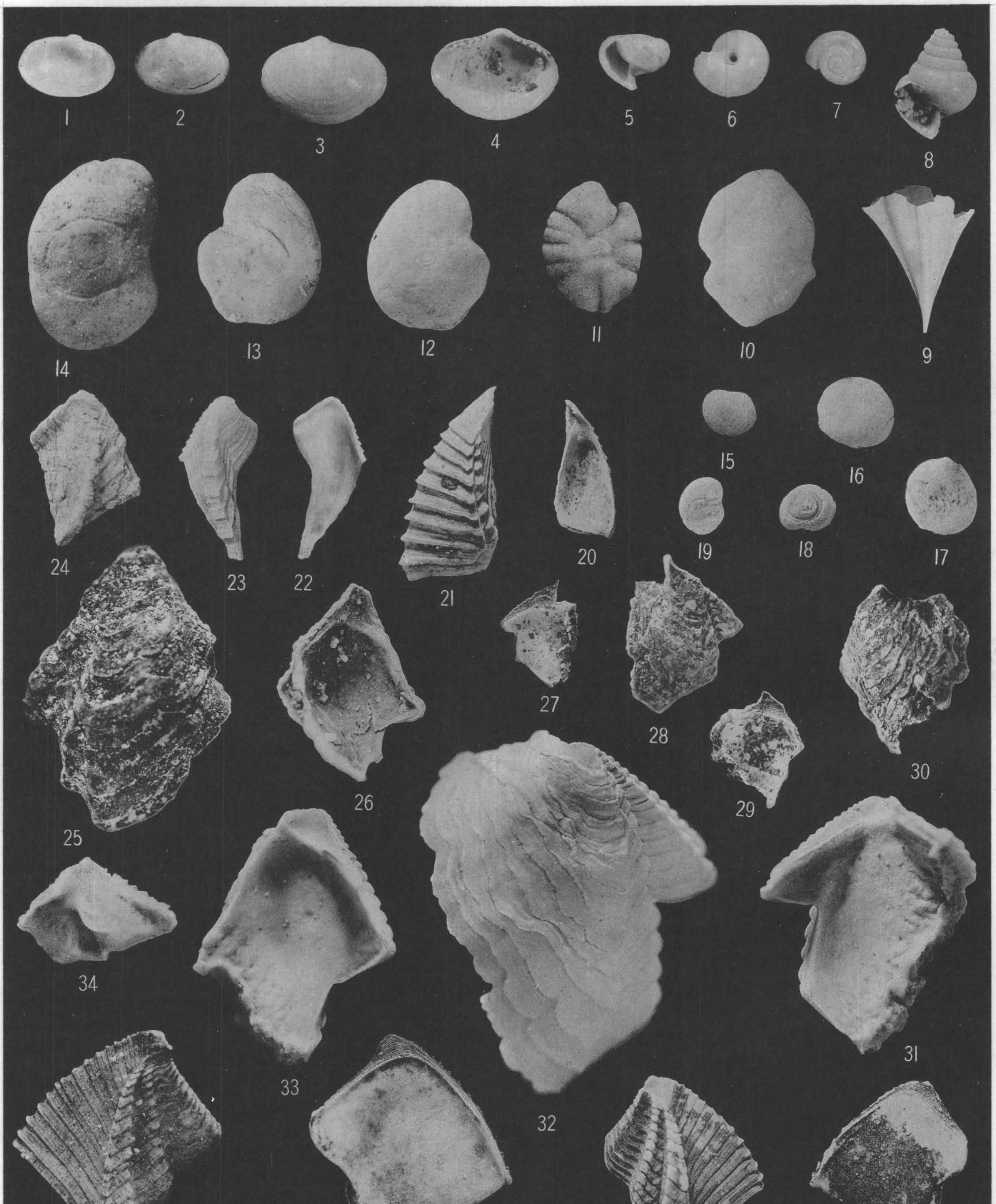
FIGURE 25. Echinoderm (?) spine. × 10. Core 12, H–133b.
26. *Pourtalesia miranda.* Primary spine. × 15. Core 12, H–117.
27. *Aceste bellidifera.* × 15. Core 12, H–35.
28. *Plexechinus hirsutus.* Primary spine. × 10. Core 12, H–47.
29. *Echinus affinis.* Base of a spine. × 10. Core 12, H–133b.
30. *Hemiaster expergitus.* Spatulate spine. × 15. Core 12, H–152.
31. *Pourtalesia miranda.* Primary spine from upper border of buccal cavity. × 15. Core 12, H–152.
32. *Pourtalesia miranda.* Primary spine from upper border of buccal cavity. × 15. Core 12, H–152.
33. *Pourtalesia miranda.* Primary spine from upper border of buccal cavity. × 15. Core 12, H–152.
34. *Echinus affinis.* Base of a spine. × 15. Core 12, H–133b.
35. *Urechinus naresianus.* Plate. × 10. Core 12, H–133b.
36. *Echinus affinis.* Part of a plate. × 10. Core 12, H–133b.
37. *Urechinus naresianus.* Plate. × 15. Core 12, H–133b.
38. *Urechinus naresianus.* Plate. × 15. Core 12, H–133b.
39. *Echinus affinis.* Interambulacral plate from actinal surface. × 10. Core 12, H–133b.
40. *Echinus affinis.* Interambulacral plate from actinal surface. Core 12, H–133b.

SHELL-BORING ORGANISM

FIGURES 41–46. Foraminifera showing work of shell-boring organism.
41. Shell of *Pyrgo*? sp. × 15. Core 12, H–134.
42. Same specimen. × 60.
43. Shell of *Pyrgo murrhina* (Schwager). × 15. Core 12, H–133b.
44. Same specimen. × 60.
45. Shell of *Pyrgo* aff. *P. depressa* (D'Orbigny). × 15. Core 12, H–134.
46. Same specimen. × 60.



MISCELLANEOUS FOSSILS FROM THE NORTH ATLANTIC DEEP SEA CORES.



MISCELLANEOUS FOSSILS FROM THE NORTH ATLANTIC DEEP SEA CORES.

PLATE 23

PELECYPODA

FIGURES 1–2. *Yoldiella expansa* Jeffreys. Left valve. × 10. 1, Exterior view; 2, interior view. Core 12, H–133a.
3–4. *Yoldiella insculpta* Jeffreys. Left valve. × 10. 3, Exterior view; 4, interior view. Core 12, H–134.

PTEROPODA

5–7. *Spiratella planospira* Rehder, n. sp. × 15. 5, Apertural view; 6, ventral view, 7, dorsal view. Core 8, H–61a.
8. *Spiratella retroversa* (Fleming). × 10. Apertural view. Core 12, H–133a.
9. *Clio pyramidata* (Linné). × 3. Core 12, H–133b.

PISCES

10–19. Unidentified otoliths of teleost fishes. × 15. 10, 11, and 14, core 8, H–61a; 12 and 13, two views of same specimen, core 12, H–131; 15, core 8, H–70; 16 and 17, two views of same specimen, core 13, H–155.
FIGURES 20–38. Barnacle plates, external and internal aspects of specimens. × 15.
20–21. Core 13, H–157.
22–23. Core 12, H–133b.
24. External only. Core 12, H–133b.
25–26. Core 8, H–75.
27–28. Core 8, H–75.
29–30. Core 8, H–75.
31–32. Core 13, H–156.
33–34. Core 13, H–156.
35–36. Core 8, H–69.
37–38. Core 3, H–158.

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