UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY AND BIOLOGY OF NORTH ATLANTIC DEEP-SEA CORES

SUMMARY, FOREWORD, AND GENERAL INTRODUCTION

PART 1. LITHOLOGY AND GEOLOGIC INTERPRETATIONS

PART 2. FORAMINIFERA

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

SUMMARY OF THE REPORT

FOREWORD, BY C. S. PIGGOT

GENERAL INTRODUCTION, BY W. H. BRADLEY

PART 1. LITHOLOGY AND GEOLOGIC INTERPRETATIONS

By M. N. BRAMLETTE AND W. H. BRADLEY

PART 2. FORAMINIFERA

By JOSEPH A. CUSHMAN AND 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]

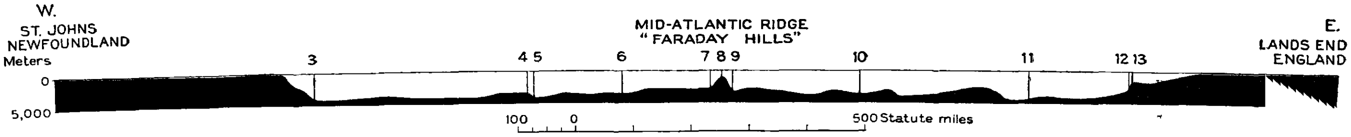

FIGURE 1.—Profile across the North Atlantic Ocean along the line of the numbered core stations shown on plate 1.

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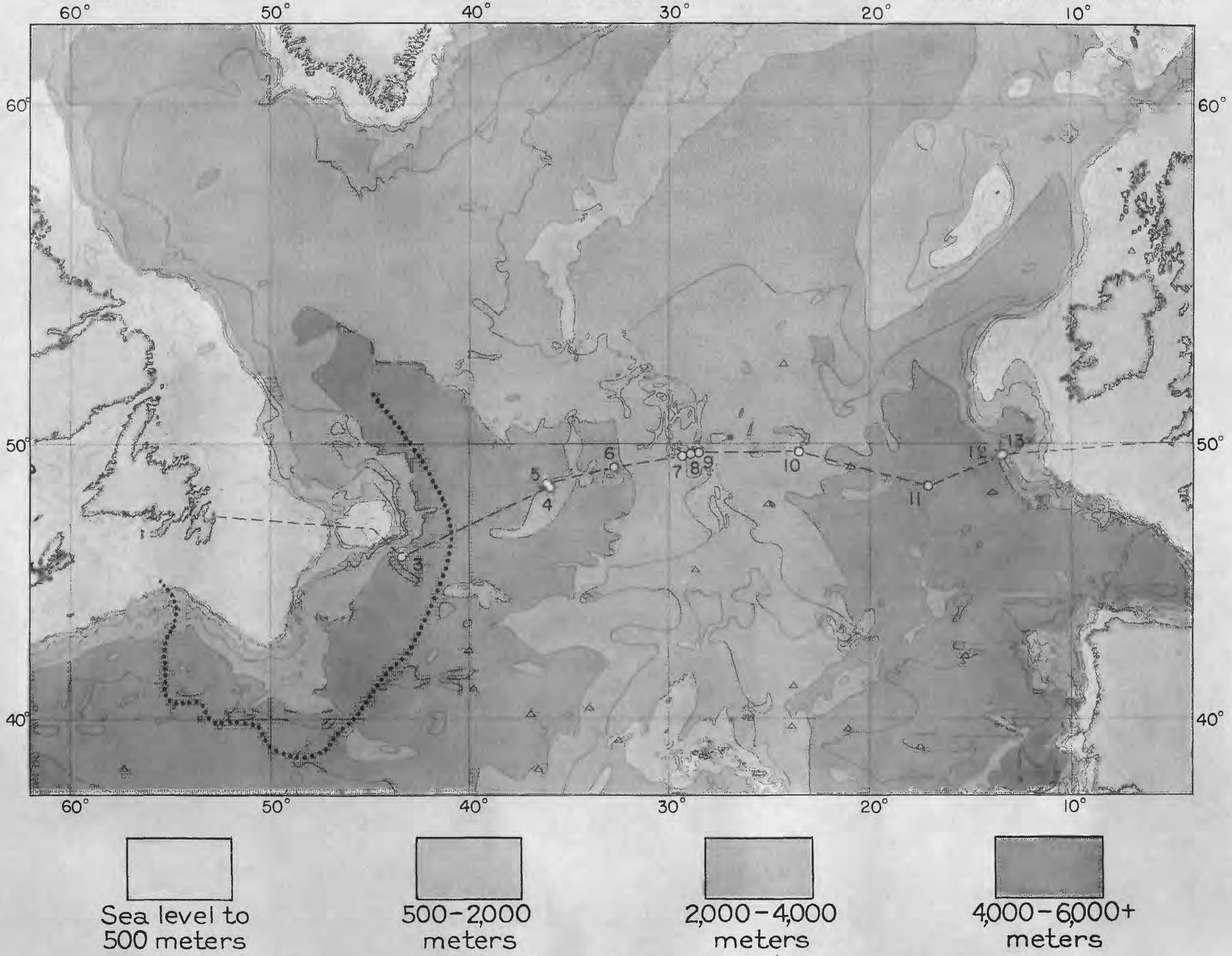
[11] Data for plate 1 and figure 1 were taken from International Hydrographic Bureau, Carte Générale Bathymétrique des Océans, 3d ed., sheets A-1 and B-1, copies of which were furnished by the U. S. Hydrographic Office.

[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).

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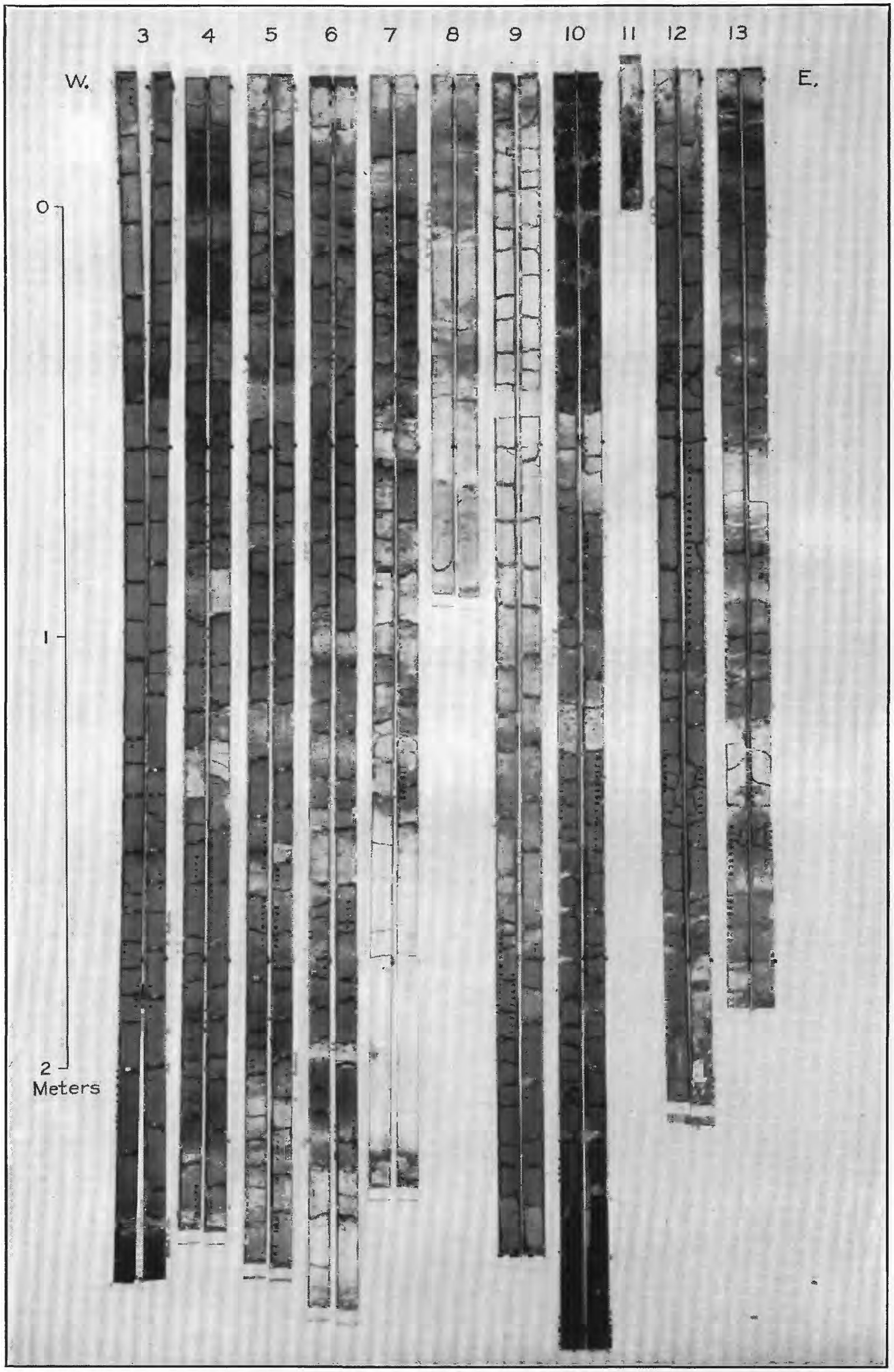

LONGITUDINAL SECTIONS OF THE AIR-DRIED CORES.

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 1. LITHOLOGY AND GEOLOGIC INTERPRETATIONS

By M. N. BRAMLETTE and W. H. BRADLEY

EXAMINATION AND ANALYSIS OF SAMPLES

Before sampling the deep-sea cores from the North Atlantic Ocean we made a record of the general aspect of the sediments, noting particularly the more obvious changes from one kind of sediment to another. These descriptive notes served as a guide in selecting the samples. As the combined length of the 11 cores is nearly 26 meters, a continuous sequence of samples 2 or 3 centimeters long would have necessitated the study of nearly 1,000 samples. With the time available it seemed preferable to take fewer samples and give them a more thorough examination than could be given so large a number. This decision was reached after the preliminary examination had shown that layers or zones of the mud penetrated were essentially uniform for considerable lengths of each core. Accordingly, the samples for the lithologic study were taken at intervals that averaged 10 to 12 centimeters, but the interval was varied from place to place in order to obtain samples representative of the obviously different lithologic types. (See pl. 3.)

Only one half of each core was used for sampling. Each sample for lithologic study was 2 or 3 centimeters long but included only part of the material, leaving the remainder at that place to be sampled for other phases of the work. Most of the individual samples represent sediment of a fairly uniform lithologic type, but the detailed examination showed that a few included sediment of two distinctly different types. Unfortunately, the samples sent to the chemical and hydrologic laboratories for determination of total carbonate and for mechanical analysis were representative portions of whole samples, taken out before the significance of the various lithologic units was realized. Therefore, in the few samples that include two types of sediment the quantity of total carbonate and the mechanical analyses are not truly representative of either type. This is illustrated most strikingly by sample B–58–59 from core 5. Microscopic examination showed that the upper part of this sample was distinctly different in composition and texture from the lower part. Had the two parts been analyzed separately the data plotted in plate 3 would have shown a clear distinction between two lithologic zones rather than features that are intermediate between the two.

The samples were first examined under a binocular microscope, at which time the film of mud that had been smeared down along the walls of the core barrel as it penetrated the sediments was removed. In the few cores taken in places where the mud through which the core barrel passed was sticky, lumps and rolls of the sticky mud were carried downward below their normal stratigraphic position and squeezed into the core. Contamination of this sort, however, was easily recognized, and the contaminating mud was removed. In the examination of the samples under the binocular microscope the general lithologic type was noted, together with any evidence of bedding or other textural or structural features, such as borings. This examination also included estimates of the percentage of Foraminifera and of recognizable inorganic constituents, such as zones of more abundant volcanic glass shards, pebbles and aggregates of tiny spherules of iron sulphide.

A little material scraped from a clean face of the sample was immersed in a liquid whose refractive index was 1.545, for examination under the petrographic microscope, and the relative abundance of the finer organic and inorganic constituents was estimated. These constituents included the diatoms and other siliceous organisms and the minute calcareous algae belonging to the Coccolithophoridae. Accurate determination of the amounts of these constituents would have required a great deal more time than seemed warranted. The relative accuracy of these estimates is considered under the heading "Carbonante content of the sediments."

The samples were next submitted to the chemical laboratory of the Geological Survey, where E. T. Erickson determined the approximate content of total carbonate in all samples by treating them with hot dilute hydrochloric acid until the solution was slightly acid as indicated by methyl orange. This procedure, though rather crude, was adopted for its speed, so that many samples could be tested. The results are subject to errors of several percent.

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In samples taken near the top, middle, and bottom of each core Erickson also determined quantitatively the MgO, CaO, and MnO in a representative part of each sample. The insoluble residues from each of the samples were then wet-screened for mechanical analysis in the hydrology laboratory of the Geological Survey, under the direction of C. S. Howard. Before screening they were shaken in a mechanical agitator for about 4 hours with a comparatively large volume of distilled water, to which had been added a small quantity of dilute sodium oxalate solution. Like the carbonate determinations, these mechanical analyses are only approximations, owing largely to the difficulty of dispersing the sediment that had been treated with acid and thoroughly dried.

The screened fractions were then examined microscopically for a closer estimate of the proportions of certain noncalcareous constituents, such as volcanic ash and siliceous organisms. In this examination the rather large percentages of clay aggregates in the sand-size fractions, obviously the result of incomplete disintegration of some of the more clayey samples, were also estimated, in order to correct the mechanical analyses, the results of which are plotted in plate 3.

This examination revealed the need of supplementary data from certain parts of the cores between samples; accordingly, additional samples were taken and subjected to the same tests, and the results were also plotted in plate 3. Much of the material between samples was then examined for a few particular features, in order to delimit the zones of volcanic glass shards and zones of glacial marine deposits and also to make certain that no zones of volcanic material had been missed.

ACKNOWLEDGMENTS

In the preparation of this chapter on the lithology and physical geology of the cores we have had the benefit of discussion with many of our colleagues in the Geological Survey and with various members of the Geophysical Laboratory of the Carnegie Institution. Acknowledgment is made at appropriate places in the text for analyses and tests made for several phases of the investigation, and we wish to express here our thanks to C. S. Howard, of the hydrology laboratory, and R. C. Wells and George Steiger, of the chemical laboratory, for their ready cooperation and for the laboratory space and facilities which, to their own inconvenience, they generously placed at our disposal.

PRESENTATION OF DATA

Many of the data obtained from the investigations outlined above are presented graphically in plate 3 to facilitate general comparison, although the variations of any one constituent are somewhat less easily followed in so comprehensive a diagram. The boundary between material of silt size and sand size as used in this report is 0.074 millimeter, instead of the 0.0625 millimeter commonly accepted as the upper size limit of silt, because, of the sieves available, the one having openings of 0.074 millimeter was the nearest. Likewise, the boundary between sand size and coarse sand size was taken as 0.59 millimeter, rather than the generally accepted 0.5 millimeter, because 0.59 millimeter was the nearest sieve size available. The proportion of coarse sand in the sand-size fraction of the sample seemed significant enough to be indicated on the diagram, but the difficulty of showing effectively small percentages necessitated special plotting. Consequently, the percentage of coarse sand in the sand-size fraction of each sample is plotted in a separate column to the right of the column representing the core. The right-hand column shows also samples that contain one or more pebbles 3 millimeters or more in mean diameter. In view of the apparent significance of these pebbles, it is unfortunate that the data are not adequate to show their relative abundance. In the course of sampling it became evident that only samples from cores of diameter much larger than the ones available could show the true quantitative distribution of pebbles as large as these, therefore no attempt was made to show in plate 3 whether the sample contained one or several. Supplementary examination of the whole cores, however, indicated that adequate data on their distribution in the cores would show more clearly their zones of occurrence in the sediments.

The column representing the core samples shows also the relative abundance of Foraminifera and of coccoliths, both of which are discussed further in connection with the carbonate content of the sediments. (See pp. 17–21.) The coccoliths are minute calcareous plates, most of which are between 0.002 and 0.015 millimeter in diameter. The symbol "common" means that they are numerous, though by reason of their small size they make up roughly only about 1 percent of the whole sample; "abundant" indicates that they make up about 5 percent or more of the sample. Even where most abundant, however, they probably do not make up more than 10 percent of the sediment.

The lines between cores shown in plate 3 indicate the correlation of zones of distinctive sediment. The evidence upon which these zones are distinguished and correlated is given below in considerable detail, together with interpretations of their significance.

STRATIGRAPHIC UNITS

VOLCANIC ASH ZONES

Shards of volcanic glass are rather abundant in the upper part of most of the cores and are sufficiently plentiful to characterize a zone. This upper volcanic ash zone is indicated in plate 3 by the uppermost stippled zone. The volcanic ash is abundant only in the lower part of the zone, and the base of the zone is rather sharply delimited. Above the base of the zone the shards rapidly decrease in abundance upward, though they are sparsely scattered through the sediment to the top of each core. The ash consists of unaltered vitric shards that have an index of refraction near 1.51, which suggests that the glass is of alkalic or calc-alkalic composition. The characteristic form of the shards makes all but the finest grains recognizable, even under the binocular miscroscope. A reexamination of material from this ash zone, including samples intermediate between those represented in plate 3, showed that near the base of the upper ash zone in most of the cores there are generally several thin layers in which the ash is distinctly more abundant or, in some samples, forms the dominant constituent; but between these more or less distinct layers shards are mixed with a greater proportion of other sediment. In cores 7 and 9 the ash is not concentrated in distinct layers and the only marked difference is the increase in abundance downward to the well-defined base of the zone. The apparent significance of this scattered distribution of the shards within the zone of volcanic ash is considered under the headings "Evidence of bottom currents" and "Role of mud-feeding organisms." (See pp. 14–15, 22–23.)

Although volcanic ash is the dominant constituent, in some of the ill-defined layers one to several millimeters thick, it rarely makes up more than 5 percent of the total sediment in an ordinary sample 2 to 3 centimeters long from the upper ash zone, and it averages nearer 1 percent. In the noncalcareous residues of these samples, however, the volcanic ash commonly makes up about 25 percent of the sand-size material and is therefore a distinguishing feature of this zone. In the upper ash zone the volcanic ash is present in greatest concentration in core 9, and there also the concentration is greatest in the lower part of the zone. Much of the scattered ash in the upper part of the zone in this core may represent contributions winnowed from the sediment on nearby areas of much shallower water. (See p. 14.)

A correlation of this upper ash zone from one core to another is suggested in plate 3, and though this correlation appears to be somewhat less certain in core 8 on the mid-Atlantic ridge and thence eastward, other lines of evidence, considered on page 6, seem to confirm the interpretation indicated.

Cores 4 to 7, on the west side of the mid-Atlantic ridge, penetrated a lower zone of volcanic ash, which is similar to the upper one. In the lower zone, the vitric shards, as in the upper zone, have a refractive index of 1.51 and are scattered through the zone rather than occurring in one or more sharply defined layers. The lower zone differs from the upper one in commonly having smaller shards and fewer of them. Reasons for the failure to find this lower ash zone in core 8, and in any of the cores east of the mid-Atlantic ridge are considered on page 6, where the correlations are discussed.

An occasional shard of volcanic glass having a refractive index of 1.51 was found in several samples between the upper and lower ash zones. Because these stray shards are so rare it seems probable that they were reworked from the lower ash zone up to their present positions by mud-feeding organisms or that they were derived from nearby mounds or ridges on the sea floor where the lower ash zone is exposed to the action of gentle currents. (See pp. 14–15.) The stray shards, however, are most common in samples B–53 and B–55 of core 5 and in sample B–214 of core 12. Taken alone, the relative abundance of volcanic ash in these samples suggests the existence of other ash zones, comparable to those just described though thinner and with a lower percentage of volcanic material. An unusual significance attaches to these three samples, however, for reasons other than their content of volcanic ash. The layers that they represent have unusually sharp boundaries at both base and top, they contain relatively little of the usual fine-grained constituents, and they have other distinctive physical characteristics, all of which suggest that they resulted from submarine slumping. These anomalous samples are considered more fully under the heading "Submarine slumping" (pp. 15–16).

The similarity of the alkalic glass shards to ash from explosive volcanic eruptions and the distribution of the shards in the upper and lower ash zones suggest that each of these zones represents an accumulation of normal volcanic ash that was transported through the air out over the ocean. No progressive increase in either the amount or grain size of the pyroclastic material in a particular direction was detected, but original variations of this sort may well have been obscured by the local variations believed to be due to redistribution of the shards.

The source of the alkalic glass shards in these cores is unknown. Geologically recent eruptions in the Azores include trachytic as well as ferromagnesian materials, and possibly the ash may have come from there. Alkalic volcanic rocks are associated with the basaltic volcanics of Iceland and Jan Mayen and, according to Peacock,[1] some of the volcanic activity in Iceland occurred during Pleistocene and post-Pleistocene time. The volcanoes of these northern islands that expelled the more silicic material may have been the source of the ash that characterizes the zones of volcanic ash in the cores.

GLACIAL MARINE DEPOSITS

From a little below the base of the upper volcanic ash zone downward for a short distance, most of the cores show a decrease in the amount of calcium carbonate and a corresponding decrease in the number of both Foraminifera and coccoliths, which are the dominant calcareous organisms. (See pl. 3.) As these limy

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[1] Peacock, M. A., Geology of Viðey, southwest Iceland: A record of igneous activity in glacial times: Royal Soc. Edinburgh Trans., vol. 54, pp. 441–465, 1925–1926.

constituents decrease the clastic sediment increases correspondingly and is marked particularly by a greater content of coarse sand, granules, and pebbles. The granules and pebbles range in diameter from several millimeters to more than a centimeter. Most of them are somewhat rounded, but some are angular. They represent a wide variety of rock types, of which limestone is the most abundant; but various types of dark-colored shale, mudstone, sandstone, and gneissic and schistose rocks are also common. Less common are granules and pebbles of dolerite, granodiorite, quartzite, granulite, chert, and probably other rocks.

The size of these rock grains and the wide range of lithologic types that are representative of continental rocks rather than rocks of volcanic islands lead us to believe that their occurrence in these deep-sea sediments, far from land, means that they were transported by drifting ice. The same explanation has been given to account for the many pebbles, cobbles, and boulders that have been dredged from different parts of the North Atlantic. Peach [2] and Flett [3] have given detailed descriptions of some of the pebbles and boulders found in the dredgings. Some of the larger pebbles and cobbles have facets and striated surfaces like the cobbles found in glacial moraines. Their transportation to deep parts of the ocean remote from land, seems to be reasonably explained only by the assumption that they were carried by drifting ice. Cobbles of this sort have been dredged from the ocean floor as far south as the Azores [4] and at stations north of Madeira,[5] which suggests that they were transported by floating ice during the Pleistocene, when glaciers filled the Irish Sea and extended out over large areas of the continental platform into the North Atlantic.

The large amount of rock debris that may be transported by drifting icebergs, particularly those from glaciers and inland ice, as contrasted with drifting shelf ice, is suggested by Tarr's statement,[6] "There are thousands of tons of boulders, gravel, and clay sent into the sea from the front of the Cornell glacier every year, and much of this passes beyond the fjord out into Baffin Bay." Pratje [7] reported that icebergs from land ice in the South Atlantic have been found to carry as much as 16 cubic centimeters of sediment per liter of ice, or about 1½ percent by volume.

Philippi's study [8] of the bottom sediments from the Antarctic collected by the *Gauss*, in part by coring and in part by dredging, helps greatly to explain analogous sediments in the North Atlantic cores. The sediments adjacent to the ice front in Antarctica contain little calcium carbonate but consist dominantly of clastic material, including coarse sand and pebbles of various metamorphic and igneous rocks. The fraction of finer sediments consists of silt rather than the clayey material that is typical of the common oceanic blue mud. These sediments, which Philippi appropriately named "glacial marine deposits," apparently extend northward only about as far as the northern limit of pack ice. Core samples from farther north, however, revealed the highly significant fact that these glacial marine deposits extend northward beneath the diatom ooze that is forming today in a wide belt north of the pack ice. Cores from yet farther north contained glacial marine deposits below a layer of globigerina ooze, which is the kind of sediment accumulating today in that part of the ocean north of the area of diatom ooze. The diatom and globigerina oozes cover the glacial marine deposits to a depth of 10 to 20 centimeters. The glacial marine deposits now being formed in the region of pack ice led Philippi to believe that the similar deposits farther north were deposited during the Pleistocene epoch, when the ice front was much farther north. He also suggested [9] that the downward decrease in calcium carbonate, commonly observed in cores of ocean-bottom sediments a meter or less in length, even in the equatorial Atlantic, reflects a climatic control and that the lesser quantity of calcium carbonate is a consequence of the colder water during the Pleistocene.

The zone of sediment underlying the upper ash zone in our North Atlantic cores (see pl. 3) is so similar to the glacial marine deposits of Philippi that it is interpreted as a glacial marine deposit of the last glacial stage of the Pleistocene. This interpretation is confirmed by Cushman and Henbest (see pl. 4), who conclude from their study of the foraminiferal faunas that this zone is characterized by a pelagic fauna from colder water than that of the overlying globigerina ooze. Below the glacial marine zone just described we found in some of our cores, particularly cores 4 to 7, which were taken west of the mid-Atlantic ridge, an alternating sequence of glacial marine zones and zones of sediment resembling rather closely those forming today in that part of the ocean. All these glacial marine zones have the distinctive features that have already been described—namely, the pebbles, the coarse sand, the relatively

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[2] Peach, B. N., Report on rock specimens dredged by the *Michael Sars* in 1910, by H. M. S. *Triton* in 1882, and by H. M. S. *Knight Errant* in 1880: Royal Soc. Edinburgh Proc., vol. 32, pp. 262–288, 1913.

[3] Flett, J. S., Report on the rock specimens and some of the oozes collected by the S. S. *Faraday* and S. S. *Minia* from the bed of the North Atlantic in 1903, in Murray, Sir John, and Peake, R. E., On recent contributions to our knowledge of the floor of the North Atlantic Ocean: Royal Geog. Soc., Extra Pub., pp. 23–30, 1904.

[4] Andrée, K., Die Geologie des Meeresbodens, p. 294, Leipzig, 1920.

[5] Idem, p. 379.

[6] Tarr, R. S., The Arctic sea ice as a geological agent: Am. Jour. Sci., 4th ser., vol. 3, p. 228, 1897.

[7] Pratje, O., Bericht über die geologische Arbeiten der deutschen atlantischen Exp. *Meteor*: Gesell. Erdkunde Berlin Zeitschr., 1926, p. 257.

[8] Philippi, E., Die Grundproben der deutschen Südpolar-Expedition, in Von Drygalski, E., Deutsche Südpolar-Expedition 1901–1903, Band 2, Heft 6, pp. 431–434, 1912.

[9] Philippi, E., Über das Problem der Schichtung und über Schichtbildung am Boden der heutigen Meere: Deutsche geol. Gesell. Zeitschr., vol. 60, pp. 346–377, 1908.

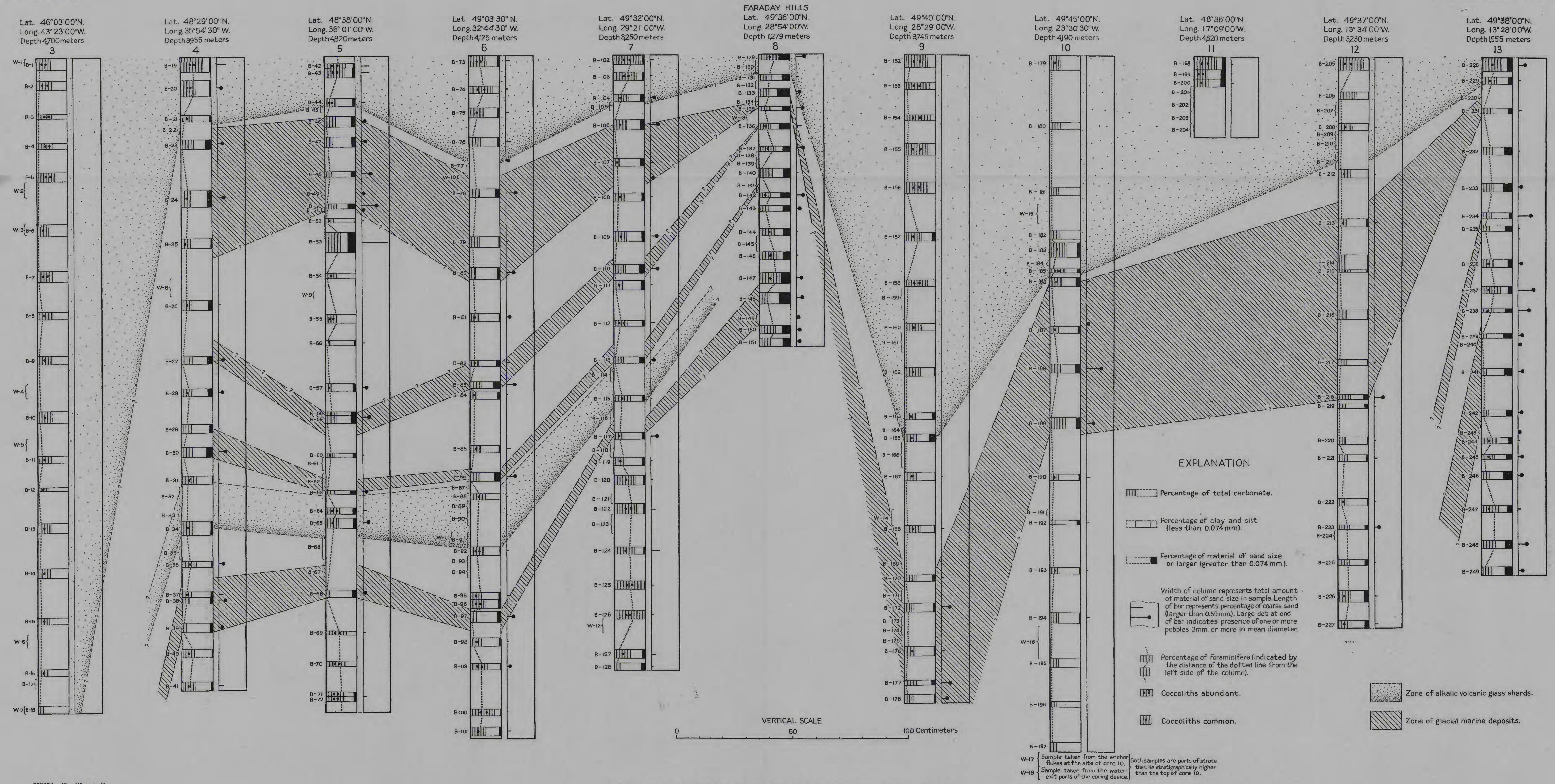

DIAGRAM SHOWING THE CORRELATION OF THE LITHOLOGIC ZONES IN THE CORES.

Each core is represented by two vertical columns. The patterned rectangular blocks in each left-hand column represent samples that were taken for routine mechanical and chemical analyses and microscopic examination. The parts of the cores from which samples were taken for special purposes or supplemental examination are indicated by braces. The samples are numbered in two series distinguished by the prefix letters B and W. The width of each column is taken to represent 100 percent by weight of the sediment, and the horizontal length of each pattern within a sample block represents the percentage of the constituent. The left-hand column shows the percentage of carbonate, clay and silt, sand, and Foraminifera and the relative abundance of coccoliths. The right-hand column indicates the percentage of coarse sand and the presence of pebbles.

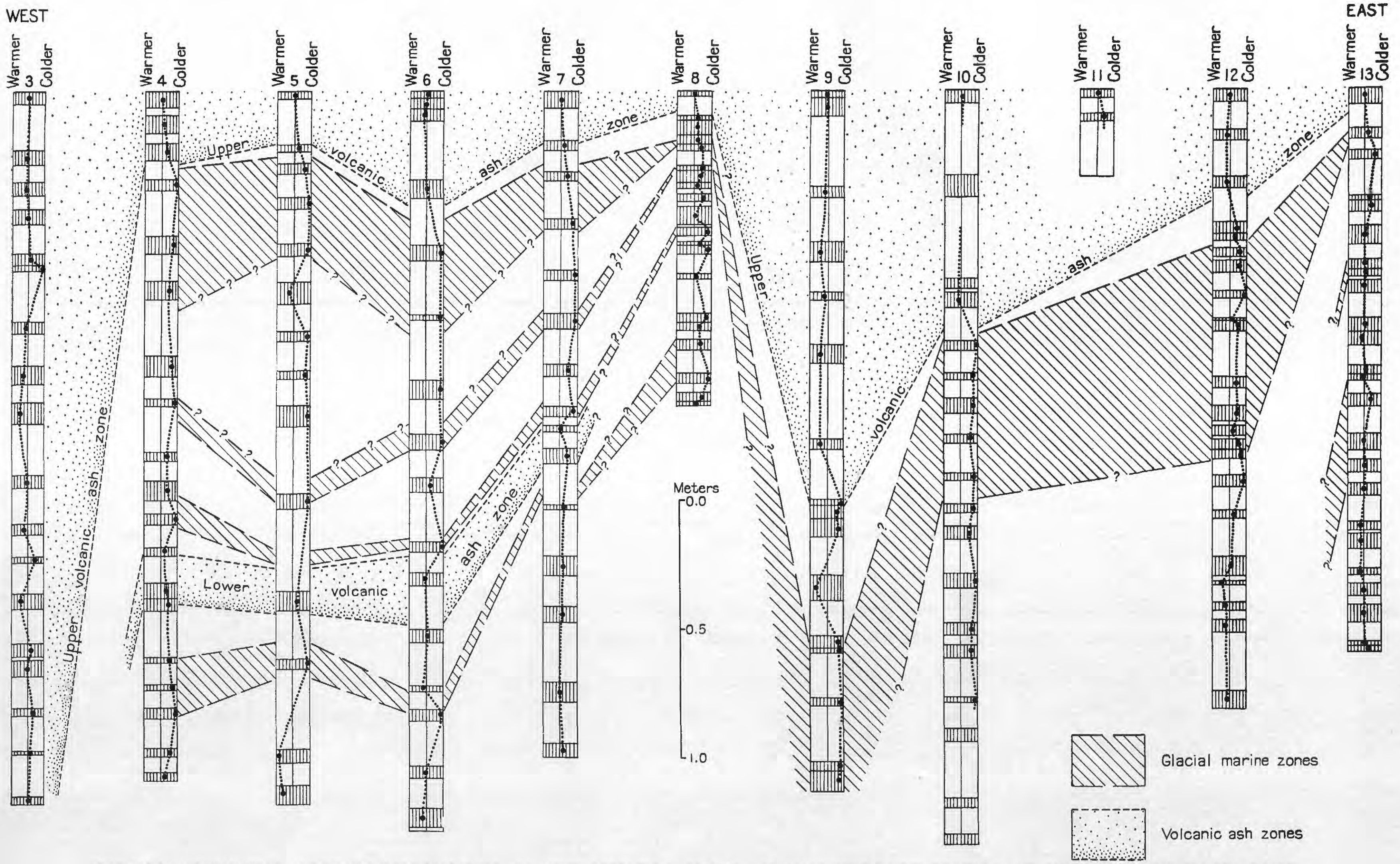

DIAGRAM SHOWING PAST FLUCTUATIONS IN THE TEMPERATURE OF THE SURFACE WATER AT THE SITE OF EACH CORE.

The shaded blocks represent samples taken for the study of the organisms by J. A. Cushman, L. G. Henbest, W. L. Tressler, Austin Clark, and H. A. Rehder. The center line of each column represents the present surface-water temperature. The large dot in each shaded block indicates qualitatively the deviation from the present temperature. The dotted line connecting these points shows the trend of the temperature change from one sample to the next. The extremes of temperature in different columns are not necessarily the same though they are comparable. Interpretation by J. A. Cushman and L. G. Henbest, based on the pelagic Foraminifera.

small percentage of calcium carbonate, the small number of Foraminifera, and the virtual absence of coccoliths. They have other features characteristic of the glacial marine deposits, such as a smaller quantity of clay, which is evident from the texture and the smaller shrinkage of the air-dried samples, and, locally at least, a lumpy structure, which appears to represent ellipsoidal or tubular borings that were subsequently filled with the adjacent mud to form coprolite-like pellets. Some of the pellets are as much as a centimeter in diameter. Whether these are coprolites or mud-filled borings of molluscs, worms, or some other organism is not known, and the significance of their occurrence in the glacial marine deposits in greater abundance than in other sediments is not apparent.

Schott's recent study [10] of the Foraminifera in the cores from the equatorial Atlantic collected by the *Meteor* expedition led to a similar interpretation of Pleistocene and post-Pleistocene deposits in that part of the ocean. His interpretation was based only on the ecology of the Foraminifera, as the sediments of that part of the Atlantic showed no accumulations of ice-rafted sand and pebbles. The cores, which averaged less than a meter in length, were sampled in the upper, middle, and lower parts. They showed a surface layer containing a warm-water fauna, a lower layer containing a cold-water fauna, and some of the longest cores showed a still lower layer containing a warm-water fauna. In the two layers that indicated a warm-water environment the Foraminifera were essentially like those living today in that part of the ocean. Schott interpreted the intermediate layer, that layer representing a cold-water environment, which in most places contained less calcium carbonate, as a deposit formed during the latest Pleistocene glacial stage; the lowest layer as a deposit of the last interglacial stage; and the uppermost layer as a post-Pleistocene deposit.

The correlation of the glacial marine zones and other distinctive zones that we found in our North Atlantic cores is discussed below, together with an interpretation of their significance.

CORRELATION OF ZONES REPRESENTED IN THE CORES

Layers or zones of alkalic volcanic ash in general are reliable for use in correlating strata because this kind of ash is erupted from volcanos of the explosive type and is distributed widely in the air. It must therefore accumulate on the sea floor at essentially the same time throughout the extent of its dispersal. When such ash zones are parts of a sequence of distinctive beds and the sequence is repeated at the several localities between which strata are to be correlated the reliability of the ash zones is further enhanced. As indicated in plate 3, cores 4, 5, 6, and 7 contain two ash zones and have the same sequence of glacial marine deposits between the ash zones. Below the lower ash zone in each core there is another glacial marine zone, which is underlain by foraminiferal marl similar to that found today at the surface of the ocean floor. The sequence of zones in these four cores agrees so well that their correlation seems well established in this area west of the mid-Atlantic ridge.

Core 3 is markedly different, as might be expected from its position within the area of terrigenous mud, or blue mud, near the Newfoundland Bank. This core consists of a remarkably uniform calcareous mud. Three thin and rather widely spaced layers of less limy mud and one thin silty layer near the bottom mark the only departures from the apparent homogeneity of this core. Small shards of alkalic volcanic ash like those in the ash zones of the other cores are very sparsely disseminated throughout this core but are not concentrated in any zone. The sediment of this core contains only an insignificant amount of sand-size clastic grains and no zones of coarse sand and pebbles, such as are found in the glacial marine zones of the other cores. The interpretation by Cushman and Henbest of the Foraminifera in this core (see pl. 4) is that the surface-water temperature was nearly uniform while the sediments represented by the core were accumulating, except for the three thin clay zones. The pelagic Foraminifera in the clay zones indicate colder water. Despite these thin cold-water zones, the distribution of the volcanic ash shards and the absence of sand and pebble zones lead us to believe that this core represents only sediments of post-Pleistocene time that accumulated in an area where the rate of sedimentation was more rapid than at the sites of the other cores. A core of greater length from this locality would be of particular interest to check this interpretation and give a basis for comparison of the post-Pleistocene rate of accumulation at this station with the rate at other core stations.

Core 3 contains no coarse sand and not even a single pebble, a fact that seems at first somewhat surprising, because this is the only one of the 11 cores that comes from within the present usual limits of drift ice. (See pl. 1.) However, the investigations of a number of explorers, notably Böggild and Nansen, have shown that much of the floor of the Arctic Ocean well within the limits of drift ice is covered with a deposit made up only of silt and clay that is free from sand and pebbles.[11] The explanation seems to be that even the berg ice in the Arctic and North Atlantic now contains but little clastic material, and apparently much of that little is dropped between Greenland and North America before it reaches the region south and southeast of the Newfoundland Banks. During the glacial epochs, however, the continental glaciers presumably furnished

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[10] 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. 120-130, 1935.

[11] Andrée, K., Geologie des Meeresbodens, pp. 378-379, 469-475, Berlin, Gebrüder Borntraeger, 1920.

many more bergs, and these bergs carried much clastic debris into the ocean.

Core 8, which was taken in 1,280 meters (700 fathoms) of water on the Faraday Hills part of the mid-Atlantic ridge, does not show the well-defined sequence of zones noted in cores 4 to 7, consequently its correlation with them is rather uncertain. The sediments throughout this core consist largely of sand and sand-size calcareous organisms, and the proportion of fine-grained material is so small that the dry core is friable. As is discussed later under the heading "Evidence of bottom currents" (pp.14–15) the sediment at this place seems to have accumulated where currents moved over the ridge with sufficient velocity to winnow out most of the finer constituents. As a result of this selective process the upper ash zone in core 8 contains comparatively few shards, but these are large and thick. Shards were found as far down as the top of sample B–131, which is therefore taken as the base of the upper ash zone. Because the shards are less numerous and the zone less well defined than in other cores, the correlation line at the bottom of the upper ash zone is indicated in plate 3 as doubtful. Although other lines of evidence make it seem probably that core 8 penetrated deep enough to have passed through the lower ash zone, no ash was found. Inasmuch as the shards in this lower zone are generally finer and less abundant than those in the upper ash zone, it is possible that they may all have been winnowed out, as have most of the shards in the upper zone, so that no trace remains at this site. The glacial marine zones are likewise less surely identifiable in this core, for the reason that the coarser sand and pebbles characteristic of the glacial marine deposits are less distinctly concentrated at definite horizons, perhaps because they have been more reworked and mixed with interglacial and postglacial sediments. Correlation of the glacial zones in core 8 with those in the other cores is therefore unsatisfactory, and this uncertainty is indicated in the correlation lines shown in plate 3.

Core 9 contains an exceptional abundance of volcanic ash in the middle part, and shards are scattered rather sparsely through it from the middle to the top. The distribution of the ash inclines us to believe that this ash zone corresponds with the upper ash zone of the cores west of the mid-Atlantic ridge. This belief is strengthened by the absence of coarse-grained material of the glacial marine type, either scattered or in beds, within the ash zone, and by the occurrence of a well-defined glacial marine zone a short distance beneath the base of the ash. The unusual concentration of thin, delicate volcanic glass shards in this core and the unusual abundance of other fine-grained constituents such as diatoms, coccoliths, and clay-size particles are discussed more fully on page 14.

The correlation of core 10 with the others is somewhat unsatisfactory for two reasons—first, the coring device penetrated deeper than the length of the core barrel, so that an unknown amount of sediment was lost through the water ports above the top of the core barrel; and second, at this station there are two rather thick beds of an extraordinary type of mud not represented in any of the other cores. At the time this core was taken Piggot collected some of the mud that had come out of the top of the core barrel and lodged in the water-exit ports. This sample (W–18) was of the same peculiar mud that makes up the uppermost quarter of the core, but it contained a moderate quantity of small pebbles and coarse sand. Piggot also collected, at this same station, a sample (W–17) of the globigerina ooze that stuck to the anchor flukes. Thus we know that at this station globigerina ooze blankets the sea floor, as it does at all the other stations except No. 3. Apparently all of the layer of globigerina ooze, the thickness of which is unknown, and some of the peculiar mud that makes up the top of core 10 was lost through the water ports. Nevertheless, it seems probable that the volcanic ash zone in this core is the upper ash zone of the other cores because of the abundance and general coarseness of the shards; because the shards continue upward, though sparsely, to the top of the core; because they were found also in the globigerina ooze above; and because there is a relatively thick glacial marine zone just below the base of the ash. The coarse sand and pebbles in the mud a little above the top of this core might be interpreted as material dropped from a stray iceberg as are other scattered or isolated pebbles found outside the glacial marine zones in the other cores. However, as this particular sample came from a disturbed core, not too much significance can be attached to its peculiarities.

Core 11 struck hard volcanic rock before penetrating any of the recognizable zones used in correlating the cores. This rock was hard enough to bend the core bit and stop it after it had penetrated the sediments for only about 34 centimeters. The thin deposit of globigerina ooze overlying the rock contains no shards of alkalic glass such as are scattered through the other cores, sparingly but continuously, from the base of the upper ash zone to the surface of the sea floor. The possible significance of this is considered on page 32, where the volcanic rock encountered in this core is discussed.

Core 12 penetrated the upper volcanic ash zone and the usual subjacent zone of glacial marine deposits, which at this site is thicker and somewhat less clearly defined than in most of the other cores, particularly those west of the mid-Atlantic ridge. This lack of clear definition may be due to the location of the station at which the core was taken, near the base of the continental slope, where material swept from the platform above may have diluted the glacial marine deposit. The bottom half-meter of this core consists of sediment containing an abundance of calcareous organisms of types that indicate a warm-water pelagic fauna.

(See pl. 4.) It also contains a larger percentage of sand and granules than the postglacial deposits at the top of the core. The larger grain size and the presence in abundance of pteropods and ostracodes suggest that the material in the lower part of this core may have accumulated in water shallower than now exists at this place, namely 3,230 meters (1,770 fathoms). According to Murray and Hjort,[12] 2,740 meters (1,500 fathoms) is about the extreme lower limit for pteropod shells, and ooze characterized by pteropods is rarely found in water deeper than about 1,825 meters (1,000 fathoms). It should be borne in mind, however, that the depth at which pteropod shells dissolve is dependent upon the saturation of the water with respect to calcium carbonate and that in the geologic past the ocean water may at one time have been saturated with calcium carbonate to a depth considerably greater than it is today and at another time less. The number of ostracodes in the lower part of core 12 is rather unusual. According to Tressler (chapter on "Ostracoda"), these organisms are more plentiful in the cores from less depth, particularly core 8, from 1,280 meters, and core 13, from 1,955 meters.

As the pteropod-bearing sediment in water deeper than would be expected is in the general vicinity of core stations 10 and 11, where volcanic rock was found, the suggestion is offered that foundering of the ocean floor may have occurred contemporaneously with the volcanic activity. Additional cores might provide interesting data bearing on the possibility that this part of the North Atlantic represents a foundered part of the Arctic or Thulean basaltic province,[13] which includes part of northwestern Scotland, northern Ireland, Iceland, Jan Mayen, and southeastern Greenland. Another possibility is that at the time this pteropod sediment was accumulating the water was saturated with calcium carbonate to greater depth than it is today and for that reason the pteropod shells were not dissolved. A third suggestion, that the sediment containing the pteropods, ostracodes, and sand may have slumped from its original position higher on the continental slope, is discussed more fully on pages 15–16.

Core 13 resembles core 8 in having throughout an abundance of sand, pebbles, sand-size Foraminifera, and rusty stain. As in core 8, nearly every part of core 13 is friable, owing to the relatively small quantity of fine-grained constituents. The position of this core near the edge of the continental platform suggests a further analogy with core 8, namely, that it owes its textural characteristics and the general indistinctness of the ash and glacial marine zones to the combined action of bottom currents and the activity of bottom-dwelling organisms.

The correlation of strata in the cores is thus less satisfactory from core 8 eastward than it is west of the mid-Atlantic ridge, but the consistent relation between an upper ash zone and the uppermost glacial marine zone appears to be a reliable basis for tying together all the cores except 3 and 11. The number and correlation of the glacial marine zones east of the mid-Atlantic ridge and on the ridge are somewhat dubious.

INTERPRETATION OF THE GLACIAL MARINE SUCCESSION

More than ordinary interest attaches to the interpretation of the zones of glacial marine sediments revealed by these cores because they may ultimately be correlated with events on land during the Pleistocene epoch and because cores of ocean-bottom sediments open a new approach to the study of glacial epochs. Nevertheless, before considering the various possible interpretations it may be helpful to attempt to visualize the conditions in the North Atlantic that gave rise not only to the zones of glacial marine sediment but also to sediment of the kind that lies between those zones.

SOURCES OF DETRITUS

The gravel, sand, and terrigenous silt found in the glacial marine zones must have been derived chiefly from bergs of glacial ice crowded from the land out into the sea by the continual growth of the glaciers behind. The sea ice, or pack ice, can contain no terrigenous debris, other than wind-blown material, except what it picks up by freezing to the bottom in shallow water or receives from the outwash of flooding rivers.[14] Thus, the presence of extensive layers of glacial marine deposits in the part of the North Atlantic from which these cores were taken makes it necessary to assume that the sea south of the fiftieth parallel of latitude contained much berg ice from continental glaciers and probably also much shore ice. While the sea level was low, during the glacial stages, extensive shoal-water platforms probably furnished large volumes of detritus to grounded sea ice, as described by Sverdrup [15] for the north coast of Siberia. Detritus from this source may have contributed as much as bergs. From further comparison with conditions as they now exist in both

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[12] Murray, J., and Hjort, J., The depths of the ocean, p. 173, London, Macmillan Co., 1912.

[13] Tyrrell, G. W., The principles of petrology, p. 144, London, Methuen & Co., 1926.

[14] Böggild, O. B., On the bottom deposits of the north polar sea: The Norwegian North Polar Expedition 1893–1896, Scientific results, vol. 5, pp. 50–51, 1906. Trask, P. D., The sediments: The *Marion* Expedition to Davis Strait and Baffin Bay, 1928, U. S. Treas. Dept. Coast Guard Bull. 19. pt. 1, pp. 73–74, 1932. Fuchs, V. E., and Whittard, W. F., The east Greenland pack-ice and the significance of its derived shells: Geog. Jour., vol. 76, pp. 419–425, 1930. Stetson, H. C., The bottom deposits in Scientific results of the *Nautilus* expedition, 1931, pt. 5: Massachusetts Inst. Technology and Woods Hole Oceanogr. Inst., Papers in Physical Oceanography and Meteorology, vol. 2, No. 3, pt. 5, pp. 32–35, 1933. Sverdrup, H. U., Notes on erosion by drifting snow and transport of solid material by sea ice: Am. Jour. Sci., 5th ser., vol. 35, pp. 372–373, 1938.

[15] Idem., pp. 372–373.

polar seas, we may infer that the drift ice[16] did not form a close pack or unbroken sheet over the site of the cores but instead was broken and probably was melting rather actively, for the zones of glacial marine sediment contain also some pelagic Foraminifera and diatoms that must have lived in the open water. Pelagic Foraminifera and diatoms are rare or absent from the bottom deposits beneath the continuous sheets of pack-ice in both the Arctic and Antarctic.[17]

TEMPERATURE OF THE OCEAN, AS INDICATED BY THE DEPOSITS

Rapid melting of the drift ice at essentially its southern limit in this part of the North Atlantic may well have been due to the warm North Atlantic current,[18] which probably flowed there much as it does today, though with somewhat less volume and lower temperature during the glacial maxima of the Pleistocene.[19] Many of the warm-water Foraminifera and Coccolithophoridae brought in by the current, however, are killed off when they reach the cold polar water.[20]

The convergence of a warm current from the south upon the melt water of an ice-filled sea and the tendency of the warm current to drift northward create a condition that readily accounts for a rather abrupt transition between the glacial marine zones and the overlying and underlying foraminiferal marl[21] with its warm-water fauna. As the areas of drift ice expand southward, glacial marine deposits accumulate where earlier the remains of warm-water pelagic organisms had been accumulating. So also, as the southern limit of the drift ice retreats northward, the warm current follows it northward, showering the top of the glacial marine layer with warmer-water Foraminifera and coccoliths. From this concept it follows that the zone of sediment between the uppermost pair of glacial marine zones in cores 4 to 8, which has a cold-water foraminiferal fauna and a texture intermediate between that of the glacial marine zones and the zones of foraminiferal marl, represents an interval when the southern limit of abundant drift ice had not receded much farther north than the line of core stations, or perhaps had shifted back and forth across that line. The forminiferal mud in the other parts of these cores, however, with its fauna of the type that lived in surface water, nearly but not quite so warm as that of today, indicates stages during which the drift ice had retreated nearly as far north as it is today.

The succession of events that led to the deposition of glacial marine and other sediments in alternating sequence may be illustrated somewhat as Lidén[22] illustrated a sequence of Pleistocene events in northern Europe. (See fig. 2.)

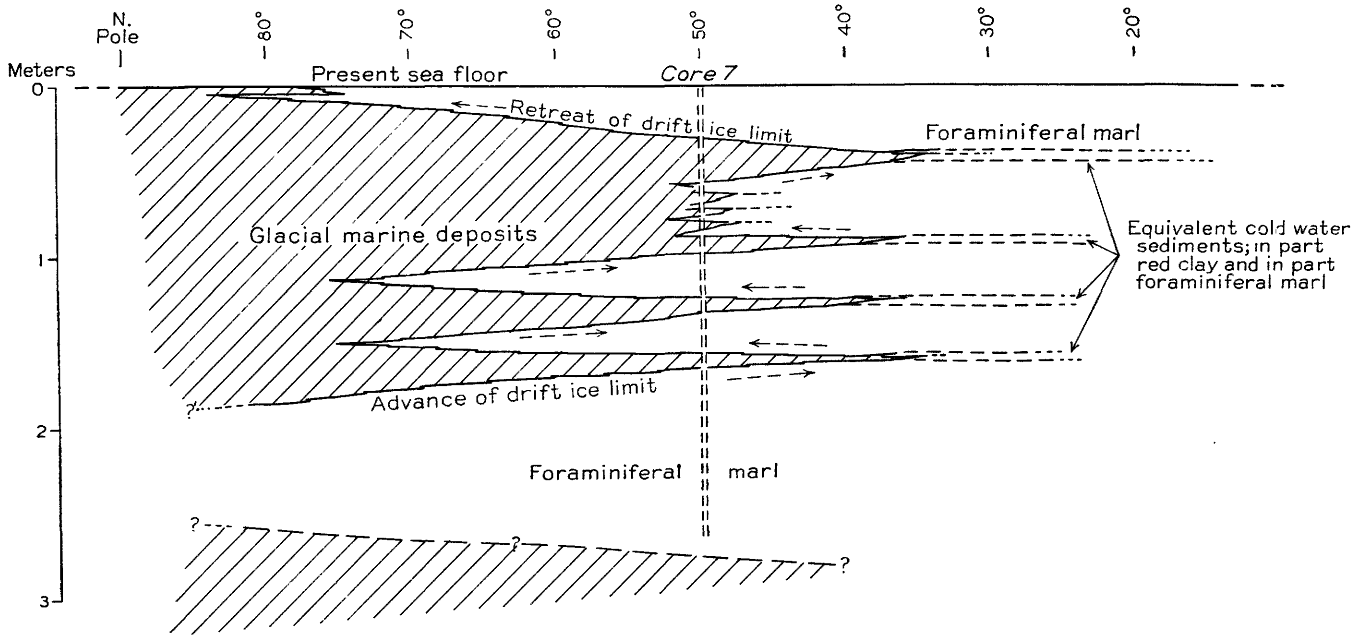

FIGURE 2.—Diagram showing the distribution of glacial marine deposits and foraminiferal marl in core 7 and the inferred distribution of these two types of deposit in a meridional section running through the site of this core. The maximum southward extension of the glacial marine deposits and the northward extension of the foraminiferal marl are unknown and are therefore purely hypothetical. The inference that other glacial marine deposits may underlie the bottom of core 7 is likewise hypothetical and is based only upon the physical characteristics of the bottom of core 7 and the absence of any suggestion of pre-Pleistocene Foraminifera. Core 7 was chosen for this diagram because it represents the longest period of time of any of these cores.

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[16] The term drift ice is used essentially as Priestly defined it (Wright, C. S., and Priestly, R. E., Glaciology: British (*Terra Nova*) Antarctic Expedition, pp. 393–394, London, 1922), that is floating ice where the pieces of ice are separated by open water whose area exceeds that of the ice. The ice is derived from any source whatever. It is equivalent to "open pack ice" and to the German "Treibeis."

[17] Nansen, F., The oceanography of the North Polar Basin: The Norwegian north polar expedition 1893–1896, Scientific results, vol. 3, pp. 422–427, 1902. Philippi, E., Die Grundproben, in Von Drygalski, E., Deutsche Südpolar-Expedition 1901–1903, Band 2, Heft 6, pp. 433–434, 1912. Stetson, H. C., Op. cit., pp. 32–35.

[18] The northeastward extension of the Gulf Stream according to Iselin's nomenclature. Iselin, C. O., A study of the circulation of the western North Atlantic: Massachusetts Inst. Technology and Woods Hole Oceanogr. Inst., Papers in Physical Oceanography and Meteorology, vol. 4, No. 4, pp. 73–75, 1936.

[19] Brooks, C. E. P., Climate through the ages, pp. 89–90, New York, R. V. Coleman, 1926.

[20] Nansen, F., op. cit., pp. 422–427. Hendey, N. I., The plankton diatoms of the southern seas: *Discovery* Repts., vol. 16, pp. 156–159, 1937.

[21] Definitions of the terms foraminiferal marl and globigerina ooze as used in this report are given on p. 17.

[22] Lidén, Ragnar, Geokronologiska studier öfver det Finiglaciala skedet: Sveriges Geol. Undersökning, ser. Ca., No. 9, pl. 7, 1913.

If traced northward from the latitude of the cores, the top of the uppermost glacial marine deposits should rise in relation to the surface of the sea floor until in the region of perennial pack ice, it or its Arctic equivalent, should form the surface deposit, the wedge of foraminiferal marl having thinned out and disappeared somewhere south of the region of drift ice. This is suggested by the deposits now forming in the western part of Davis Strait in latitude 60° to 65° N., which are derived chiefly from the ice brought there by the Labrador current,[23] whereas, according to Murray and Hjort,[24] foraminiferal marl carpets the sea floor a little farther southeast between Greenland and Labrador. If traced southward from the latitude of the cores, the uppermost glacial marine deposits should wedge out or grade into a southern equivalent—perhaps red clay or foraminiferal marl.

Data obtained by Schott in his recent work [25] on the Foraminifera from the cores taken on the *Meteor* expedition suggest that the uppermost glacial marine zone of the Piggot cores may be represented in the equatorial Atlantic by a zone of sediment containing Foraminifera that indicate surface water cooler than that now found in the same locality. Schott interprets this zone as probably the equivalent of the last glacial maximum in higher and lower latitudes. In parts of the equatorial Atlantic he found also that the upper boundary of the cool-water zone coincided approximately with the top of a zone of red clay of unknown thickness. The top of this zone, which lacks the tropical pelagic Foraminifera, ranges in depth below the surface of the sea floor from 10.5 to 66 centimeters. In our cores from the North Atlantic, except 3, 9, 10, and 11, the top of the uppermost glacial marine zone ranges in depth below the sea floor from a little less than 20 to a little more than 60 centimeters. In cores 3, 9, and 10 it ranges from more than 1 meter to 3 meters or more (core 3). The zone in the equatorial region that contains relatively cool-water Foraminifera is underlain in some places by globigerina ooze containing the same tropical forms that are now accumulating there. The cool-water zone averages a little more than 22 centimeters in thickness.

The probability that this cool-water zone in the equatorial Atlantic may be the equivalent of the uppermost glacial marine deposit of the North Atlantic cores is strengthened somewhat by Philippi's description and interpretation of the cores taken by the *Gauss* in the South Atlantic and southern Indian Ocean.[26] Philippi pointed out the absence of tropical Foraminifera in a layer of ooze below that now forming and noted that the lower boundary of the zone of tropical Foraminifera coincided with the top of red clay deposits in several parts of the South Atlantic and Indian Oceans. He interpreted both the absence of the tropical Foraminifera and the presence of red clay below a blanket of globigerina ooze as indicating generally colder water throughout the ocean and suggested that the deposits formed at that time probably represented the last glacial stage. Red clay was deposited in many parts of the ocean at depths where now foraminiferal marl is accumulating and in places where only the more delicate shells are being dissolved. It seems reasonable to conclude, as he did, that the greater extent of areas in which red clay was deposited in the past was due to the solvent and oxidizing effect of the greater quantities of carbon dioxide and oxygen that the cold water of that epoch could hold. As has already been noted, Philippi found in cores of bottom sediments from the southern Indian Ocean at approximately latitude 45° S., globigerina ooze overlying glacial marine deposits, and in cores from latitude 50° S. southward to the ice front, diatom ooze overlying glacial marine deposits.

An epoch when all the oceans were colder than they are today seems to be implied by the fact that three types of cool-water or cold-water deposits formerly had a greater areal extent than they do today and are, therefore, locally buried beneath a comparable thickness of foraminiferal ooze or limy blue mud such as that now forming in various parts of the ocean. The old glacial marine deposits extended much farther from the poles, in both northern and southern hemispheres, than the glacial marine deposits now forming; the areas of red-clay deposition were much larger; and the sediments characterized by a colder-water foraminiferal fauna extended even into the equatorial regions. Some very general cause seems necessary to explain these three types of colder-water deposits, all buried beneath a comparable thickness of warmer-water deposits. The conclusion seems logical that they are all essentially contemporaneous and represent the last glacial maximum of the Pleistocene. How much of the Pleistocene may be represented by these and other deeper-lying cold-water deposits penetrated by the cores is quite another question, which leads us back to further consideration of cores 4 to 7, from the western part of the North Atlantic. Each of which shows four more or less distinct zones of glacial marine deposits.

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[23] Trask, P. D., The sediments: The *Marion* Expedition to Davis Strait and Baffin Bay, 1928, U. S. Treas. Dept. Coast Guard Bull. 19, pt. 1, pp. 70–78, 1932.

[24] Murray, J. and Hjort, J., The depths of the ocean, map 4, London, Macmillan & Co., 1912.

[25] Schott. W., Die jüngste Vergangenheit des äquatorialen Atlantischen Ozeans auf Grund von Untersuchungen an Bodenproben der *Meteor*-Expedition: Naturf. Gesell. Rostock. Sitzungsber. Abh., ser. 3, Band 4, pp. 48–57, 1933. 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.

[26] Philippi, E., Die Grundproben, in Von Drygalski, E., Deutsche Südpolar-Expedition 1901–1903, Band 2, Heft 6, pp. 591–595, 1912.

INTERPRETATION OF THE GLACIAL MARINE ZONES IN TERMS OF STAGES OR SUBSTAGES OF THE PLEISTOCENE

Three possible interpretations have been considered: First, that each glacial marine zone represents a separate glacial stage of the Pleistocene epoch; second, that the two upper glacial marine zones, which are less distinctly separated, represent a bipartite last-glacial (Wisconsin) stage, whereas each of the two lower glacial marine zones represents a pre-Wisconsin glacial stage; and third, that all four glacial marine zones represent only substages of advance and retreat within the Wisconsin stage. (See fig. 3, A, B, C.)

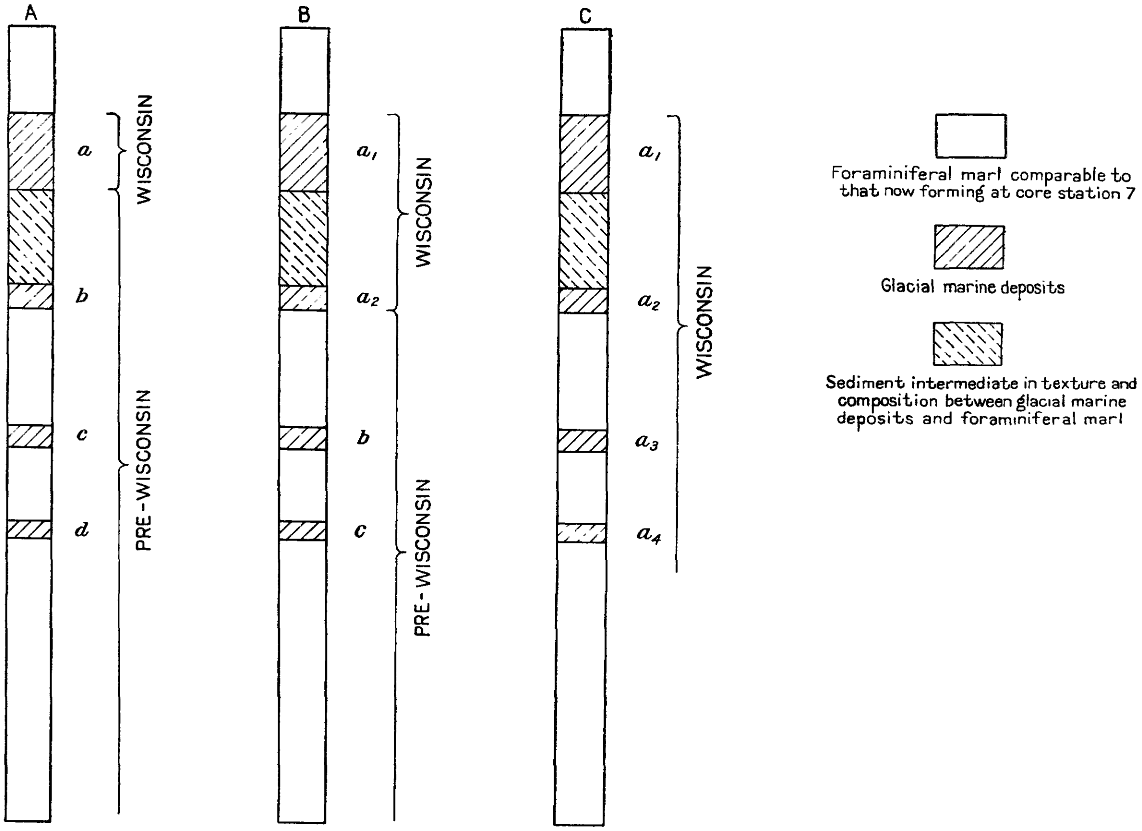

FIGURE 3.—Diagram showing three possible interpretations, A, B, and C, of the glacial marine zones in core 7, in terms of stages or substages of the Pleistocene. *a* signifies the latest, or Wisconsin stage; *b*, *c*, and *d* signify earlier, separate glacial stages of the Pleistocene. a_1, a_2, a_3, and a_4 signify glacial substages of the Wisconsin stage. Core 7 was chosen for this diagram because it represents the longest period of time of any of the cores.

The hypothesis that each of the four glacial marine zones represents a separate glacial stage of the Pleistocene (see fig. 3, A) now seems to us least probable, although this was the opinion we held earlier in the investigation.[27] Cushman and Henbest found, however, that the Foraminifera in the zone between the uppermost two glacial marine zones indicate, in general, water quite as cold as do those in the glacial marine deposits. (See pl. 4.) This, together with the texture and composition of the sediment in this zone, which is intermediate between glacial marine deposits and foraminiferal marl, leads us to believe that, in the interval between these two uppermost glacial marine zones, the southern limit of drift ice repeatedly migrated back and forth across the site of these cores. The uppermost two glacial marine zones seem to be too closely connected by deposits that represent conditions that were almost glacial for us to regard them as separate glacial stages of the Pleistocene. They seem rather to represent greater southward extensions of ice in the sea at the beginning and end of a single glacial episode.

According to the second interpretation, which postulates for the upper zones a single glacial stage marked by a moderate retreat of the ice between two greater extensions, the upper two glacial marine zones would correspond to the early and late substages of the Wisconsin.[28] (See fig. 3, B.) The lower two glacial marine zones in cores 4 to 7 might represent pre-Wisconsin stages, as they are separated from each other and from the upper glacial marine zones by foraminiferal marl, which contains pelagic Foraminifera that indicate surface water nearly or quite as warm as exists there today—in short, foraminiferal marl approaching the type now forming in that part of the North Atlantic. (See pp. 17–18.) The zones or layers of foraminiferal marl in the lower parts of cores 4 to 7 have approximately the same average thickness as the layer of postglacial

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[27] Bradley, W. H., Bramlette, M. N., and others, Preliminary report on the North Atlantic deep-sea cores taken by the Geophysical Laboratory, Carnegie Institution: Am. Geophysical Union Trans., pp. 224–226, 1937; The Geological Survey's work on the Piggot North Atlantic deep-sea cores: Am. Philos. Soc. Proc., vol. 79, pp. 41–46, 1938.

[28] Chamberlain, T. C., and Salisbury, R. D., Geology, vol. 3, pp. 392–394, New York, Henry Holt & Co., 1906.

foraminiferal marl at the tops of these same cores (see pl. 3), and it is assumed that they accumulated at approximately the same rate. This suggests that the intervals of time separating the two lower glacial marine zones from one another and from the next higher glacial marine zone were about equal in length to postglacial time and that during each interval the southern limit of the pack and berg ice in the sea retreated markedly, though probably not quite so far north as it now is. This hypothesis, if true, suggests that each of the lower two glacial marine zones represents a distinct glacial stage of the Pleistocene, but that each stage was set off by interglacial stages of no greater length than postglacial time. At the bottom of core 7 the number of Foraminifera and coccoliths and the quantity of calcium carbonate decrease markedly. In these same samples the percentage of sand increases conspicuously. Both these changes suggest proximity to the top of another glacial marine zone, yet the Foraminifera indicate that surface-water temperatures were quite as high as when the globigerina ooze just above was forming—that is, temperatures much like those that prevail today in that part of the North Atlantic. (See pl. 4.)

This second possible interpretation of the glacial marine zones seems to imply too short a time for the whole Pleistocene epoch, for each of the upper two interglacial zones indicates an interval of time about equal to postglacial time, whereas, the interglacial stage indicated in the lowest part of core 7 is evidently much longer than any of those above it, and may be even longer than this core seems to indicate. Moreover, the length of time represented by the glacial marine deposits must be considered. At present we have no means of estimating this, but the time represented by the glacial marine deposits might conceivably be much longer than that represented by the thicker foraminiferal marls between them.

The third possible interpretation is that all four glacial marine zones represent only substages of the Wisconsin stage (see fig. 3, C), though the latest two substages are not separated by a clearly defined nonglacial substage. For the greater part of the Wisconsin stage this interpretation apparently implies a greater latitudinal range of glacial phenomena both in the North Atlantic Ocean and in eastern North America than is evident in the record of continental glaciation. It implies that for periods of time measured in thousands of years the North Atlantic at approximately latitude 50° N. alternately contained an abundance of drift ice and then again for thousands of years was nearly or quite free of ice. This seems to indicate that, except in the intervals between the latest two glacial marine zones, the continental ice sheet not only withdrew from the coast but probably retreated well back toward its centers of dispersal so that the marine climate of the western North Atlantic was not greatly different from what it now is. Two observations on the deposits that lie between the glacial marine zones support this inference—the deposits contain Foraminifera and coccoliths that indicate surface-water temperatures about like those now prevailing, and they contain virtually no ice-borne material.

In the interval between the latest two substages, the drift ice in that part of the North Atlantic must have been only a little less plentiful than at the times of maxima, but the other glacial substages are set off from one another by intervals during which the surface-water temperature along the line of cores was nearly as warm as it is today. According to the third hypothesis, the thick unit of globigerina ooze in the lower part of core 7 may represent all or part of the interglacial stage that preceded the Wisconsin. Its foraminiferal fauna, which indicates surface water as warm, or perhaps warmer, than now prevails at that locality, is in accord with this inference.

Although the evidence available is insufficient to determine which of these interpretations of the glacial marine succession is the more nearly correct, we are inclined to favor the third interpretation—that all four glacial marine zones are substages of the Wisconsin stage. Only more and longer cores can provide adequate data for a completely satisfactory answer.

The speculation may serve a useful purpose in bringing to the attention of those interested not only the possible interpretations but also the factors involved. To pursue it further at this time seems fruitless. We do not know enough about the extent of the sea ice and its movements in the North Atlantic during the Pleistocene to correlate its advances and retreats with those recognized in the continental ice sheet and therefrom to give a valid interpretation of the glacial marine succession. These few cores do not give enough information on the areal extent and number of glacial marine zones to reveal their full significance. A series of similar but longer cores taken along a line running in a general southeast direction from Davis Strait through the vicinity of core stations 4 and 5 and on southward past the southern limit of the glacial marine deposits, would perhaps shed light on phases of the glacial epoch not decipherable on land. Such a marine record has the advantage of being continuous, and the mechanism that operated to bring about recognizable changes in the marine sediments probably was far more sensitive to climatic changes than a continental ice sheet. This sensitivity is suggested by Philippi's observations [29] in the south polar region. He observed there that lime-poor glacial marine deposits now forming within the limit of the pack ice are underlain at shallow depth by a thin layer of a more limy foraminiferal marl, which in turn overlies glacial marine deposits that contain almost no lime. This thin layer

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[29] Philippi, E., Andeutnngen von postglazialen Klimaschwankungen in der Südpolar-Region, in Die Veränderungen des Klimas: Eleventh Internat. Geol. Cong. Stockholm Ber., pp. 457–459, 1910.

of limy ooze he interpreted as the reflection of a brief postglacial amelioration of climate, during which the front of the pack ice was considerably farther south than it now is. Brooks[30] suggests that this warmer epoch which Philippi postulates may be the "climatic optimum."

It may be that the glacial marine history, when fully worked out, will provide the best means of testing Milankovitch's hypothesis[31] that the several glacial and interglacial stages of the Pleistocene were a function of solar radiation. Surely the expansion and contraction of areas in the sea that contain much drift ice would be more directly and immediately affected by changes in the sun's heat than would the advance and retreat of thick continental ice sheets. The relation between the drift ice and the glacial marine record is simple and direct, whereas the relation between the advance and retreat of continental ice sheets is indirect and complicated. Yet, despite this apparent directness in the linkage between the sun's radiation and the glacial marine record, the expansion and contraction of drift-ice areas in the sea are influenced by other factors, some of whose effects, taken singly or in combination, may exceed those of solar radiation or be out of phase with the solar radiation. One of these factors, analyzed by Brooks,[32] is that there is a critical polar temperature below which a polar ice cap forms and expands rapidly to a maximum size. The great cooling effect of floating ice accounts for the rapid growth of ice caps and their stability.

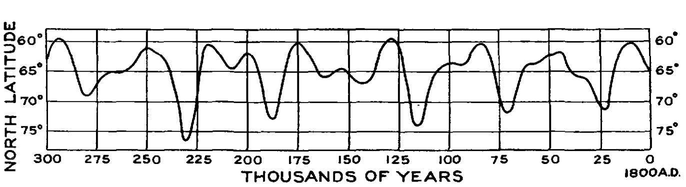

FIGURE 4.—Curve showing amplitudes of solar radiation changes at latitude 65° N. during the warm half of each year for the past 300,000 years. The variations in the amount of heat emitted are expressed in terms of an imaginary shift of geographic latitude. Time is reckoned from 1800 A. D. (After Milankovitch.)

Milankovitch, according to Zeuner,[33] calculated the variations in the solar radiation, which depend upon three periodical alterations of certain elements of the earth's orbit, as follows: (1) the eccentricity of the earth's orbit, with a period of 92,000 years, (2) the obliquity of the ecliptic, with a period of 40,000 years, and (3) the heliocentric longitude of the perihelion, with a period of 21,000 years. Milankovitch's[34] curve based on these calculations of solar radiation for the summer months is reproduced here as figure 4. The three radiation minima at 23,000, 72,000, and 115,000 years are regarded by Milankovitch, Zeuner,[35] and Blanc[36] as correlative with the three stages of the Würm glacial epoch in Europe.

Milankovitch's solar radiation curve, taken alone, does not seem to indicate four cold epochs corresponding to the four glacial marine zones which we think may be substages of the latest, or Wisconsin, glacial stage. No attempt, however, will be made here to explain this, or to relate the curve to the glacial marine record, because the glacial marine record is clearly fragmentary and the relationship is probably more complex than has been assumed by Milankovitch, Zeuner, and others.

POSTGLACIAL CLIMATIC CHANGES

Certain minor features of these cores may perhaps be explained by changes of climate that had either local or regional effects during the postglacial interval. In core 3, which we believe consists wholly of post-glacial sediment, there are three rather well-defined but thin layers that contain more clay, less calcium carbonate, and fewer Foraminifera and coccoliths than the rest of the core. These are indicated in plate 3 by sample numbers B–6, B–12, and B–18. They are also discernible in the photograph of the cores, plate 2. The physical character, together with the low surface-water temperature indicated by the Foraminifera in the upper two, suggests that these clay layers represent comparatively brief, cold episodes when sea ice containing no land-derived coarse detritus covered that part of the sea continuously; on the other hand, the Foraminifera in the third clay layer (at the bottom of the core) do not suggest surface-water temperatures lower than exist there today and thereby weaken the argument for this explanation. The sharp lower boundaries of at least the upper two clay layers (the base of the other clay layer was not penetrated by the core barrel) suggest that they may represent slumped material from the steep slopes of the adjacent Newfoundland banks. For further discussion of submarine slumping see pages 15–16.

The only other suggestions of postglacial climatic changes are the surface-water temperatures inferred from the pelagic Foraminifera by Cushman and Henbest. (See pl. 4.) The Formanifera in cores 3, 6, 9, and 12 (as shown in plate 4) indicate that during roughly the middle part of the postglacial interval the surface-water temperature in those areas in the North Atlantic was somewhat higher than prevails there today. This change is probably shown best in these particular cores because in them the zone of postglacial deposits is considerably thicker than in the other cores, where the postglacial record is compressed into much smaller compass.

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[30] Brooks, C. E. P., Climate through the ages, pp. 411–412, New York, R. V. Coleman, 1926.

[31] Milankovitch, M., Théorie mathématique des phénomènes thermiques produits par la radiation solaire: Acad. Yougloslave Sci. Arts de Zagreb., pp. 246–291, Paris, 1920.

[32] Brooks, C. E. P., Climate through the ages, pp. 32–45, New York, R. V. Coleman, 1926.

[33] Zeuner, F. E., The Pleistocene chronology of central Europe: Geol. Mag., vol. 72, p. 361, 1935.

[34] Milankovitch, M., Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen, Handbuch der Klimatologie, Band 1, Teil A, p. 141, Berlin, Gebrüder Borntraeger, 1936.

[35] Op. cit., pp. 362–372.

[36] Blanc, A. C., Low levels of the Mediterranean Sea during the Pleistocene glaciation: Geol. Soc. London. Quar. Jour., vol. 93, pp. 643–646, 1937.

A change to lower surface-water temperatures is indicated by the Foraminifera a little below the middle of core 9 (samples B–165 and 166, pl. 3). This change to colder conditions occurs at and a little below the base of the upper volcanic ash layer. It appears to have been a rather brief episode. Such brief episodes could not be revealed in the much more condensed sedimentary record of the other cores except by a larger number of thinner samples. Judging by the sparsity of ash in the lower part of core 3 this core did not reach the horizon represented by the cold zone in core 9. This temperature change shown in core 9 may, however, reflect only a local change in the fauna owing perhaps to some temporary change of currents.

RATE OF DEEP-SEA SEDIMENTATION

In order to estimate the rate of sedimentation as indicated by these cores it is necessary to make certain assumptions about the horizon in this oceanic stratigraphic sequence that corresponds most reasonably with a certain phase of the last glacial stage in North America. Only one horizon seems to us likely to have real meaning in this correlation, and this is the top of the uppermost glacial marine zone. This horizon is assumed to represent the beginning of the postglacial epoch as defined by Antevs, who says:

> The postglacial epoch is considered as having commenced when the temperature in the southern parts of the previously glaciated area had risen to equal that of the present time. In eastern North America the ice sheet was then probably confined to Labrador Peninsula. This was probably, in round figures, 9,000 years ago.[37]

The age of the horizon in the cores that we have adopted is, of course, subject to considerable error, because we do not know the rate at which the southern limit of the drift ice retreated. The drift ice, which contains the detritus-laden berg and shore ice, is much thinner than the ice of a continental glacier and has more surface exposed, so it would surely break up and disappear more quickly than the continental ice sheet, particularly in the North Atlantic, where the comparatively warm North Atlantic current tends continually to spread northward. Just as foraminiferal marl is now accumulating on the sea floor in latitudes farther north than the southern part of the Greenland ice sheet, so in the early waning phases of the last glacial stage the sea probably cleared of ice at latitudes farther north than that of the retreating front of the continental ice sheet.

Accordingly, the age of the top of the uppermost glacial marine zone in these cores is probably greater than 9,000 years; but, if we assume for the moment that it is 9,000 years, we can estimate the maximum rate of deposition for the postglacial deposits. The average thickness of the postglacial sediment in cores 4 to 7 is 34 centimeters. If this was deposited in 9,000 years, the rate of accumulation would have been about 265 years per centimeter. As pointed out above, however, 9,000 years is probably too short for the time elapsed since foraminiferal marl began to form at the sites of these cores after the last glacial marine deposits were laid down. The rate of accumulation of the foraminiferal marl near the tops of these cores may be nearer 1 centimeter in 500 years than 265, but a closer estimate based on these cores is hardly warranted.

A comparison of the thickness of the postglacial sediment in different cores shown graphically in plate 3 makes it plain that the rate of accumulation differs considerably from place to place even in the ocean abyss. The differences depend upon local conditions, as is illustrated by core 8, where currents have removed much of the normal fine sediment, with the result that the building up of the sea floor there has progressed at a comparatively slow rate. At the site of core 9, not far away, currents and perhaps other factors have caused an abnormally rapid rate of accumulation. The blue mud in core 3 evidently accumulated at least 10 times faster than the postglacial sediment in core 4.

Schott,[38] in his study of the stratification indicated by the Foraminifera in the cores taken by the *Meteor* in the equatorial region, assumed that the postglacial warm-water type of ooze began to accumulate there about 20,000 years ago. He calculated the average rate of accumulation of globigerina ooze in 48 cores to be approximately 1 centimeter in 415 years, and the range to be from 1 centimeter in 235 years to 1 in 950 years. For 6 blue muds he got an average rate of about 1 centimeter in 282 years, with a range from about 1 in 151 to 1 in 556 years. For 7 red clays the average was about 1 centimeter in 584 years.

It is interesting to compare these estimates with an estimate by H. Lohmann[39] based on the population and rate of growth of the Coccolithophoridae, published in 1909. Many assays of the plankton population showed that about 500 million of these minute calcareous plants grow under each square meter of open sea in the North Atlantic. These divide, on the average, about every 3 days, and as their total number, year in and year out, remains nearly constant, about one third of the population dies and sinks each day. From this rate and from the volume of the tiny plates or coccoliths into which the limy shells separate after the death of the organism he calculated that if the bottom deposits consisted of coccoliths alone they would accumulate at the rate of one millimeter in 1,000 years. But in the oozes he examined he estimated that coccoliths made up 30 to 70 percent of the sediment, which would mean that the sediment accumulated at something like 1 millimeter in 300 to 700

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[37] Antevs, Ernst, Late glacial correlations and ice recession in Manitoba: Canada Geol. Survey Mem. 168, p. 6, 1931.

[38] 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, p. 129, 1935.

[39] Lohmann, H., Plankton-Ablagerungen am Boden der Tiefsee: Naturwiss. Ver. Schleswig-Holstein Schr., Band 14, pp. 399–403, 1909.

years, or at an average rate of about 1 millimeter in 500 years. Although his samples came from depths of 2,400 to 4,800 meters in the North Atlantic, few of the samples from our cores contained more than 10 percent of coccoliths and most of them contained less. According to Correns,[40] Schott also estimated from the *Meteor* samples that the coccoliths, even where most abundant, made up not more than 13 percent of the total. If it be assumed the coccoliths make up 10 percent of the sediment now accumulating, Lohmann's figures would indicate a rate of about 1 millimeter in 100 years or 1 centimeter in 1,000 years. Probably a coccolith content of 3 percent would be nearer the average value for the sediment in the upper parts of cores 4 to 7, and this would indicate a rate of accumulation of about 1 centimeter in 300 years. This estimate, like the others, is obviously subject to considerable error, yet it is of the same order of magnitude as those given above, which were reached by a quite different line of reasoning.

The rate in the open ocean, as might be expected, is much slower than in inland seas or fjords, where more clastic material is supplied; for example, in the Clyde Sea [41] the varves in the mud indicate that the mud there accumulates at the rate of 1 centimeter in 2.1 years, whereas in Drammensfjord, Norway,[42] the varves indicate an accumulation rate of one centimeter in 6.7 years. In some of the larger inland seas the rate is apparently more nearly comparable with oceanic rates, as is illustrated by the deeper parts of the Black Sea, where, according to Archanguelsky, [43] the varves indicate an accumulation rate of about 1 centimeter in 50 years for the kind of ooze now being deposited.

EVIDENCE OF BOTTOM CURRENTS

The texture and structural features of the sediments in several parts of these cores seem to indicate rather plainly that, locally, currents move over the sea bottom with sufficient velocity to sweep the finer particles from the higher ridges and scatter them about over the bottom of the adjacent deeper parts of the ocean. The evidence for these currents is manifested most clearly in core 8, which was taken at a depth of 1,279 meters of water on the top of the Faraday Hills—a part of the mid-Atlantic ridge—and in core 13, taken at a depth of 1,955 meters on the continental slope off the Irish coast. (See fig. 1.) In these two cores the sediment contains an unusually large proportion of sand, the calcareous organisms are predominantly of sand size, and there is relatively so little binding matrix of clay-size material that the dry sediments are friable. These features are less obvious from the graphical illustration of the mechanical composition shown in plate 3 than they are when one examines the dry material under a binocular microscope, because a considerable proportion of the clay-size material is within the tests of the Foraminifera.

Evidently bottom currents move across these two core sites, winnow out most of the finer material, and carry it into deeper water. The evidence for this action is to be found not alone in the texture of the sediments of these two cores but more particularly in a comparison of the texture of core 8 with that of the next adjacent core 9, which, though relatively near, as shown in the profile (fig. 1), was taken at a depth of 3,745 meters of water. The postglacial zone in core 9 is more than 10 times as thick as it is in core 8, and it is made up predominantly of very fine grained material, as the data from the mechanical analyses plotted in plate 3 show. That much of this fine material came from the top of the mid-Atlantic ridge is suggested by the abnormal abundance of volcanic glass shards in core 9. These shards are mostly small and delicate, whereas the upper ash zone of core 8 contains but few shards and those are coarse and heavy. As the shards were brought to the ocean through the air, their distribution in the surface water was presumably uniform, therefore the sorting between cores 8 and 9 must have been subaqueous. Moreover, the scarcity of fine material in the sediment at the site of core 8 strongly suggests that the currents that did the winnowing were bottom currents.

Diatoms, coccoliths, and other minute organisms are rare in core 8, but they are abnormally abundant in core 9. These organisms are all minute and, like the volcanic ash shards, have large surface area with respect to their weight. Therefore, it seems probable that they also were removed from the Faraday Hills and concentrated in the deeper water by the same currents that brought the other fine material. The possibility has been suggested that for some ecological reason the surface waters just east of the Faraday Hills were particularly favorable for the growth of these organisms but it seems unnecessary to postulate such a special explanation to account for their concentration at the site of core 9.

The occurrence of coarser-grained sediment on the tops of ridges and mounds and fine-grained sediment in the deeper basins and depressions is apparently a common relationship.[44] Correns' work [45] on the many deep-sea samples of the *Meteor* expedition also showed that the coarser-grained sediment was found on the ridges

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[40] Correns, C. W., Die Sedimente des äquatorialen Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925–27, Band 3, Teil 3, Lief. 2, pp. 208–209, 1937.

[41] Moore, H. B., The muds of the Clyde Sea area: Jour. Marine Biol. Assoc., Plymouth, vol. 17, No. 2, new ser., pp. 348–351, 1931.

[42] Strøm, K. M., Land-locked waters: Norske vidensk.-akad. Oslo, Skr., 1936, No. 1, fig. 41, 1937.

[43] Archanguelsky, A. D., On the Black Sea sediments and their importance for the study of sedimentary rocks: Soc. naturalistes Moscou Bull., sec. Géol. new ser., tome 35, pp. 276–277, 1927.

[44] Trask, P. D., Origin and environment of source sediments of petroleum, pp. 87–94, Houston, The Gulf Publishing Co., 1932.

[45] Correns, C. W., Anzeichen von Beziehungen zwischen Strömungen und Bildung kustenferner (eupelagischer) Sedimente: Neues Jahrb., Beilage-Band 57, Abt. A, pp. 1113–1117, 1928.

and swells of the ocean floor, and this relationship was interpreted by him as a result of deep-sea bottom currents. He also showed that in areas where Foraminifera made up most of the sediment the deposits on ridges and mounds were richer in lime than those deposited in the adjacent basins, because the currents swept away the less calcareous clay fraction from the ridges.

The depth of 1,280 meters on the top of the mid-Atlantic ridge, where core 8 was taken, is almost surely too great for any surface wave effects, and the deep circulation of polar water southward is estimated [46] to be too slow to have much effect on the bottom. The effects of tidal currents, however, at these depths may be considerable, and deserve further investigation. Murray and Hjort [47] wrote "We now know that tidal currents prevent the formation of muddy deposits on the top of the Wyville-Thompson Ridge in depths of 250 to 300 fathoms, while just below the summit of the ridge on both sides mud is deposited." Tidal currents might be significant at even great ocean depths where ridges constrict the cross section of a large volume of slowly moving water.

The material in cores 8 and 13 is considerably more oxidized than in the other cores. They are stained with hydrous iron oxides and some manganese oxide, and they contain no iron sulphide. This relatively greater degree of oxidation apparently reflects the continual supply of oxygen from the water that circulates freely over these parts of the sea floor. Near the site of core 13 the *Michael Sars* dredged cobbles and boulders that appeared to have been only partly buried in the globigerina ooze.[48] Above a well-defined line these cobbles are stained with iron and manganese oxides, and to them are attached siliceous sponges, serpulae, horny worm tubes, and hydroids. These cobbles were dropped there from floating ice. Peach thought they probably fell into a flocculent ooze and sank until they reached a more tenaceous layer. Results of the present study suggest that it is perhaps more probable that they fell into glacial marine deposits and were subsequently covered, or partly covered, with globigerina ooze. That part of the interpretation is, however, much less pertinent than how they continue to remain partly emergent. Peach wrote: [49] "Their presence at the surface is probably due to a current that is just strong enough not only to sweep away the falling pelagic organisms that mainly go to form the ooze, but also to denude some of the looser top deposit and partially to expose the stones." The thinness of the postglacial deposits in core 13 and the conspicuous amount of sand and pebbles that are mixed with the postglacial types of Foraminifera support Peach's interpretation that currents of appreciable velocity sweep the bottom close to the edge of the continental shelf.

Currents of sufficient velocity to move silt and sand sized particles may not be restricted to these more exposed parts of the sea floor but may also operate to an appreciable extent even at depths exceeding 4,820 meters. The distribution of the shards of volcanic glass in both ash zones of these cores presents evidence that may be interpreted as the result of such currents. The shards that are scattered through a considerable thickness of sediment above the base of each ash zone may be so distributed because, for a long time, gentle currents continued to remove them from the tops of low mounds or ridges on the ocean floor and scatter them about over the adjacent flatter areas while the foraminiferal ooze continued to be deposited. This implies that, by reason of the currents, parts of an ash zone remain exposed for a long time on the mounds and ridges to supply shards to the adjacent areas. Such a hypothesis to account for the distribution of the shards in the ash zones might be tested conclusively in some particular locality by a group of cores that sampled the sediment on the top of a low ridge and on the adjacent flatter parts of the ocean floor.

Another and perhaps more plausible explanation of the distribution of the shards in the ash zones is given on pages 22–23 under the heading "Role of mud-feeding organisms."

SUBMARINE SLUMPING

Several layers of sediment in these cores that are rather sharply set off from the adjacent material by distinctive textural changes suggest submarine slumps. Two of these are in core 5 (samples B–53 and B–55) and another in core 12 (bottom part of sample B–214). Sample B–53 consists of a mixture of sand and Foraminifera which contains so little fine-grained material that it is decidedly friable. It contrasts markedly with the underlying homogeneous clayey sediment, which contains very few Foraminifera. The contact between them is sharp, but the most distinctive feature of sample B–53 is its gradation in grain size from coarsest at the base to fine at the top, as is shown in table 2.

TABLE 2.—*Grain-size distribution in sample B–53 from core 5 and approximate composition*

Distance above base of sample (centimeters)	Average diameter (millimeters)			Composition (percent, estimated)			Other constituents
	Clastic grains	Foraminifera	Mud pellets	Foraminifera	Clastic grains	Clay pellets	
8	0.06	0.24		30	45		Finely comminuted foraminiferal shells, 25 percent.
7	.09	.25		30	70		
6	.11	.24		40	60		
5	.13	.23		65	35		
4	.14	.25	Small	60	40	Rare	
3	.18	.27	Small	60	40	Rare	
2	.28	.27	0.4	55	42	2	Basaltic glass scoria, 1 percent.
1	.46	.32	.9	75	3	20	Basaltic glass scoria, 2 percent.
0	.45	.39	.8	55	40	5	

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[46] Defant, A., Über die wissenschaftlichen Aufgaben und Ergebnisse der Expedition; die deutsche atlantische Expedition auf dem Forschungs- und Vermessungsschiff *Meteor:* Gesell. Erdkunde Berlin Zeitschr., pp. 362–366, fig. 53, 1927.

[47] Murray J., and Hjort, J., The depths of the ocean, p. 170, London, Macmillan Co., 1912.

[48] Peach, B. N., Report on rock specimens dredged by the *Michael Sars* in 1910, by H. M. S. *Triton* in 1882, and by H. M. S. *Knight Errant* in 1880: Royal Soc. Edinburgh Proc., vol. 32, pp. 267–275, 1913.

[49] Idem, p. 272.

The regular gradation in size of this material, the sharp boundary at the base, the irregular occurrence of clay pellets, and the gradation into material of yet finer grain above suggest that this sample consists of material thrown into suspension by a submarine slump, carried beyond the slide itself, and deposited rapidly. Material thus thrown into suspension would be expected to settle according to the respective settling velocities of the various constituents. Clouds of suspended sediment are known to have travelled far beyond the outermost limit of subaqueous slides in lakes.[50] The average slope of the lake bottom over which one of these slides moved was a little less than 5 percent. Archanguelsky [51] describes numerous subaqueous slides in the sediments of the Black Sea and says they "seem to exist wherever the inclination of the bottom attains 2° to 3°, but at places occur even there, where the angle of the slope does not exceed 1°." Schaffer [52] cites apparently good reasons for believing that submarine slides have occurred off the Spanish and Portuguese coasts. Stetson and Smith [53] have recently referred to a large submarine slide which broke the Western Union Telegraph Co's. cable off the Newfoundland Banks following the earthquake of November 1929.

Another reason for thinking that the material in sample B–53 was derived from a submarine slide is the anomalous temperature indicated by its Foraminifera. The analysis of these Foraminifera by Cushman and Henbest indicates surface water temperatures warmer than prevail there today; whereas the Foraminifera in all other samples from the zone between the uppermost two glacial marine zones in cores 4 to 7 indicate temperatures nearly, or quite, as cold as in the glacial marine zones. (See pl. 4.) The presence of these warmer-water Foraminifera at this place in the core suggests that the sliding segment of mud—perhaps from a steeper part of the slope between cores 4 and 5 (see fig. 1)—was thick enough when it broke away from the slope to include at its base part of a layer of warm-water sediment similar to, or perhaps actually correlative with, that which makes up the lowest parts of cores 4 and 5.

Sample B–55, also in core 5, is sharply set off from the adjacent mud by its coarser grain and friability, by its greater abundance of Foraminifera, Radiolaria, coccoliths, and alkalic volcanic glass shards, and by its ill-defined lamination. This layer is as sharply defined at the top as at the base and has no discernible upward gradation in grain size. These features suggest that it resulted from a slump comparatively nearby, the finer-grained particles of which were carried beyond the site of this core. The presence in this layer, about midway between the upper and lower ash zones, of more shards of alkalic volcanic glass than in the adjacent sediment suggests that this slump, at its source, may have cut down into the lower ash zone. Such a layer might also be explained as a product of a local bottom current which, for some unknown reason, flowed more rapidly for a time and then either shifted its course or ceased to flow; but the abruptness of the change from one kind of sediment to another at both top and bottom of this layer makes this explanation less plausible. Near the bottom of core 3 is a sharply defined silty layer with obscure lamination which, though it consists largely of terrigenous silt, is similar in texture to B–55 in core 5 and presumably had the same origin. (See pl. 2.)

A very thin layer in the bottom part of sample, B–214, which was taken from a thick glacial marine zone in core 12, is like sample B–55 in being sharply defined at top and bottom and in showing no obvious upward gradation in grain size, though the material is somewhat coarser grained than the sediments immediately above and below. This layer at the base of sample B–214 contains more calcium carbonate, more coccoliths, and more shards of alkalic volcanic glass than the rest of the sample. Its Foraminifera indicate warmer water than the adjacent samples in the glacial marine zone within which it lies. (See pl. 4.) These facts, together with the distinctive texture and sharp boundaries of the layer, suggest either material that settled out from the suspended material of a submarine slump or perhaps material sorted by local and temporary currents. The presence of the alkalic glass shards suggests, as in B–55, that if it is the result of slumping, the slump may have carried down in its basal part material from a lower ash zone. But no matter how the shards got into sample B–214 it is plausible to assume that they provide evidence that the lower alkalic ash zone is present east of the mid-Atlantic ridge though none of these cores reached it.

Lower in core 12 the material from the general horizon of sample B–223 nearly to the bottom has a somewhat lumpy appearance and is sandy and friable. This part also contains small granules, some rather cleanly sorted fine reddish sand, and at least one red sandstone pebble more than a centimeter across. The texture and composition of the material in this part of the core and the fact that the core was taken on the lower part of the continental slope (see fig. 1) suggests that this lumpy material may have slid from a position higher on the banks and that the slide included some glacial marine material. An alternative interpretation was given on page 7.

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[50] Heim, Arnold, Über rezente und fossile subaquatische Rutschungen und deren lithologische Bedeutung: Neues Jahrb., 1908, Band 2, pp. 137–140. Nipkow, F., Über das Verhalten der Skellete planktischer Kieselalgen und geschichteten Tiefenschlamm des Zürich—und Baldeggersees: Rev. Hydrologie, 4 année, pl. 1, pp. 114–115, 1927.

[51] Archanguelsky, A. D., Slides of sediments on the Black Sea bottom and the importance of this phenomenon for geology: Soc. naturalistes Moscou Bull., Sci. Géol. new ser., tome 38, p. 80, 1930.

[52] Schaffer, F. X., Über subaquatische Rutschungen: Centralbl. Mineralogie 1916, Abt. A, p. 24.

[53] Stetson, H. C., and Smith, J. F., Behavior of suspension currents and mud slides on the continental slope: Am Jour. Sci., 5th ser., vol. 35, p. 12, 1938.

CARBONATE CONTENT OF THE SEDIMENTS

The total amount of carbonate in these samples was determined by treating the material with hot dilute hydrochloric acid until the solution was slightly acid as indicated by methyl orange. The amounts of total carbonate plotted in plate 3 are therefore only approximate determinations, subject to errors of several percent. Among the variety of factors that introduce errors are the partial solubility and the base exchange of the clay minerals and the incomplete solution of carbonate particles by reason of clay films that protect them from the acid. The figures given for total carbonate include both calcium and magnesium carbonates, and in the following discussion "carbonate" refers to these amounts of total carbonate unless stated otherwise. Actually, the magnesium-carbonate content of the 31 samples in which it was determined averages only 2.19 percent, which is probably within the range of uncertainty of the total carbonate determinations, so that it may be neglected in the following consideration, and the total carbonate may be considered as all calcium carbonate. In support of this suggestion K. J. Murata of the Geological Survey's chemical laboratory has pointed out to us how closely the relationship of the CaO and CO_2 in the 20 precise analyses given by Edgington and Byers in the chapter "Selenium content and chemical analyses" agree with the relations of CaO to CO_2 in pure calcite. This relationship is shown in figure 5. Many of the points in this figure lie above the line of pure calcium carbonate. This suggests that a small part of the total calcium in the samples is present in a noncarbonate form. The points that fall below the line apparently represent magnesian calcite or mixtures of calcium and magnesium carbonate. Sample 5A12, for example, contains 4.14 percent of $MgCO_3$, and samples 10A5, 3A9, and 13A3 each contain several percent of $MgCO_3$. Sample 10A4, which contains comparatively little carbonate, owes its anomalous position with respect to the line representing the composition of calcite to the abundance of basaltic debris in the mud. The rest of the samples approximate rather closely the composition of calcite.

Before considering the distribution of the carbonate it is desirable to consider briefly the terminology of carbonate-rich sediments. Murray and Chumley [54] defined globigerina ooze as deep-sea sediment that has a carbonate content of 30 percent or more. The average carbonate content of all their samples is 64.72. Correns [55] points out that this means of defining globigerina ooze on the basis of carbonate content is unsatisfactory, because many deep-sea sediments contain 30 percent or more of carbonate, yet only a few *Globigerina* or any other Foraminifera. As a substitute he proposes to define globigerina ooze by the foraminiferal number, which is the number of Foraminifera per gram within the size range 0.2 to 2.0 millimeters. Samples with a foraminiferal number of 6,000 or more he calls globigerina ooze. This would mean that certainly more than a quarter and generally about half of the sediment would consist of foraminiferal shells. He found that most of the *Meteor* samples had a carbonate content of 60 percent or more. According to this definition many of our samples should not be classed as globigerina ooze, but the Foraminifera in our samples have not been counted, and it is not possible to compare them directly with the *Meteor* samples. In this report the term globigerina ooze is used loosely to designate the sediment in which roughly half or more of the sediment, by weight, consists of Foraminifera. By bulk, these hollow shells are obviously the predominant constituent. Limy muds containing a lesser but still conspicuous number of Foraminifera are referred to by the more qualitative term "foraminiferal marl."

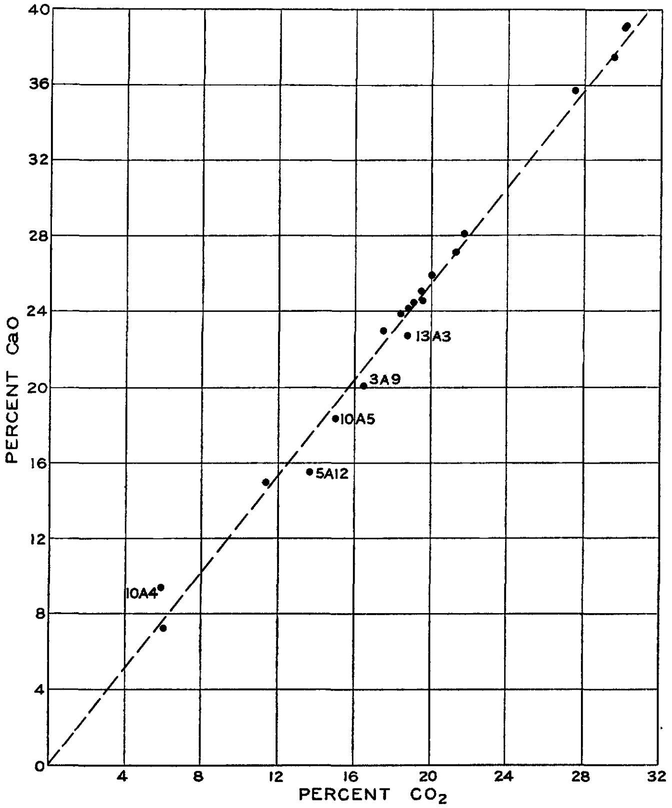

FIGURE 5.—Graph showing the $CaO-CO^2$ ratios of core samples (represented by dots) in relation to the $CaO-CO_2$ ratio of pure calcite (represented by the diagonal line). All data are from analyses made by Edgington and Byers, and the numbers by some of the dots are sample numbers given in their table of analyses.

The tests of Foraminifera, most of which are nearly whole and thus easily recognizable, were estimated to make up approximately 47 percent, by weight, of the carbonate of the sediment that is classed as globigerina ooze in these cores, whereas in the globigerina ooze collected by the *Challenger* the Foraminifera (pelagic

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[54] Murray, J., and Chumley, J., The deep sea deposits of the Atlantic Ocean: Royal Soc. Edinburg Trans., vol. 54, pt. 1, p. 217, 1924.

[55] Correns, C. W., Die Sedimente des äquatorialen Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925-27, Band 3, Teil 3, Lief. 2, pp. 206-208, 1937.

and bottom-dwelling) make up 61 percent.[56] For the North Atlantic samples the percentages of Foraminifera shown in plate 3 are rough estimates. In making these estimates there is a tendency to overestimate the percentage by weight, owing to the relatively large volume of the shells in proportion to their weight. A correction for this difference was attempted while making the estimates under a binocular microscope, and the fact that the small comminuted fragments of Foraminifera were not included in the estimates tends further to compensate for any overestimate of the weight of the whole shells. We believe, therefore, that these estimates, though subject to rather large errors, give a fairly reliable picture of the distribution of the Foraminifera in the cores.

Globigerina ooze blankets the sea floor in all parts of the North Atlantic where all these cores were taken except at core station 3, which is in the blue mud zone, and at core station 9 where the mud is very limy but contains relatively few Foraminifera. Similar globigerina ooze makes up the lower parts of cores 5, 6, and 7, below the lowest glacial marine zone. The carbonate content of the globigerina ooze at the tops of the cores and in the lower parts of cores 5 to 7 ranges from 46.6 percent to 90.3 percent by weight and averages 68.2 percent. In the foraminiferal marl the average carbonate content is generally somewhat lower, but the range is large; for example, sample B–60 in core 5, contains 25.7 percent carbonate, and at the other extreme are samples B–152 to 156 in core 9, which have an average carbonate content of 78 percent.

The only other calcareous organisms that commonly form a quantitatively significant part of the calcium carbonate in these cores, are the minute algae belonging to the Coccolithophoridae. These are flagellate brown algae, the commonest of which have globular coatings or shells of calcium carbonate made up of plates. These plates, the coccoliths, separate readily when the plant dies, and in the sediment only these minute plates of various shapes are commonly found. The smallest of these coccoliths are only about 0.002 millimeter in diameter, and few of the largest exceed 0.015 millimeter in diameter. They belong to several different types among the many genera and species that have been described by Schiller.[57] We have made no attempt to differentiate the various genera and species.

In the more calcareous sediments the coccoliths are usually common, but because of their small size they rarely constitute more than a few percent by weight of the total carbonate. Where they reach their maximum abundance in the upper parts of cores 9 and 3, they were estimated to make up about 10 percent of the sediment by weight. They can be recognized only at high magnifications, and as many hundred coccoliths would equal only one of the smaller Foraminifera, a careful separation into grade sizes and determination of the percentages within these fractions would be necessary to obtain satisfactory estimates. Therefore, only the relative abundance of the coccoliths, based on rough estimates, is shown in plate 3.

Rhabdoliths represent a type of calcareous algae living in warmer water, but none were observed in any of the samples.

A small number of echinoid spines and plates of their tests were noted in samples from most of the cores. Ostracodes are about equally rare, and shells and fragments of mollusks are still more rare. These are discussed further in the chapters on "Echinodermata," "Mollusca," "Ostracoda," and "Miscellaneous fossils." Pteropods constitute a few percent of the calcareous material in some samples, notably B–131 near the top of core 8, between samples B–225 and 226 in core 12, and B–231 in core 13. Calcareous organisms other than Foraminifera and coccoliths occur so sparingly that in most samples they are quantitively insignificant.

In the more highly calcareous samples, most of which are to be classed as globigerina ooze, it is obvious that the calcium carbonate consists predominantly of the tests and comminuted fragments of calcareous organisms, but the particles of calcite of fine silt size and smaller are only in part recognizable. The irregular shape and range in size of these indeterminate particles of calcite suggest that they are largely the finest debris of the comminuted organisms rather than a chemical precipitate of calcium carbonate. Particles resembling the aragonite needles described by Vaughan[58] from the Bahama Banks region, if present, are too rare to have been noted. The large percentage of calcium carbonate in some of the finer-grained sediment, such as that making up most of cores 3 and 9, is mostly of indeterminate origin. It seems probable that these fine-grained sediments would contain the largest amount of chemically precipitated calcium carbonate if any were to be found, but no adequate criteria for recognizing such a chemical deposit have been noted. The presumption is, therefore, that the greater part of this finely divided carbonate of irregular shapes and sizes consists of the most finely comminuted particles of calcareous organisms that have been winnowed out, along with other fine particles, from the Newfoundland Banks (core 3) and the mid-Atlantic ridge (core 9).

Well-formed crystals of calcite, commonly intergrown so as to form clusters or rosettes, have been noted in many of the samples, but in no sample are they abundant. Some of these calcite crystals are distinctly zoned. These obviously inorganic calcite grains are generally 0.1 to 0.2 millimeter in diameter. Because of their comparatively large size, crystal form, and

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[56] Murray, J., and Chumley, J., op. cit., pp. 222–223.

[57] Schiller, J., Coccolithineae: Rabenhorst's Kryptogamen-Flora, Band 10, Ab. 2, 1930.

[58] Vaughan, T. W., Chemical and organic deposits of the sea: Geol. Soc. America Bull., vol. 28, pp. 933–944, 1917.

habit, it seems more probable that they are the result of growth within the mud than of chemical precipitate in the water above the mud or in the surface water. They form only a negligible portion of the carbonate content of the cores but seem to be more common in the glacial marine zones than elsewhere.

The large amount of chemical data on ocean water obtained by the *Meteor* expedition and discussed by Wattenberg[59] indicates that much of the water is approximately saturated with calcium carbonate under existing conditions of equilibrium, and a slight departure from these conditions may therefore cause precipitation. Revelle[60] has pointed out the possibility that Wattenberg's figure for the solubility-product constant of calcium carbonate in sea water may be somewhat too low and that, in consequence, less of the ocean water is saturated with calcium carbonate than Wattenberg believes. It is generally agreed, however, that the water at greater depths is not saturated and tends to dissolve carbonates. Accordingly, even though carbonates were precipitated at the surface of the ocean as tiny needles of aragonite, they would probably be redissolved before reaching the bottom, because this form of calcium carbonate is relatively unstable, particularly in minute particles. The high alkalinity determined by Wattenberg[61] for the water close to the bottom suggests solution of calcium carbonate, probably of the more finely divided particles and particularly those in the form of aragonite. The dissolved carbonates in these waters near the deep ocean bottom may thus reach a concentration sufficient to cause some reprecipitation of calcite crystals within the bottom sediments. It is noteworthy in this connection that shells of pteropods, which are composed of aragonite, are seldom found below a depth of 2,740 meters and are generally restricted to deposits formed in water shallower than that containing the remains of other pelagic organisms whose shells are composed of calcite.[62] Pteropods were found only in cores 8, 13, and the lower part of 12, which are the cores from the shallowest water of the series. In cores 8 and 12 these pteropods occur in parts of the cores classed by Cushman and Henbest as warmer-water deposits. (See pl. 4.) The pteropod shells are well preserved in several samples of core 13, but in sample B–235 and between samples B–240 and B–241 their former presence is revealed only by clay casts of the shells. These samples from which the shells have been dissolved were taken from glacial marine zones, and it therefore appears that, like the present polar waters, the cold water of the glacial marine epochs was a more effective solvent of calcium carbonate than the warmer water of nonglacial epochs.

Among the pebbles and granules of the glacial marine deposits, the most common rock types are limestone and dolomitic limestone. Grains of these types are likewise recognizable in the sediments of coarse and medium sand sizes, in some of which they are estimated to make up 10 to 15 percent. If there is a similar or greater proportion of clastic limestone grains, in the grains of finer sand and silt size, as may be expected from the relative softness of limestone, it seems probable that clastic carbonate constitutes the major part of the carbonate content of the glacial marine deposits in which Foraminifera are few and coccoliths absent.

The amounts of MgO and CaO in the acid-soluble portions of 31 samples selected from the top, middle,and bottom of each core were determined quantitatively. The CO^2 was not determined, but it was assumed that all the MgO was present in the form of carbonate. A small but unknown amount of the MgO calculated here as carbonate is doubtless present as exchangeable base obtained from the acid treatment of the sediment. Lacking the CO_2 determinations it is impossible to say how much is exchangeable base.

The percentages of magnesium carbonate in these 31 samples are given in table 3. The percentage of magnesium carbonate in the 20 samples of foraminiferal marl in which magnesia was determined ranges from 0.63 to 2.66, and the average is 1.32 percent. In the blue mud of core 3 the average magnesium carbonate content is 3.46 percent, and the average for the 6 samples of glacial marine deposits in which magnesia was determined is 4.01 percent.

TABLE 3.—*Distribution of magnesium carbonate within cores 3 to 13, percent*

Position of sample in core (approximate)	3	4	5	6	7	8	9	10	11	12	13	Average[1]
Top	2.59	1.25	0.9	1.33	0.94	1.17	1.75	[2] 4.08	1.34	0.73	1.09	1.31
Middle	3.11	[3] 4.85	[3] 4.14	[3] 5.19	1.38	1.36	2.15	[3] 6.48	-----	[3] .79	1.25	1.85
Bottom	4.67	1.55	1.8	2.66	.63	1.25	[3] 2.61	[2] 1.46	-----	.88	.90	1.79

[1] Exclusive of the glacial marine deposits and the peculiar mud in core 10.
[2] For peculiarities of this mud see pp. 32–34.
[3] Glacial marine deposits.

The distribution of the magnesium carbonate with respect to depth in each core is shown in table 3. It is evident from this table that the blue mud of core 3, the glacial marine deposits of all the cores, and at least part of the peculiar mud in core 10 (see pp. 32–34), contain, on the average, considerably more magnesium carbonate than the rest of the sediment in the cores. The greater quantity of magnesium carbonate in the glacial marine deposits probably can be accounted for by the recognizable grains of dolomite and dolomitic limestone, though a part may perhaps be ascribed to

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[59] Wattenberg, H., Kalciumkarbonate-und Kohlensäuregehalt des Meerwassers: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor,* 1925–27, Band 8, Teil 2, pp. 206–227, 1933.

[60] Revelle, Roger, Physico-chemical factors affecting the solubility of calcium carbonate in sea water: Jour. Sedimentary Petrology, vol. 4, pp. 105–106, 1934.

[61] Op. cit., pp. 165–172.

[62] Murray, J., and Chumley, J., Deep sea deposits of the Atlantic Ocean: Royal Soc. Edinburg Trans., vol. 54, pt. 1, p. 234, 1924.

differential solution of fine-grained calcite with respect to fine-grained dolomite by the colder water of the glacial epochs. (See p. 9.) The greater content of magnesium calculated as carbonate in the upper and lower clayey mud zones of core 10 may be due to partial solution of the basaltic constituents that they contain in addition to the scattered shards of alkalic glass. (See pp. 32–34.) If we exclude from consideration the glacial marine deposits and the peculiar muds of core 10, we find that cores 3, 4, 5, 6, 8, and 12, which have top and bottom sediments that are comparable in type, all show a slightly greater percentage of magnesium carbonate at the bottom than at the top. But in cores 7, 8, and 13 the middle samples contain more magnesium carbonate than the samples above or below them, and in cores 7 and 13 the bottom samples contain the lowest percentage for those cores.

Perhaps the uniformity in composition and texture of the sediment in core 3 makes the progressive increase of magnesium with depth in that core considerably more significant than the distribution of magnesium in any of the other cores. The magnesium content in core 3 is not complicated by glacial marine deposits nor by zones of either alkalic or basaltic volcanic material. Further investigation of the distribution of magnesium in depth in the oceanic blue muds is certainly warranted for what light it may throw on the tendency toward dolomitization with age and depth of burial.

The analyses showing MgO are so few, however, that averages of the figures given in table 3 can hardly be conclusive as indicators of a possible tendency to diagenetic dolomitization with increasing depth below the sea floor, as was suggested by the increasing magnesium carbonate content of the reef limestone in the deep boring at Funafuti.[63] The Funafuti boring, of course, represented a much greater range of depth than these cores.

The relation between magnesia and lime in these samples is not wholly consistent, yet it is generally true that the greater the percentage of total carbonates in the sediment the smaller the percentage of magnesia. This is in part, at least, an accidental relationship that depends upon the presence of clastic grains of dolomite and dolomitic limestone in the glacial marine deposits, which are relatively poor in total carbonates. Had some transporting agent dropped the clastic dolomite and dolomitic limestone grains into globigerina ooze the relationship would have been different. In part also the concentration of magnesia in the samples having relatively low percentages of total carbonates is due to the zones of peculiar mud in core 10. These muds contain less carbonate than any other samples in the series, yet by reason of their basaltic debris, they are relatively rich in magnesia. Analyses of the carbonates in core 3 illustrate the reciprocal relation of CaO to MgO in some of these core sediments. The uppermost sample in core 3 contains 40 percent $CaCO_3$ and 2.59 percent $MgCO_3$, the middle sample contains 37.8 percent $CaCO_3$ and 3.11 percent $MgCO_3$, and the bottom sample contains 29.1 percent $CaCO_3$, and 4.67 percent $MgCO_3$.

The *Challenger* samples also contained a larger percentage of magnesia in those samples that contained relatively small percentages of total carbonates. This relationship was interpreted by Murray and Hjort[64] as probably due to preferential solution of calcium carbonate over magnesium carbonate.

As much of the carbonate in these samples was derived from foraminiferal shells it is interesting to compare the CaO–MgO ratios of the samples given in table 4 with the CaO–MgO ratios of analyzed foraminiferal shells. According to Clarke and Wheeler,[65] the average lime-magnesia ratio of two samples each consisting of a single species of pelagic Foraminifera dredged from the ocean is about 35. These particular Foraminifera evidently contain much more magnesium carbonate than some of the globigerina ooze of the North Atlantic cores, as for example in the upper and lower parts of core 7, which consist predominantly of pelagic Foraminifera. (See table 4.) Murray and Hjort[66] in commenting on the fact that magnesium carbonate makes up only a small percentage of the total carbonate on the sea floor wrote: "Since the proportion of Mg to Ca, primarily in rocks and secondarily in river-waters, is much larger than this, it is clear that dissolved magnesium is accumulating in the ocean." Recent experiments in base exchange by A. C. Spencer and K. J. Murata[67] have shown that for certain pure clays each 100 grams of clay brought into the ocean by rivers adsorbs nearly 0.2 gram of Mg from the sea water. This amount of Mg abstracted from the sea water is added to that which the fine clastic particles had already adsorbed when they were constituents of soils and which they held while in transit. Thus, as most of these particles are deposited in the zone of terrigenous deposits relatively near the coast, they fix therein whatever adsorbed Mg they brought with them from the land and also an additional amount which they adsorbed from the sea water. This may explain in part why there is relatively more Mg in the blue mud of core 3 than in the other limy sediments more remote from the coast. The base-exchange experiments also showed that when this same clay was transferred from normal river water to sea water it released about 0.9 gram of Ca for each 100 grams of clay. Thus more Ca and less Mg is delivered to the ocean water

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[63] Judd, J. W., the chemical examination of the materials from Funafuti, in The atoll of Funafuti, pp. 364-365, London, Royal Soc., 1904.

[64] Murray, J., and Hjort, J., The depths of the ocean, p. 181, London, Macmillan Co., 1912.

[65] Clarke, F. W., and Wheeler, W. C., The inorganic constituents of marine invertebrates: U. S. Geol. Survey Prof. Paper 124, p. 2, 1922.

[66] Op. cit., p. 181.

[67] Spencer, A. C., and Murata, K. J., oral communication.

than chemical analyses of river water alone indicate. If this additional Ca brought into the ocean is precipitated as carbonate, for example, it may account, in part, for the greater excess of Ca over Mg in the deep-sea sediments. As noted above, because we lack the CO_2 determinations, it is impossible to say how much of the Mg and Ca are present in these samples as carbonates and how much as exchangeable base obtained from the acid treatment of the samples.

TABLE 4.—*Lime-magnesia ratios (to the nearest whole number of the samples shown in table 3)*

Position of sample in core (approximate)	3	4	5	6	7	8	9	10	11	12	13
Top	18	59	14	60	100	51	44	[1]3	49	118	60
Middle	14	[2]5	[2]6	[2]5	32	34	34	[2]7	-----	[2]28	52
Bottom	7	23	34	27	106	26	[2]8	[1]7	-----	44	52

[1] For peculiarities of this mud see pp. 32–34.
[2] Glacial marine deposits.

SULPHATES

K. J. Murata called our attention to the fact that the SO_3 reported by Edgington and Byers (see chapter on "Selenium content and chemical analyses") is roughly twice as much as would be expected from the amounts of Cl if the SO_3/Cl ratio were the same in the entrained sea salts as it is in sea water. Abnormally large quantities of SO_3 were also found in another core sample analyzed by E. T. Erickson in the Geological Survey's chemical laboratory. A number of corals, echinoderms, bryozoa, and other calcareous marine organisms contain appreciable quantities of sulphate[68] and Mr. Murata suggested that the excess sulphate in these core samples might be a part of the normal composition of the calcareous foraminiferal shells and coccolith tests. As a result of this suggestion, J. J. Fahey, of the Geological Survey's chemical laboratory, determined the SO_3 in three fractions of a sample of globigerina ooze (W–17, core 10; see pl. 3). Two fractions consisted almost wholly of foraminiferal shells, but the third fraction consisted of the material that had passed through a 200-mesh screen. All three fractions contained SO_3 but definitely less than 0.01 percent. In preparing this sample (W–17) for mechanical analysis the entrained sea salts had been thoroughly leached out with large volumes of distilled water. Analyses of the leachate of several other samples from various cores contained, like the fusion analyses of Edgington and Byers, nearly double the amount of SO_3 that would be expected. These facts suggest that the sediments contain small quantities of a soluble sulphate, possibly gypsum. Bannister[69] reported euhedral gypsum crystals from the Weddell Sea sediments, but we did not recognize any during the microscopic examination of the North Atlantic sediments. To be sure, there remains the possibility that calcium sulphate makes up a small part of the calcareous shells and that the long leaching removed it from them.

SILICEOUS ORGANISMS

The remains of siliceous organisms generally form less than 1 percent of the sediment of the cores. Diatoms, Radiolaria, and sponge spicules are the most common forms, and any one or another of them may be the most numerous in a given sample. In cores 8 and 13 sponge spicules are the only siliceous remains, but these spicules are relatively coarse and heavy as compared with the diatoms. The presence in these two cores of only the spicules—the heavier forms—is apparently to be explained as a residual enrichment, the lighter diatoms, Radiolaria, and other small particles having apparently been swept away by the currents that move over these sites. (See pp. 14–15.) In contrast with the rarity of diatoms in core 8, these delicate siliceous tests are unusually abundant in core 9, only a little farther to the east. Indeed, the sediment in some of the middle part of core 9 may properly be classed as diatom ooze, as diatom frustules make up 50 percent or more of it. This most diatomaceous part of core 9 is in the lower part of the upper volcanic ash zone. In core 10, the upper volcanic ash zone also contains thin beds in which diatoms are unusually abundant. West of the mid-Atlantic ridge diatoms are rather more common in the upper ash zone than in other parts of the cores, though much less common than in the ash zone of cores 9 and 10. This is another illustration of the common association of diatom remains and pyroclastics which has been pointed out by Taliaferro[70] and others.

Lohman's systematic work on the diatoms in these cores (see chapter on "Diatomaceae") shows that these bottom deposits contain no remains of the very delicate forms that constitute a large element of open-sea pelagic diatom flora. This agrees with the findings of Brockmann[71] and with his interpretation that the tests of the more delicately silicated diatoms are dissolved before reaching the bottom, even in relatively shallow water, such as that of the North Sea. In the lower parts of several of the cores some of the diatoms had apparently been leached out after burial on the sea floor, for shallow cavities that appeared to be molds of frustules were observed in the clayey matrix. More study is required, however, to establish definitely that the silica of the diatoms was removed after burial. In certain samples also the central canals of sponge spicules appeared to be corroded. Enlargement of sponge-spicule canals by solution on the sea floor has been described by Schulze.[72]

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[68] Clarke, F. W., and Wheeler, W. C., The inorganic constituents of marine invertebrates: U. S. Geol. Survey Prof. Paper 124, pp. 7–56, 1922.

[69] Bannister, F. A., Report on some crystalline components of the Weddell Sea deposits: *Discovery* Repts., vol. 13, p. 66, 1936.

[70] Taliaferro, N. L., The relations of volcanism to diatomaceous and associated siliceous sediments: California Univ. Pub., vol 23, No. 1, pp. 1–55, 1933.

[71] Brockmann, Chr., Diatomeen und Schlick im Jade-Gebiet. Senckenberg, naturf. Gesell. Abh. 430, p. 6, 1935.

[72] Schulze, F. E., Report on the Hexactinellidae: *Challenger* Rept., Zoology, vol. 21, pp. 26–27, 1887.

ROLE OF MUD-FEEDING ORGANISMS

Apparently mud-feeding animals have played a significant part in reworking the sediment, even on the floor of the abyssal parts of the ocean. This seems to be best illustrated by the distribution of the volcanic ash shards in both ash zones, although an alternative explanation for the distribution of the shards was suggested on page 15. We know that explosive eruptions of volcanoes are brief episodes and that when the ash from them falls into quiet water it accumulates in thin, sharply defined layers, as indicated in figure 6, *A*. The glass shards in the deposits of the North Atlantic, however, are not so concentrated in thin layers; instead, they are distributed as shown in figure 6, *B*, with the greatest concentration at the base in one or several ill-defined layers and the remainder scattered at random up through a considerable thickness of sediment above. One might think that this distribution is due to differential settling of the shards through several thousand meters of water. This seems improbable, however, as many of the shards are half a millimeter or more across, and they show no size gradation upward in the sediment but are apparently quite unsorted. A more conclusive argument against differential settling is as follows: The columns in figure 6 are so drawn that the interval through which the shards are scattered represents nearly all postglacial time, that is, thousands of years. A calculation based on Stokes' law shows that the shards in these ash zones would have reached the bottom in less than 5 years.

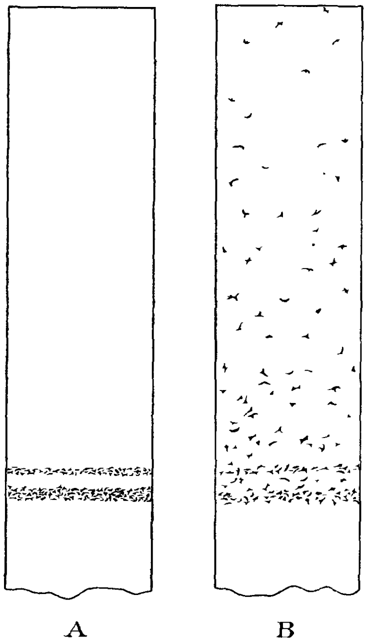

FIGURE 6.—*Diagram showing distribution of volcanic ash shards in sediments. A, Ash shards that accumulated in quiet water from two explosive eruptions; B, ash shards from two similar explosive eruptions that accumulated in water where mud-feeding animals continually worked over the sediment while ash-free sediment continued to accumulate so that the shards were incorporated in successively younger deposits. For an alternative explanation of this distribution of the shards, see p. 15.*

We infer that mud-feeding animals living on the sea floor at the time the ash layer was newly formed must have passed through their intestines mud consisting largely of ash shards and that succeeding generations of these animals picked up progressively fewer shards as the sediment became more and more diluted by the continual influx of the normal constituents of foraminiferal marl. Each time an animal scooped up mud and later excreted it on the sea floor, most of the mud particles must have been deposited at a level a little above their original position. Apparently it was this raising by successive small increments that eventually resulted in the distribution of the shards through a considerable thickness of overlying sediment. Grains of fine sand and even some coarse grains are scattered through the zones of foraminiferal marl between and above the layers of glacial marine sediment. Presumably these grains were originally deposited in the glacial sediment but, like the ash shards, have been reworked into younger sediments. Probably detritus of other kinds, including the shells and spicules of animals, has been similarly reworked, but it is difficult or impossible to tell how much their positions have been shifted.

The animals that are supposed to have performed this work are, of course, not known, but it seems probable from what is known of the abyssal fauna today that holothurians were largely responsible, though echinoids, annelids, and ophiurids doubtless also contributed. Théel [73] wrote:

> But the first inspection [of the Holothuroidea dredged by the *Challenger*] made it evident that the forms from great depths, now displayed for the first time, were of the greatest interest by making it manifest that holothurians are living there not merely in great numbers but belonging to many species, and that a large majority of them present certain peculiarities that render them strikingly different from the littoral forms hitherto known, and make them constitute perhaps the most characteristic group of the whole abyssal fauna.

All of these deep sea forms belong to one order, the Elasipoda, of which he wrote further:[74]

> It is evident that some of the Elasipoda, living together in great multitudes, pass along the bottom of the sea; this seems especially to be the case with *Laetmogone wyville-thomsoni* and *L. violacea*, *Oneirophanta mutabilis*, several species of the genus *Benthodytes*, *Kolga nana*, *Scotoplanes globosa*, etc., of which great numbers have sometimes been dredged at the same station. But numerous different species were also found together; thus, no less than ten forms were obtained from station 157, five from station 158, six from station 160, six from station 298, etc. The nature of the bottom of the sea is doubtless of great importance in regulating the distribution of the Holothuroidea, and they are found most numerous and in greatest abundance on a bottom of red clay, globigerina ooze, or diatom ooze.

Most of these came from depths ranging between 1,825 and 5,300 meters.

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[73] Théel, Hjalmar: Report on the Holothurioidea dredged by H. M. S. *Challenger* during the years 1873–1876, Part 1: *Challenger* Rept., Zoology vol. 4, p. 1, 1882.

[74] Idem, p. 9.

The calcareous plates of holothurians were found in the cores but they were much less numerous than fragments of echinoids and ossicles of ophiurids. It may be that the large surface per unit volume of the limy plates, wheels, and spicules of the deep-sea holothurians has been responsible for their disappearance by solution rather than that the animals themselves were scarce. Murray and Renard,[75] in discussing the occurrence of organic remains in deep-sea deposits said:

> Representatives of the various orders of Echinodermata are widespread over the sea bottom at all depths, and one would expect to find their remains somewhat abundant in the deposits now forming in the ocean; like Crustacea, however, the areolar nature of the shells seems to determine the removal of the hard parts in solution shortly after the death of the animal. It is seldom that a large sample of Globigerina ooze or Pteropod ooze can be examined without some fragments of Echini spines being observed, but it is the exception to meet with any other remains in the deep-sea deposits.

If the sediments in these cores have been as much reworked by mud-feeding animals as we infer from the distribution of volcanic ash shards and sand grains, we might expect them to have a more or less well-defined coprolitic structure. Ellipsoidal and elongate or cylindrical pellets that appear to be fecal pellets are plentiful in the mud at the top of cores 10 and 12. (See pl. 5, *A* and *B*.) They were not found elsewhere. Some of the elongate forms shown in plate 5 may be filled borings. Considerably larger ellipsoidal and somewhat irregularly shaped pellets are rather characteristic of the sediment in the glacial marine zones. Whether these are fecal pellets or filled borings is not clear. No attempt was made to identify any of these pellets with the fecal pellets described by Moore[76] and Galliher.[77]

Inasmuch as these pellets that appear to be of fecal origin are restricted to parts of the cores that contain a rather large percentage of clay it suggests that only excreted pellets containing enough clay to act as a binder persisted long enough to be preserved. It seems probable that fecal matter bound only by mucous or other organic substances that could serve as nutriants for bacteria would be entirely disaggregated before they could be buried on the ocean floor, where sedimentation is so slow. This might account for the absence of coprolitic structure in the foraminiferal marl.

In addition to the work done in redistributing various constituents of the sediments, mud-feeding animals probably also are responsible, along with free-swimming animals in the water above, for the comminuted particles of foraminiferal shells and other small shells found in the foraminiferal marl.

MINERALOGY OF THE CLASTIC SEDIMENTS

No systematic study of the mineralogy of the clastic grains was made, but notes were taken on the mineral components of the sand in many samples. The examination of the sand-size material was sufficient to show that the mineralogy of the clastic grains did not differ markedly from one horizon to another within individual cores and also that it did not differ conspicuously from core to core. More detailed study, however, would probably show a greater difference in the mineral content of sediments from the eastern and western parts of the North Atlantic than was evident in the examination given them. Casual examination, for example, showed that grains and pebbles of red sandstone are rather common in cores 12 and 13, whereas they are rare or absent from the cores in the middle and western parts of the North Atlantic.

In general, quartz is more plentiful than the feldspars. The feldspars include orthoclase, microcline, sanidine, and plagioclase feldspars ranging from albite to labradorite. The mineral grains in the sand-size portions of the samples were not separated into light and heavy fractions. However, simple inspection showed that grains of heavy minerals are rather common in the glacial marine deposits. In many samples of the glacial marine deposits the content of heavy minerals was estimated to be 5 to 10 percent, but in the sand between and above the glacial marine deposits it seemed to be generally less. Quantitative data on this relationship might indicate whether or not the sand in the nonglacial deposits was material that had been reworked from glacial marine deposits.

Green hornblende is the most plentiful heavy mineral, particularly in samples west of the mid-Atlantic ridge. Augite, hypersthene, and diopside are fairly common. Black opaque minerals consisting largely of magnetite and ilmenite are plentiful, as are also micas. Epidote, apatite, and garnet are less common but were found in all samples examined. Olivine was found in some samples, but it is rare, particularly in the cores from the western part of the North Atlantic. The rarer minerals, whose relative abundance in different samples could not be even roughly compared without first separating and concentrating the heavy minerals, include sillimanite, kyanite, zircon, rutile, titanite, and tourmaline. Nevertheless, the relatively small proportion of such common heavy minerals as zircon and tourmaline is noteworthy.

Throughout the cores, but especially in the glacial marine deposits, well-rounded sand grains, mostly of quartz though in part of feldspar (usually microcline), are rather common. These range from about 0.1 to 1.0 millimeter in diameter, but those with diameters of about 0.5 millimeter are most plentiful. The rounded grains generally have a more or less distinctly frosted surface common to grains that have been rounded by either wind or water. The proportion of well-rounded

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[75] Murray, J., and Renard, A. F., Deep-sea deposits, *Challenger* Rept., p. 265, 1891.

[76] Moore, H. B., The specific identification of faecal pellets: Marine Biol. Assoc. United Kingdom Jour., vol. 17, No. 2, pp. 359-365, 1931; The faecal pellets of the Anomura: Royal Soc. Edinburgh Proc., vol. 52, pt. 3, pp. 296-308, 1932.

[77] Galliher, E. W., Organic structures in sediments: Jour. Sedimentary Petrology, vol. 2, pp. 46-47, 1932.

sand grains seems to vary only a little either vertically within the cores or laterally from one core to another.

Stetson[78] has recently described a remarkable concentration on the outer edge of the continental shelf off New England of very well-rounded quartz grains that have a mat surface and that range in diameter from a little less than 0.3 millimeter to a little more than 1.0 millimeter. These grains decrease in abundance both seaward and landward but were found in cores taken as far down as the bottom of the continental shelf, at depths exceeding 6,000 meters. They are virtually absent, however, from a wide strip of the continental shelf adjacent to the coast and also from the beach sands and even the dunes on Cape Cod. Stetson interprets these deposits of well-rounded sand as remnants of an area of dunes formed during one or more times in the Pleistocene when the sea had retreated from the continental shelf and when periglacial winds were exceptionally strong.

Although the well-rounded, mat-surfaced sand grains in our cores are similar to those found on the edge of the continental shelf off the New England coast and although they may have come from the places where Stetson found them or from similar sites around the margin of the North Atlantic, they may quite as well have come from other kinds of deposits of rounded sand grains. The means by which these grains were distributed all across the North Atlantic and scattered through the glacial and nonglacial zones of sediment are not evident.

Although these grains may have been frosted, or both rounded and frosted, by wind action, it seems improbable to us that even large storms of exceptional violence could carry quartz grains of such size for great distances. Morover, if the rounded sand in our cores had been formed on the emerged continental shelves during glacial maxima and transported to the sites of the cores by great wind storms, by shore ice, or even by drifting seaweeds, it should now be restricted to the glacial marine zones. The fact that these rounded grains are scattered through both the glacial and nonglacial sediments suggests that they, along with other sand grains of similar size, were derived from reworking glacial marine deposits by mud-feeding animals. If, on the other hand, the rounded and frosted grains were not derived from deposits on the outer edge of the continental shelves but from some place nearer the present coast when the ocean level was higher than in glacial maxima, then there remains the possibility that they (and perhaps also the isolated pebbles found in deposits other than those of the glacial marine zones) were carried out to sea by drifting seaweeds, such as *Fucus*. It would be interesting to see if similar clastic material is common in the sediments of the Sargasso Sea, where seaweeds of this type are plentiful and glacial marine deposits are probably absent.

Little has been done with the clay minerals in the sediment of these cores other than to note that the minute flaky particles of the clay minerals commonly have the optical properties of the beidellite or hydrous mica groups. For one sample of the peculiar mud from the upper part of core 10 (sample W–15) P. G. Nutting of the Geological Survey determined a dehydration curve. This curve is shown in figure 7, with the dehydration curves of typical samples of halloysite, montmorillonite, and a red clay from the Pacific Ocean. The steep uppermost parts of these curves represent adsorbed water, most of which is driven off at relatively low temperatures. The steep portions of the curves between 400° and 600° C. represent loss of water that was held within the crystal lattice of the mineral particles. Inspection of these curves shows that the halloysite type of clay contains much more crystal lattice water than the montmorillonite clay and also that the mud from the North Atlantic core 10 contains a quantity of crystal lattice water more nearly like that of halloysite than montmorillonite. That the bench between 100° and 400° C. on the curve of sample W–15 is lower than the comparable bench on

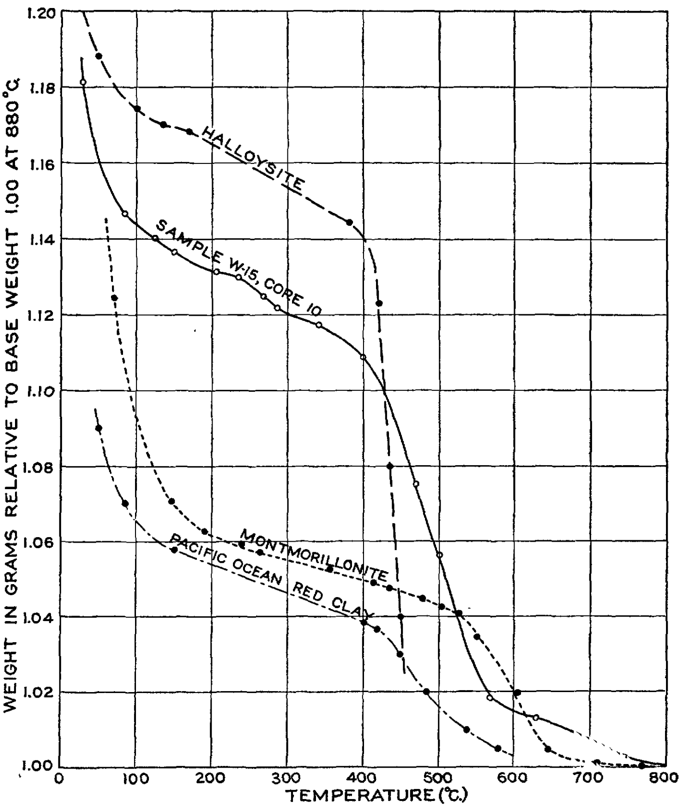

FIGURE 7.—Dehydration curves of basaltic mud from core 10 (sample W–15), a red clay from the Pacific Ocean (lat. 32°27′ N., long. 145°30′ W., depth 5,584 meters), and typical halloysite and montmorillonite from clay deposits in the United States. Data by P. G. Nutting.

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[78] Stetson, H. C., The sediments of the continental shelf off the eastern coast of the United States: Massachusetts Inst. Technology and Woods Hole Oceanogr. Inst., Papers in Physical Oceanography and Meteorology, vol. 5, No. 4, pp. 14–20, 34–36, 1938.

the curve for halloysite, Nutting[79] believes to be due probably to the mixture of the silt- and clay-size particles of basaltic minerals and glass with the clay minerals. The form of the curve, although determined largely by the clay minerals, is probably modified by the dehydration of the basaltic glass. The moderate slope between 400° and 570° C. may also be due to the dehydration of the basaltic glass, but it may be due in part to the minute size of the clay flakes—indeed, some of the clay appears even at high magnification to be gel-like and virtually isotropic. This gel-like material, however, is filled with distinct but very small crystalline flakes. Most of these flakes are so thin that they appear to have a very feeble birefringence, but larger and thicker flakes show the higher birefringence that characterizes a beidellite or hydrous mica type of clay. Adequate discussion of the clay minerals in these sediments must await more study than we were able to give them.

In the Atlantic bottom samples collected by the *Meteor,* montmorillonite, halloysite, and kaolinite were reported.[80] These identifications were based partly on petrographic methods and partly on X-ray analyses by V. Leinz and O. E. Radczewski.

Glauconite is present in most samples, but it is rare and generally forms a very small fraction of 1 percent of the sediment. It occurs as tiny pellets that range in color from bright green to brownish green. Most of this glauconite may have been carried into the ocean along with the other clastic constituents, for similar glauconite grains were observed in some of the sandy limestone and limy sandstone pebbles of the glacial marine deposits. However, glauconite grains are somewhat more common in cores 12 and 13, and at least some of them may have formed in place on the sea floor.

Iron sulphide, the nearly black, probably hydrous form, was found in small amounts throughout cores 3 and 9, but even in these cores it seems to make up only a small fraction of 1 percent of the sediment. It commonly occurs as aggregates of minute spherules lining the borings of small organisms such as worms. Small amounts of this iron sulphide also occur in much of core 12, but not in the uppermost or lowermost parts. It was not found in any of the other cores. A considerable amount of iron oxide coats the clastic grains and foraminiferal tests in cores 8 and 13, giving the sediment as a whole a rusty-buff color. This brown iron oxide was found in parts of some other cores, also, but less plentifully. The distribution of the sulphide and oxides of iron in the cores suggests that in the deeper depressions on the ocean floor, where the finest sediment accumulates in quiet water at a comparatively rapid rate, reducing conditions exist and the iron accumulates as the sulphide, whereas on ridges and mounds where the water circulates more freely and the sediment accumulates more slowly, the iron is converted to the oxide. (See the positions of cores 3, 8, 9, and 13 with respect to the submarine topography in the profile, fig. 1.)

A coating of brownish-black manganese oxide was found on some grains of sediment and is particularly common on the granules of fine-grained basalt, tachylite, and altered basic glass. As is discussed more fully on page 32, the volcanic rock penetrated by core 11 contains a large amount of manganese oxide. The MnO soluble in hot dilute hydrochloric acid was determined in the 31 samples listed in table 3 (p. 19) and ranges from a trace to a maximum of 0.03 precent. In the fusion analyses by Edgington and Byers (see ch. on "Selenium content and chemical analyses") the MnO ranges from 0.04 to 0.28 percent, but in neither series of determinations does the amount of MnO show any discernible relationship to the composition or the stratigraphic units of the sediments in the cores. Correns[81] found that in the *Meteor* samples the MnO varied with the content of $CaCO_3$, but in the Edgington and Byers analyses the MnO shows only a random distribution when plotted against the CO_2.

Metallic beads of extra-terrestrial origin, which Murray[82] called cosmic spherules, are rare in oceanic deposits but somewhat less rare in the red clay. Only one minute cosmic spherule was noted in these North Atlantic core samples and that only incidentally, as no special attempt was made to concentrate these rare grains. It had a brilliant metallic luster and the characteristic circular pit. Correns[83] reported only two cosmic spherules in the *Meteor* cores.

SPECTROSCOPIC TESTS

At our request, George Steiger, of the Geological Survey, made spectrographic tests for 12 of the less common or rare elements whose presence was not tested for in any other way in these investigations. The samples tested are as follows: W–2 from core 3, W–9 from core 5, W–13 from core 8, B–181 from core 10, B–211 from core 12, and B–232 from core 13. The positions of these samples in their respective cores are indicated in plate 3. The specimens were tested by placing a small portion directly in the carbon arc. Each sample gave distinct evidence of barium and rather weak evidence of boron. All samples were tested for antimony, beryllium, bismuth, cadmium, germanium, lead, silver, tin, and zinc, but if present they were in quantities too small to be revealed by a 10-inch spectrograph.

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[79] Oral communication.

[80] Correns, C. W., Die Sedimente des äquatorialen Atlantischen Ozeans; Auswertung der Ergebnisse: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor,* 1925–27, Band 3, Teil 3, Lief. 2, pp. 247–248, 263, 281–285, 1937.

[81] Correns, C. W., op. cit., pp. 223–224.

[82] Murray, John, and Hjort, Johan, The depths of the Ocean, pp. 154–155, London, Macmillan Co., 1912.

[83] Correns, C. W., Die Sedimente des äquatorialen Atlantischen Ozeans; Auswertung der Ergebnisse: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor,* 1925–27, Band 3, Teil 3, Lief. 2, p. 287, 1937.

Goldschmidt and Peters [84] analyzed many substances spectrographically and found that igneous rocks are generally poor in boron but that sea salts contain approximately 0.1 percent and recent marine clays contain on the average about 0.03 percent. They found that globigerina oozes collected by the *Challenger* contained 0.05 percent. The sediments that Mr. Steiger tested for us included both clayey muds and globigerina ooze.

POROSITY OF THE SEDIMENTS

The original porosity of some of these sea-bottom deposits can be calculated approximately from the porosity of the air-dried core and the known amount of shrinkage that has occurred upon drying. Because the texture and composition of the sediment in core 3 was nearly homogeneous, samples from it were selected for porosity determinations. Fine-grained calcareous mud makes up 82 percent of this core. At depths of 60, 185, and 279 centimeters below the top of the core, however, are layers of less calcareous clay, and near the bottom there is one thin layer of rather cleanly sorted silt. Of the seven samples whose porosity was determined, five (W–1, W–2, W–4, W–5, and W–6) came from the calcareous mud and two (W–3 and W–7) came from clay layers. The positions of these samples are shown in plate 3.

The amount that a wet mud shrinks depends not only on the grain size but also upon the size distribution and the relative proportions of granular and flakelike mineral particles. Uniform shrinkage of a core of sediment, therefore, implies uniform physical constitution of the sediment. Core 3 shrank with remarkable uniformity. Exclusive of the clay layers, the thin silt layer, and the uppermost piece of the core (which is discussed separately below), the dried calcareous mud core has an average width of 4.165 centimeters, but the maximum width is only 0.125 centimeter greater than the average, and the minimum width only 0.145 centimeter less than the average. These figures are based on 34 measurements. In all the other cores the range of differential shrinkage is many times greater, except in core 8, which is uniformly coarse-grained. The apparent homogeneity of the calcareous mud in core 3 makes it seem well-suited for investigation of the question of whether or not the pore space decreases progressively with depth of burial even in the uppermost few meters.

Because the sediment may have been compacted somewhat as the core barrel was driven into it an attempt was made to evaluate this factor before computing the original porosity. The experiments recently made by Wrath [85] in cooperation with H. C. Stetson at the Woods Hole Oceanographic Institution suggest that the sediment in our cores may be considerably compacted, especially in the upper part, as a result of friction along the walls of the core barrel. Wrath coated the outer surface of the coring tube with shellac just before taking each sample and so was able to measure the penetration of the tube. In soft mud the average length of the recovered cores was a little less than 50 percent of the depth of penetration, in sandy silt about 50 percent, and in sand nearly 68 percent. The coring device was a simple weighted tube.

Similar results were obtained by the *Meteor* expedition with a comparable type of core sampler, but after they adopted a core bit whose cutting edge had an inside diameter a little smaller than the core tube, the cores recovered were almost exactly equal in length to the distance penetrated by the coring device.[86]

In the Piggot coring device used to take these North Atlantic cores, the inside diameter of the core bit is a little smaller than the inside diameter of the barrel of the sample tube.[87] Judged by the experience reported by the *Meteor* expedition, this feature should have been conducive to the recovery of full-length cores. The greater diameter of the sample tube of the Piggot sampler (4.9 centimeters as compared with 2.2 centimeters in the *Meteor* sample tube) should also have reduced the amount of compaction. The core bit of the Piggot sampler entered the sediments at high velocity and this makes it seem unlikely that much water could have been squeezed from so fine grained a mud as that in core 3. Then too, the mud core at this station is 2.92 meters (9 feet 7 inches) long, which is very nearly the full length of the core barrel, 3.05 meters (10 feet). The device may have penetrated 32 centimeters more than the full length of the core barrel—that is up to the water-exit ports—but it seems improbable that it penetrated more deeply than that because no mud was found in the water-exit ports, where it surely would have lodged if these ports had been submerged in mud as they were at station 10. (See p. 6.) The sediment in core 3, therefore, may have been compacted by the operation of coring as much as 14 percent but probably not more than that. If the mud was compacted to this degree, the computed original porosities may be a few percent too low.

The original porosity of the mud just after the core was taken can be calculated from the volume and porosity of the dried mud and the volume of the core barrel. P. G. Nutting of the Geological Survey determined for us the mean grain and lump densities and the porosities of seven dried samples from core 3 and one sample from core 10. These data, together with the calculated original porosities, are given in

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[84] Goldschmidt, V. M., and Peters, Cl., Zur Geochemie des Bors: Gesell. Wiss. Göttingen, Math.-phys. Kl. Nachr., No. 31, pp. 535–544, 1932.

[85] Wrath, W. F., Contamination and compaction in core sampling: Science, vol. 84, pp. 537–538, 1936.

[86] Pratje, Otto, Gewinnung und Bearbeitung der Bodenproben: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925–27, Band 3, Teil 2, Lief. 1, p. 26, 1935.

[87] Piggot, C. S., oral communication.

table 5. The densities and percent voids refer to material dried at 160° C. for 18 hours. The procedure used in calculating the porosity is outlined here briefly.

TABLE 5.—*Grain and lump density and porosity of dried mud from cores 3 and 10, and calculated original porosity*

[Data by P. G. Nutting, except calculated original porosity]

	Core 3							Core 10
	W–1	W–2	W–4	W–5	W–6	W–3	W–7	W–15
Mean grain density	2.51	2.57	2.51	2.56	2.61	2.59	2.54	2.54
Mean lump density	1.23	1.19	1.21	1.23	1.34	1.38	1.47	1.14
Percent voids	51.83	53.76	51.85	51.82	48.64	46.77	42.17	54.97
Calculated original porosity	76.4	73.8	70.2	71.6	65.8	76.6	75.6	81.0

The volume of each dried core segment whose original porosity was to be calculated was determined as follows: The area of the irregular cross section of half of the dried core (A_2) was determined by comparing the weight of its replica traced on paper with the weight of a paper replica of half the cross section of the inside of the brass core barrel, the area of which (A_1) was calculated. The volume of 1 centimeter length of the dried core (V_2) is then A_2 cubic centimeters. The average longitudinal shrinkage per centimeter (S_a) was estimated from the average width of the transverse cracks that divide the core into segments (in the uppermost part of the core the longitudinal shrinkage was greater than in the rest of the core (see pl. 2). The original undried volume (V_1) of the selected dry sample of 1 centimeter in length was therefore $(1 \text{ cm.} + S_a)\ A_1$.

The difference between the original volume and the volume of the dried segment is the volume of water lost in shrinking down to the size of the dried segment. As the water occupied the pores in the wet mud, the volume of water lost in that shrinkage equals the volume of pore space lost. Then the total volume of pore space or voids in the original wet mud was the volume of the water lost in drying down to the size of the dried segment plus the pore space (P) of the dried segment. The percentage of pores, or the porosity, of the original wet mud therefore was $\frac{V_1 - V_2 + P}{V_1}$.

The calculated original porosities for samples W–3, W–4, and W–7 are somewhat less reliable than the others because the area of the cross section of the dried samples was calculated from the diameter of the dried segment and an assumed semicircular outline rather than a traced outline.

In figure 8 the calculated original porosities of the samples from core 3 (W–1 to W–7) are plotted against the distance below the top of the core. The decrease in porosity with depth for the calcareous mud is fairly regular, but the calculated porosities for samples W–3 and W–7 suggest that the clay is compacted less rapidly than the calcareous mud. The amount of total carbonate shown in plate 3 for sample W–3 is greater than that for sample W–7, which suggests that these two clays are not strictly comparable. However, two samples are not enough to be significant and, as noted above, the calculated original porosities for samples W–3, W–4, and W–7 are somewhat less reliable than the others.

H. B. Moore[88] in his studies of the Clyde Sea muds found that the water content by volume (=porosity) of the fresh muds within 2.5 centimeters of the mud surface at 17 stations ranged from 50.7 to 84.6 percent and averaged 77.1 percent. At a depth of 25 to 27.5 centimeters the muds at 12 of these same stations (figures for the other 5 lacking) had an average water content of 74.3 percent. These figures are comparable with the porosities calculated for the sediment in cores 3 and 10 (see table 5). Moore[89] found also that the water content of the Clyde Sea muds decreased much more rapidly in the top 5 or 10 centimeters of the mud columns than in the lower parts.

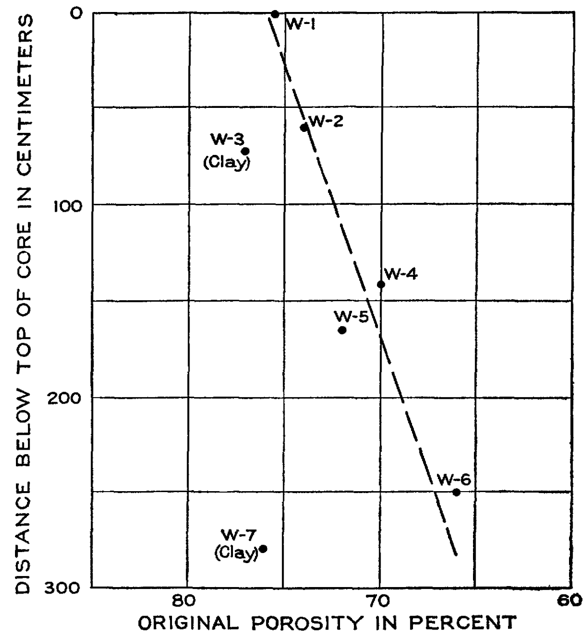

FIGURE 8.—Relation of calculated original porosity of blue mud in core 3 to depth below top of core.

The marked upward narrowing of the dried mud at the top of the left half of core 3 (see pl. 2) suggests that the sediment at the top of this core was considerably more watery than that lower down. Although the calculated porosities given in figure 8 show that the top sample has a greater porosity than in the others, it is not so disproportionately large as the marked shrinkage of the sample would lead one to expect. The sediment at the top of this core, however, apparently was modified somewhat after the core was taken. The evidence for this modification is shown in figure 9, which shows that the right-half of the dried core at

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[88] Moore, H. B., The muds of the Clyde Sea area, part 3: Marine Biol. Assoc. United Kingdom Jour., vol. 17, new ser., pp. 331–332, 1931.

[89] Idem, pp. 333–335.

the top is as wide as the left-half at the first transverse shrinkage crack, 13 centimeters below the top. At about 6 centimeters down from the top the two are about equal. For these two halves of a core of originally homogeneous wet mud to shrink so differently upon drying to the shrinkage limit implies that the average grain size of the part on the right side is considerably coarser than that on the left side. The inference seems to be that this core lay with the right half down for a considerable time after the core was taken and that during that time the coarser and heavier particles settled to that side leaving chiefly the finer clayey particles in the upper (now left) half of the core. This inference is strengthened by the fact that this core barrel came up from the sea floor slightly bent, and the bend is such that when the core barrel was placed on deck it must have lain so that what is now the bottom of either the left or right half of the core barrel was down. (See pl. 2.) The average width of the two halves of the dried core in this uppermost 13 centimeters is 3.44 centimeters, as compared with 4.17 centimeters for the average width of this kind of material in the rest of the core, which also suggests that this upper part was more watery.

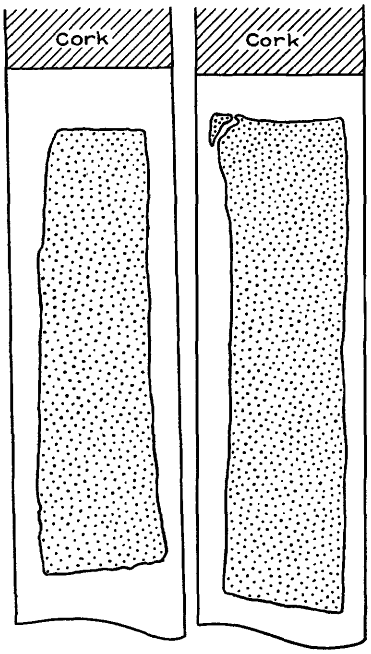

FIGURE 9.—Sketch of the two halves of the top part of core 3 showing differential shrinkage.

MECHANICAL ANALYSES

The preparation for complete mechanical analysis of fine-grained sediments is time-consuming, particularly of those which are not in their original wet state. Only four samples were analyzed, therefore, but these samples were selected so as to represent four types of sediment found in these cores. They include a blue mud (sample W–2) from core 3; a gravelly foraminiferal deposit (sample W–13) from the top of the mid-Atlantic ridge, core 8; a fine-grained globigerina ooze (sample W–17), taken from the anchor flukes at the site of core 10; and a distinctive clay (sample W–18) like that in the upper part of core 10 but taken from the water-exit ports of the coring device when core 10 was hauled inboard. The coring device buried itself deeply at the site of core 10, and an unknown amount of mud passed upward through the water-exit ports and was lost. Samples W–17 and W–18 had been kept moist but the other two were thoroughly air-dried. Unfortunately no complete mechanical analysis of a sample of a glacial marine deposit was made, but the size distribution of sample W–13 is somewhat similar except that this sample contains an abundance of Foraminifera, whereas the glacial marine deposits probably contain a greater quantity of silt-size clastic material.

All the samples contained either sea water or salts left from the evaporation of sea water, and they were therefore first leached in large volumes of distilled water on a steam bath. The sediment was stirred frequently, and after long settling the clear water above the sediment was siphoned off. This was repeated until the leach water showed no reaction for chloride with acidulated silver nitrate. The leaching required a month or more. Next, enough dilute sodium-oxalate solution was added to each sample to bring the whole suspension to a concentration of approximately N/100, following Krumbein's [90] dispersing procedure. The samples were then stirred until the dispersion seemed to be at a maximum. Thereafter they were analyzed by the pipette method according to the technique outlined by Krumbein.[91] After the pipette samples had been taken, the remainder of each sample was wet-screened to obtain the size distribution of the constituents larger than would pass a 200-mesh sieve.

The results obtained by Grippenberg [92] indicated that better dispersion of the finest particles probably would have been obtained if the sea salts had been removed by electrodialysis.[93] Indeed, better dispersion probably would have been obtained had the suspensions been analyzed immediately after leaching and before the sodium oxalate was added. This was shown by two other samples, which were leached and finally brought into a high state of dispersion but which quickly coagulated when the sodium oxalate solution was added. These samples were discarded. More experimentation should have been carried out to find the most effective means of dispersing these carbonate-rich sediments, but the time available precluded it. In fact, these complete

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[90] Krumbein, W. C., The dispersion of fine-grained sediments for mechanical analysis: Jour. Sedimentary Petrology, vol. 3, pp. 126–127, 1933.

[91] Krumbein, W. C., The mechanical analysis of fine-grained sediments: Jour. Sedimentary Petrology, vol. 2, pp. 144–146, 1932.

[92] Grippenberg, Stina, Sediments of the North Baltic and adjoining seas: Fennia, vol. 60, No. 3, pp. 60–70, 1934.

[93] According to C. S. Ross (personal communication), electrodialysis definitely breaks down some clay minerals and is, therefore, not satisfactory for dispersing fine-grained sediments.

mechanical analyses suffered throughout by reason of the press of other work that had to be done simultaneously.

Many minute crystals of calcium oxalate were found in most of the pipette samples, although none were ever found in the sediment [94] not treated with sodium oxalate. After the globigerina ooze (sample W–17) had been mechanically analyzed, the fine fraction that had passed through a 200-mesh sieve was analyzed for calcium oxalate by K. J. Murata of the Geological Survey chemical laboratory. He found that 5 percent by weight of this dried material consisted of calcium oxalate. Almost precisely 50 percent of the oxalate that had been introduced as sodium oxalate had been precipitated as calcium oxalate. As these calcium oxalate crystals are only a few microns across, they are concentrated in the fraction of sediment made up of the finest particles, which is correspondingly 5 percent heavier than in the original sediment.

The sample of blue mud (W–2) from core 3 was not properly dispersed, and of the sieved fraction made up of grains that range in size from 0.074 to 0.15 millimeter, 45 percent consists of clay aggregates. (See pl. 6.) The diatoms in this sample were coated with a thin film of clay, and clay flocs probably account for some other irregularities. (See fig. 10.)

In presenting the results of these mechanical analyses two methods have been used—pyramidal diagrams (pl. 6) and cumulative curves (fig. 10). In both, the size of particles less than 0.074 millimeter is calculated by Stokes law from the settling velocity. The sizes shown, therefore, are the sizes of ideal spheres that have the same mean density and the same settling velocity as those observed; they do not represent the true particle size, but they probably approximate it closely enough for this purpose. In calculating the sizes allowance was made for the mean grain density of the particles and the density and viscosity of the liquid at the time each pipette sample was taken. The mean grain densities were determined by P. G. Nutting of the Geological Survey.

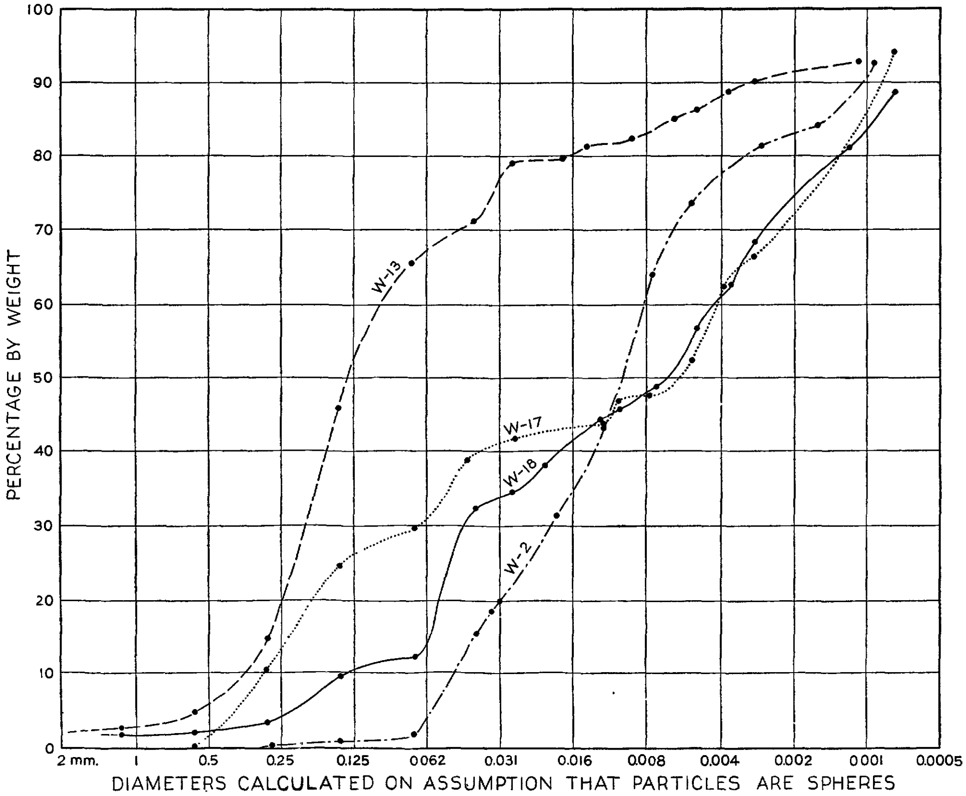

FIGURE 10.—*Cumulative curves showing the size distribution of the organisms and mineral particles in samples representing sediments of four types.* W–2, Blue mud (core 3); W–13, gravelly foraminiferal marl (core 8); W–17, globigerina ooze, and W–18, clay (site of core 10).

In the pyramidal diagrams given in plate 6 the abcissae represent percentages by weight of each size group and the ordinates represent a logarithmic scale of the size ranges. Descriptive notes, with some estimates of proportions, have been added for each block or group of blocks in order to show, at least in a rough way, how the various constituents are distributed with respect to size. A few blocks will serve to illustrate how the characteristic features of certain sediments are revealed by these diagrams. The graph for sample W–13 from the top of the mid-Atlantic ridge shows that there is an abundance of sand concentrated in the size range 0.15 to 0.30 millimeter and that Foraminifera are also abundant but that their size range extends

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[94] Crystals of both calcium oxalate and citrate were found in the bottom deposits of the Weddell Sea by F. A. Bannister (Report on some crystalline components of the Weddell Sea deposits: *Discovery* Repts., vol. 13, pp. 60–69, Cambridge, 1936).

from 0.074 to 0.6 millimeter. The graph for sample W–18 shows a highly anomalous feature for a marine mud. Concentrated in the coarse silt range (between 0.04 and 0.74 millimeter) is an abundance of magnetite, augite, labradorite, and basaltic glass. This type of mud is discussed more fully on pages 32–34, where a complete chemical analysis of a similar sample (W–15) is also given. (See also dehydration curve, fig. 6.) Sample 18 also has a considerable number of coarse sand grains and pebbles, the presence of which seems explicable only on the assumption that they were dropped from an erratic iceberg that went far beyond the normal range of drift ice. (See pl. 1.) Consequently this sample is less satisfactory than one taken from the core itself, but this particular sample was chosen because it had been kept wet and was therefore easier to disperse. The mud that makes up the top of core 10, and is in all other respects identical with sample W–18, contains no particles larger than silt size. (See the gross mechanical composition as plotted in pl. 3, samples B–179 and B–180.) In the graph for sample W–17 (the globigerina ooze) the height of the blocks spanning the size range 0.001 to 0.003 millimeter should be reduced by about 5 percent because, as pointed out on page 29, they contain about 5 percent by weight of calcium oxalate, which is not a normal constituent of the sediment. Probably the other pyramidal diagrams should have a similar correction.

The cumulative curves of figure 10 also show that in sample W–13 a much larger percentage of the constituents are relatively coarse-grained, whereas in sample W–2 the dominant constituents are concentrated in the finer silt and clay sizes. These curves are markedly irregular, and although some of the irregularities are due to faulty dispersion of the sediment and to errors in size of the pipette samples, others are clearly due to concentrations of various constituents within fairly narrow ranges of size. For example, the high hump between sizes 0.031 and 0.062 millimeter on the curve for sample W–18 reflects the concentration of coarse silt-size grains of magnetite, augite, labradorite, and basaltic glass, already noted. So also the two humps on the curve for sample W–17, one at about 0.150 millimeter and the other between 0.031 and 0.062 millimeter evidently reflect the abundance of foraminiferal shells in the two size groups.

BASALTIC PYROCLASTICS AND THEIR ALTERATION

As pointed out earlier in the report, pumiceous fragments and smaller shards of basaltic volcanic glass are scattered throughout all the cores, but are somewhat more common east of the mid-Atlantic ridge than west of it. Rarely do these fragments make up as much as 1 percent of a sample. Notable exceptions to the general distribution of the basaltic glass are core 3, which contains very few pieces, and the unusual basaltic mud in core 10, which contains an abundance of basaltic glass. Although some samples contain more than others, this basaltic volcanic glass shows no conspicuous concentration either in distinct beds or in zones, as does the alkalic volcanic glass.

The basaltic glass generally appears to be homogeneous, is clear in thin slivers, and in transmitted light has a brown or greenish-brown color. In reflected light it is almost black. The index of refraction of the unaltered glass is between 1.59 and 1.60, and most of it is nearer 1.60. Basaltic glass of this type has been named sideromelane by Von Waltershausen.[95] According to Peacock and Fuller's terminology,[96] the less clear and less homogeneous basaltic glass containing many microlites would be termed tachylite. Tachylite is distinctly less common in these cores, but gradations from this type to granules of fine-grained basalt consisting of labradorite, magnetite, augite, and in some, olivine were found. Some of the clear basaltic glass contains minute phenocrysts of labradorite and augite. Larger pieces of the basaltic glass, a few of which are as much as a centimeter across, are vesicular and about as "frothy" as a pumice formed from more alkalic glass. Like the basaltic glass pumice noted by Murray,[97] it tends to have cavities that are more nearly spherical than those in most alkalic glass, which are generally elongate.

In many samples the basaltic glass has a thin surface film of an alteration product that may be classed under the broad term palagonite. (See pl. 7,*C*.) This alteration product shows a considerable variation in properties, and although two distinct and common types were distinguished in the material studied, both are classed here as palagonite. One of these is nearly colorless and has a refractive index ranging from 1.49 to 1.52. The other, probably richer in iron, is yellow to amber-colored and its refractive index is much higher, ranging from 1.57 to 1.59. In the alteration film on some of the basaltic glass these two types of palagonite alternate with an agatelike interbanding, and in some of these alteration films not only are the two types of palagonite interbanded, but with them are equally thin laminae consisting of radiate needles of a birefringent mineral, apparently one of the clay minerals or possibly a chlorite mineral.

In the samples from core 9 the pieces of basaltic glass are generally fresh, with only a few showing very thin alteration films of the colorless palagonite that has the low index of refraction. The pieces of basaltic glass from cores 4, 5, 6, and 7 generally have alteration films. Some of these alteration films include both types of palagonite, and a few, on the more deeply altered pieces, include also laminae of the claylike mineral. But in cores 8 and 13 the pieces of basaltic

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[95] Von Waltershausen, Sartorius, Über die vulkanische Gesteine in Sicilien und Island und ihre submarine Umbildung, pp. 202–204, Göttingen, 1853.

[96] Peacock, M. A., and Fuller, R. E., Chlorophaeite, sideromelane, and palagonite from the Columbia River Plateau: Am. Mineralogist, vol. 13, pp. 360–383, 1928.

[97] Murray, J., and Renard, A. F., Deep-sea deposits, *Challenger* Rept., p. 296, 1891.

glass are most conspicuously altered. Indeed, most of the grains and pieces are completely altered or contain only a small central nucleus of the basaltic glass. The alteration products in these more completely altered fragments are largely palagonite and a clay mineral resembling beidellite, but they commonly include minute prismatic crystals of a zeolite which, according to H. E. Merwin[98] of the Geophysical Laboratory, is probably phillipsite. (See pl. 7, A.) Lozenge-shaped crystals of an unidentified mineral were also found in the alteration product. Some of these minute crystals were isolated and submitted to Charles Milton, of the Geological Survey's chemical laboratory, who reported the following properties:

The refractive indices range from 1.56 to 1.57, optically positive, strong dispersion both of bisectrices and optic axes ($\rho > \nu$). The crystals are flat, tabular parallel to 010 and have good development of 100, 201, and 001. The optic angle is medium-sized, and an axis emerges not far from the normal to 010. The crystals have excellent basal cleavage, indicating 001. The crushed fragments almost invariably show albite twinning, the fragments resting on the 001 cleavage; Carlsbad twinning was also observed. Good microchemical tests for calcium and aluminum were obtained. The crystals are insoluble in HCl and float in bromoform (density 2.80).

Were it not that these crystals are apparently secondary, that they seem to be very much more fragile than feldspars, and that the optic angle is only moderate, they would unhesitatingly be called labradorite.

The degree of alteration of the basaltic glass in cores 8 and 13 is obviously greater than in core 9. This appears to be significant, as cores 8 and 9 are rather close together, and the difference in alteration is consistent throughout the length of these two cores. The sediment of core 9 evidently accumulated more rapidly and under less oxidizing conditions than that of cores 8 and 13 (see pp. 14–15), which suggests that perhaps the dominant factors in the alteration of basaltic glass on the ocean floor are the amount of oxygen in the water and the length of time the particles are exposed to the oxidizing water. The relation between alteration and oxidation is suggested by the composition of the basaltic glass and of the palagonitic alteration product given by Murray,[99] which show that most of the iron was changed from the ferrous to ferric form in the alteration from basaltic glass to palagonite. The same sort of thing is shown by Correns' analyses[1] of the light-brown glass rind of a basalt fragment dredged from the mid-Atlantic ridge. The iron determinations, in percent, from the analyses of Murray and Renard and of Correns are given in table 6.

TABLE 6.—*Relative oxidation of iron in fresh basaltic glass and in basaltic glass altered on the sea floor*

	Challenger analyses		*Meteor* analyses	
	Fresh glass (percent)	Altered rim (percent)	Fresh glass (percent)	Altered rim (percent)
Fe_2O_3	1.73	14.57	2.30	16.56
FeO	10.92	----------	7.55	.93

The oxygen in the bottom waters is derived from the cold polar surface water, which sinks in the higher latitudes and flows generally equatorward below the warmer, and therefore lighter, surface water of the middle latitudes. The amount of dissolved oxygen that is available for oxidizing particles on the ocean floor is therefore a function of the distance from the polar seas, the speed of the bottom current, and of the environmental conditions of the abyssal organisms that consume oxygen. Correns[2] has pointed out that in the deep parts of the ocean the constriction in the cross section of large, slow-moving currents where they flow across ridges on the ocean floor increases their velocity enough to winnow out the finest particles and thereby increase the proportion of coarse grain-size in the sediments accumulating on the ridges. Thus, in such sites where the bottom water moves relatively fast, oxygen-rich water is continuously in contact with the sediment, and the carbon dioxide formed by oxidation of organic matter in the sediment is continually swept away. But where the bottom water moves more slowly and in places sheltered by ridges, the oxygen content of the water close to the bottom decreases, and its carbon dioxide content increases. Wattenberg's[3] abundant data on the relation between oxygen content and depth in the equatorial Atlantic show clearly this oxygen diminution within a few hundred meters of the bottom, particularly in the western Atlantic.

On the other hand, not all the alteration of the basaltic glass occurred while the glass was exposed on the sea floor. Some of the alteration was a diagenetic change that occurred after the glass was buried in the sediment, as is indicated by a piece of vesicular basaltic glass from the lower part of core 5. This piece of basaltic glass scoria, which was nearly a centimeter in diameter, was embedded in a foraminiferal marl. The glass had a thin surficial film of the colorless palagonitic material of low refractive index, and a zone of the sediment surrounding the glass was stained buff with iron oxide. This stain faded out rather abruptly in all directions away from the nucleus of basaltic scoria.

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[98] Oral communication.

[99] Murray, John, and Renard, A. F., Deep-sea deposits, *Challenger* Rept., p. 307, 1891.

[1] Correns, C. W., Die Sedimente des äquatorialen Atlantischen Ozeans: Auswertung der Ergebnisse: Wiss. Ergeb. Duetschen Atlantischen Exped. *Meteor*, 1925–27, Band, 3, Teil 3, Lief. 2, pp. 288–289, 1937.

[2] Correns, C. W., Anzeichen von Beziehungen zwischen Strömungen und Bildung küstenferner (eupelagischer) Sedimente: Neues Jahrb., Beilage-Band 57, Abt. A., pp. 1109–1117, 1928.

[3] Wattenberg, H., Die deutsche atlantische Exped. *Meteor;* Bericht über die chemischen Arbeiten: Gesell. Erdkunde Berlin Zeitschr., pp. 309–314, 1927.

The depth of alteration and the variety of alteration products derived from the basaltic glass contrast sharply with the freshness of the alkalic volcanic glass in the upper and lower ash zones of these cores.

VOLCANIC ROCK IN CORE 11

Core 11 represents only 34 centimeters of the sea floor because of the hard rock encountered at this depth. The hardest rock at the base of this core is an olivine basalt, according to Dr. H. E. Merwin,[4] of the Geophysical Laboratory, who examined a thin section of it. The upper 15 centimeters of the core is a globigerina ooze, which rests on and within irregular cavities of the upper surface of a clayey rock illustrated in plate 7, *B*. This clayey rock grades downward through closely similar rock that is strongly impregnated with manganese oxide and that contains nodular lumps of much altered basalt. Below the manganiferous part the clayey rock grades into the hard, more nearly fresh basalt at the base. The lower part of this core is described in some detail because it suggests that the material represents an altered rock which may be a submarine lava flow, though the evidence is inadequate and additional cores in that area are necessary to test this possibility.

The material immediately beneath the globigerina ooze (see pl. 7, *B*) is composed largely of a clay mineral resembling beidellite. Within this clay are scattered grains of more or less rounded sand and foraminiferal shells. The Foraminifera include globigerinas and other calcareous types like those that occur in the overlying ooze, but their original calcium carbonate tests have been replaced by a zeolite resembling phillipsite. (See pl. 7, *C*.) Some of the lozenge-shaped crystals of the unidentified mineral described on page 31 are also present in the clay matrix. In places this clay matrix contains brown films that outline "ghost" areas of shapes resembling shards and pumiceous fragments. The similarity of this clayey rock in form and mineral composition to the small altered fragments of basaltic glass in cores 8 and 13 suggests that this clayey part of the rock is altered basaltic glass. The gradation downward from clay that has a vesicular upper surface (see pl. 7, *B*) through manganese-stained clay that contains lumps of deeply altered basalt into comparatively fresh olivine basalt at the base suggest the possibility of a submarine lava flow which, in moving over the bottom, incorporated some of the sand, Foraminifera, and other bottom sediments in its more brecciated and apparently glassy surface part. The alteration of this glassy surface part is obviously much more complete and deep than the alteration rims of the small fragments of basic volcanic rock scattered through the sediment of the other cores. The greater depth of alteration of this rock may have been due to the heat supplied by a large mass of lava. This heat may also have accounted for the replacement of the calcium carbonate of the foraminiferal tests by the zeolite—a reaction not found elsewhere in these sediments. Much of the manganese in the lower part of this core is in the form of small, ellipsoidal pellets separated more or less distinctly from one another by thin lenses or irregular layers of clay-like material. This is very closely similar to the manganese-impregnated zone around the basalt pieces dredged by the *Discovery* from the Carlsberg Ridge.[5] The presence of hard and nearly unaltered basalt at the base of this core would not necessarily indicate that all the brecciated and altered zone of the supposed flow rock had been penetrated, for this fresh rock may be only a larger and therefore not completely altered fragment similar to the smaller, more deeply altered, but nevertheless crystalline lumps of basalt in the clay matrix above.

If this rock in core 11 represents an unusually large boulder of basaltic rock of ice-rafted origin, it must have been altered after it reached the sea floor, because the soft, clayey zone of altered material could hardly have been preserved during the plucking and transportation by ice. If it is a transported boulder whose alteration occurred on the sea floor, it is peculiar that the alteration should be so much more extensive than is found on the small pieces of basaltic glass and other basic rock scattered through the cores; furthermore, such a hypothesis would leave quite unexplained the conversion of the tests of pelagic Foraminifera to the zeolite. The possibility that the rock represents a volcanic island which subsided so recently that only 15 centimeters of globigerina ooze has accumulated on it seems rather improbable and also leaves unexplained the type of alteration and the replacement of the tests of the pelagic Foraminifera.

The globigerina ooze overlying the altered volcanic rock in core 11 does not contain shards of alkalic volcanic glass of the upper ash zone, as do the tops of all the other cores. This absence of shards may not be of much significance, for in the other cores the shards decrease in abundance upward and are rather sparse at the top. On the other hand, the absence of shards from the upper part of core 11 might mean that a submarine lava flow had been extruded on the sea floor above the upper ash zone, which it covered and partly incorporated. According to this hypothesis, no ash-bearing sediment is accessible so that it can be reworked into the uppermost layer of globigerina ooze.

BASALTIC MUD IN CORE 10

The sediment in core 10 differs from all the others by reason of a large proportion of highly distinctive clayey mud. As noted on page 6, the coring device buried itself in the soft mud at this station. From the glo-

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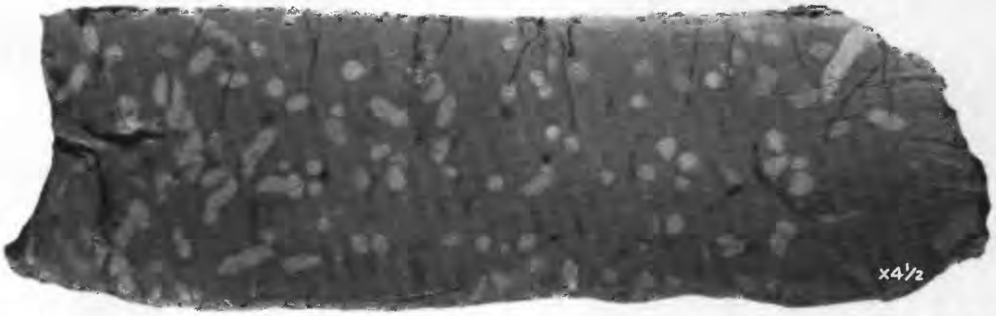
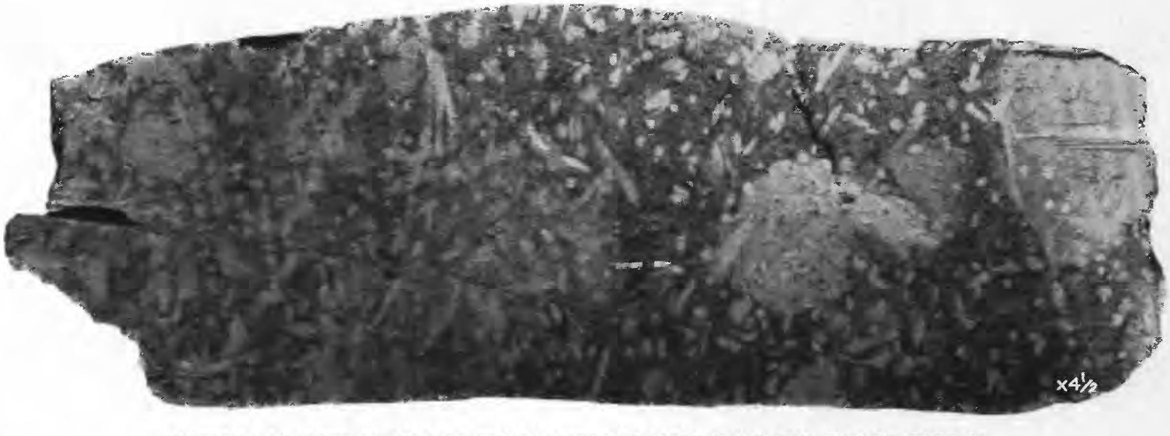
[4] Oral communication.

[5] Wiseman, J. D. H., Basalts from the Carlsberg Ridge, Indian Ocean: British Mus. (Nat. Hist.), John Murray Exped., Sci. Rept., vol. 3, No. 1, pp. 4-5, fig. 2-A, 1937.

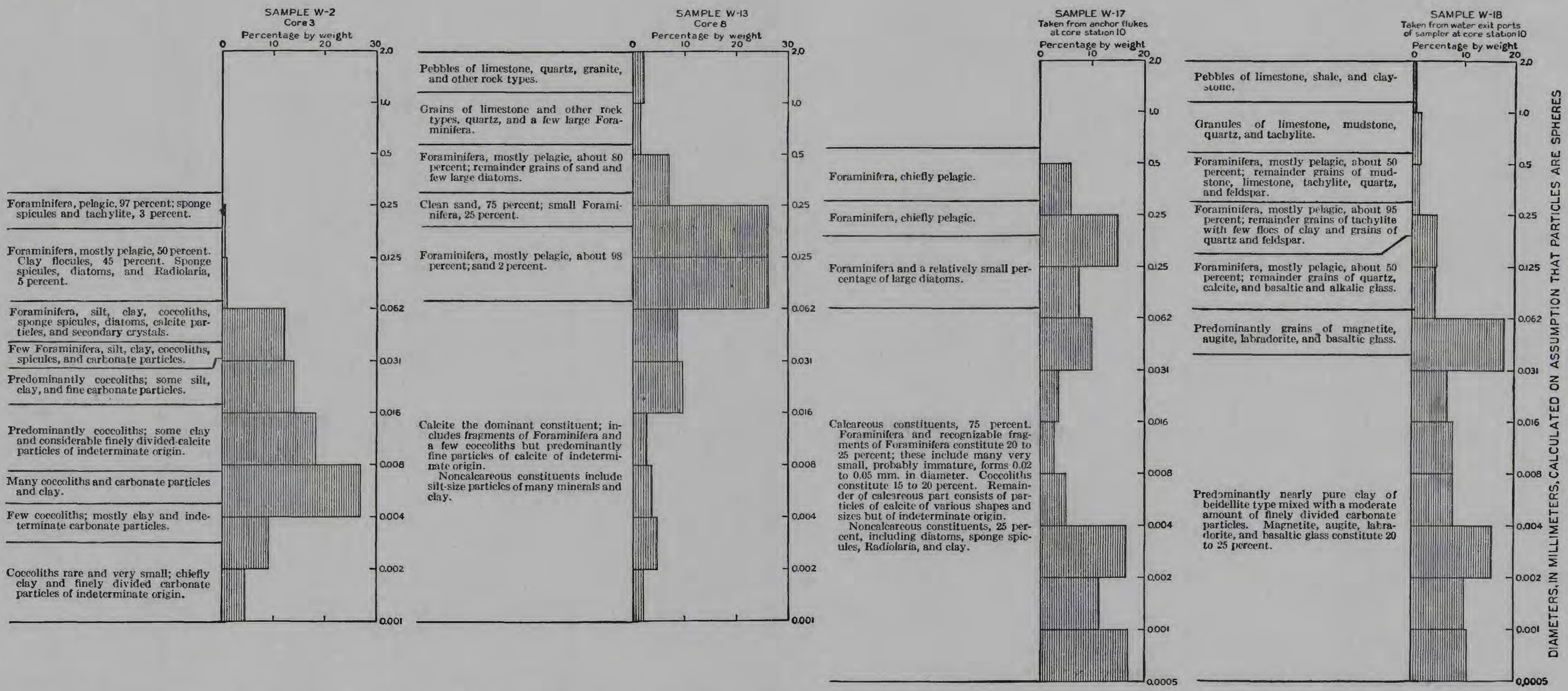


A. FECAL PELLETS OR FILLED BORINGS IN THE BASALTIC MUD AT THE TOP OF CORE 10. SAMPLE B-179.



B. FECAL PELLETS IN MUDDY FORAMINIFERAL MARL NEAR THE TOP OF CORE 12.

Some of the long tubular bodies may perhaps be filled borings. The large, irregular, roundish pellets or lumps are rather common in the glacial marine deposits, but their origin is *unknown*. *Sample* B-207.



Foraminifera, pelagic, 97 percent; sponge spicules and tachylite, 3 percent.

Foraminifera, mostly pelagic, 50 percent. Clay flocules, 45 percent. Sponge spicules, diatoms, and Radiolaria, 5 percent.

Foraminifera, silt, clay, coccoliths, sponge spicules, diatoms, calcite particles, and secondary crystals.

Few Foraminifera, silt, clay, coccoliths, spicules, and carbonate particles.

Predominantly coccoliths; some silt, clay, and fine carbonate particles.

Predominantly coccoliths; some clay and considerable finely divided calcite particles of indeterminate origin.

Many coccoliths and carbonate particles and clay.

Few coccoliths; mostly clay and indeterminate carbonate particles.

Coccoliths rare and very small; chiefly clay and finely divided carbonate particles of indeterminate origin.

Pebbles of limestone, quartz, granite, and other rock types.

Grains of limestone and other rock types, quartz, and a few large Foraminifera.

Foraminifera, mostly pelagic, about 80 percent; remainder grains of sand and few large diatoms.

Clean sand, 75 percent; small Foraminifera, 25 percent.

Foraminifera, mostly pelagic, about 98 percent; sand 2 percent.

Calcite the dominant constituent; includes fragments of Foraminifera and a few coccoliths but predominantly fine particles of calcite of indeterminate origin.

Noncalcareous constituents include silt-size particles of many minerals and clay.

Foraminifera, chiefly pelagic.

Foraminifera, chiefly pelagic.

Foraminifera and a relatively small percentage of large diatoms.

Calcareous constituents, 75 percent. Foraminifera and recognizable fragments of Foraminifera constitute 20 to 25 percent; these include many very small, probably immature, forms 0.02 to 0.05 mm. in diameter. Coccoliths constitute 15 to 20 percent. Remainder of calcareous part consists of particles of calcite of various shapes and sizes but of indeterminate origin.

Noncalcareous constituents, 25 percent, including diatoms, sponge spicules, Radiolaria, and clay.

Pebbles of limestone, shale, and claystone.

Granules of limestone, mudstone, quartz, and tachylite.

Foraminifera, mostly pelagic, about 50 percent; remainder grains of mudstone, limestone, tachylite, quartz, and feldspar.

Foraminifera, mostly pelagic, about 95 percent; remainder grains of tachylite with few flocs of clay and grains of quartz and feldspar.

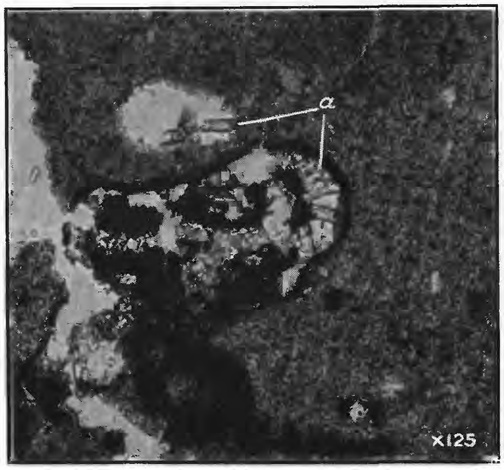
Foraminifera, mostly pelagic, about 50 percent; remainder grains of quartz, calcite, and basaltic and alkalic glass.

Predominantly grains of magnetite, augite, labradorite, and basaltic glass.

Predominantly nearly pure clay of beidellite type mixed with a moderate amount of finely divided carbonate particles. Magnetite, augite, labradorite, and basaltic glass constitute 20 to 25 percent.

STANDARD PYRAMID DIAGRAM SHOWING THE SIZE DISTRIBUTION, KINDS OF ORGANISMS, AND MINERAL PARTICLES IN SEDIMENTS OF FOUR TYPES FROM THE NORTH ATLANTIC.

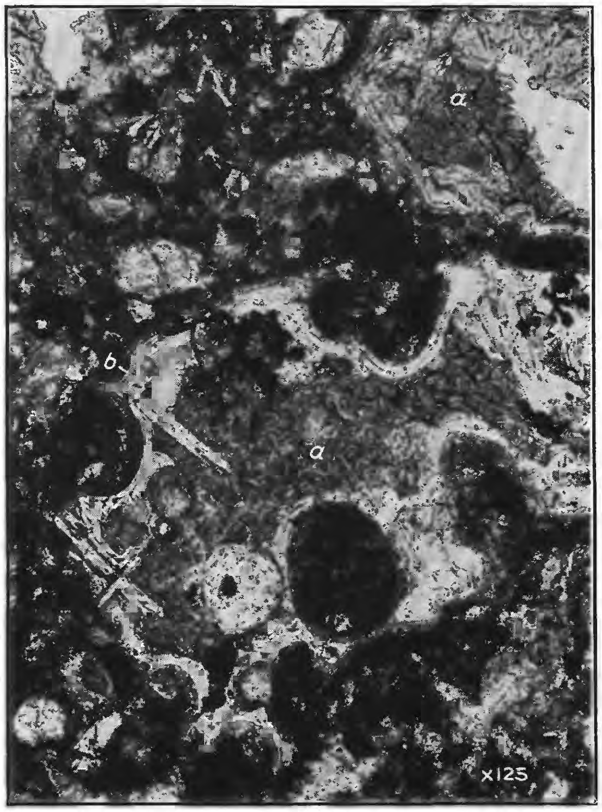
Sample W-2, blue mud from core 3; sample W-13, a gravelly foraminiferal marl from core 8, top of mid-Atlantic ridge; sample W-17, a fine-grained globigerina ooze taken from anchor flukes at site of core 10; sample W-18, a distinctive clay like that in the upper part of core 10, taken from water-exit ports of coring device when core 10 was hauled aboard.



A. ZEOLITE CRYSTALS (*a*) PROBABLY PHILLIPSITE, IN THIN SECTION OF THE CLAYEY ROCK SHOWN IN 7, *B*.

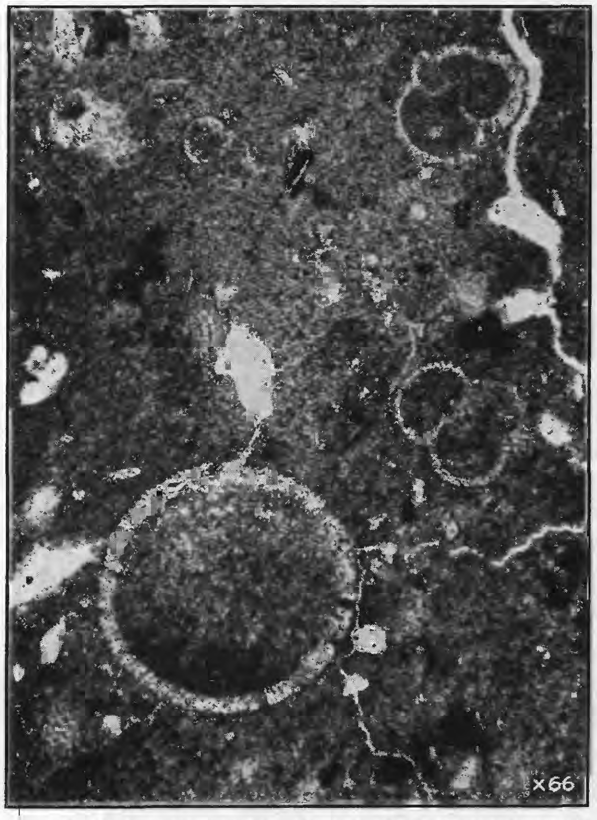
B. VESICULAR UPPER SURFACE OF CLAYEY ROCK THAT IS INTERPRETED AS AN ALTERATION PRODUCT OF THE BASALTIC LAVA AT THE BOTTOM OF CORE 11.

The surface of this clayey rock appears to have retained the vesicular form of a lava.



C. PALAGONITE RIMS SURROUNDING FRAGMENTS OF UNALTERED BASALTIC GLASS.

Basaltic glass at *a*. Delicate concentric banding within the palagonite rims is visible at *b*.



D. FORAMINIFERA SHELLS REPLACED BY A ZEOLITE RESEMBLING PHILLIPSITE.

These are embedded in the clayey rock shown in 7, *B*.

bigerina ooze collected from the anchor flukes we know that the floor of the sea is covered with normal globigerina ooze, and from the presence of mud in the water-exit ports 32 centimeters above the top of the core we know that the peculiar mud at the top of the core was at least a little thicker than is represented in the core. Approximately 1 meter at the bottom of this core and 80 centimeters at the top consist of the distinctive mud—a homogeneous, dark-gray sediment that shrank greatly upon drying. (See pl. 2.) Although about 50 percent of this mud is made up of silt-sized particles of basaltic glass, magnetite, augite, and calcic plagioclase, it contains but little quartz sand or other common clastic material, and exceedingly few Foraminifera. The remainder of this mud consists predominantly of clay minerals resembling beidellite or hydromica. The distribution of these constituents is shown in the diagram, plate 6 (sample W–18), which is based on a complete mechanical analysis of this same type of mud that was collected from the water-exit ports of the coring device. As noted on page 30, however, that particular sample was abnormal because it contained some coarse sand and pebbles.

A few normal and common types of pelagic and bottom-dwelling Foraminifera were found in the uppermost part of core 10 (sample H–95). In sample W–18, which came from the water-exit ports of the coring device, above the top of the core, pelagic Foraminifera are rather common (see pl. 6), but, as Foraminifera are virtually absent from the lower part of the upper clayey mud zone and increase in abundance at the top, it is suggested that this mud may grade upward into the overlying globigerina ooze, just as the lower clayey mud zone grades into the foraminiferal marl between the mud zones. The basal part of the upper mud zone (B–182) is somewhat more silty and has a sharp contact with the underlying foraminiferal marl. (See pl. 2.)

A sample of this basaltic mud (W–15), taken 67 centimeters below the top of core 10, was analyzed by E. T. Erickson in the chemical laboratory of the Geological Survey. Before analysis this sample was leached of its sea salts in distilled water, as is shown by the small amount of Cl reported. This analysis is given here as reported and also recalculated to 100 percent without calcium-magnesium carbonate. In this recalculation it was assumed that all the carbon dioxide was present in the form of carbonates and that the CaO and MgO were combined with it in the same proportions that they were found to be present in the fraction of the sample soluble in hot dilute HCl. This analysis was recalculated on a carbonate-free basis so as to compare it with analyses of other sediments on a carbonate-free basis. The analysis of this basaltic mud is not much like those of the common sediments, shale, mudstone, or clay; nor, on the other hand, is it like the analyses of basalt. It is surprisingly similar, however, to the analysis of a large group of oceanic red clays, despite the fact that the basaltic mud is quite unlike the red clays in appearance and mineral composition. (See table 7, B and C.) The most striking difference between these two analyses is the state of oxidation of the iron. More than half the iron in the mud from core 10 is in the ferrous state, whereas less than one tenth of that in the red clays is ferrous iron.

TABLE 7.—*Analyses of mud from core 10 (Sample W–15) and oceanic red clays*

	A	B	C
SiO_2	44.14	52.27	54.48
Al_2O_3	12.44	14.73	15.94
Fe_2O_3	5.74	6.80	8.66
FeO	3.22	3.81	.84
MnO_2	Not det.		1.21
MgO	3.94	2.65	3.31
CaO	10.32	2.76	1.96
Na_2O	1.31	1.55	2.05
K_2O	2.19	2.59	2.85
H_2O-	3.66	4.33	7.04
H_2O+	5.48	6.49	
TiO_2	1.52	1.80	.98
CO_2	6.28		
P_2O_5	.05	.06	.30
SO_3	.12	.14	
Cl	.02	.02	
BaO, Cr_2O_3, CuO, and other rare constituents	Not det.		.38
	100.43	100.00	100.00

A. Sample taken 67 centimeters below top of core. Analysed by E. T. Erickson.
B. Analysis A recalculated as free from $CaCO_3$, $MgCO_3$.
C. Composite of fifty-one samples of "red clay." Analyzed by G. Steiger, with special determinations by W. F. Hillebrand and E. C. Sullivan.

Although the chemical composition of the basaltic mud in core 10 is similar to that of the red clays we believe the basaltic mud probably had a quite different origin and history. The abundance of basaltic minerals and fresh basaltic glass points to a volcanic source, and the extreme scarcity of Foraminifera and coccoliths suggests deposition so rapid that they were masked out by the bulk of the other material.

Basaltic particles comparable with those found in the basaltic mud zones of core 10 presumably were discharged into the water of the Mediterranean over the Nerita Bank off the coast of Sicily during the submarine eruption of 1831, for according to Washington's[6] account "* * * the surface of the sea was seen to rise to a height of 80 feet, the column maintaining itself for 10 minutes, and then again sinking down. This was repeated every quarter to half an hour, and was accompanied by a dense cloud of black smoke and loud rumblings." The black smoke presumably consisted of basaltic dust particles.

It is perhaps futile to speculate further upon the possible origin of the volcanic muds in core 10. Nevertheless, the basaltic composition, the restriction to core 10, and the fact that the upper mud zone has, at least approximately, the same stratigraphic position as the volcanic rock in core 11 suggests a genetic relationship with deeply altered volcanic rock like that found in core 11.

The clay particles and basaltic grains in the greater part of this upper mud zone make up a homogeneous

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[6] Washington, H. S., The submarine eruptions of 1831 and 1891 near Pantelleria: Am. Jour. Sci., 4th ser., vol. 27, pp. 133–134, 1909.

mixture in which there is no discernible tendency (other than the comparatively thin basal silty layer) toward size gradation according to different settling velocities. This suggests that the bulk of the material did not settle at the site of this core from a cloud of particles thrown into suspension. Had the material been diffused upward even a few meters in such a suspension, most of the dense, silt-sized mineral and glass particles would have settled out from the cloud of minute particles of flaky clay minerals. A submarine volcanic eruption, perhaps in the vicinity of core 11, may have discharged into the sea finely divided basaltic particles and at the same time have thrown into suspension much clay, derived largely from the deeply altered surface of earlier submarine lava flows. Such a mixture of material, having settled to the bottom, would, by reason of its fine grain, make a quite labile sediment that would tend to collect in the deeper depressions or areas on the sea floor. It might move into these lower places either as mud flows on gentle slopes or by reworking under the influence of bottom currents, perhaps set up by the eruption. The homogeneity of the basaltic mud zones in core 10, with the sharply defined base (of the upper one) and gradational upper parts, suggests that most of the material reached its present site as mud flows and that mud-feeding animals reworked the uppermost material long thereafter, so that it grades upward into the overlying sediment. That mud-feeding animals were effective in reworking the upper part of the basaltic mud is indicated by the abundance of coprolitic pellets and mud-filled borings in the mud at the top of core 10. (See pl. 5, *A*.)

Additional cores in the part of the North Atlantic where cores 10, 11, and 12 were taken should prove to be of exceptional interest, for it is only in this way that submarine volcanic activity and its extent can be definitely established. Such information might also reveal the time of the postulated volcanic activity and perhaps, as suggested on page 7, relate it to foundering of a part of the Thulean basaltic province, which includes part of northwestern Scotland, northern Ireland, Iceland, Jan Mayen, and southwestern Greenland.

As with so many phases of this work, only with additional and longer cores can the questions raised in this investigation be satisfactorily answered.

PART 2. FORAMINIFERA

By JOSEPH A. CUSHMAN and LLOYD G. HENBEST

PREPARATION OF SAMPLES

The procedure followed in sampling the cores from the North Atlantic was essentially the same as that described in the report on a deep-sea core collected in 1935 southeast of New York City.[1] The cores were split longitudinally into two parts and allowed to dry before they were sampled. With drying, most of the sediments became hard enough to be handled more or less like indurated rock, so that it was possible to remove with a hacksaw segments from any part of a core desired. Several of the globigerina oozes, however, remained friable, and required a different method of sampling.

At the outset it was decided that to examine thoroughly every centimeter of the cores would require more time and assistance than we could devote to this study; so, it was necessary either to take long samples and thereby run the risk of combining different facies, or to take short but representative samples from every lithologic zone. Inasmuch as such zones were recognizable by differences in texture, color, composition, manner of contracting on drying, or other peculiarities, the latter plan was not only feasible but gave opportunity to obtain data that are more significant. In addition to some supplementary sampling for studies not recorded separately, 184 samples were taken from the cores. These are indicated as the "H" series of samples, except three which are indicated as belonging to the "B" series.

To avoid contamination, constant care was exercised in all operations. Each zone of friable sediment was cleared as far as possible of extraneous material, and the sample was scooped out with a small spoon shaped from thin sheet iron. The difficulty of avoiding contamination can easily be appreciated, yet it is almost certain that whatever contamination existed was insufficient to change the results of the paleontologic studies. Fortunately, only a few zones of very friable sediment were encountered. Most of the sediment was hard enough after drying to be handled and to withstand without breakage the trimming away of the thin layers of dragged material that were formed on the outside of the core by the core barrel and through the center of the core by the band saw used for splitting the cores. Generally it was easy to distinguish the layer of extraneous material from the undisturbed sediment. The zone of drag on the outside of the cores was, in most places, only 2 to 4 millimeters deep, but locally this depth was increased by the presence of pebbles.

The samples were very carefully washed through 200-mesh bolting silk, constant care being taken to avoid contamination. After drying, each sample was searched for metazoan fossils as well as for unusual foraminifers and lithologic specimens. The sample was then divided and about three-fifths of it, along with foraminifers that were picked out during the search for metazoan fossils, was sent to the Cushman Laboratory, where Miss Frances L. Parker thoroughly searched the samples for Foraminifera and arranged and mounted the specimens.

ACKNOWLEDGMENTS

The samples were washed by F. S. MacNeil of the Geological Survey. The authors are especially indebted to Miss Frances L. Parker of the Cushman Laboratory, who searched the samples for Foraminifera and made a preliminary classification of the specimens, and to W. H. Bradley of the Geological Survey for a very careful criticism of the text. The illustrations on plates 8–10 were drawn by Miss Patricia G. Edwards of the Cushman Laboratory.

DISTRIBUTION IN THE CORES AND LIST OF SPECIES

The species of Foraminifera found in the cores are divided into two groups, according as they are of pelagic or bottom-living habit, and their distribution in each core is plotted on a separate chart. (See figs. 11–21.) The numbers in the following list of species correspond with those appearing on the charts (figs. 11–21). Some of these Foraminifera listed have not been specifically identified, because specific identification would involve considerably more detailed work than has been attempted for this paper.

PELAGIC SPECIES

1. *Globigerina pachyderma* Ehrenberg. (Living habits are not definitely known, but despite the fact that it is apparently bottom-dwelling during a part if not all of its life history, it has been included with the other globigerinids among the pelagic forms.)
2. *Globigerina bulloides* D'Orbigny.
3. *Globigerina inflata* D'Orbigny.

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[1] 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, p. 1298, 1937.

4. *Globorotalia scitula* (H. B. Brady). (Not definitely known to be pelagic.)
5. *Globorotalia hirsuta* (D'Orbigny).
6. *Globorotalia truncatulinoides* (D'Orbigny).
7. *Globorotalia menardii* (D'Orbigny).
8. *Orbulina universa* D'Orbigny.
9. *Globigerinoides rubra* (D'Orbigny).
10. *Globigerinoides conglobata* (H. B. Brady).
11. *Globigerinella aequilateralis* (H. B. Brady).

BOTTOM-DWELLING SPECIES

12. *Karreriella bradyi* (Cushman).
13. *Quinqueloculina oblonga* (Montagu).
14. *Quinqueloculina venusta* (Karrer).
15. *Massilina tenuis* (Czjzek).
16. *Sigmoilina schlumbergeri* A. Silvestri.
17. *Triloculina tricarinata* D'Orbigny.
18. *Pyrgo murrhina* (Schwager).
19. *Pyrgo serrata* (L. W. Bailey).
20. *Pyrgo irregularis* (D'Orbigny).
21. *Ophthalmidium acutimargo* (H. B. Brady).
22. *Ophthalmidium inconstans* (H. B. Brady).
23. *Nonion barleeanum* (Williamson).
24. *Nonion pompilioides* (Fichtel and Moll).
25. *Nonion* sp. (?).
26. *Bolivinita* ?, n. sp. (?).
27. *Bulimina aculeata* D'Orbigny.
28. *Bulimina inflata* Seguenza.
29. *Bulimina rostrata* H. B. Brady.
30. *Buliminella elegantissima* (D'Orbigny).
31. *Virgulina subdepressa* H. B. Brady.
32. *Virgulina advena* Cushman.
33. *Virgulina campanulata* Egger.
34. *Bolivina* sp. (?).
35. *Bolivina subspinescens* Cushaman.
36. *Uvigerina* sp. *A*.
37. *Uvigerina* sp. *B*.
38. *Uvigerina* sp. *C*.
39. *Uvigerina* sp. *D*.
40. *Eponides umbonata* (Reuss).
41. *Gyroidina soldanii* D'Orbigny.
42. *Patellina corrugata* Williamson.
43. *Epistomina elegans* (D'Orbigny).
44. *Pulvinulinella* sp. *A*.
45. *Pulvinulinella* sp. *B*.
46. *Cassidulina subglobosa* H. B. Brady.
47. *Cassidulina crassa* D'Orbigny.
48. *Cassidulina laevigata* D'Orbigny.

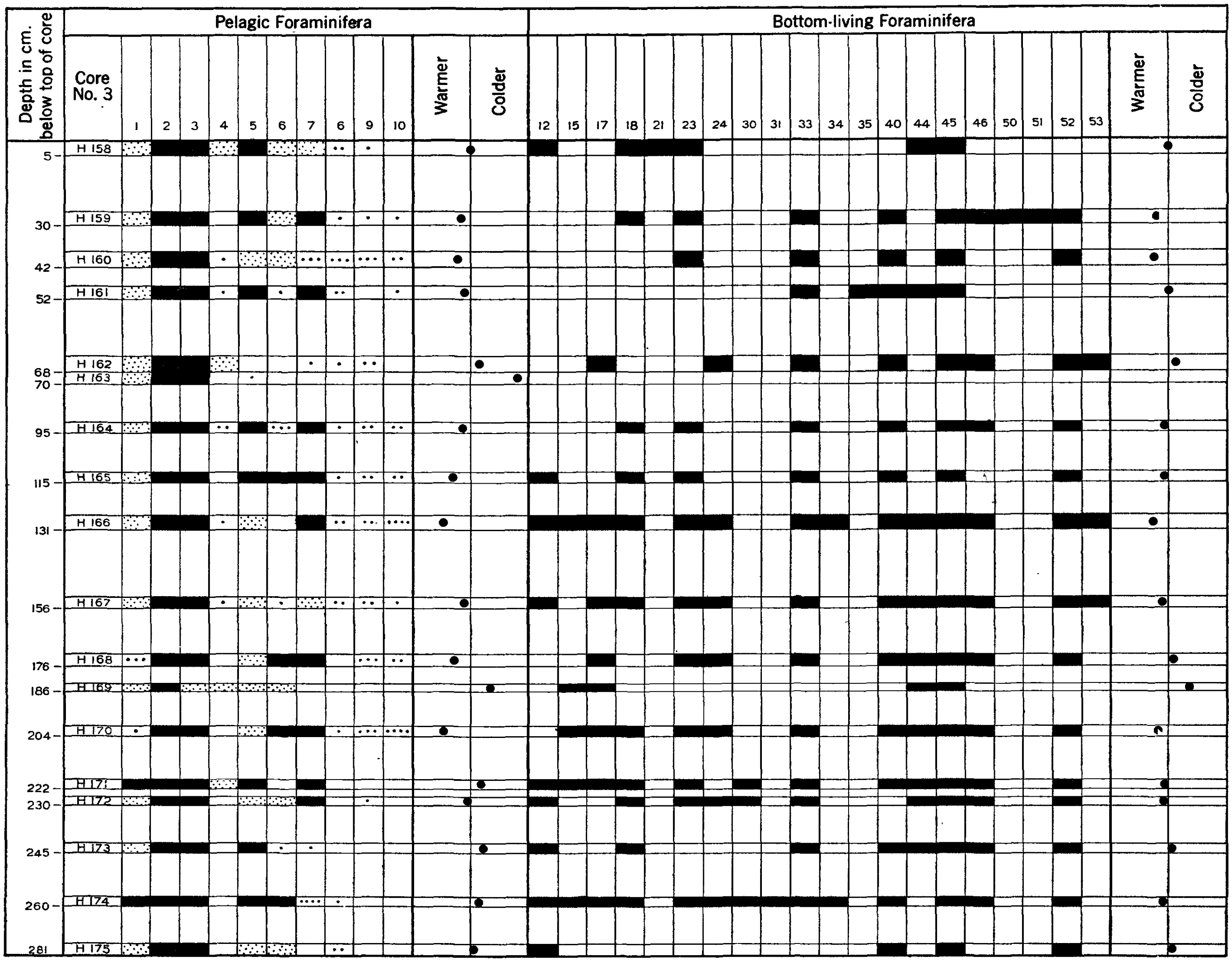

FIGURE 11.—Distribution and temperature significance of Foraminifera in core 3.

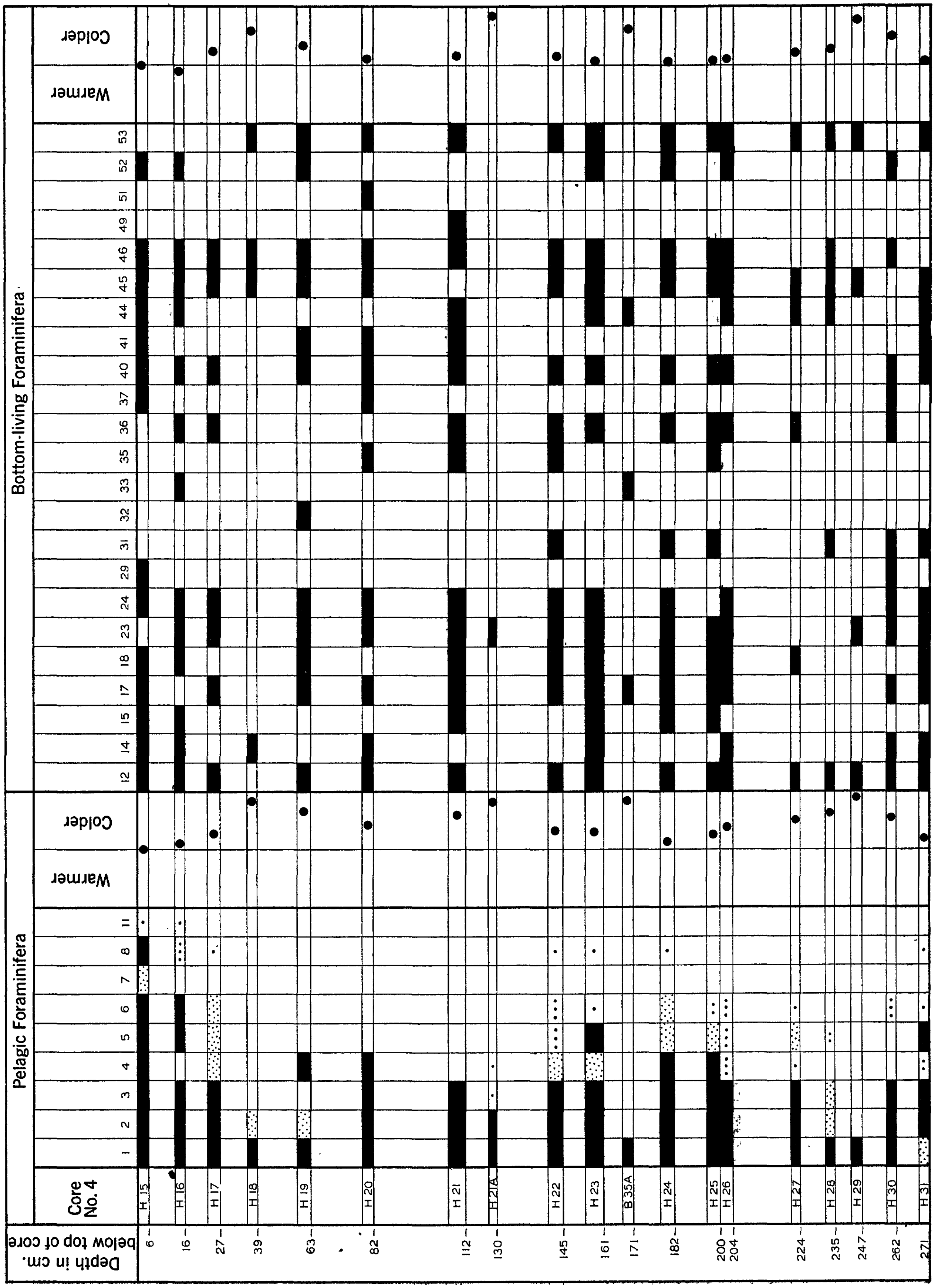

FIGURE 12.—Distribution and temperature significance of Foraminifera in core 4.

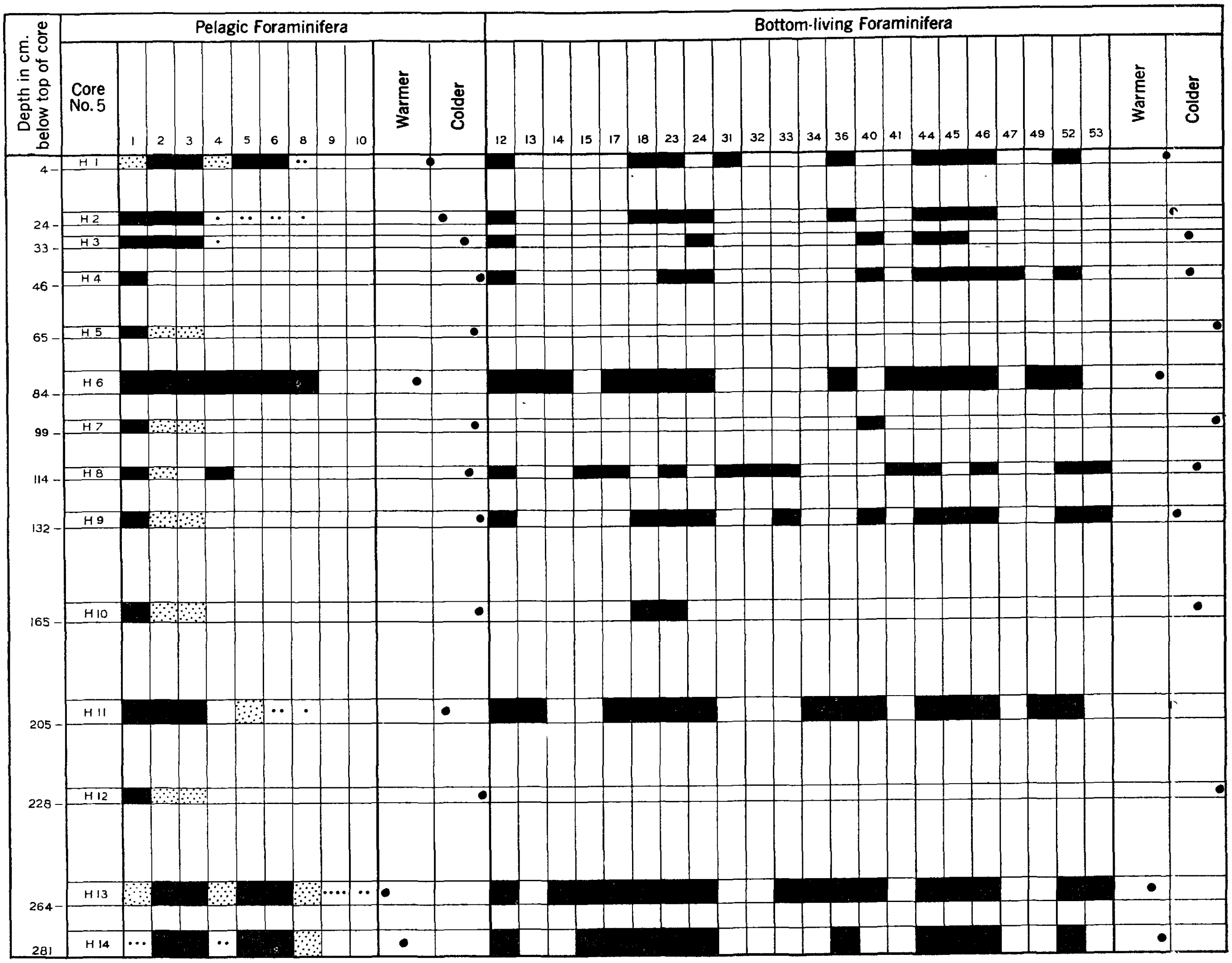

FIGURE 13.—Distribution and temperature significance of Foraminifera in core 5.

49. *Ehrenbergina serrata* Reuss.
50. *Chilostomella ovoidea* Reuss.
51. *Sphaeroidina bulloides* D'Orbigny.
52. *Pullenia sphaeroides* D'Orbigny.
53. *Pullenia quinqueloba* (Reuss).
54. *Rupertia stabilis* Wallich.
55. *Laticarinina pauperata* (Parker and Jones)
56. *Elphidium* sp. (?).

The specimens illustrated on plates 8–10 represent the character of the species used in this work for temperature determinations even though their exact nomenclature or classification cannot now be presented. The specimens illustrated were taken, wherever possible, from the surface or topmost sample of a core.

On the charts (figs. 11–21) the first two columns show the number and depth of each sample. The vertical length of the sample and its position in centimeters below the top of the core are plotted as nearly as possible to scale. Three of the samples have the letter B before the number (B–35A in core 4; B–108 and B–109½ in core 8). All others have prefixed the letter H.

For the pelagic forms a black rectangle indicates that the particular species is abundant or common; a stippled rectangle indicates 6 to 25 specimens; and 1 to 5 dots in a rectangle represent the exact number of specimens found.

For the bottom-dwelling forms a black rectangle indicates merely the presence of one or more specimens. Not all bottom-living species were plotted, because lack of time for an exhaustive study prevented giving attention to rare specimens, to species found in only one core, or to species that otherwise appeared to have little significance. For this reason the relative abundance of bottom-living species was not estimated.

The temperature significance was determined and plotted separately for the pelagic and the bottom-living Foraminifera. Relative temperature is indicated in the columns headed "warmer" and "colder" by large black dots so plotted as to show departures from the norm (represented by the vertical line separating the two columns), which is based on the temperature conditions exhibited by the Foraminifera in the top sample of each core and thus represents the present-day temperature of the water at that collecting station.

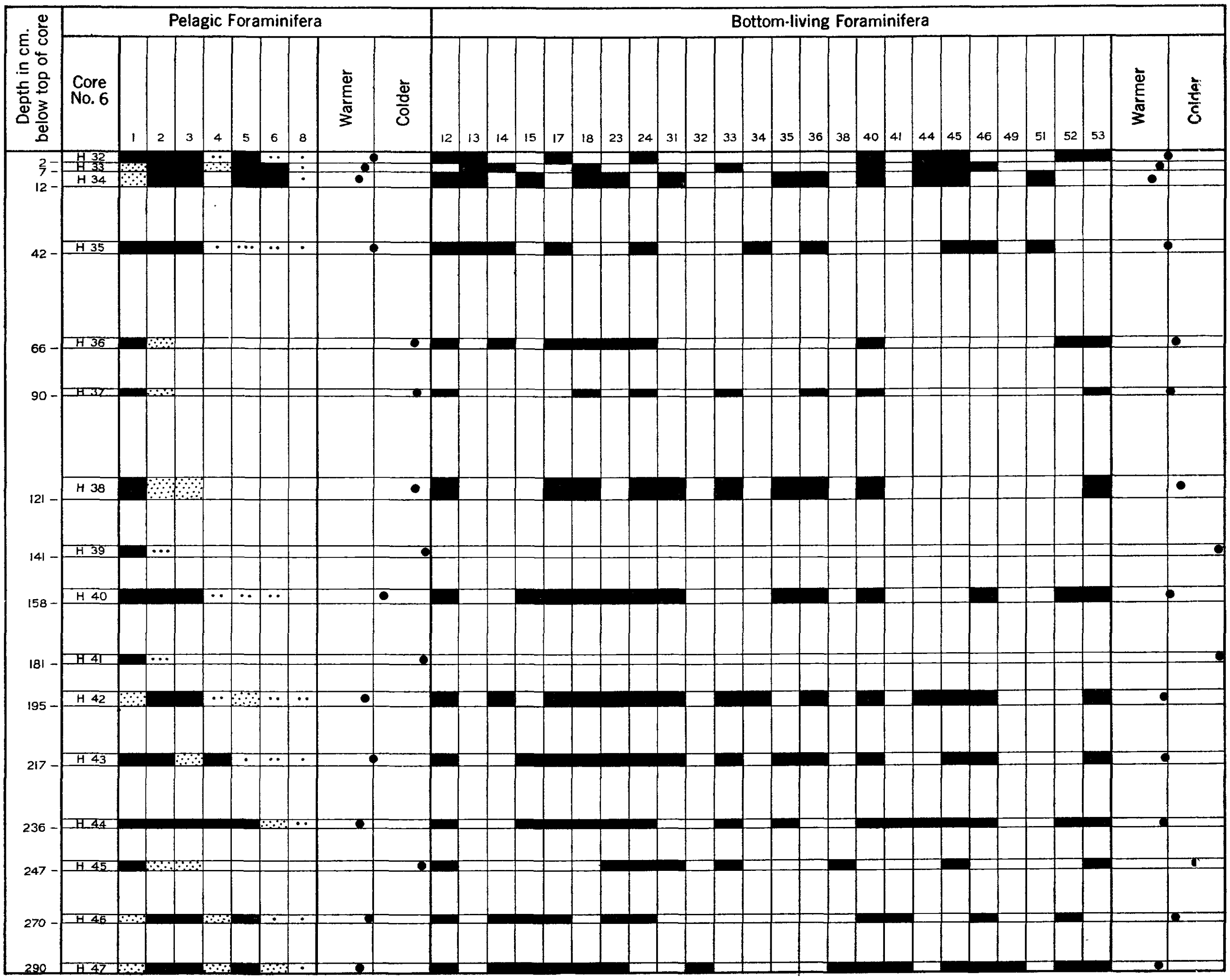

FIGURE 14.—Distribution and temperature significance of Foraminifera in core 6.

PELAGIC FORAMINIFERA

Although the record of foraminifers that have a pelagic habit is probably incomplete, enough townet samples have been taken from the seas to demonstrate that comparatively few genera and species occupy the pelagic realm.

The pelagic species of the world belong to the genera *Globigerina*, *Globigerinoides*, *Globigerinella*, *Orbulina*, *Hastigerina*, *Hastigerinella*, *Pulleniatina*, *Sphaeroidinella*, and *Candeina*, all of which are members of the family Globigerinidae, and to the globorotalid genera *Globotruncana* and *Globorotalia*. *Tretomphalus* is free swimming during the later part of its life but is normally restricted to near-shore or shallow-water areas.

Approximately 26 species of pelagic habit have been described. This small number of species and genera and their general similarity of shell morphology and moderate size may make them appear, from the standpoint of taxonomy, as insignificant members of the order Foraminifera, but the principal pelagic species produce an enormous number of individuals. They have been in the first rank of recognizable lime-precipitating agents during and since the middle of the Mesozoic. The small number of pelagic species and their comparatively simple taxonomy, their independence of local bottom conditions that do not disturb the chemical and physical stratification of the water, and their exceptionally broad distribution within their marine climatic realms make them a valuable source of information on paleoecology.

All the globigerinids in the core samples except *Globigerina pachyderma*, an Arctic species, are supposed to be pelagic. The globigerinids characteristic of very warm surface water were not found in abundance in the top samples of the cores, but in some of the lower zones in several cores warm-water species are present in great abundance, thus indicating that at the time when the sediments of these zones were deposited the Gulf Stream must have extended farther north than it does at the present time.

The fauna at the top of each core reflects the temperature of the present time and may, therefore, be

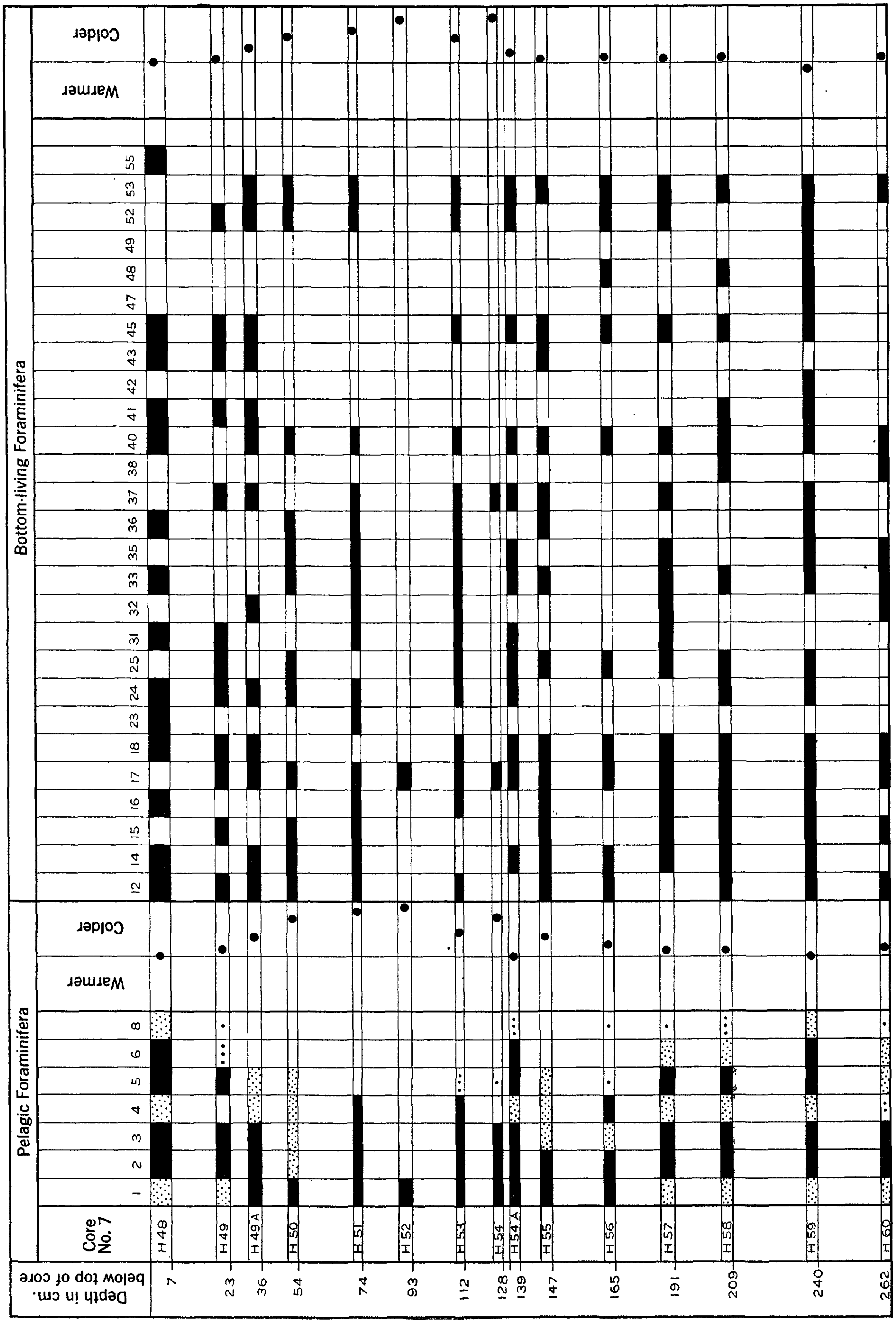

FIGURE 15.—Distribution and temperature significance of Foraminifera in core 7.

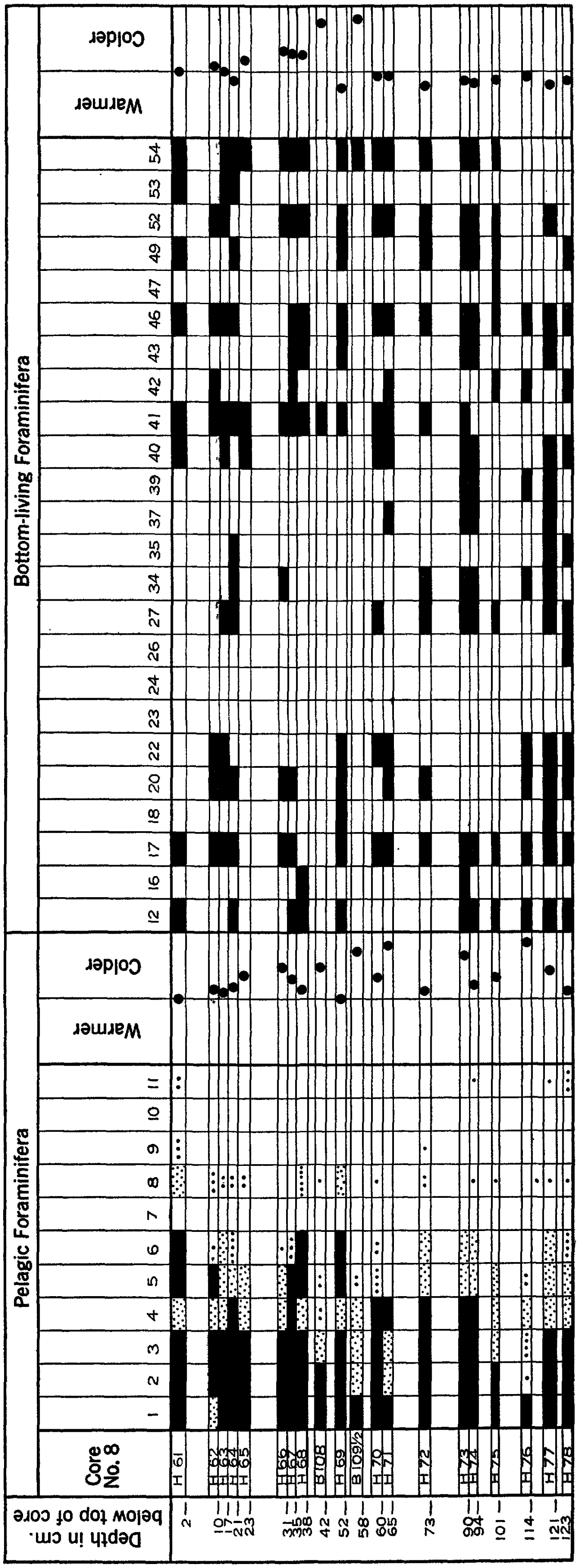

FIGURE 16.—Distribution and temperature significance of Foraminifera in core 8.

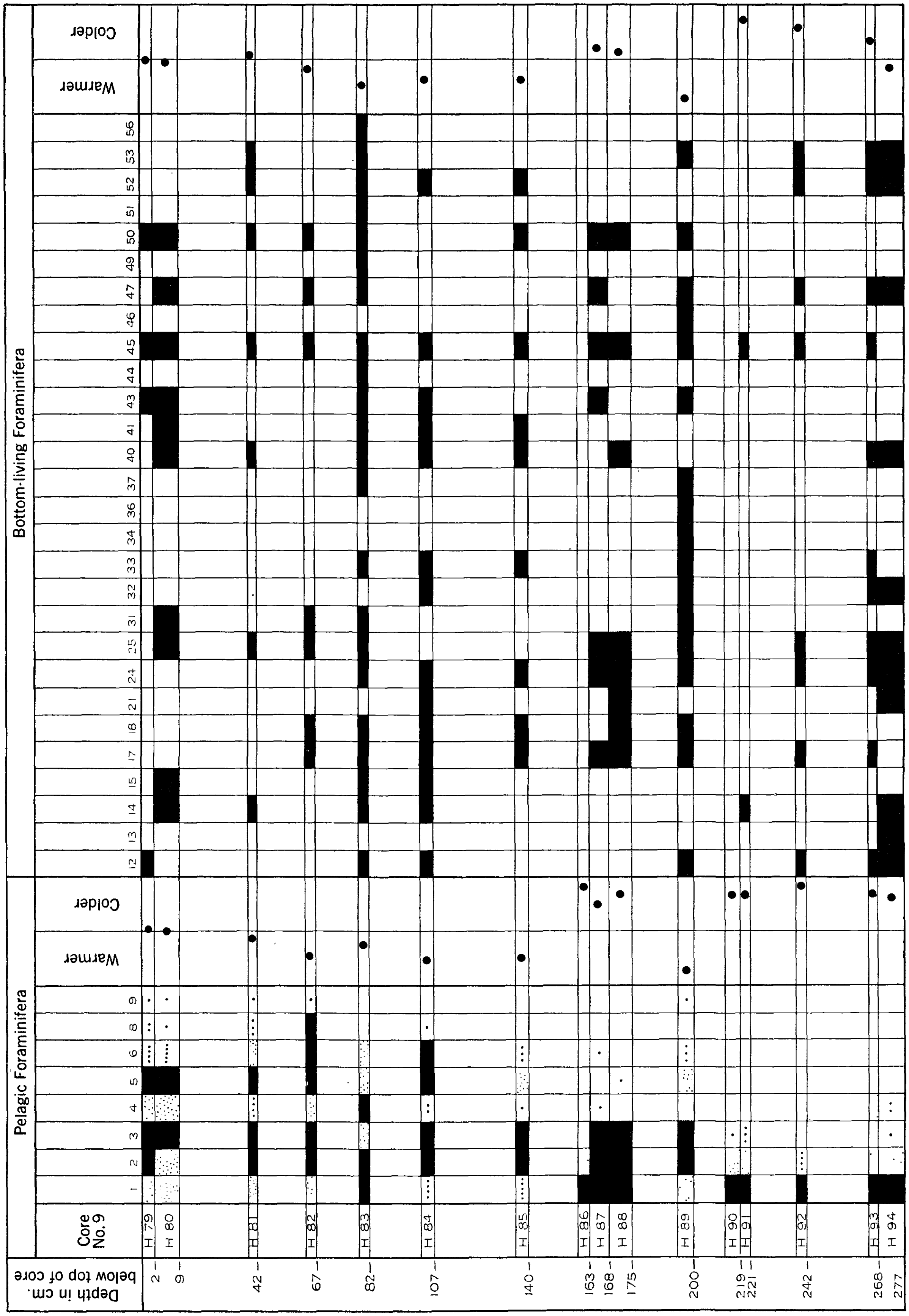

FIGURE 17.—Distribution and temperature significance of Foraminifera in core 9.

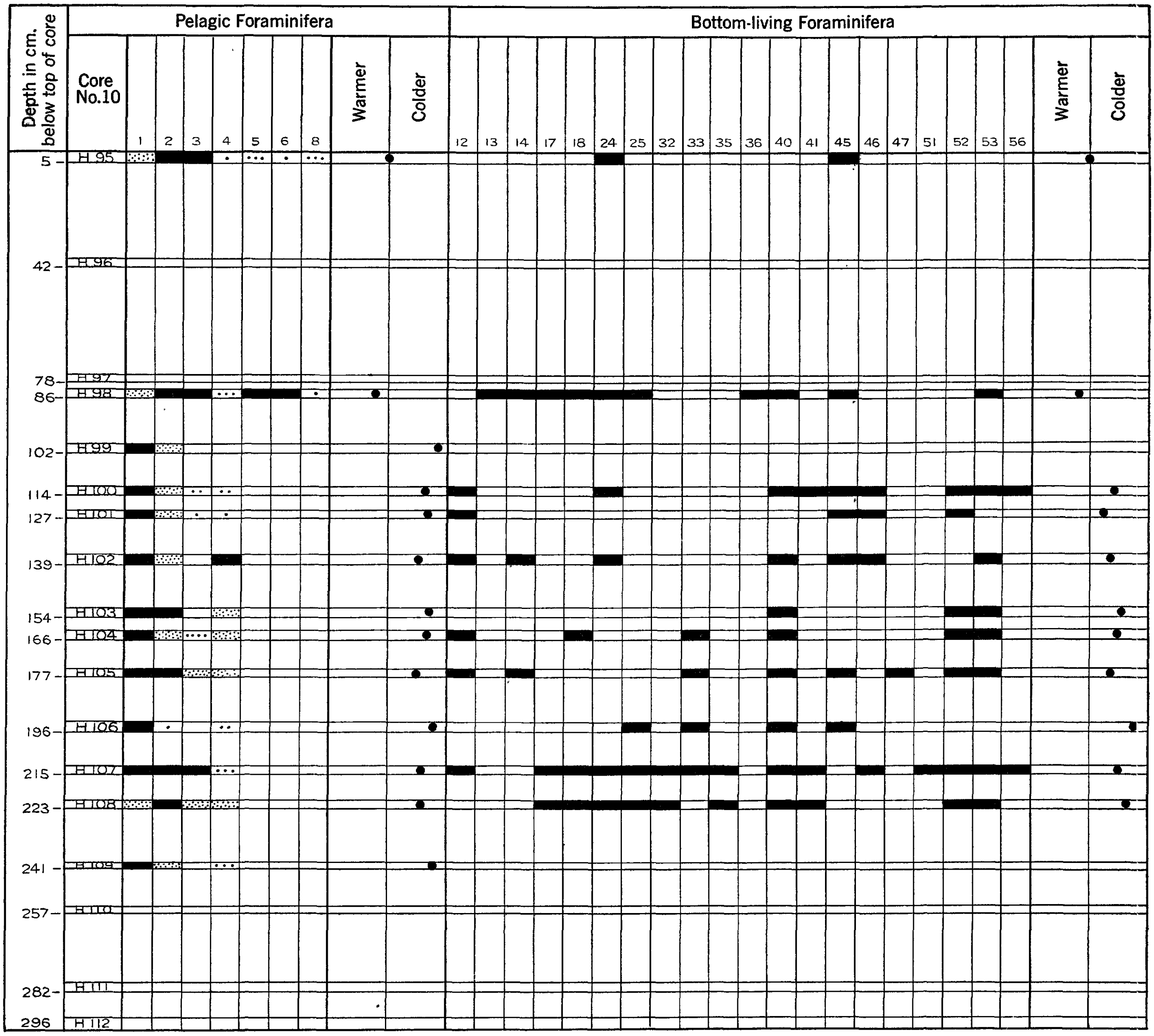

FIGURE 18.—Distribution and temperature significance of Foraminifera in core 10.

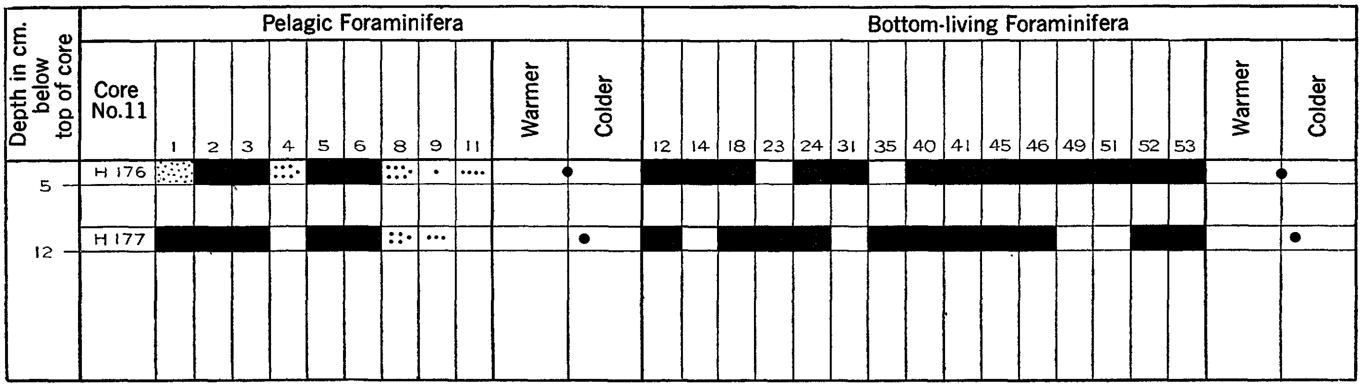

FIGURE 19.—Distribution and temperature significance of Foraminifera in core 11.

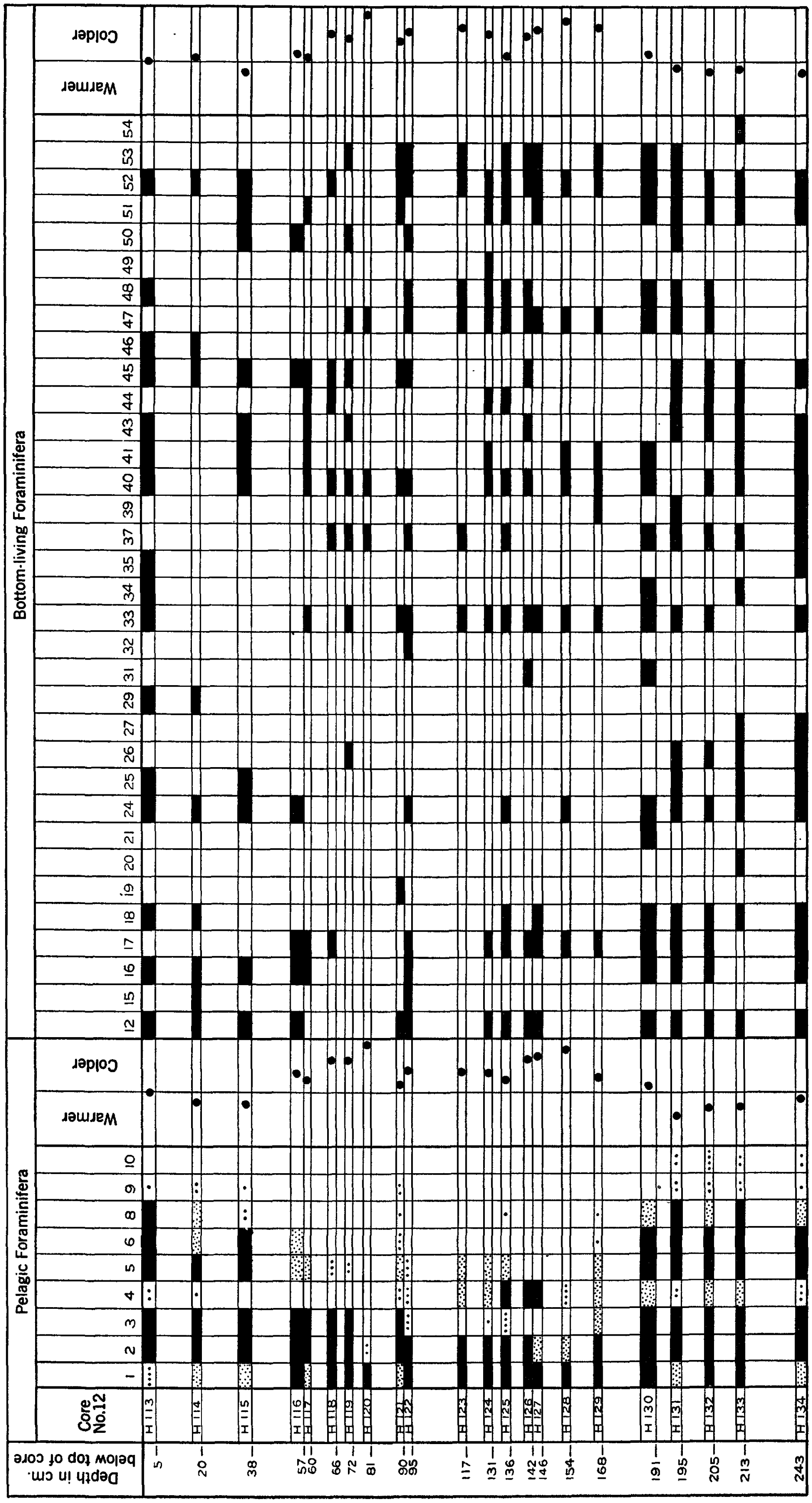

FIGURE 20.—Distribution and temperature significance of Foraminifera in core 12.

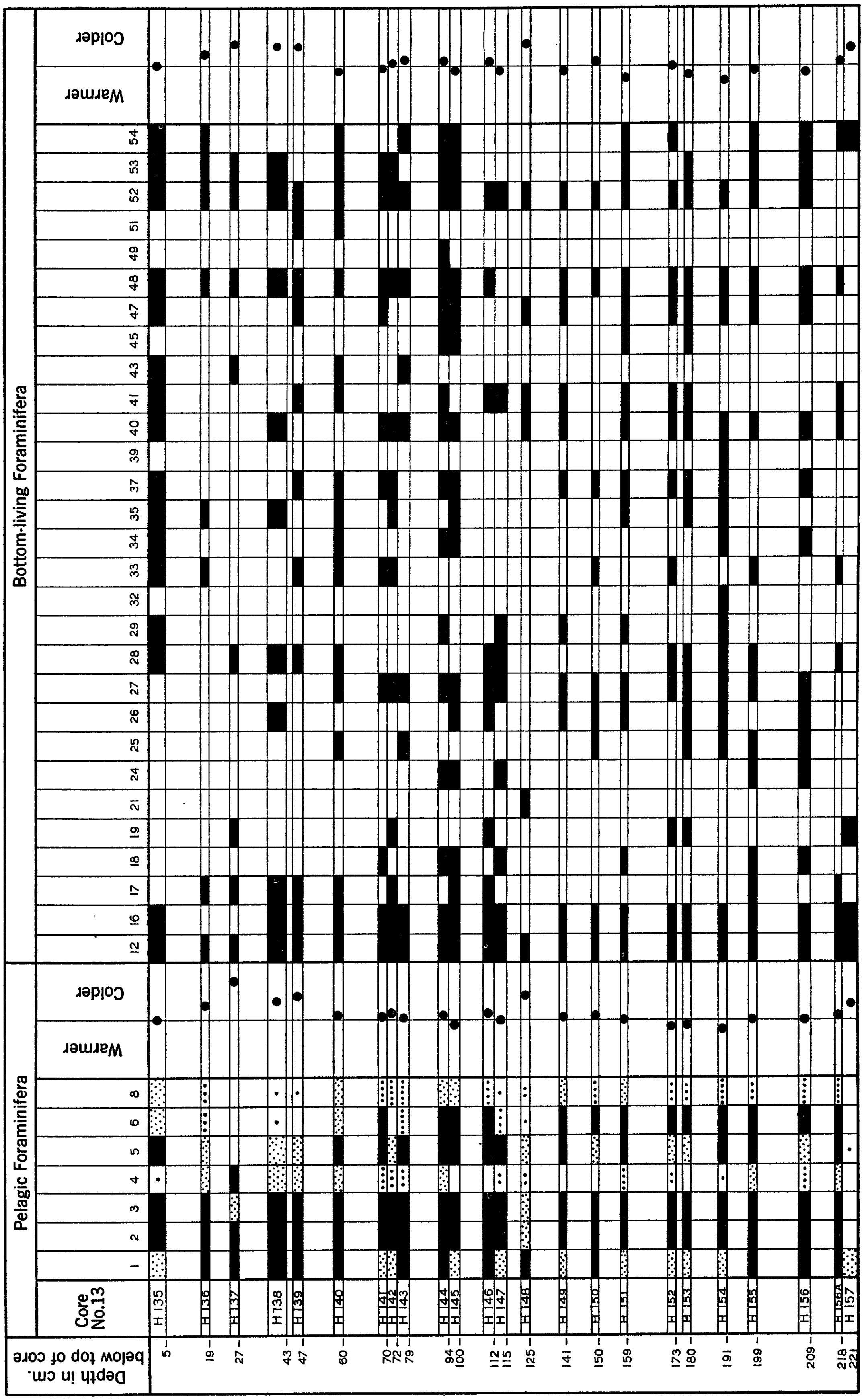

FIGURE 21.—Distribution and temperature significance of Foraminifera in core 13.

used as a convenient norm with which the temperatures indicated by the faunas below can be compared and plotted. The departures from the temperature norms as indicated by the foraminifers have been plotted in figures 11 to 21. It is evident from these charts that several alternations of periods colder and warmer than the present have occurred during the time represented by the sediments in these cores. The zones containing Foraminifera of a more tropical or a more arctic facies than that represented by the top of the core will be referred to respectively as warm or cold, whereas those of an intermediate aspect or resembling present-day temperatures will be referred to as normal.

Globigerina bulloides D'Orbigny (pl. 8, figs. 2a, b, c.) is one of the most generally distributed globigerinids in the core samples. It is abundant in all warm and normal temperature zones, and though abundant in a few of the cold zones it is commonly subordinate, rare, or absent in the coldest ones. The distribution of this species in the present oceans is somewhat uncertain, because the taxonomic limits of the form are under question. Brady and others have considered it almost universal, but they may have used too much latitude in its taxonomy. In the tropical Atlantic its occurrence is spotty, though locally very abundant according to Schott.[2] Heron-Allen and Earland [3] report it as abundant in the New Zealand area and very widely distributed elsewhere.

Globigerinoides rubra (D'Orbigny) (pl. 8, fig. 9) is extensively distributed in the tropical and warm-temperate waters of the North and South Atlantic, Pacific, and Indian Oceans, and in the Mediterranean Sea. The species was originally described from the West Indies, where it seems to be more prolific and more typical than elsewhere. Schott [4] indicates in the *Meteor* report that *G. rubra* is one of the more prolific species collected in net hauls from the tropical Atlantic. In core 3 it is rare throughout and absent from the cold zones. It is present in the lower warm zone of core 5 (H–13). It is rare in samples H–61 (top) and H–72 of core 8, rare in 5 samples of core 9, rare in the globigerina ooze of core 11, rare in the warmer zones of core 12, and absent from all of the other samples.

Globigerinoides conglobata (H. B. Brady) (pl. 8, fig. 10) is a characteristic tropical Gulf Stream form. Brady [5] reports its range in the Atlantic as from latitude 40° north to 35° south; he found its distribution in the Pacific to be more restricted. Later investigators have extended somewhat its range in the Pacific region. This species was observed in several of the net hauls of the *Meteor* expedition in the tropical Atlantic. It appears to be most characteristic and most numerous in the tropical part of the Gulf Stream. *G. conglobata* is found sparingly in only the warm zones in core 3, and in the lowest warm zone in cores 5 and 12. Elsewhere, it is absent.

Globorotalia menardii (D'Orbigny) (pl. 8, fig. 3) is a very prolific species in the pelagic fauna of the tropical and temperate waters of the North and South Atlantic. It is reported as abundant in the Pacific around the Hawaiian and Philippine Islands, where the shells are a prominent constituent of the globigerina oozes. It has been reported elsewhere in the tropical Indian and Pacific Oceans and off the Juan Fernandez Islands. Heron-Allen and Earland [6] failed to find the species in the Antarctic Ocean, even at stations where preceding investigators had reported its occurrence. Brady [7] reports that its northern limit in the Atlantic Ocean is 55°11′ north latitude and its southern limit 50° 36′ south latitude. As now recognized, the species has a world-wide distribution in the tropical and warm-temperate zones. *G. menardii* is present in all samples in core 3, except those from two cold zones. Only a few specimens were found in two moderately cold zones. The remaining zones in core 3 are near normal or warmer than normal. In core 4 it is present only in the top sample. The climate represented by the other samples in core 4, as indicated by the pelagic foraminifers, was colder than that represented by the top sample. *G. menardii* is absent from the other cores.

In analyzing the significance of the Foraminifera in the cores taken by the *Meteor*, Schott [8] used *G. menardii* as an indicator of surface water temperatures comparable to those now prevailing in the tropical part of the Atlantic. *G. menardii* is a common constituent of the globigerina ooze now accumulating in that region. The cores taken by the *Meteor*, however, revealed a zone of sediment 20 to 30 centimeters below the sea floor that does not contain *G. menardii.* Schott interpreted this zone as representing a period of cold water belonging to the last glacial stage of the Pleistocene. The sediment underlying this zone of colder water contains *G. menardii* and was thought by Schott to represent the last interglacial epoch.

BOTTOM-LIVING FORAMINIFERA

Information on the distribution of bottom-dwelling Foraminifera relative to temperature is less detailed and definite than that for the pelagic forms. The pelagic foraminiferal faunas are comparatively simple in composition, for they contain relatively few but very prolific species that generally have a very broad geographic distribution. On the contrary, many bottom-

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[2] Schott, W., Die Foraminiferen in dem aquatorialen Teil des Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped., *Meteor*, 1925–27, Band 3, Teil 3, Lief. 1, pp. 59, 95, etc., 1925.

[3] Heron-Allen, Edward, and Earland, Arthur, Foraminifera: British Antarctic (*Terra Nova*) Exped., vol. 6, No. 2, p. 187, 1922.

[4] Op. cit., pp. 62, 63, 100.

[5] Brady, H. B., Foraminifera: *Challenger* Rept., Zoology, vol. 9, p. 603, 1884.

[6] Heron-Allen, Edward, and Earland, Arthur, Foraminifera: British Antarctic (*Terra Nova*) Exped., vol. 6, No. 2, p. 26, 1922.

[7] Op. cit., p. 691.

[8] Schott, W., Die jüngste Vergangenheit des aquätorialen Atlantischen Ozeans auf Grund von Untersuchen an Bodenproben der *Meteor* Expedition: Naturf. Gesell. Rostock Sitzungsber. u. Abh., 3d ser., Band 4, pp. 54–57, 1933.

dwelling faunas are composed of a large number of species whose distribution is variously involved with local factors, such as depth, temperature, kind of bottom, intensity of light, and food supply. Although existing bottom faunas have been rather extensively described, the record of their environment is not yet sufficiently definite or comprehensive to be used as the basis of ecological determinations with as much assurance as is possible with the pelagic faunas. Nevertheless, the climatic distribution of several bottom-living species is fairly well-known, a few being characteristic of cold water and others of warm water.

The information on the bathymetric distribution of the bottom-dwelling Foraminifera is less satisfactory than that on climatic distribution. Investigations now under way at the Cushman Laboratory in cooperation with the Woods Hole Oceanographic Institution promise to yield much definitive information, but the studies are not sufficiently advanced to apply the results to the study of these cores.

Among the enigmatic problems encountered in the study of the core faunas is the occurrence in a few unrelated samples of solitary specimens, in part broken or worn, of *Elphidium* or the closely related genus *Elphidiella*. It seems significant that in nearly all samples in which it was found, there was only a single specimen. Those found in samples H–74, H–83, and H–133 are in zones indicated as warm by other Foraminifera, but those found in samples H–5, H–22, H–100, and H–107 are in zones indicated as colder than normal.

Species of *Elphidium* and *Elphidiella* are characteristic of shallow-water, near-shore marine faunas, especially in the northern hemisphere, and they have been an increasingly prolific constituent of such foraminiferal faunas during and since the Miocene. An exception in the North Pacific Ocean has been recorded by Cushman [9] and apparently another in the North Atlantic Ocean by Cushman, Henbest, and Lohman.[10] Specimens have been dredged in deep water near Islands in the Pacific, but the eroded shells and the anomalous location indicate that they had been transported from shallow to deep water. The presence of *Elphidium* and *Elphidiella* in these deep-sea cores can hardly be construed as evidence for shallow water, because the rarity of specimens in our samples, in contrast with their great abundance in their normal habitat, suggests that they are not indigenous. For these reasons we must look for a more satisfactory explanation of their presence.

We have not yet encountered a record of *Elphidium* and *Elphidiella* living as pelagic organisms. The records of deep-water dredgings almost uniformly indicate their absence from the abyssal benthos. Transportation of shells of these organisms for many hundreds of miles by currents on the ocean bottom seems unlikely. Flotation of shells for a few days by gas generated in dead sarcode is not entirely improbable, though not yet observed or described. However, icebergs and seaweed are transporting agents of great capacity and wide distribution and seem to be the most likely factors in these and similar problems of erratic distribution.

Rafting by icebergs seems possible under conditions that would enable the ice to gouge out or incorporate and carry shallow-water or littoral sediments. It is probably a common occurrence for shallow-water or littoral sediments to become incorporated in ground ice, shore ice, or the bottoms of grounded icebergs and later to be carried to sea when the ice breaks up. At least one of the specimens, *Elphidiella groenlandica* (Cushman), known only from the shallow water around Greenland (found in core 5, sample H–5), suggests this mode of transportation, because the indigenous Foraminifera in this sample indicate a cold-water environment such as would be expected in areas occupied by floating ice.

Seaweed is another important rafting agent. The transportation, for example, of near-shore living micro-organisms as well as certain larger organisms by sargasso weed broken loose from the West Indies and carried to sea by currents is widely known. That mode of rafting is by no means restricted to the Sargasso Sea.

A similar problem of erratic specimens was encountered among the macrofossils. See chapter on "Miscellaneous fossils and faunal distribution."

Rupertia stabilis Wallich (plate 10, fig. 15) was found only in cores 8, 12, and 13, the cores from the shallowest water. It is especially common in core 8 and rather common in core 13, but in core 12 it was found in only one sample (H–133). The distribution is about evenly divided between warm, medium, and cold zones, thus indicating that temperature is not a critical factor in its distribution. The absence of this foraminifer from the cores taken in deeper water, between cores 8 and 12, suggests that depth is an important control. This suggested conclusion is modified, however, by the possibility that the texture of the substrate in cores 9, 10, and 11 might be a factor as well as depth. In cores 8 and 13, *R. stabilis* is found in globigerina ooze of rather coarse texture. The ooze in cores 9, 10, and 11 is generally finer in texture and contains more clay. If depth is a principal control of the distribution of *R. stabilis*, the absence of this species from the cores from greater depths in the eastern Atlantic would indicate that the ocean level was probably not low enough during the glacial stages to bring the abyssal bottom of the region within the depth range of this species. This evidence, though indefinite, lends some support to the conclusion, originally reached in a study of the other

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[9] Cushman, J. A., A monograph of the Foraminifera of the North Pacific Ocean: U. S. Nat. Mus. Bull. 71, pt. 4, pp. 30–34, 1914.

[10] 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, p. 1304, 1937.

invertebrate fossils in the cores, that extreme changes in ocean level have not occurred during the time represented by our core samples.

Globigerina pachyderma Ehrenberg (plate 8, figs. 1a, b, c) is of particular interest. Most of the species of globigerinids and globorotalids in the core samples are exclusively pelagic, except *Globigerina pachyderma* Ehrenberg and possibly *Globorotalia scitula* (H. B. Brady) (plate 8, figs. 5a, b, c). *G. pachyderma* may be pelagic in its early stages, but little is definitely known of this aspect of its habits. It is a cold-water form originally described from the Davis Straits by Ehrenberg. Brady,[11] Heron-Allen and Earland,[12] and others have considered this form as an indicator of cold water. Brady states that *Globigerina pachyderma* is peculiar to the high latitudes. Its southernmost range observed in the North Atlantic is in the "cold area" in the Faeroe Channel at about latitude 60° north. Brady writes [13] "Within the Arctic Circle it is the most common representative of the genus, occurring sometimes alone and sometimes in company with small specimens of *Globigerina bulloides*. I have never succeeded in finding it in tow net gatherings, although small examples of the tropical *Globigerina bulloides* are not uncommon amongst the surface organisms of the same areas."

In dredgings from the North Atlantic Ocean, *Globigerina pachyderma* constantly appears in inverse ratio to such pelagic species as *Globigerinoides rubra*, *G. conglobata*, and *Globorotalia menardii*, which are known to be characteristic of tropical and warm-temperate surface water like that of the Gulf Stream.

The presence of *Globigerina pachyderma* or a homeomorph thereof in the Antarctic Ocean was definitely established by Heron-Allen and Earland.[14] They proposed the idea that this species is a precise homeomorph of the true *G. pachyderma* from the Arctic Ocean and that in the Antarctic Ocean the supposed *G. pachyderma* is a variant of the Arctic species *G. dutertrei*. If this is true, *G. pachyderma* is not an example of bipolarity, as sometimes supposed. These authors agree with Brady's conclusions that the species is probably not, as reported by Murray,[15] a pelagic form.

BATHYMETRIC DISTRIBUTION

In general, the bottom-dwelling Foraminifera are most prolific and varied in the cores from the shallowest water and least so in those from the deepest water. In this respect they exhibit, in common with the metazoan fossils, a bathymetric distribution that is parallel with that of marine bottom-living animals of the present day. Although the distribution of fossils in the cores is treated at greater length in the chapter on "Miscellaneous fossils and significance of funal distribution," it is appropriate here to direct attention to a few general features of the distribution of the Foraminifera.

Cores, 3, 4, and 9 represent rather well the character of the foraminiferal population in the cores from the deepest water. In these cores the bottom-dwelling Foraminifera occupy a very subordinate position in number of individuals and include generally a small number of species.

Core 3 contains pelagic foraminifers in all of the 18 samples that were extracted but bottom-living forms are comparatively rare throughout.

In core 4, 13 samples contain a great abundance of pelagic forms; the remaining 6 samples also contain them but they are less abundant. In all 19 samples the bottom forms are comparatively rare.

In core 9, 4 samples out of 16 contain an abundance of pelagic foraminifers; the remainder, with one exception, contain a moderate number. The bottom forms are generally subordinate, in some samples very rare or absent. In 7 samples, diatoms (mainly *Coscinodiscus*) compose a large part of the sediment. In one sample of diatom ooze (H–86), bottom-dwelling foraminifers, excepting *Globigerina pachyderma*, are absent, and metazoans are represented only by echinoid spines and silica sponge spicules. Shards of alkalic volcanic glass are present in large numbers. The pelagic foraminifers indicate cold water.

The core from the shallowest water, No. 8, contains not only a large amount of globigerina ooze but also a varied and prolific to moderately prolific bottom fauna of foraminifers. Throughout this core, the pelagic fauna is generally very prolific. Large diatoms (*Coscinodiscus*) and radiolarians were not seen in the samples studied for Foraminifera. The bottom fauna, both protozoan and metazoan, is more varied and profuse than in the other cores. The core from the next shallowest water, No. 13, and the third shallowest, No. 12, contain bottom faunas decreasing in variety and numbers. The cores from water of intermediate depth are intermediate in these aspects of faunal character.

Though relatively pure globigerina oozes are common in the cores, as well as those that are more argillaceous and arenaceous, shells of bottom-dwelling foraminifers are hardly numerous enough in any core to characterize the sediment, unless *Globigerina pachyderma* is included among the bottom-living species.

In passing from west to east, core 7 is the first to include species of Foraminifera that are European in character. In cores 8 to 13 the character becomes increasingly European.

TEMPERATURE INDICATIONS

In attempting to determine the temperature changes of the past, the top sample of each core was taken as normal, because the top sample represents the present-

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[11] Brady, H. B., Foraminifera: *Challenger* Rept., vol. 9, p. 600, 1884.

[12] Heron-Allen, Edward, and Earland, Arthur, Foraminifera: British Antarctic *Terra Nova* Exped., Protozoa, vol. 6, No. 2, pp. 33–36, 1922.

[13] Brady, H. B., Foraminifera: *Challenger* Rept., vol. 9, p. 600, 1884.

[14] Heron-Allen, Edward, and Earland, Arthur, op. cit., pp. 33–36.

[15] Murray, John, The ocean, p. 165, New York, Holt & Co., 1913.

day conditions at each collecting locality, except core station 10. In core 10 the top sample cannot be taken to represent present-day conditions, because the core bit penetrated farther than its length into the bottom sediment, as indicated by the presence of sediment in the water-exit port.

The pelagic and bottom-living Foraminifera were studied separately for indications of temperature, and the results were plotted separately in figures 11 to 21. No attempt was made to express the appraisals in terms of degrees, but a relative scale was established for each core. The top sample of each core, representing the present-day temperature at the collecting locality, was taken as the normal. Departures from this norm are plotted as warmer or colder, and the apparent extent of the departure is indicated on the chart by the distance from the norm. Both positive and negative evidence was used in the temperature determinations, the absence of known cold-water forms being given a certain amount of weight, particularly if such negative evidence was supported by absence of cold-water species in the samples next above and below.

The temperature changes indicated by the individual samples within each core are generally greater than the temperature differences similarly indicated as existing between the top samples of the different cores. However, a standard or norm of temperature for the whole set rather than for individual cores could not be attempted at the present time, because factors of depth and geographic distribution [16] affect the composition of the existing bottom faunas more than temperature alone and to a degree probably greater than the difference in temperature existing in the area represented by these cores. These three major factors are variously concomitant and are only partly separable in faunal analyses. Of course, it must be admitted that the temperature norms could not be maintained for each individual core entirely separate from the others, because the background of previous information on ecology naturally tended to introduce a common denominator for the entire series.

Though the trends of change are generally similar, the pelagic and bottom-dwelling foraminifers do not always indicate temperature changes that are exactly parallel nor equally divergent from the arbitrary norm. This lack of parallelism is to be expected, because extensive chemical and thermal stratification of ocean water makes the connection between local climate and the bottom layers in abyssal areas more indirect than such a connection with the surface layers that are inhabited by the pelagic Foraminifera. Extensive climatic changes are probably always accompanied by more or less local irregularity. Inasmuch as the temperature of the surface water of the North Atlantic Ocean is controlled at the present time principally by the climate of the tropical Atlantic Ocean and Caribbean Sea and as the temperature of the bottom layer of water is controlled by the climate of the Arctic region, it would seem likely that a lack of parallelism in the climatic changes of the tropical and Arctic regions would result in a corresponding lack of parallelism in the temperature changes of the surface and bottom layers of water of the North Atlantic. It therefore seems more likely that the lack of precise parallelism in the temperature changes indicated by the Foraminifera were rather a result of temporary climatic changes than of broad, large-scale geoclimatic changes. The depositional record of the Foraminifera does not show annual or short-period oscillations.

At the present time, temperature, as well as many other ecological factors, usually cannot be interpreted on the basis of shell anatomy alone. Some exceptions or partial exceptions are known, but no consistently workable principles have been discovered. The most reliable source of information on the ecology of foraminiferal faunas is still the known distribution of the species composing the fauna.

AGE AND CORRELATION

The Foraminifera in the cores are species or varieties that have been recorded in existing oceans or in Recent and Pleistocene sediments. No Foraminifera known to be exclusively characteristic of Pliocene or earlier epochs were found. These circumstances set a limit to the time span with which we have to deal, but a number of difficulties, that are for the present insurmountable, stand in the way of determining precisely the age and correlation of the faunas by strictly paleontologic methods. One of the principal obstacles is that the historical range of the pelagic species remains as indefinite, within certain limits, as their taxonomy is generalized. Another is that good stratigraphic sequences of beds bearing late Cenozoic to Recent Foraminifera are rare and few of these have been completely described. This is true not only for the Foraminifera enclosed in sediments of epeiric seas, from which most marine faunas heretofore available to paleontologists are derived, but it is particularly true for deep-sea faunas. All the bottom faunas in the cores are of a deep-sea facies and therefore belong to the group whose history is least known.

The evolutionary and faunal changes in the Foraminifera as a whole during and since the Miocene have been so gradual that the historical aspect of faunal differences cannot be clearly distinguished from the complex of existing geographic differences. For example, the shallow-water Foraminifera now living off the coast of eastern Florida and those living in the abyss at the location of core 12 differ from each other more than the Pleistocene Foraminifera at Cornfield

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[16] Factors of geographic distribution include the areal pattern of such ecologic controls as submarine topography, chemical composition of the water, bottom conditions, turbidity, and food supply that set limits to migration.

Harbor, near Point Lookout, Md.,[17] differ from those now living off the coast of Maryland.

Because of these obstacles, our method of determining the age of the faunas and the associated sediments was the indirect one of comparing the temperatures indicated by the Foraminifera with the physical history of the Recent and Pleistocene epochs. The faunal differences related to ecology and geographic distribution were also obstacles to the direct use of the Foraminifera as agents for the detailed correlation of horizons from core to core; however, by indicating warm and cold periods that were presumably of broad geographic extent, the Foraminifera did furnish criteria that could be used along with zones of volcanic ash and peculiarities of lithology for suggested correlations, which have been worked out by Bramlette and Bradley. (See pp. 5–7.)

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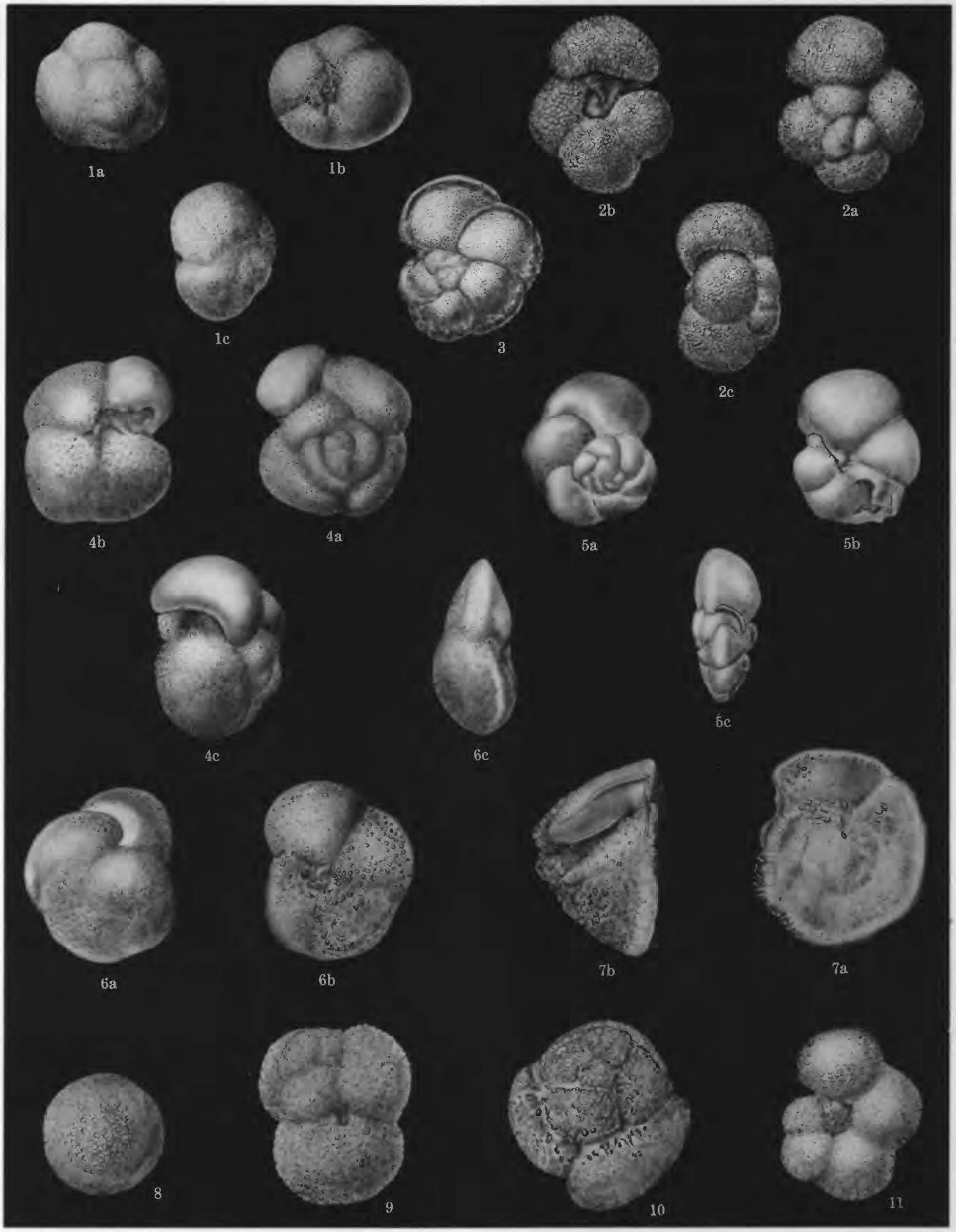
[17] Cushman, J. A., and Cole, W. S., Pleistocene Foraminifera from Maryland: Cushman Lab. Foram. Research Contr., vol. 6, pt. 4, pp. 94–100, pl. 13, 1930.

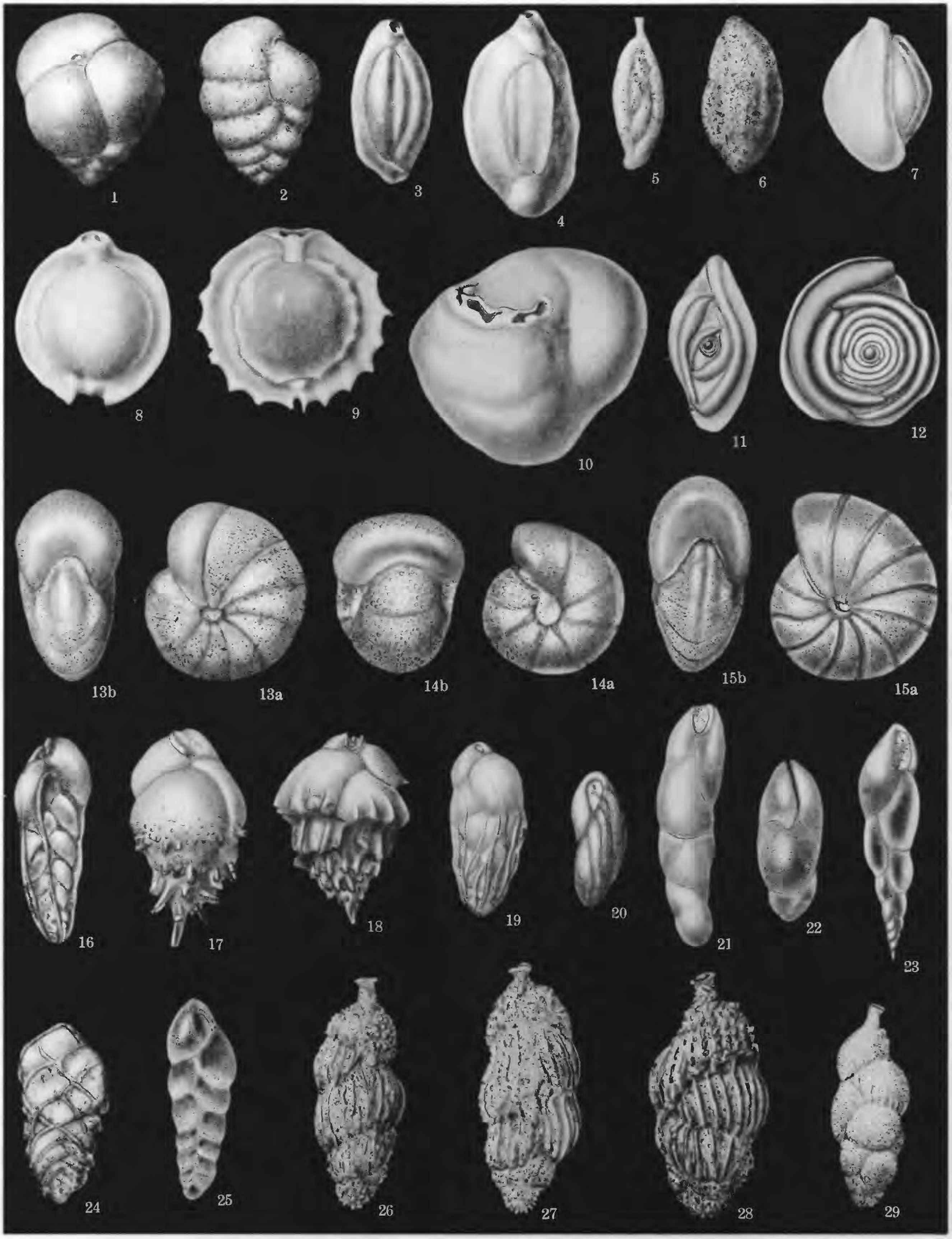
PLATES 8–10

PLATE 8

FIGURE 1. *Globigerina pachyderma* Ehrenberg. × 90. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 3, H–158.
2. *Globigerina bulloides* D'Orbigny. × 60. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 4, H–15.
3. *Globorotalia menardii* (D'Orbigny). × 40. Dorsal view. Core 3, H–166.
4. *Globigerina inflata* D'Orbigny. × 60. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 4, H–15.
5. *Globorotalia scitula* (H. B. Brady). × 70. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 4, H–15.
6. *Globorotalia hirsuta* (D'Orbigny). × 50. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 3, H–158.
7. *Globorotalia truncatulinoides* (D'Orbigny). × 50. *a*, Dorsal view; *b*, peripheral view. Core 4, H–15.
8. *Orbulina universa* D'Orbigny. × 33. Core 3, H–158.
9. *Globigerinoides rubra* (D'Orbigny). × 70. Core 3, H–160.
10. *Globigerinoides conglobata* (H. B. Brady). × 40. Core 12, H–132.
11. *Globigerinella aequilateralis* (H. B. Brady). × 50. Core 8, H–78.



PELAGIC FORAMINIFERA FROM THE NORTH ATLANTIC DEEP-SEA CORES.



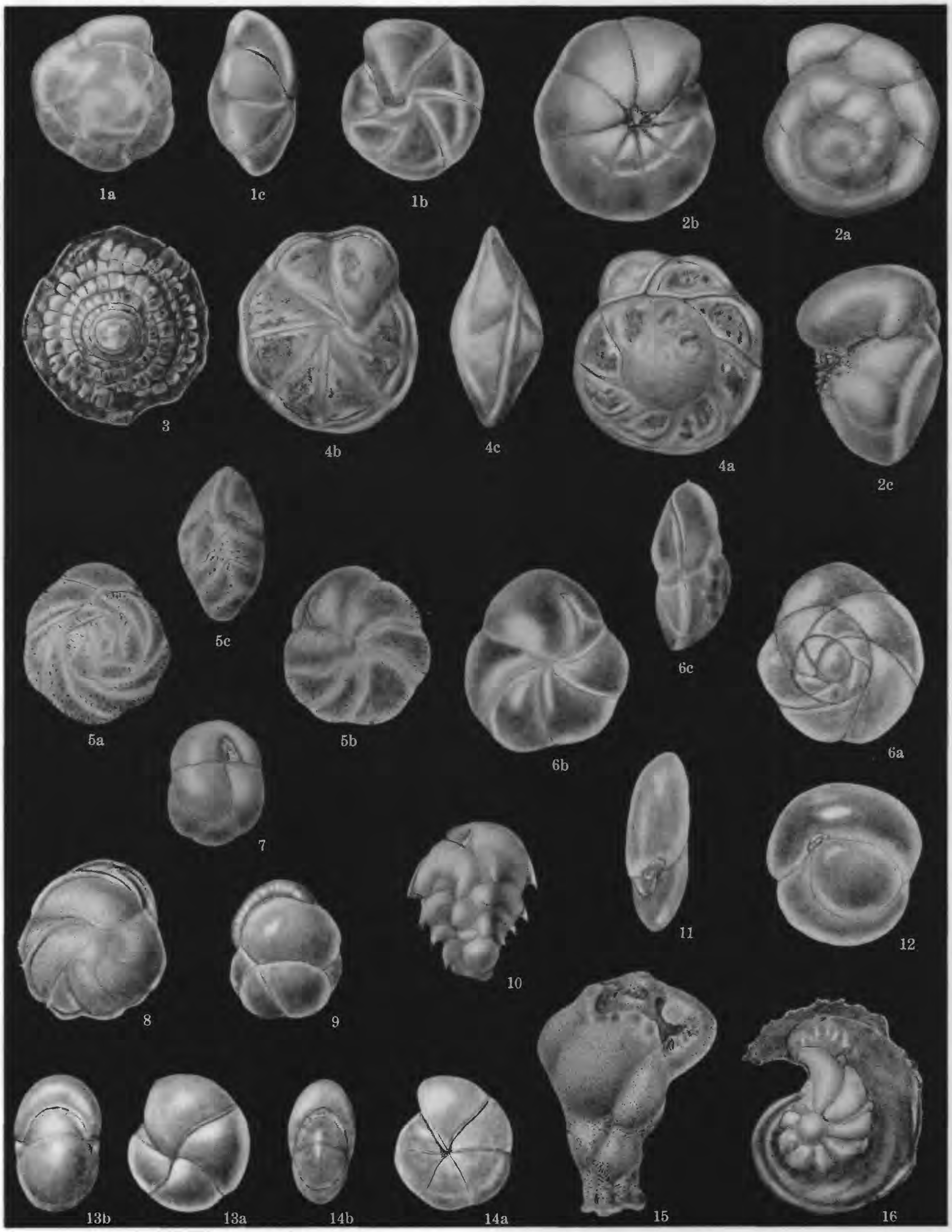
BOTTOM-LIVING FORAMINIFERA FROM THE NORTH ATLANTIC DEEP-SEA CORES.

PLATE 9

FIGURES 1, 2. *Karreriella bradyi* (Cushman). 1, Young stage, ×90; 2, adult stage, × 50. Core 7, H–48.
3. *Quinqueloculina oblonga* (Montagu). × 70. Core 6, H–33.
4. *Quinqueloculina venusta* Karrer. × 33. Core 5, H–13.
5. *Massilina tenuis* (Czjzek). × 50. Core 5, H–14.
6. *Sigmoilina schlumbergeri* A. Silvestri. × 35. Core 7, H–48.
7. *Triloculina tricarinata* D'Orbigny. × 50. Core 5, H–6.
8. *Pyrgo murrhina* (Schwager). × 50. Core 4, H–15.
9. *Pyrgo serrata* (L. W. Bailey). × 33. Core 13, H–142.
10. *Pyrgo irregularis* (D'Orbigny). × 25. Core 8, H–69.
11. *Opthalmidium acutimargo* (H. B. Brady). × 65. Core 3, H–158.
12. *Opthalmidium inconstans* (H. B. Brady). × 50. Core 8, H–71.
13. *Nonion barleeanum* (Williamson). × 65. *a*, Side view; *b*, apertural view. Core 7, H–48.
14. *Nonion pompilioides* (Fichtel and Moll). × 65. *a*, Side view; *b*, apertural view. Core 7, H–48.
15. *Nonion* sp. (?). × 65. *a*, Side view; *b*, apertural view. Core 12, H–133.
16. *Bolivinita* (?) sp. (?). × 40. Core 12, H–133a.
17. *Bulimina aculeata* D'Orbigny. × 40. Core 12, H–133a.
18. *Bulimina inflata* Seguenza. × 50. Core 13, H–140.
19. *Bulimina rostrata* H. B. Brady. × 90. Core 4, H–15.
20. *Buliminella elegantissima* (D'Orbigny). × 145. Core 3, H–171.
21. *Virgulina subdepressa* H. B. Brady. × 50. Core 4, H–30.
22. *Virgulina advena* Cushman. × 50. Core 9, H–89.
23. *Virgulina campanulata* Egger. × 80. Core 4, H–15.
24. *Bolivina* sp. (?). × 90. Core 13, H–145.
25. *Bolivina subspinescens* Cushman. × 70. Core 5, H–11.
26. *Uvigerina* sp. *A*. × 50. Core 5, H–1.
27. *Uvigerina* sp. *B*. × 65. Core 5, H–1.
28. *Uvigerina* sp. *C*. × 50. Core 13, H–156.
29. *Uvigerina* sp. *D*. × 50. Core 12, H–131.

PLATE 10

FIGURE 1. *Eponides umbonata* (Reuss). × 80. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 3, H–159.
2. *Gyroidina soldanii* D'Orbigny. × 50. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 4, H–15.
3. *Patellina corrugata* Williamson. × 120. Core 8, H–78.
4. *Epistomina elegans* (D'Orbigny). × 50. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 7, H–48.
5. *Pulvinulinella* sp. *A*. × 90. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 3, H–158.
6. *Pulvinulinella* sp. *B*. × 130. *a*, Dorsal view; *b*, ventral view; *c*, peripheral view. Core 3, H–158.
7. *Cassidulina subglobosa* H. B. Brady. × 90. Core 5, H–1.
8. *Cassidulina laevigata* D'Orbigny. × 65. Core 13, H–156.
9. *Cassidulina crassa* D'Orbigny. × 120. Core 12, H–130.
10. *Ehrenbergina serrata* Reuss. × 60. Core 5, H–6.
11. *Chilostomella ovoidea* Reuss. × 70. Core 9, H–79.
12. *Sphaeroidina bulloides* D'Orbigny. × 130. Core 5, H–1.
13. *Pullenia sphaeroides* D'Orbigny. × 65. *a*, Side view; *b*, apertural view. Core 7, H–48.
14. *Pullenia quinqueloba* (Reuss). × 70. *a*, Side view; *b*, apertural view. Core 13, H–135.
15. *Rupertia stabilis* Wallich. × 25. Core 8, H–69.
16. *Laticarinina pauperata* (Parker and Jones). × 50. Core 7, H–48.



BOTTOM-LIVING FORAMINIFERA FROM THE NORTH ATLANTIC DEEP-SEA CORES.

INDEX

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

PART 3. DIATOMACEAE

By K. E. LOHMAN

INTRODUCTION

This report is one of a series bearing on different phases of the investigation of the deep-sea cores collected in the North Atlantic by C. S. Piggot in 1936. (See Foreword of this professional paper.) Its scope is confined to the diatoms found in the cores. The report is divided into two parts. The first part deals with the distribution of diatoms in the cores, with a discussion of their ecologic and geologic significance; the second part gives a systematic description of the diatoms. The geographic location of these cores is shown on plate 1 in part 1 of this professional paper.

COLLECTION OF SAMPLES

During the winter of 1936–37, 67 samples were selected from the cores at the Geophysical Laboratory in Washington by W. H. Bradley, of the Federal Geological Survey, and myself. The location in the core of each sample and the location of all samples taken by the different investigators studying the material were carefully plotted by Mr. Bradley on a photographic chart that he had prepared. Portions sawed from pieces of the core were stored in labeled screw-cap bottles for future study. As the core had dried sufficiently, it was possible to get solid pieces, which reduced the possibility of contamination from neighboring parts of the core to a minimum. Although each sample was examined with a 10 × hand lens as it was collected, only the large discoid diatoms could be seen and then only when fairly abundant. The large amount of fine material present or the abundance of Foraminifera generally made it impossible to determine by inspection with a hand lens which sample contained diatoms.

Core 5 was sampled first at intervals ranging from 9 to 40 centimeters. The 14 samples from this core were prepared and studied before further sampling was done in an attempt to determine the justifiable frequency of sampling for the other cores. Diatoms were found in only 4 of the 14 samples collected from this core, and all were in the upper half.

In the meantime, M. N. Bramlette, who collected at short intervals from all the cores for his lithologic studies, had looked at the whole lot under the microscope and had noted, among other things, the presence or absence of diatoms in each sample. The results of Mr. Bramlette's preliminary examination served as an excellent guide for sampling the remainder of the cores, and acknowledgment is here made to him for the very material saving in time effected by his help. Mr. Bramlette reported no diatoms from cores 8 and 11, and therefore they were not sampled by me.

The location of the samples collected, the numbers assigned to them for use in this report, to which reference will be made frequently, their permanent Federal Geological Survey diatom locality numbers, and the presence or absence of diatoms is indicated in the following table:

TABLE 8.—*Locations and numbers of the diatom samples*

Core No.	Location of station		Depth of water (meters)	Sample No.	Position of sample in core, in centimeters below top	Diatoms present (+) or absent (−)	U.S G.S. diatom locality No.
	Lat. N.	Long. W.					
3	46°03′00″	43°23′00″	4,700	L–1	5–8	+	2863
				L–2	40–48	+	2864
				L–3	81–89	+	2865
				L–4	130.5–137	+	2866
				L–5	185–187	+	2867
					190–192		
				L–6	233–238	+	2868
				L–7	253–257	+	2869
4	48°29′00″	35°54′30″	3,955	L–8	7.5–9.5	+	2831
				L–9	29–33	−	2832
				L–10	74–79	+	2854
				L–11	83–87	−	2833
				L–12	132–136	−	2834
				L–13	177–179	−	2835
				L–14	207–210	−	2836
				L–15	264–268.5	−	2837
5	48°38′00″	36°01′00″	4,820	L–16	0–2	+	2817
				L–17	21–23	−	2818
				L–18	30–32	−	2819
				L–19	34–38	+	2830
				L–20	46–48.5	+	2820
				L–21	58–61	−	2821
				L–22	95–99	−	2822
				L–23	111–113	+	2823
				L–24	124–126	−	2824
				L–25	158–159	−	2825
				L–26	203–205	−	2826
				L–27	225–228	−	2827
				L–28	262–264	−	2828
				L–29	277–281	−	2829
6	49°03′30″	32°44′30″	4,125	L–30	0–4.5	+	2838
				L–31	38.5–42	+	2839
				L–32	81.5–85	+	2840
				L–33	118–122	+	2841
				L–34	152–158.5	−	2842
				L–35	183–188	+	2892
				L–36	200–203	−	2843
				L–37	226–230	+	2893
				L–38	244–248	−	2844
				L–39	275–281	+	2894

TABLE 8.—*Locations and numbers of the diatom samples*—Con.

Core No.	Location of station		Depth of water (meters)	Sample No.	Position of sample in core, in centimeters below top	Diatoms present (+) or absent (−)	U.S.G.S. diatom locality No.
	Lat. N.	Long. W.					
7	49°32′00″	29°21′00″	3, 250	L–40	3. 5–7	+	2845
				L–41	55–58	−	2846
				L–42	94–96	−	2847
				L–43	119–123	−	2848
				L–44	158–161	+	2849
				L–45	183–187	−	2850
				L–46	190–192. 5	+	2853
				L–47	233–237	−	2851
				L–48	258–262	−	2852
9	49°40′00″	28°29′00″	3, 745	L–49	0–6. 5	+	2855
				L–50	47–53	+	2856
				L–51	108–114	+	2857
				L–52	142–151	+	2858
				L–53	178–188	+	2859
				L–54	206–213	+	2860
				L–55	246–250	+	2861
				L–56	267–272	+	2862
10	49°45′00″	23°30′30″	4, 190	L–57	29–33	−	2870
				L–58	80–86	+	2871
				L–59	86–89	+	2872
				L–60	233–237	+	2873
				L–61	258–263	+	2874
12	49°37′00″	13°34′00″	3, 230	L–62	0–5	+	2875
				L–63	30. 5–33	+	2876
				L–64	90. 5–95	−	2877
13	49°38′00″	13°28′00″	1. 955	L–65	0–7	+	2878
				L–66	141–143	−	2879
				L–67	182–187. 5	−	2880

PREPARATION OF MATERIAL

All the samples were given as nearly as possible the same treatment in the cleaning and concentrating operations in order that the relative abundance of species from the different samples would be comparable. All possible precautions were taken to prevent contamination from other samples or from outside sources. Briefly, the method used was as follows:

All outside (possibly contaminated) material was removed from each sample with a knife (washed between samples), leaving a small block with a volume of about 2 cc. This was boiled in 1:1 hydrochloric acid for about 30 minutes to remove calcareous and other acid-soluble constituents and to disintegrate the material. The remaining acid, various chlorides in solution, and fine clastic material in suspension were removed by repeated decantations after definitely timed settling periods. The coarse fraction, which had a more rapid settling rate than the diatoms, was removed by reversing the process. At this stage in the process the samples were carefully examined for diatoms, merely to determine their presence or absence. Several large drops of the concentrated residue were removed with a clean pipette and examined under a microscope. Those showing no diatoms or diatom fragments were discarded as barren.

Organic matter was removed by boiling the above residue in concentrated sulphuric acid until it was well blackened and then adding granular sodium nitrate. Another series of timed decantations removed the acid and the remaining fine clastic material. In some of the samples containing a large percentage of clay, the boiling in sulphuric acid caused a pronounced flocculation, which was dispersed by adding 20 cc. of concentrated sodium hydroxide solution to one of the decantations. Contrary to popular belief, diatoms are not visibly affected by standing in cold sodium hydroxide solutions of medium strength for more than a year. In the treatment described here the diatoms were exposed to the caustic solution for a few hours at the most.

The residue from the above procedure was snow white and consisted of diatoms, radiolaria, sponge spicules, volcanic ash, and quartz and other resistant minerals, all of which were presumably present in the original sample. This was separated into a coarse and a fine fraction by short-time settling and decantation and bottled for study. The fine fraction contained most of the diatoms and fine ash particles whereas the coarse fraction contained the heavy minerals, quartz, radiolaria, coarse ash particles, and in some fractions a few very large diatoms. A drop of 40-percent formaldehyde solution was added to each bottle to prevent the growth of a mold, which, by some strange quirk of nature, can prosper on freshly washed diatoms and distilled water.

During the preparation described above, every effort was made to arrange the timing of the decantations so that few, if any, small diatoms were lost. This necessarily resulted in a final concentrate that still contained a little clastic material, but this was deemed of much less importance than the preservation of the original relative abundance of the diatoms as nearly as possible. The "beautifully cleaned material" of many diatomists is nearly always obtained at the cost of losing some of the smaller diatoms.

METHOD OF STUDY

As a result of the cleaning and concentrating operations described above, 29 samples were discarded as barren, leaving 38 samples containing diatoms in varying amounts. A total of 66 strewn slides mounted in Hyrax were made of the 38 samples, using 18-mm. round cover glasses. These were systematically traversed with a mechanical stage under a magnification of 350 diameters, and with sufficient overlap so that no part of the slide was missed. Diatoms were recorded in terms of the coordinates of the mechanical stage. A total of 380,000 separate fields were examined.

In addition, a number of arranged group slides on which the diatoms were individually selected and mounted under the microscope by means of the mechanical finger were prepared, primarily for convenience in making the photomicrographs used to illustrate this report.

The frequency of occurrence of each species on a slide was observed and recorded for each slide and furnished the basis for the fourfold grouping into abundant, common, frequent, and rare, indicated on the check list of species given in table 9.

TABLE 9.—*Distribution and relative abundance of diatoms from* Lord Kelvin *cores, North Atlantic Ocean*

[× Now living in North Atlantic Ocean. Ecology: M, Marine; B, brackish water; F, fresh water; N, neritic; O, oceanic; C, cold; T, temperate; W, warm. Relative abundance: R, Rare; F, frequent; C, common; A, abundant]

	Core no.			3							4		5				6							7			9								10				12		13
	Sample no.			L–1	L–2	L–3	L–4	L–5	L–6	L–7	L–8	L–10	L–16	L–19	L–20	L–23	L–30	L–31	L–32	L–33	L–35	L–37	L–39	L–40	L–44	L–46	L–49	L–50	L–51	L–52	L–53	L–54	L–55	L–56	L–58	L–59	L–60	L–61	L–62	L–63	L–65
	Depth below top of core (centimeters)			5–8	40–48	81–89	130.5–137	185–192	233–238	253–257	7.5–9.5	74–79	0–2	34–38	46–48.5	111–113	0–4.5	38.5–42	81.5–85	118–122	183–188	226–230	275–281	3.5–7	158–161	190–192.5	1–6.5	47–53	108–114	142–151	178–188	206–213	246–250	267–272	80–86	86–89	233–237	258–263	0–5	29.5–33	0–7
Melosira granulata (Ehrenberg) Ralfs ×	F		T										R											R		R															
sulcata (Ehrenberg) Kützing ×	M	N	T–C	R	R	R	R	R	F	R			R	R		R	R	R	F	R	R				F		R	R	R		R		R	R			F	R	F	F	F
Podosira stelliger (Bailey) Mann ×	M	N	T			R																				R															F
Endictya oceanica Ehrenberg	M	O	W																											R											
robusta (Greville) Hanna and Grant	M	N	C		F	F	F		R			R	R	F		R	F	F	R								R	F	F		R			R		F					
Thalassiosira baltica (Grunow) Ostenfeld	B	N	C–T			R	R																																		
decipiens (Grunow) Joergensen ×	M	N	T	R	R									R				F											F												
Stephanodiscus astraea (Ehrenberg) Grunow	F–B		T																															R							
Coscinodiscus excentricus Ehrenberg ×	M	O	W	R	R	R	R		R			F			F			R	R	F		C		R			R	R	F	F	R	F		F	R		R	R			F
lineatus Ehrenberg ×	M	N	W	R	R	R	F					F		R	F		C	F	R	F		C					R	R	F	F		R	F	F		F	R		F		C
circumdatus Schmidt	M		W														F																								
stellaris Roper ×	M	O	C																										R	R											
africanus Janisch	M	N	W				R																						R			R									
argus Ehrenberg	M	N	W															R											R												
asteromphalus Ehrenberg	M	N	C–W		C	F	R																							R		R	R	R							
convexus Schmidt	M	?	?				R	R																			R	F	F	C		R		R		F			F		
decrescens Grunow	M	N	C																	R								R													
kurzii Grnnow	M	?	?									F																		R											
marginatus Ehrenberg ×	M	N	W–T	R	F	F	F			R	R	R		C	R			F	C	F									F	F		F	F	F	R	C	R				
nodulifer Schmidt ×	M	N	W		F		F		R									R											F	R			R			R					R
oculus-iridis Ehrenberg var. borealis (Bailey) Cleve	M	N–O	C	F	A	A	A		C	F		F	R	F				R	F	R		F					R		F	A		A			R	F	R		R		
radiatus Ehrenberg ×	M	N–O	W		R	R	F	R	F	F		F	R	F		R	F	F	F	F		F			R		R			F		C	R	F	R	C			F		F
bicurvulatus Lohman, n. sp	M	----	----		R		R										R												R	R		R				R	R				
crenulatus Grunow var. nodulifer Lohman, n. var	M	----	----														R												R	R											
curvatulus Grunow ×	M	O	T		R													R												F		F									
curvatulus var. *minor* (Ehrenberg) Grunow	M	O	T				R																							F											
denarius Schmidt	M–B	N	T?		R	R	F			R			R	R	R			R	R	F		F							R			R						R			
divisus Grunow	M	N	T				F		R			F			R		F	F		F		F					R		F	R		F		R		F	R				F
subtilis Ehrenberg	M	N	C			R	F		R																																
Actinocyclus curvatulus Janisch	M	N?	T?														R										R	R	F	R					R		R				R
octonarius Ehrenberg (=A. ehrenbergii Ralfs) ×	M	N	T		F	F	C					F																	F			R									R
Roperia tessellata (Roper) Grunow	M	N–O	T–W		R		F		R			R					F												R	R											F
Hemidiscus cuneiformis Wallich *sensu lato*	M	N–O	W	R	F		C		F								F										R		F	R		R				F					C
Asteromphalus roperianus Ralfs var. atlanticus Castracane	M	O	T																													R									
Actinoptychus bipunctatus Lohman, n. sp	M																R	F										R	R	F		F				R					
campanulifer Schmidt	M	?	W?																																				R		R
senarius Ehrenberg (= A. undulatus of authors) ×	M	N	W–T									F				R		R	R			R								R											
Chaetoceros atlanticum Cleve ×	M	O	C														R													F											
Rhizosolenia bergonii H. Peragallo ×	M	O	W																														R								
styliformis Brightwell ×	M	O	C–W		F	R	F		R								F	R				F										R									
Rhaphoneis surirella (Ehrenberg) Grunow)	M–B	N	W																																						R
Thalassiothrix longissima Cleve and Grunow ×	M	O	C	F	F	F	A		R	R	R	C	R	C	F	F	A	A	C	F		C					R	F	C	C	R	C	F	C		R		R			
Eunotia praerupta Ehrenberg var. bidens (W. Smith) Grunow	F		T																				R																		
Pseudo-Eunotia doliolus (Wallich) Grunow	M	N	W									R										R							R	R											
Rhoicosphenia curvata (Kützing) Grunow	F–B		T									R																													
Navicula pennata Schmidt	M	N	W		R																																				R
Diploneis interrupta (Kützing) Cleve	M–B	N	C–W																			R																			
smithii (Brébisson) Cleve	M	N	C–W																										R								R				
weissflogii (Schmidt) Cleve	M	N	T–W				R																																		
Pleurosigma naviculaceum Bréhisson	M	N	W																																				R		F
Nitzschia panduriformis Gregory	M–B	N	T																																			R			
marina Grunow	M	N?	C–W					F				F					F	F				F							R			R				R					R

DISTRIBUTION OF DIATOMS IN THE CORES AND THEIR ECOLOGIC SIGNIFICANCE

The distribution of samples in the cores and the relative abundance of the diatoms in them are shown graphically in plate 11. The diatom occurrences were extremely spotty, for which no adequate explanation was found as a result of this investigation. In cores 3, 6, and 9, diatoms were fairly well distributed throughout, although in each core they were more abundant in the upper parts. Cores 3 and 9 were the only ones from which every sample collected contained diatoms, and core 9 was the most highly diatomaceous of all. Parts of this core are really impure diatomite. In addition to the three mentioned above, cores 7 and 10 contained a few diatoms in the lower part. The other cores contained diatoms only in the upper parts. The barren samples contained Foraminifera in varying degrees of abundance, some ostracodes, coccoliths, radiolaria, sponge spicules, and molluscan fragments, clastic material ranging from extremely fine clay to coarse sand and pebbles, and a considerable amount of volcanic ash which was restricted to definite zones. As these constituents have been studied by other investigators, they will not be considered here.

The diatom flora from the cores consists of 52 species and varieties distributed, with respect to geologic age, as follows:

Recent only	12
Recent and fossil	36
Fossil only (?)	1
New species and varieties	3
	52

The only diatom in the core (aside from the two species and one variety here described as new) that is not known definitely from floras living today is *Coscinodiscus convexus* Schmidt, described originally from Miocene rocks on the island of Barbados[1] and also reported from middle Miocene rocks in California by Hanna.[2] Heiden and Kolbe[3] reported this species from Observatory Bay, Kerguelen, but did not state whether or not the diatom was in a living state when found. It was found commonly to rarely in most of the samples from core 9, but no geologic significance could be inferred from this occurrence. The remainder of the species are either Recent only or are found both in living material and in fossil beds ranging from Cretaceous to Pleistocene. Therefore, no geologic age can be assigned to any parts of the core purely on the basis of the diatoms.

An analysis of the ecologic conditions represented by the diatom flora proved much more fruitful.

Of the 52 species and varieties of diatoms found in the 38 diatomaceous samples from the cores, only 17, or 33 percent, have been reported by Lebour,[4] as living in the North Atlantic at the present time. These have been indicated in the first column of the check list. Although it is true that the 67 percent that are missing from the cores include many plankton diatoms that are only slightly silicified and hence might not have been preserved in the sediments, the fact remains that some of these slightly silicified plankton diatoms were found. *Chaetoceros atlanticum* Cleve, a planktonic diatom of this type, was found in an excellent state of preservation in the top of core 6 and in a sample taken 142–151 centimeters below the top of core 9. *Rhizosolenia styliformis* Brightwell, another species of the same type, was found at various depths in three cores down to 238 centimeters below the top. Furthermore, many of the species in the missing 67 percent are heavy-walled, massive species belonging to the genera *Biddulphia*, *Triceratium*, and *Hemiaulus*, which would have been preserved had they been present.

Diatoms, particularly the planktonic species, are necessarily so constructed that they have a very large surface per unit weight and hence are able to float in the water. Their settling time in 2 to 3 miles of sea water, turbulent in the upper part and having relatively high density and viscosity in the lower part, must be very long. The large number of variables present, many of which are unknown, make any computation of the settling time uncertain, but it must be measured in hundreds of years. If this is true the difference between the flora from the cores and that living in the overlying sea today is not so surprising as it appears to be at first sight. Apparently many of the species found at present in the upper waters of this part of the North Atlantic are not deposited on the sea floor directly beneath but are carried away by currents and deposited elsewhere.

This idea is greatly strengthened by the fact that a very large percentage of the diatoms from the cores are warm-water forms that thrive in subtropical and even in tropical waters today and were probably introduced into the North Atlantic by currents such as the northward-flowing Gulf stream.

In order to obtain some roughly quantitative data that would lead to an approximate determination of the origin of the diatoms found in the cores, three columns giving the ecology have been included in the check list, table 9.

In these columns, the second, third, and fourth, an attempt has been made to list the broader subdivisions of ecologic conditions into which the living counterparts of the diatoms from the cores are found today. The type of water (marine, brackish, or fresh) in which the species lives today is indicated in the second column. The type of environment with respect to the coast line, oceanic (living and reproducing in the open sea) or neritic (living and reproducing near the coast), is indicated in the third column. In the fourth column are listed the dominant temperature facies for each species in a threefold qualitative classification of warm, temperate, and cold. In all three columns species that are found living in two or more ecologic subdivisions are so indicated; for example, C–W indicates that a species is more or less indifferent to considerable temperature differences and can prosper in all types of water from cold to warm.

The distribution of species with respect to the ecologic facies represented is summarized according to two methods of approach in table 10. In the first column on the right, the percentage of the total number of species and varieties found (52) is given for each classification. In the second column on the right the percentage of the total number of individuals in each classification is given. This second column has been computed from the data given in the check list, weighting the different diatoms according to their abundance as follows: R (rare)=1; F (frequent)=3; C (common)=6; and A (abundant)=10. These figures are purely arbitrary but represent the order of magnitude of the relative abundance and certainly give a much more accurate ecologic census than the unweighted figures in the first column.

The high percentage of marine species is to be expected, as the nonmarine forms are obviously accidentally introduced, either by ocean currents carrying fresh-water and brackish-water forms out from the mouths of rivers or by floating icebergs.

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[1] Schmidt, Adolf, Atlas der Diatomaceenkunde, pl. 60, fig. 15, 1878.

[2] Hanna, G. D., The diatoms of Sharktooth Hill, Kern County, California: California Acad. Sci. Proc., 4th ser., vol. 20, No. 6, p. 179, pl. 6, figs. 2, 3; pl. 7, fig. 1, 1932.

[3] Heiden, Heinrich, and Kolbe, R. W., Die marinen Diatomeen, in Von Drygalski, E., Die deutsche Sudpolar-Expedition 1901–1903, Band 8, Botanik, Heft 5, p. 497, 1928.

[4] Lebour, M. V., The planktonic diatoms of northern seas, Ray Soc. Mon. 116, 244 pp., 1930.

TABLE 10.—*Ecologic census of the cores as a whole*

	Percent (unweighted, based on number of species)	Percent (weighted according to relative abundance)
A. Type of water:		
Marine	82. 8	96. 8
Marine and brackish	7. 7	2. 5
Brackish	1. 9	. 2
Brackish and fresh	3. 8	. 2
Fresh	3. 8	. 3
	100. 0	100. 0
B. Relation to coast:		
Neritic	52. 0	45. 9
Oceanic	19. 2	23. 0
Neritic and oceanic	7. 7	23. 7
Indeterminate	21. 1	7. 4
	100. 0	100. 0
C. Temperature:		
Warm	28. 8	28. 6
Warm-temperate	7. 7	9. 5
Temperate	27. 0	14. 6
Temperate-cold	3. 8	5. 2
Cold	15. 4	32. 0
Cold to warm	7. 7	4. 1
Indeterminate	9. 6	6. 0
	100. 0	100. 0

The relatively high percentage of neritic forms is much more significant, as most of the diatoms constituting the present-day plankton of the North Atlantic are oceanic forms.

The distribution of different temperature facies for the cores as a whole shows a slight predominance of cold-water forms, although the percentage of warm-water forms is high for the latitude in which the cores were taken.

In order to show the change in the various ecologic factors from core to core the percentages of the different classifications were determined for each core, weighted according to relative abundance by the method used above. The results are shown in table 11.

The presence in core 7 of only five species, represented by a very small number of individuals, makes the percentages from this core erratic and misleading. For this reason core 7 will not be considered in the discussion to follow.

In all the cores the percentage of neritic species is much higher than the percentage of oceanic species. Furthermore, there is an increase in the percentage of neritic species going from core 3 to core 13, that is, from west to east. The percentage of oceanic species is much less in the eastern cores than in the western ones.

The change in temperature indicated by the diatoms is equally striking. The percentage of warm-water forms increases from west to east, with an even more rapid decrease in the percentage of cold-water forms in the same direction.

One of the most striking features on the profile across the North Atlantic along the line of the cores (see fig. 1) is the sharp mid-Atlantic ridge, which at that locality is known as the Faraday Hills. It seems reasonable to believe that such a pronounced topographic feature must affect ocean currents, at least in the immediate vicinity. To test this hypothesis with the data at hand, the percentages of diatoms falling in the last two groups (relation to coast and temperature) were determined and weighted according to the method

TABLE 11.—*Ecologic census by cores, percent, weighted according to relative abundance*

	Core 3	Core 4	Core 5	Core 6	Core 7	Core 9	Core 10	Core 12	Core 13
A. Type of water:									
Marine	96	98	92	95	75	98½	97	100	98
Marine and brackish	3	--------	6	5	--------	1	3	--------	2
Brackish	1	--------	--------	--------	--------	--------	--------	--------	--------
Brackish and fresh	--------	2	--------	--------	--------	½	--------	--------	--------
Fresh	--------	--------	2	--------	25	--------	--------	--------	--------
	100	100	100	100	100	100	100	100	100
B. Relation to coast:									
Neritic	45	47	49	48	50	39	54	56	60
Oceanic	17	25	31	30	12	28	9	--------	8
Neritic and oceanic	36	18	18	16	12	20	27	22	30
Indeterminate	2	10	2	6	26	13	10	22	2
	100	100	100	100	100	100	100	100	100
C. Temperature:									
Warm	22	25	24	30	25	27	32	44	62
Warm-temperate	9	15	16	10	--------	8	14	--------	8
Temperate	13	18	11	14	37	15	14	--------	20
Temperate-cold	5	--------	6	4	38	3	7	33	8
Cold	40	35	43	35	--------	31	20	6	2
Cold to warm	9	--------	--------	4	--------	3	2	--------	--------
Indeterminate	2	7	--------	3	--------	12	11	17	--------
	100	100	100	100	100	100	100	100	100

described above and placed in two columns (table 12), one containing the percentages of all diatoms occurring west of the ridge (cores 3, 4, 5, and 6) and the other containing the percentages of all diatoms occurring east of the ridge (cores 9, 10, 12, and 13). The group for the type of water is not included as it does not appear to have any significance.

TABLE 12.—*Ecology of diatoms west and east of the Faraday Hills*

	Percent, weighted according to relative abundance	
	West of Faraday Hills	East of Faraday Hills
B. Relation to coast:		
Neritic	47	52
Oceanic	26	11
Neritic-oceanic	22	25
Indeterminate	5	12
	100	100
C. Temperature:		
Warm	25	41
Warm-temperate	13	8
Temperate	14	12
Temperate-cold	4	13
Cold	38	15
Cold-warm	3	1
Indeterminate	3	10
	100	100

The distribution shown in table 12 indicates a marked difference in the ecologic significance of the diatom floras on each side of the mid-Atlantic ridge.

The flora from the cores east of the ridge contains a much larger proportion of neritic species than the one from the cores west of the ridge. Still more obvious is the marked difference in temperature shown by the two floras. The eastern flora contains more than twice as many warm-water species as the western flora. In figure 22 the directions of ocean currents according to Schott are shown. The cores west of the mid-Atlantic ridge lie in the path of contact of the warm Gulf Stream and the cold Labrador Current, which means that a large percentage of the flora was probably introduced by the cold waters from the north. On the east side of the mid-Atlantic ridge, however, the warmer Gulf Stream is the dominant current and has undoubtedly contributed a large share of the diatoms found in cores 9 to 13, inclusive. In addition to the warm-water species introduced by the Gulf Stream, the sediments on the east side of the ridge probably received many warm-water diatoms brought northward along the European coast by a warm deep current from the Mediterranean Sea, which, according to Harvey [5] has been found by Nansen as far north as Ireland. The proportion of the warm-water species found in the cores east of the mid-Atlantic ridge that were introduced by this deeper current is not known, but it may be rather high, as the percentage of warm-water forms increases rapidly going east from the ridge.

Although the mid-Atlantic ridge may not have a pronounced effect on the dominantly surficial currents of the sea, such as the Gulf Stream, it appears highly probable that the deep-seated outflow from the Mediterranean would be largely restricted to the eastern basin of the North Atlantic by it.

The lithologic studies of Bramlette and Bradley in part 1 of this report have shown the existence of two zones of volcanic ash and four zones in which sand and

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[5] Harvey, H. W., Biological chemistry and physics of sea water, p. 116, 1928.

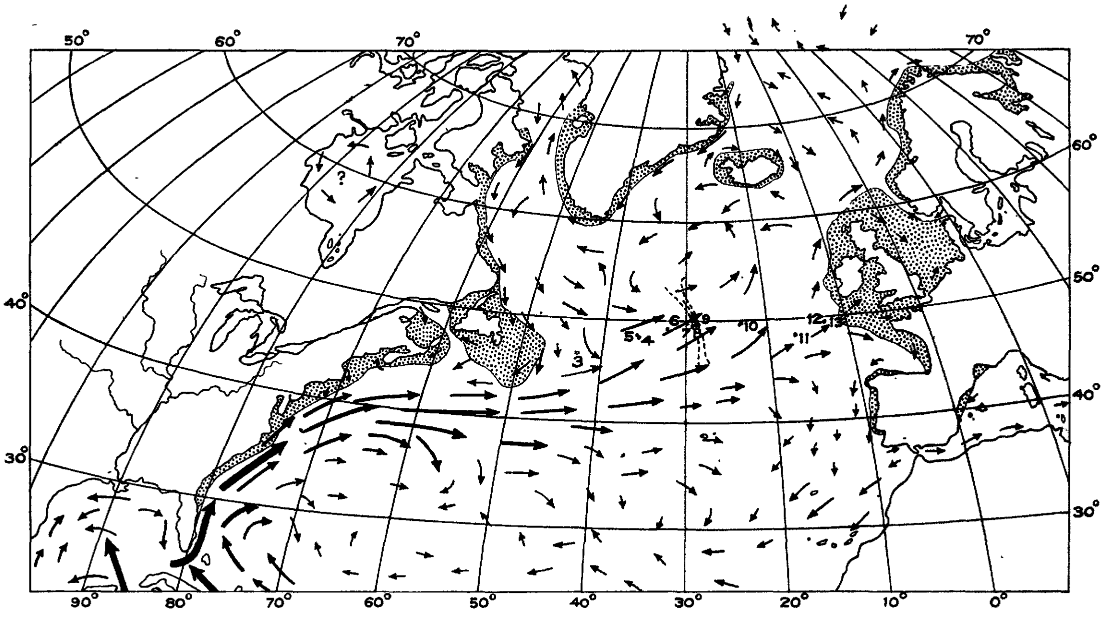

FIGURE 22.—Map of the North Atlantic Ocean showing the location of the core stations, by numbers, and the distribution of the surface currents, by arrows. The larger arrows indicate the most rapid currents and the smaller arrows slower currents. The stippled areas represent places where tidal currents predominate. (After Schott, Gerhard, Geographie des atlantischen ozeans, 2d ed., pl. 15, 1926.)

pebbles are relatively abundant and calcareous organisms are scarce. The zones of sand and pebbles are interpreted as glacial marine deposits formed probably during the latter part of the Pleistocene. The alternation of warmer and colder zones was substantiated by the independent work of Cushman and Henbest, who studied the Foraminifera from the cores. (See part 2, Foraminifera.)

In order to determine whether or not the evidence offered by the diatoms agreed with this determination, the distribution of the diatoms in each core was studied statistically by the following method, suggested by Parker D. Trask, of the Geological Survey, to whom acknowledgment is here made.

The diatoms were weighted according to relative abundance in a threefold classification of warm, temperate, and cold, for each sample. Species having more than one temperature facies represented in the check list, such as warm-temperate or temperate-cold, etc., were given equal counts for each temperature. The warm-water totals were multiplied by +1, the temperate totals by 0 and the cold-water totals by −1. The algebraic sum of the totals for the warm-water and cold-water columns was then divided by the sum of the totals for warm, temperate, and cold forms, and the resulting ratio was taken as the mean for each sample. The means, obviously, varied between the limits of +1 and −1 and were used as numerical indicators of the temperature facies represented by the diatom flora as a whole in each sample. The probable error was computed by the method of least squares in order to give some idea of the reliance (from a purely statistical point of view) to be placed on each determination.

The results are given in table 13 and are shown graphically on plate 11.

TABLE 13.—*Distribution of the diatoms according to temperature facies*

	Sample No.	Weighted totals			Mean	Probable error
		Warm	Temperate	Cold		
Core 3	L-1	4	3	7	−0.21	±0.16
	L-2	23	11	26	−.05	±.08
	L-3	10	10	23	−.30	±.10
	L-4	31	23	38	−.08	±.05
	L-5	1	1	1	.00	--------
	L-6	10	5	13	−.11	±.12
	L-7	4	3	5	−.08	±.17
Core 4	L-8	1	1	1	.00	--------
	L-10	15	12	13	+.05	±.09
Core 5	L-16	1	3	4	−.37	±.24
	L-19	10	9	13	−.09	±.10
	L-20	8	3	3	+.36	±.19
	L-23	2	2	5	−.33	±.23
Core 6	L-30	21	8	21	.00	--------
	L-31	14	13	19	−.11	±.09
	L-32	12	11	13	−.03	±.09
	L-33	12	10	5	+.26	±.12
	L-35	0	1	1	Indet.	--------
	L-37	21	7	17	+.09	±.09
	L-39	0	1	0	Indet.	
Core 7	L-40	1	1	0	+.50	±.16
	L-44	1	3	3	−.29	±.22
	L-46	0	2	0	Indet.	--------
Core 9	L-49	4	3	4	.00	--------
	L-50	2	2	8	−.50	±.24
	L-51	18	16	15	+.06	±.08
	L-52	19	13	21	−.04	±.08
	L-53	1	1	3	−.40	±.34
	L-54	17	12	19	−.04	±.08
	L-55	10	4	5	+.26	±.16
	L-56	13	6	9	+.14	±.12
Core 10	L-58	3	2	1	+.33	±.27
	L-59	16	6	8	+.27	±.12
	L-60	5	4	3	+.17	±.17
	L-61	1	3	2	−.17	±.21
Core 12	L-62	8	3	4	+.27	±.17
	L-63	0	3	3	−.50	±.29
Core 13	L-65	28	16	5	+.47	±.11

The temperature facies indicated by the diatoms from different parts of the cores when plotted by the above method bear no apparent relation to those obtained by Bramlette and Bradley from the lithologic evidence and by Cushman from foraminiferal evidence. In the most extreme disagreement, sample L-20 in core 5, the diatoms show an abrupt change to relatively warm conditions during the middle of one of the glacial stages outlined by the above authors. W. H. Bradley[6] has suggested that the temperature picture given by the diatoms may be correct but out of phase with the lithological and foraminiferal evidence on account of the much longer settling time of the diatoms. This appeared to be a promising lead, which was tested by sliding the chart for the lithologic and foraminiferal evidence (pl. 4, pt. 1) up and down over plate 11. It seems reasonable to believe that, if this hypothesis were correct, the difference in phase might be approximately the same for all the cores. When the diatom chart was superimposed upon the lithologic chart of Bramlette and Bradley and displaced downward a distance equal to 46 centimeters of the core, a good agreement was obtained in cores 5 and 12, and a fair agreement in cores 6 and 9. The displacement is in the right direction, but the amount of the displacement necessary for a reasonably good agreement seems excessive. W. H. Bradley,[7] in calculating probable rates of deposition for the sediments comprising the deep-sea cores, arrived at a figure of approximately 15,000 years per foot of sediment. The 46 centimeters difference in phase mentioned above would correspond to some 23,000 years as the difference in settling time between the coarse clastic material and the diatoms, which does not appear at all reasonable or probable.

Attempts to apply Stoke's law concerning the settling velocity of spherical particles in a viscous medium to the problem of determining the settling time of diatoms

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[6] Oral communication.

[7] Oral communication.

in sea water were abandoned, owing to the difficulty in arriving at an adequate means of correcting for the deviation from a sphere in the shape of the diatoms and in arriving at an even reasonably accurate figure for their effective density. It appeared that a figure giving more nearly the correct order of magnitude would be obtained by extrapolating an experimentally determined rate of settling under known conditions.

Experiments on the settling time of some of the diatoms from the cores were, therefore, made in a short vertical column 10 centimeters high, and an average time of 60 minutes for the smaller forms (10μ to 20μ in diameter) was found to be necessary for settling in undisturbed distilled water at 20° C. The difference in density between sea water and distilled water was disregarded, but the relatively great increase in viscosity with reduced temperature was considered in the calculation. The figures obtained were 52 years for distilled water at 5° C. and 64 years for distilled water at 0° C. These figures appear to be very small, especially when compared with the former figure of 23,000 years, but they are at least reasonable, if several factors are taken into account whose magnitudes are difficult to estimate even approximately. The figures of 52 years for water at 5° C. and 64 years for water at 0° C., are probably of the right order of magnitude for the conditions stated but are only very roughly approximate at best. Furthermore, they are tremendous extrapolations from very meager data and even if correct would be so only for undisturbed distilled water. The conditions in a deep ocean basin, such as the North Atlantic, are so much more complex than the ideal conditions under which the calculations were made that the figures when applied to the ocean basin are no longer even of the right order of magnitude. Amid all these uncertainties, however, one thing is certain. The actual settling time for the diatoms found in the cores must have been much greater than the 64 years computed for the hypothetical conditions. A large part of this increase is due to the greater density and viscosity of sea water. The net effect of turbulence in the surficial waters on the settling time is probably zero because as many diatoms would be accelerated as retarded, but the slow upwelling of deeper waters might locally retard settling. A final broad approximation of several hundred years appears to be the order of magnitude of the settling time for the diatoms in the cores from the North Atlantic. This order of magnitude, although approaching the realm of pure speculation, appears at least qualitatively reasonable.

This figure is not sufficiently precise to offer a means of adjustment for the discrepancies between the temperature variations plotted on plate 11 and those of Bramlette and Bradley, but it does offer a means of investigation of some of the anomalies that have occurred in the data presented previously.

Even if the minimum figure of several hundred years for the settling time of diatoms in deep ocean basins is accepted, it is obvious that any interpretation of the ecologic factors involved in the composition of a diatom flora found at great depth is greatly complicated by other factors. The lack of light at great depths rules out the possibility of any diatoms living attached to the bottom. The turbulence of the upper waters and various ocean currents render it extremely improbable that any diatoms living in the surface waters will be eventually deposited on the sea floor directly beneath. It follows, then, that the path of a diatom from the surface to the bottom is never along a vertical line but always along an inclined one, the direction and degree of inclination of which may change many times before the final landing. The path is further complicated by the fact that diatoms are used as food by many marine animals, and the frustules may be transported unknown distances before being ejected and allowed to begin new paths toward the bottom. Furthermore, according to Bramlette and Bradley (pt. 1, Lithology and geologic interpretations), the alkalic volcanic glass shards have apparently been reworked from the tops of mounds and ridges on the sea floor and have been drifted about over large areas by bottom currents so that they are now distributed through a considerable thickness of sediment above the original ash layers. Any such bottom currents would of course also move diatoms about over the sea floor and tend further to augment the randomness of their ultimate distribution in the sediments. All these variable factors affect the final resting place, but, unfortunately, few can be evaluated even to the order of magnitude.

Thus the discrepancy between the present-day surface diatom flora in the North Atlantic and that found in the cores is not surprising and needs no further comment.

The large percentage of warm-water species in the cores is not surprising as more than sufficient time was available for their transportation from warm habitats. Some of the diatoms necessarily started for the bottom many hundreds or possibly thousands of miles from their final resting place. Even if no other agency influenced its course, a diatom might travel many miles before it got out of the zone of influence of the Gulf Stream alone.

The fact that, even by displacing vertically the plotted temperature deviations indicated by the diatoms (pl. 11) from those obtained by other means, only partial agreement was obtained is not anomalous when the slow settling rate is considered. Although the settling rate for diatoms in still water might be nearly the same in different parts of the ocean of equal depth, it is highly improbable that the various complicating factors operated to produce the same net effect on the settling rates for the diatoms in all of the cores, or even for all the samples in any one core. For example, in

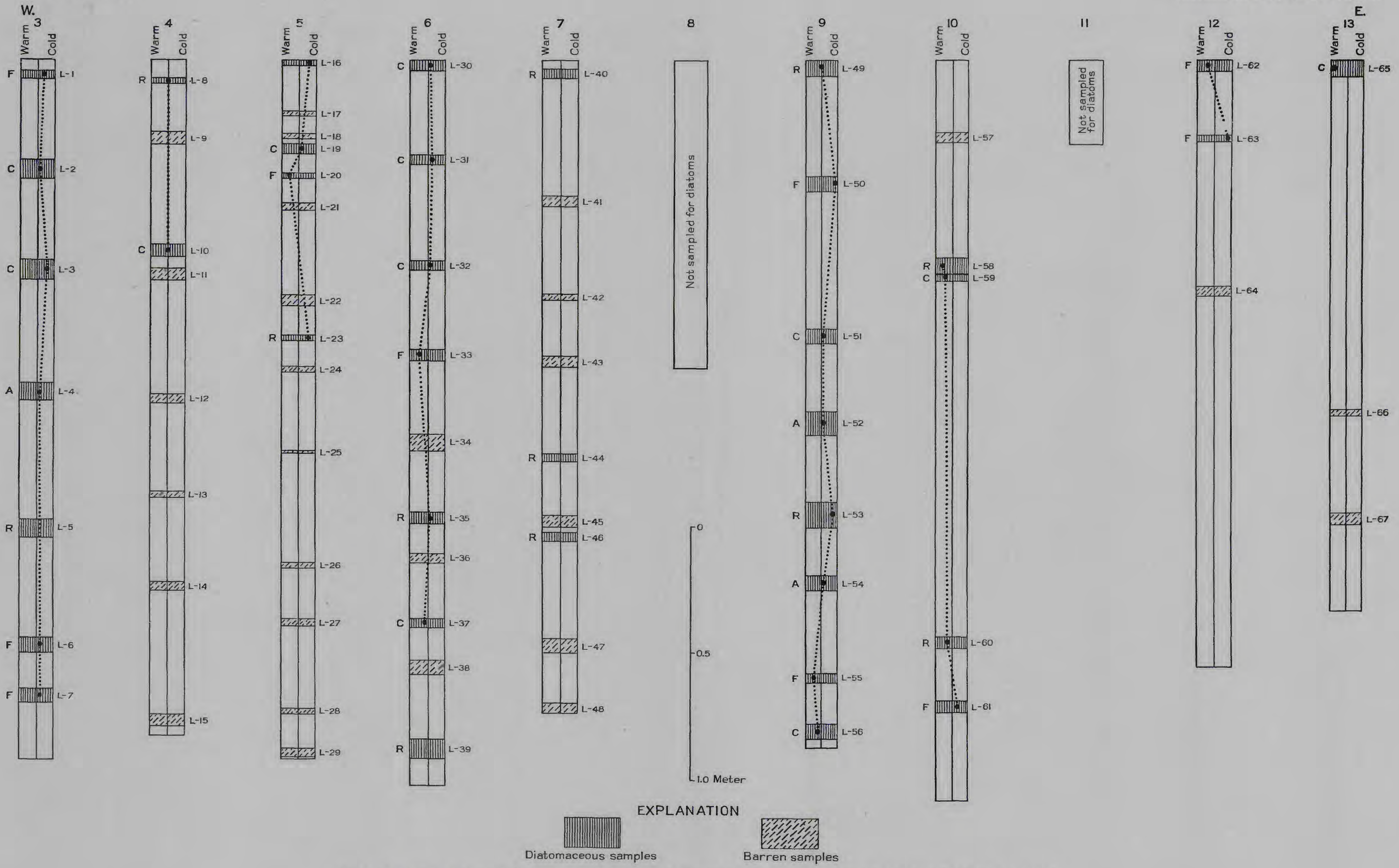

CHART SHOWING DISTRIBUTION AND TEMPERATURE SIGNIFICANCE OF THE DIATOMS IN THE CORES.

Each core is represented by a column whose length is indicated by the meter scale below column 8. The samples are indicated by patterned rectangles. At the right of each rectangle is the sample number, and at the left is a letter indicating the relative abundance of the diatoms: R, rare; F, frequent; C, common; and A, abundant. The mean temperature facies indicated by the diatom flora of each sample is indicated by the position of a dot within the sample rectangle. The distance of the dot from the center line of the column is a measure of the warmness or coldness of the diatom environment indicated by the assemblage of diatoms in the sample. As a visual aid, these dots in the rectangles are connected by dotted lines.

core 8, taken at the top of the mid-Atlantic ridge, the absence of diatoms as well as other fine constituents has been explained by Bramlette and Bradley as due to the winnowing out of the fine material from the top of the ridge during deposition by a bottom current apparently flowing eastward. This idea is strengthened by the unusually high percentage of fine material and diatoms found in core 9, taken at the eastern base of the ridge.

The maximum settling time for the diatoms is probably of the order of magnitude of several hundred years, based on the extrapolation of the laboratory experiments. This is so different from the very large figure of 23,000 years obtained by vertical shifting of the plotted temperature deviations (pl. 11) that the larger figure appears to have little significance. If this is so, the partial agreement in temperature variation between the diatom data on the one hand and the foraminiferal and lithologic data on the other may be entirely fortuitous. This possibility is strengthened by the fact that the agreement was not uniform for all the cores. Dr. Roger Revelle, of the Scripps Institution of Oceanography, has suggested [8] that the partial agreement between the two lines of evidence may not be fortuitous but may be due to changes in ocean currents caused by the advance and recession of the ice during glacial and interglacial epochs. At present (see fig. 22) the warm Gulf Stream swings in a general northeasterly direction along the line of the cores, particularly in the region from the mid-Atlantic ridge eastward. It seems highly probable that during the maximum southerly advance of the drift ice in a glacial epoch the Gulf Stream would be deflected southward. Presumably the cold Labrador Current would be weaker during a glacial epoch than during an interglacial one. Thus, although the Gulf Stream bringing the tropical forms northward would actually be deflected somewhat to the south, nevertheless the slackening of the Labrador Current might result in the deposition of a higher percentage of warm-water diatoms along the line of the cores in a glacial epoch than in an interglacial epoch. Furthermore, owing to probable lobelike extensions on the southern limit of the glacial ice in the North Atlantic, the difference in phase between diatoms and Foraminifera might be quite different in the different cores.

This idea is included here as a frank speculation, as it cannot be proved with the available data. The results of subsequent comparisons of temperature facies based on diatom and foraminiferal data may corroborate this speculation and form one method of approaching the almost untouched field of paleo-oceanography.

The most definite generalization that has come out of my study of the cores from the North Atlantic is that much more caution is needed in making geologic or ecologic interpretations of diatom floras from very deep ocean basins than from shallow basins where the chances are much greater that the organism will be deposited in nearly the identical geographic location as the one in which it lived.

SYSTEMATIC DESCRIPTIONS

The classification of diatoms has occupied the attention and exercised the imagination of many students of these organisms during more than a hundred years, and has been based primarily, by different authors, upon the mode of living, the nature and distribution of the endochrome, the presence or absence of a raphe, the external shape of the valves, the type of symmetry developed by the markings on valves, and upon various combinations of the above.

From the point of view of the paleontologist, any system of classification that depends, even in part, upon the soft (and hence usually unfossilized) parts is not satisfactory. Although relatively few of the students of diatoms have been geologists or paleontologists, nevertheless a great many workers have studied fossil diatoms in the eternal search for new and interesting species. As a result, only the classifications based on the shape, structure, and markings of the "indestructible" siliceous shell have survived.

During the last 30 or 40 years the excellent classification proposed by Schütt in Engler and Prantl's Natürliche Pflanzenfamilien, which was published in 189, has been almost universally followed. In Schütt's scheme the diatoms were divided into two suborders, the Centricae, in which the structure and markings were related to a central point, and the Pennatae, in which the structure and markings were related to a longitudinal line. Aside from minor changes in the naming of the suborders and slight rearrangement of families, little real change and almost no improvement have been introduced during the 40 years following the first appearance of Schütt's classification. In 1937 Hendey [9] proposed a new classification based in part on Schütt's earlier one but eliminating the twofold separation into centric and pennate forms. As Hendey points out, such genera as *Biddulphia*, *Chaetoceros*, *Rhizosolenia*, *Anaulus*, and *Triceratium* do not fall into either of Schütt's major divisions. For convenience Schütt and all who have followed him have included the above genera, as well as others equally unfit, in the Centricae. Hendey considers the diatoms as a class of Algae, Bacillariophyceae, comprising 1 order, Bacillariales, which is divided into 10 suborders. The 10 suborders are again divided into families and subfamilies in the customary manner. The scheme is simple and workable and removes many of the anomalies and ambiguities inherent in the older system. It is unfortunate that Hendey included in his classification only a few genera outside of those he encountred in the material from the southern seas. Although it is

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[8] Personal communication.

[9] Hendey, N. I., The plankton diatoms of the southern seas: *Discovery* Repts., vol. 16, p. 199, 1937.

true that other authors will undoubtedly add genera with which they happen to be working, it would seem better if the one who proposed a new classification would make it as complete as possible. In spite of this lack it is a most valuable contribution and is the system followed in this report.

A synonymy is given for each species, arranged according to standard practice in the Geological Survey. The description by the founder of the species is cited first; next, references to the species and genus as at present accepted, in chronologic order; and last, synonyms and misidentifications, also in chronologic order. Complete synonymies have not been attempted, as to do so would have lengthened the report out of all proportion. For the same reason, descriptions have been given only for species that were considered to be new or inadequately described elsewhere. All species are illustrated, however, and references are given either to adequate descriptions or illustrations, or both.

ALGAE

Class BACILLARIOPHYCEAE
Order BACILLARIALES
Suborder DISCINEAE
Family COSCINODISCACEAE
Subfamily MELOSIROIDEAE
Genus MELOSIRA Agardh, 1824

Melosira granulata (Ehrenberg) Ralfs

Plate 12, figure 9

Gaillonella granulata Ehrenberg, K. Akad. Wiss. Berlin Abh., 1841, p. 127, many figures, 1843.
  Ehrenberg, Mikrogeologie, pl. 33, group 2, fig. 15, 1854.
Melosira granulata (Ehrenberg) Ralfs, in Pritchard, A., History of the Infusoria, 4th ed., p. 820, 1861.
  Van Heurck, Synopsis diatomées Belgique, pl. 87, figs. 10–12, 1882.
  Schmidt, Atlas der Diatomaceenkunde, pl. 181, figs. 57, 58, 1893.
  Boyer, Acad. Nat. Sci Philadelphia Proc., vol. 78, supplement, p. 30, 1926.
  Hustedt, Die Kieselalgen Deutschlands, Osterreichs, und der Schweiz, Teil 1, p. 248, fig. 104, 1927.
  Hustedt, in Pascher, Die Süsswasser-Flora Mitteleuropas, Heft. 10, 2d ed., p. 87, fig. 44, 1930.

This fresh-water diatom was found rarely in sample L–16 from the top of core 5 and in samples L–46 from core 7. It may have been deposited from a melting iceberg or may have been carried out to sea from the mouth of some river. Its presence in the cores indicates the extent of the migration of diatom tests in the open sea. The nearest land is the Azores, some 600 to 700 miles distant.

The spelling of *Gaillonella* is variable, *Gallionella*, *Gaillionella*, and *Gaillonella* often occurring in different parts of the same paper. Hustedt,[10] noting that the word is taken from Gaillon, prefers the form here given, although in the same work he also used *Gallionella*.

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 1928–1): Length, 20μ; diameter, 7μ. From sample L–16 (U. S. G. S. diatom locality 2817), 0–2 cm. below the top of core 5.

Found rarely in samples L–16, L–40, and L–46.

Melosira sulcata (Ehrenberg) Kützing

Plate 12, figure 1

Gaillonella sulcata Ehrenberg, Die Infusionsthierchen als vollkommene Organismen, p. 170, pl. 21, fig. 5, 1838.
Melosira sulcata (Ehrenberg) Kützing, Die kieselschaligen Bacillarien oder Diatomeen, p. 55, pl. 2, fig. 7, 1844.
  Van Heurck, Synopsis diatomées Belgique, pl. 91, figs. 15, 16, 1882.
  Schmidt, Atlas der Diatomaceenkunde, pl. 178, figs. 1–5, 7–19, 22–24, 1893.
  Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 276, figs. 118, 119, 1928.
  Hendey, *Discovery* Reports, vol. 16, p. 235, 1937.
Orthosira marina W. Smith, Synopsis of the British Diatomaceae, vol. 2, p. 59, pl. 53, fig. 338, 1856.
Paralia sulcata Cleve, K. Svenska Akad. Handl., Bihang, Band 1, no. 13, p. 7, 1873.
  Schmidt, Atlas der Diatomaceenkunde, pl. 178, figs. 28, 32–39, 42–44, 46, 1893.
Orthosira sulcata O'Meara, Royal Irish Acad. Sci. Proc., vol. 2, ser. 2, p. 252, 1876.

This cosmopolitan species was found in nearly every sample examined, ranging in abundance from rare to frequent. It is fundamentally a littoral form, although sporadically found in plankton. It is fairly uniformly distributed throughout most of the cores. *Melosira sulcata* has a long geologic history. It is known from the Eocene to the Recent, and Schulz[11] has recently reported a variety, *siberica* Grunow, from a Cretaceous coral rock in Danzig Bay. In littoral deposits of various ages it is usually common to abundant. Hendey[12] has commented on its rarity in the Antarctic Ocean.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1983–1), 32 μ. From sample L–63 (U. S. G. S. diatom locality 2876), 30.5–33 cm. below the top of core 12.

Found rarely in samples L–1, L–2, L–3, L–4, L–5, L–16, L–19, L–23, L–30, L–31, L–33, L–35, L–49, L–50, L–51, L–53, L–55, L–56, and L–61 and frequently in samples L–6, L–32, L–44, L–60, L–62, L–63, and L–65.

Genus PODOSIRA Ehrenberg, 1840

Podosira stelliger (Bailey) Mann

Plate 12, figures 5, 6

Hyalodiscus stelliger Bailey, Smithsonian Contr. Knowledge, vol. 7, p. 10, 1854.

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[10] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 226, 1930.

[11] Schulz, Paul, Diatomeen aus senonen Schwamgesteinen der Danziger Bucht: Bot. Archiv. Band 37, p. 393, fig. 3, 1935.

[12] Hendey, N. I., The plankton diatoms of the southern seas: *Discovery* Repts., vol. 16, p. 235, 1937

Podosira stelliger (Bailey) Mann,, Contr. U. S. Nat. Herbarium, vol. 10, part 5, p. 242, 1907.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 286, fig. 128, 1928.

Hyalodiscus stelliger Bailey. Van Heurck, Synopsis diatomées Belgique, p. 213, pl. 84, fig. 1, 2, 1882.

Van Heurck, Treatise on the Diatomaceae, p. 448, fig. 173; pl. 22, fig. 650, 1896.

Wolle, Diatomaceae of North America, pl. 69, figs. 4–5, 1894.

Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, Supplement, p. 34, 1926.

Hendey, Discovery Repts., vol. 16, p. 236, 1937.

Podosira polita Hanna and Grant, California Acad. Sci. Proc., 4th Ser., vol. 15, p. 164, pl. 20, fig. 5, 1926.

The synonymy of this interesting diatom could be continued for some length, but enough is given above for the present purpose. Bailey's original description (first citation above) follows: "Discoid, bases with a broad margin, covered with distinct rectilinear rows of dots, arranged in sectoral groups, so as to produce a stellate appearance." The economy of words and ideas in this description and the absence of a figure may explain some of the misunderstandings that have arisen in regard to it. But the difficulties connected with the species pale into insignificance when compared with the much greater ambiguities surrounding the two genera into which it has been placed by different authors. An excellent review of these difficulties up to 1907 is given by Mann,[13] who proposed that *Podosira* and *Hyalodiscus* be combined under the older name, *Podosira*. He gave a detailed description of the combined genus, retaining what he considered to be the most important and diagnostic characteristics of each of the former genera. Mann, as well as many of his predecessors, was so obsessed by the fact that both genera possessed an umbilicus that he came to look on this as the most important characteristic of both genera, and hence consistent differences between the two were overlooked. Since individuals belonging to both genera grow singly or in groups of several frustules attached to each other by means of short gelatinous stipes, the relative size and presence or absence of an umbilicus (caused by this method of growth) is of little significance as a specific, and even less as a generic character.

Hustedt[14] has recently separated Mann's *Podosira* back into *Podosira* and *Hyalodiscus*, disregarding the variable and uncertain umbilicus as a generic characteristic. He included in *Podosira* all species in which the markings outside the umbilicus (when present) are arranged in definite radial sectors, and in *Hyalodiscus* those in which the outer markings exhibit no sectorial arrangement. Other minor generic characters separate the two, but the presence or absence of a sectorial arrangement is the most significant. This appears to be the best solution of the difficulty. Although the number of sectors is variable in *Podosira* and is of little or no value as a characteristic, the presence or absence of sectors appears to be significant and provides a definite ground for separation.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1984–2), 56μ. From sample L–65 (U. S. G. S. diatom locality 2878), 0–7 cm. below the top of core 13. Two views are given, as it is impossible to obtain sufficient magnification and resolution to show the finer markings and sufficient depth of focus to show the entire diatom sharp at the same time.

Found rarely in samples L–3 and L–46 and frequently in sample L–65.

Subfamily SKELETONEMOIDEAE

Genus ENDICTYA Ehrenberg, 1845

Endictya Ehrenberg, K. Akad. Wiss. Berlin, Ber., p. 76, 1845.
Dictyopyxis Ehrenberg, in part.
Melosira Agardh, in part.
Orthosira Thwaites, in part.
Coscinodiscus Ehrenberg, in part.

The genus *Endictya* Ehrenberg has been in a nomenclatorial tangle for many years. Rattray[15] included *Endictya* in the already large and unwieldy genus *Coscinodiscus* without observing the true nature of the differences between the two. He says, when discussing *Coscinodiscus concavus* (Ehrenberg) Gregory, "Specimens sometimes named *Endictya oceanica* differ from *C. concavus* only in showing the markings somewhat more irregular."[16] Mann[17] doubtfully followed Rattray after clearly stating the differences between the two genera. His remarks are worth repeating here:

> The most unsatisfactory member of the above combination to me is *Endictya* Ehrenb. The close resemblance of its members to the evident Coscinodiscus forms *C. robustus* Grev. and *C. marginatus* Ehrenb. is responsible for this union. But they are also close to some specimens of Stephanopyxis and besides have certain peculiarities found in no other Coscinodiscus. The valves are not flat or convex disks, but cups; not bounded by a ring-like margin, but when viewed from the valval side, encircled by a somewhat raised and pointed edge from which the valves turn vertically downward to form a band, ornamented like the face of the valve with a rugged network; so that the two valves if placed together form, without the connecting girdle, a cylindrical pill box.

By 1925 Mann[18] formally accepted Ehrenberg's *Endictya*. Hustedt[19] has also recognized the distinctness of *Endictya* and has published the best description to date.

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[13] Mann, Albert, Diatoms of the *Albatross* voyages: U. S. Nat. Herbarium, vol. 10, part 5, p. 240, 1907.

[14] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Osterreichs, und der Schweiz, Teil 1, p. 279 (*Podosira*), and p. 290 (*Hyalodiscus*), 1928.

[15] Rattray, John, A revision of the genus *Coscinodiscus* and some allied genera: Royal Soc. Edinburgh Proc., vol. 16, p. 450, 1889.

[16] Idem, p. 470.

[17] Mann, Albert, Diatoms of the *Albatross* voyages: Contr. U. S. Nat. Herbarium, vol. 10, part 5, p. 246, 1907.

[18] Mann, Albert, Marine diatoms of the Philippine Islands: U. S. Nat. Mus. Bull. 100, vol. 6, part 1, p. 75, 1925.

[19] Hustedt, Friedrich, Die Kieselagen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 296, 1928.

Endictya oceanica Ehrenberg

Plate 12, figure 3

Endictya oceanica Ehrenberg, K. Akad. Wiss. Berlin Ber., p. 76, 1845.
  Ehrenberg, Mikrogeologie, pl. 35A, group 18, figs. 6, 7, 1854.
  Schmidt, Atlas der Diatomaceenkunde, pl. 65, figs. 10, 12, 13, 1881.
  Van Heurck, Treatise on the Diatomaceae, p. 445, fig. 169, 1896.
  Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 297, fig. 136, 1928.
Endictya cribrosa Brébisson, Annals and Mag. Nat. History, ser. 2, vol. 19, p. 11, pl. 2, fig. 15, 1857.
Orthosira oceanica Brightwell, Quart. Jour. Micr. Sci., vol. 8, p. 96, pl. 6, fig. 14, 1860.
Coscinodiscus concavus Gregory, in part.

Individuals from the Atlantic cores assigned to this species have a very narrow mantle, usually about 7µ wide, and do not exhibit the secondary structure shown by Hustedt (fig. 136c, 5th citation above). Only one valve was found that could be photographed, and it is not very good. Some of the areolae in the central part of the valve have air bubbles entrapped, which makes them appear darker than the rest. Parts of the valve show evidences of corrosion, probably of a chemical rather than a mechanical origin. None of the other species present in the sample from which this came (L–52, core 9) showed evidence of chemical corrosion, and this, taken together with the fact that the species was present in no other core, suggests transportation for some considerable distance by ocean currents before deposition. It is found commonly along the coast of southern Europe, in the Black Sea, near the Philippine Islands, and generally in warmer waters than occur in the North Atlantic.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1970–16), 84µ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below the top of core 9.

Found rarely in sample L–52.

Endictya robusta (Greville) Hanna and Grant

Plate 12, figure 4

Coscinodiscus robustus Greville, London Micr. Soc. Trans., new ser., vol. 14, p. 3, pl. 1, fig. 8, 1866.
Endictya robustus (Greville) Hanna and Grant, California Acad. Sci. Proc., 4th ser., vol. 15, no. 2, p. 144, pl. 16, figs. 2, 3, 1926.
Coscinodiscus robustus Greville, Schmidt, Atlas der Diatomaceenkunde, pl. 62, figs. 16, 17, 1878.
  Rattray, Royal Soc. Edinburgh Proc., vol 16, p. 511, 1889.
  Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 258, pl. 48, fig. 4, 1907.
  Boyer, Synopsis of North American Diatomaceae, p. 54, 1926.
Coscinodiscus subvelatus Grunow. Schmidt, Atlas der Diatomaceenkunde, pl. 65, fig. 9, 1881.
Coscinodiscus kinkerianus Truan and Witt, Die Diatomaceen der Polycystinenkreide von Jérémie in Hayti, p. 13, pl. 3, fig. 1, 1888.

This species is frequently confused with *Coscinodiscus marginatus* Ehrenberg, as both are without central space or rosette and have similar markings. The principal difference between the two is the generic characteristic that defines *Endictya*, namely, that in *Endictya* the areolae do not terminate at the margin as in *Coscinodiscus* but turn abruptly and form the mantle. In valve view, the areolae forming the mantle in *Endictya robusta* have much the same appearance as the marginal striae in *C. marginatus*. In *Endictya* it is possible to focus vertically through several rows of areolae in the mantle (when seen in valve view), whereas in *Coscinodiscus* the limit is the depth of the margin. The remarkable connecting zone or girdle of *E. robusta* is a feature which immediately distinguishes it when present. Rattray's brief description [20] of this girdle is worth repeating here:

> In a Santa Monica form 0.13 mm. in diameter, discovered by Dr. Rae, the usual striated border was surrounded by a second more sharply defined but narrower band, with a slightly convex surface, and bearing delicate striae, 8 to 10 in 0.01 mm.; at one place this band is interrupted and somewhat more convex on the two sides of the break. This gives it the appearance of an elastic spring enveloping the valve.

Brun [21] has also found a specimen of *Coscinodiscus crassus* Bailey with a similar girdle, but there is no possibility of confusing *Endictya robusta* with *C. crassus* as they are different in many respects.

This cosmopolitan species was found in many samples from six of the cores and usually occurred most frequently in the upper part of each core. It is a cool-water diatom most abundant today in the northern hemisphere and has had a wide distribution since the middle Tertiary, reaching its heydey in upper Miocene time.

Diameter of figured specimen (U. S. G. S. diatom catalog, no. 1958–2), 108µ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below the top of core 9.

Found rarely in samples L–6, L–10, L–16, L–23, L–32, L–49, L–53, and L–56, and frequently in samples L–2, L–3, L–4, L–19, L–30, L–31, L–50, L–51, and L–59.

Subfamily THALASSIOSIROIDEAE

Genus THALASSIOSIRA Cleve, 1873

Thalassiosira baltica (Grunow) Ostenfeld

Plate 12, figure 11

Coscinodiscus polyacanthus var. *baltica* Grunow, K. svenska vetensk. akad. Handl., Band 17, No. 2, p. 112, 1880.
Coscinodiscus balticus Cleve. Soc. Fauna Flora Fenn. Acta, Band 8, No. 2, p. 68, 1891.
Thalassiosira baltica (Grunow) Ostenfeld, Nyt mag. naturvidensk., Band 39, Heft. 4, p. 290, 1901.
  Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 328, fig. 164, 1928.

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[20] Rattray John, A revision of the genus *Coscinodiscus* and some allied genera: Royal Soc. Edinburgh Proc., vol. 16, p. 512, 1889.

[21] Brun, Jacques, Diatomées marines fossiles ou pelagiques: Genève Soc. Physique Histoire Nat. Mém., Tome 31, pt. 2, no. 1, p. 21, pl. 20, fig. 3, 1891.

The prominent marginal apiculi, which are characteristic of this species, are well exhibited on the specimens from the cores but, unfortunately, are extremely difficult to show in a photomicrograph. The high magnification required to reproduce this tiny specimen on an adequate scale is incompatible with the depth of focus needed to show both apiculi and areolae in focus simultaneously. In the present instance this difficulty was augmented by the fact that the most nearly whole specimen found was slightly tilted in mounting.

Lebour [22] gives the following distribution for this brackish-water neritic diatom: "Southern part of North Sea, Danish seas, Cattegat, Great and Little Belts, Gulf of Finland, Gulf of Bothnia, common in the Baltic. Also recorded from Gulf of Maine and California."

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1965–4), 27μ. From sample L–3 (U. S. G. S. diatom locality 2865), 81–89 cm. below the top of core 3.

Found rarely in samples L–3 and L–4.

Thalassiosira decipiens (Grunow) Joergensen

Plate 12, figure 8

Coscinodiscus decipiens Grunow, in Van Heurck, Synopsis des diatomées Belgique, pl. 91, fig. 10, 1882.

Thalassiosira decipiens (Grunow) Joergensen, Hydrogr. biol. inv. Norwegian fjords, p. 96, pl. 6, fig. 3, 1905.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 322, fig. 158, 1928.

Hendey, Discovery Repts., vol. 16, p. 238, pl. 11, fig. 9, 1937.

Thalassiosira gelatinosa Henson, Komm. Wiss. untersuchung deutschen Meere in Kiel Ber., p. 87, 1887.

This species usually has very prominent marginal apiculi, but many specimens found in the cores have very faint ones. In the specimen photographed, the apiculi are present, but in order to show them it would have been necessary to focus so far down as to obscure the markings over two-thirds of the valve. The small excentric nodule that indicates the point of attachment of the gelatinous stipe that connects the frustules together to form a chain is well shown.

This species is neritic along the coast of Europe and is occasionally found in oceanic waters. It is fairly common in temperate waters in the Northern Hemisphere.

Reinhold [23] has recorded the earliest known geologic occurrence of this species from rocks doubtfully assigned to the lower Eocene near Maastricht, Netherlands.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1970–4), 30μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below and top of core 9.

Found rarely in samples L–1, L–2, and L–19 and frequently in samples L–31 and L–52.

Subfamily COSCINODISCOIDEAE

Genus STEPHANODISCUS Ehrenberg, 1845

Stephanodiscus astraea (Ehrenberg) Grunow

Plate 12, figure 2

Discoplea astraea Ehrenberg, Berlin Akad. Wiss. Ber., 1844, p. 267, 1844.

Stephanodiscus astraea (Ehrenberg) Grunow, K. Svenska vetensk. akad. Handl., Band 17, no. 2, p. 114, 1880.

Schmidt, Atlas der Diatomaceenkunde, pl. 226, figs. 1–5, 1901.

Boyer Acad. Nat. Sci. Philadelphia Proc., vol. 78, Supplement, p. 61, 1927.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 368, fig. 193, 1928.

The wide distribution of this fresh-water and brackish-water species and its rare occurrence in a marine environment suggest that its occurrence in only one sample (L–56), near the bottom of core 9, is the result of transportation from shore. Fricke [24] has reported it from Flensburg as Recent marine, but it appears possible that his specimen was also introduced into the sea from some stream. It has not been observed actually living in a marine environment. Only one specimen was found in the core and it was badly worn.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1962–1), 38μ. From sample L–56 (U. S. G. S. diatom locality 2862), 267–272 cm. below the top of core 9.

Found rarely in sample L–56.

Genus COSCINODISCUS Ehrenberg, 1838

Section EXCENTRICAE Rattray

Coscinodiscus excentricus Ehrenberg

Plate 12, figure 7; plate 13, figure 8

Coscinodiscus excentricus Ehrenberg, Berlin K. Akad. Wiss., Physical Abh., 1839, p. 146, 1841.

Smith, Synopsis of the British Diatomaceae, vol. 1, p. 23, pl. 3, fig. 38, 1853.

Ehrenberg, Mikrogeologie, pl. 18, fig. 32; pl. 21, fig. 6, 1854.

Schmidt, Atlas der Diatomaceenkunde, pl. 58, figs. 46–49, 1878.

Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 461, 1889.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 388, fig. 201, 1928.

Hendey, Discovery Repts., vol. 16, p. 242, 1937.

Coscinodiscus minor Schmidt, Atlas der Diatomaceenkunde, pl. 113, fig. 9, 1888.

Coscinodiscus labyrinthus Roper, Quart. Jour. Micr. Sci., vol. 6, p. 21, pl. 3, fig. 2a–b, 1858.

It is frequently difficult to separate this species from *Planktoniella sol* (Wallich) Schütt,[25] particularly when individuals like that shown on plate 13, figure 8 are found. This particular individual (U. S. G. S. diatom

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[22] Lebour, M. V., The planktonic diatoms of northern seas, p. 61, 1930.

[23] Reinhold, Th., Diatoms from rocks, possibly belonging to the Danian (or Lower Eocene), near Maastricht, The Netherlands: Nederland Jaarv. geologisch Bureau Jaarv., 1930, p. 17, pl. 1, fig. 12, 1931.

[24] Fricke, Friedrich, in Schmidt, Atlas der Diatomaceenkunde, pl. 226, fig. 5, 1901.

[25] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs und der Schweiz, Teil 1, p. 465, fig. 259, 1929.

catalog no. 2000–3) has very faint apiculi, which do not show in the photograph and might easily be taken for the center of *Planktoniella sol*, the slightly silicified outer portion of which is rarely found preserved in fossils. The normal form with prominent apiculi is shown on plate 12, figure 7.

Coscinodiscus excentricus ranges all through the Tertiary, and Schultz[26] has recently reported it from a coral rock of probable Cretaceous age in Danzig Bay.

Diameter of figured specimens: U. S. G. S. diatom catalog no. 1968–8, from sample L–51 (U. S. G. S. diatom locality 2857), core 9, 108–114 cm. below top, 45μ; U. S. G. S. diatom catalog no. 2000–3, from sample L–52 (U. S. G. S. diatom locality 2858), core 9, 142–151 cm. below top, 39μ.

Found rarely in samples L–1, L–2, L–3, L–4, L–6, L–31, L–32, L–40, L–49, L–50, L–53, L–58, L–60, and L–61, frequently in L–10, L–20, L–33, L–51, L–52, L–54, L–56, and L–65, and commonly in L–37.

Coscinodiscus circumdatus Schmidt

Plate 12, figure 12

Coscinodiscus circumdatus Schmidt, Atlas der Diatomaceenkunde, pl. 59, fig. 3, 1878.
Van Heurck, Synopsis diatomées Belgique, pl. 131, fig. 4, 1883.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 466, 1889.

Valve usually flat but occasionally slightly domed; without rosette or central space; diameter, 60–70μ; covered with polygonal areolae, 7 to 8 in 10μ over center three-fourths of valve, 10 to 11 in 10μ near margin; arranged in nearly straight to slightly sigmoid decussating rows. Border complex, consisting of narrow zone, 2μ wide, filled with fine decussate markings, 14–16 in 10μ and crossed by very narrow radial apiculi having a length equal to the width of the marginal zone and an average spacing of 3μ and with a very narrow margin having short radial striae, 11 to 13 in 10μ.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1941–2), 62μ. From sample L–30 (U. S. G. S. diatom locality 2838), 0–4.5 cm. below top of core 6.

Rattray's description (last citation above) of this diatom was apparently written from Schmidt's figure (first citation above) and not from an actual specimen and as a result is very misleading. The border appears hyaline under a dry objective but clearly shows the decussate markings when viewed under an oil immersion objective. The valve might be mistaken for *C. excentricus* Ehrenberg, as the markings on *C. circumdatus* are frequently (but not always) arranged so as to resemble *C. excentricus*. The distinctive border at once sets this species apart. A sort of pseudo rosette occurs frequently, consisting of a somewhat indefinite circlet of areolae surrounding a central one, all of which are the same size.

Although this species has been known for 50 years, it has been reported previously only from the original occurrence at Yokohama. No information is available as to the source of Schmidt's original specimen, which was collected by Gründler. Its second occurrence in the North Atlantic core is very interesting, particularly so in view of the fact that it was found frequently in one sample (L–30) from the top of core 6, and not even a recognizable fragment was found in any other sample studied.

Section LINEATAE Rattray

Coscinodiscus lineatus Ehrenberg

Plate 12, figure 10

Coscinodiscus lineatus Ehrenberg, Berlin K. Akad. Wiss., Physical. Abh., 1838, p. 129, 1839.
Ehrenberg, Mikrogeologie, pl. 18, fig. 33; pl. 22, fig. 6; pl. 35A, group 16, fig. 3; group 17, fig. 7, 1856.
Schmidt, Atlas der Diatomaceenkunde, pl. 59, figs. 26–32, 1878; pl. 114, fig. 13, 1888.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 472, 1889.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 392, fig. 204, 1928.
Hendey, Discovery Repts., vol. 16, p. 242, 1937.
Coscinodiscus ehrenbergii O'Meara, Royal Irish Acad. Proc., 2d ser., vol. 2, p. 264, pl. 26, fig. 24, 1875.

This cosmopolitan species has a world-wide distribution in the oceanic and neritic plankton of temperate and subtropical seas. Its known geological range is from Cretaceous[27] to Recent.

Most of the cores contained this diatom at various depths and in amounts ranging from rare to common.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1967–5), 89μ. From sample L–51 (U. S. G. S. diatom locality 2857), core 9, 108–114 cm. below top.

Found rarely in samples L–1, L–2, L–19, L–32, L–49, L–50, L–54, and L–60, frequently in L–4, L–10, L–20, L–31, L–33, L–51, L–52, L–55, L–56, L–59, and L–62, and commonly in L–30, L–37, and L–65.

Section STELLATAE Rattray

Coscinodiscus stellaris Roper

Plate 13, figure 2

Coscinodiscus stellaris Roper, Quart. Jour. Micr. Sci., vol. 6, p. 21, pl. 3, fig. 3, 1858.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 497, 1889.
Schmidt, Atlas der Diatomaceenkunde, pl. 164, fig. 4, 1891.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 396, fig. 207, 1928.
Lebour, Planktonic diatoms of northern seas, p. 49, pl. 1, fig. 4, 1930.

Grunow's *Coscinodiscus symbolophorus*[28] differs from *C. stellaris* in having much coarser structure. I agree with the following statement by Mann:[29]

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[26] Schulz, Paul, Diatomeen aus senonen Schwamgesteinen der Danziger Bucht: Bot. Archiv., Band 37, p. 387, 1935.

[27] Schulz, Paul, Diatomeen aus senonen Schwammgesteinen der Danziger Bucht: Bot. Archiv, Band 37, p. 390, 1935.

[28] Grunow, Albert, Die Diatomeen von Franz Josefs-Land: Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 48, p. 82, pl. D, figs. 3–6, 1884.

[29] Mann, Albert, Diatoms of the *Albatross* voyages: Contr. U. S. Nat. Herbarium, vol. 10, part 5, p. 257, 1907.

I am convinced that there is no reasonable ground for Grunow's *C. symbolophorus* as distinguished from Roper's older name *C. stellaris*. Grunow admits that the difference is one of relative fineness of marking—too slight a character for creating a new species, especially when this difference is by no means striking and many intermediate forms are obtainable.

Mann, however, in his early zeal for strict priority, tried to throw the two well-known species, *C. stellaris* and *C. symbolophorus*, into obscurity by reviving Ehrenberg's old name *pentas*. Apparently his reasoning was as follows: Starting with the defensible contention that there was less than specific difference between *C. stellaris* and *C. symbolophorus*, he lumped both into Grunow's species *symbolophorus*. Grunow, however, had taken his specific name from Ehrenberg's old genus *Symbolophora*, which had as its principal differentiating characteristic the central stellate cluster of irregular markings. Grunow was in considerable doubt as to the validity of his species, for he said, "Diese Art ist so nahe mit *C. subtilis* verwandt, dass es vielleicht besser wäre, sie als Varietät derselben zu betrachten."

Mann then selected Ehrenberg's specific name *pentas* (from *Symbolophora pentas*) and combined both *C. stellaris* and *C. symbolophorus* into *Coscinodiscus pentas* (Ehrenberg) Mann. Although it might be possible to justify this obscuring of two well-known names on the ground of strict priority, common sense dictates otherwise. He completely ignored Jörgensen's very satisfactory disposition of Grunow's doubtful species, which appeared in 1905, 2 years before Mann's paper was published. Jörgensen[30] made *C. symbolophorus* a variety of *C. stellaris*, thus preserving two useful names that have appeared in a great deal of diatom literature for over half a century. Boyer,[31] in 1927, ignored the whole dispute and retained *C. stellaris* and *C. symbolophorus* as separate species. Hustedt[32] followed Jörgensen in retaining Roper's specific name *stellaris* and making *symbolophora* a variety of it.

Although an oceanic, cool-water species common in both southern and northern seas, it occurred in only two samples in one core and then rarely.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1970–14), 62μ. From sample L–52 (U. S. G. S. diatom locality 2858), core 9, 142–151 cm. below top. Unfortunately the specimen was badly damaged in mounting, the central portion being broken and pushed below the rest of the valve.

Found rarely in samples L–51 and L–52, core 9.

Section **RADIATAE** Rattray

Coscinodiscus africanus Janisch

Plate 13, figures 4, 7, 10

Coscinodiscus africanus Janisch, in Schmidt, Atlas der Diatomaceenkunde, pl. 59, figs. 24, 25, 1878.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 534, 1889.
Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 247, 1907.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 428, fig. 231, 1928.
Heiden and Kolbe, Deutsche Südpolar-Expedition, Band 8, Botanik, Heft 5, p. 496, 1928.

Mann's explanation (see 3d citation above) of the spiral border markings in this species is open to considerable question. The spiral markings (see pl. 13, fig. 10) are distinctly visible with a 2-mm. oil-immersion apochromat (Mann says they are not visible with a 1/12-in. objective). He thought that the markings were illusory and were only seen when both valves of a frustule were in contact, and then only under low powers. Schmidt's original figure (4th citation above) is the best one published insofar as the border is concerned and closely approaches an accurate representation of this peculiar diatom. The actual structure appears to be as follows: The areolae terminate along an abrupt, irregular edge, which is the inner (toward the center) edge of an irregular space between the areolae and the radial marginal striae. This space appears hyaline, but careful focusing with a 2-mm. oil-immersion apochromat reveals tiny dots in no regular arrangement. The marginal striae are short, about 16μ in 10μ, and rounded, usually followed by another annular row of short, rounded striae offset from the first, the whole giving the appearance of a single ring of bifurcated striae. At intervals of 4μ to 5μ along the margin are short apiculi, which project outward from the margin into a narrow hyaline ring surrounding the valve. The apiculi turn abruptly at an angle of about 90° in the hyaline ring and bend downwards at an acute angle to the surface of the valve, giving the spiral appearance. Mann's idea of their illusory nature was probably due to the difficulty experienced in focusing these sloping (toward or away from the observer in valve view) apiculi. The sloping apiculi also account for the great difficulty experienced in photographing them at high magnifications. The term "apiculi" is here used loosely, as they are not apiculi in the ordinary sense but apparently markings in the hyaline outer ring.

C. africanus is a warm-water marine species and probably neritic. Its occurrence in the cores again suggests transportation for a considerable distance before deposition.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1972–1), 41μ. From sample L–4 (U. S. G. S. diatom locality 2866), 130.5–137 cm. below the top of core 3.

Found rarely in samples L–4, L–51, and L–54.

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[30] Jörgensen, E., The protist plankton and the diatoms in bottom samples, Hydrographical and biological investigations in Norwegian fjords; Bergens Mus. Skrifter, vol. 7, p. 196, 1905.

[31] Boyer, C. S., Synopsis of North American Diatomaceae: Acad. Nat. Sci. Philadelphia Proc., vol. 78, suppl., pp. 49–50, 1927.

[32] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 396, 1928.

Coscinodiscus argus Ehrenberg

Plate 13, figures 1, 3

Coscinodiscus argus Ehrenberg, K. Akad. Wiss. Berlin, Physikal. Abh. 1838, p. 129, 1839.
Ehrenberg, Mikrogeologie, pl. 21, fig. 2, 1854.
Grunow, Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 48, p. 72, 1884.
Schmidt, Atlas der Diatomaceenkunde, pl. 113, fig. 7, 1888.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 527, 1889.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 422, fig. 226, 1928.
Reinhold, Nederland. Geol. Bur. Jaarv. 1930, p. 15, pl. 1, figs. 9, 10 (?), and 11, 1931.
Coscinodiscus irradiatus Harting, K. Akad. Wetensch. Amsterdam Verh., No. 2, p. 8, pl. 1, fig. 1, 1864.
Coscinodiscus heteroporus Ehrenberg, K. Akad. Wiss. Berlin Ber., 1844, p. 265, 1845.
Schmidt, Atlas der Diatomaceenkunde, pl. 61, figs. 1, 4, 1878.
Coscinodiscus woodwardii Schmidt, Atlas der Diatomaceenkunde, pl. 61, figs. 2, 3, 1878.

Specimens with polygonal areolae (pl. 13, fig. 3) and with rounded areolae (pl. 13, fig. 1) that differed in no other particular were found in the same sample. Hustedt's figure (see 6th citation above) shows the rounded areolae; other authors have usually illustrated the form with polygonal areolae. Reinhold's figure 10 (see 7th citation above) is here questioned; as the markings are definitely fasciculate, there is apparently a central space, and what appear to be apiculi can be seen on the upper margin. These features definitely remove the specimen in question from *C. argus* and place it nearer to *C. fimbriatus* Ehrenberg. His figure 11 appears satisfactory, as does his later figure[33] from the upper Miocene of Java.

This is another species with a long geologic range. It has been found in beds of various ages from lower Eocene to the Recent, but the fossil species are much more numerous than the Recent. The evidence is at least suggestive that the heydey of this species has been reached and passed and that it is now declining toward extinction. The few Recent occurrences listed in the literature indicate that this is a distinctly warm-water marine species, although Hustedt[34] says, regarding its occurrence and distribution: "In allen Meeren verbreitet, aber vielleicht nur litoral unter anderen Diatomeen."

Diameter of figured specimens, plate 13, figure 3 (U. S. G. S. diatom catalog no. 1968–3), 77μ; plate 13, figure 1 (U. S. G. S. diatom catalog no. 1968–2), 71μ. Both from sample L–51 (U. S. G. S. diatom locality 2857), 108–114 cm. below the top of core 9.

Found rarely in samples L–31 and L–51.

Coscinodiscus asteromphalus Ehrenberg

Plate 13, figure 11

Coscinodiscus asteromphalus Ehrenberg, K. Akad. Wiss. Berlin Ber. 1844, p. 77, 1845.
Ehrenberg, Mikrogeologie, pl. 18, fig. 45; pl. 33, group 15, fig. 7, 1854.
Grunow, Akad. Wiss. Wien, Math-naturwiss. Kl., Denkschr., Band 48, p. 78, pl. 3 (C), fig. 9, 1884.
Schmidt, Atlas der Diatomaceenkunde, pl. 63, fig. 12, 1878; pl. 113, figs. 22, 23, 1888.
Van Heurck, Synopsis diatomées Belgique, pl. 128, figs. 1–3, 5, 1883.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 549, 1889.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 452, fig. 250, 1928.
Hendey, Discovery Repts., vol. 16, p. 243, 1937.
Coscinodiscus asteromphalus var. *conspicua* Grunow, in Van Heurck, Synopsis diatomées Belgique, pl. 130, figs. 1, 2, 5, 6, 1883.

The distribution in the cores of this large and ornate diatom was very peculiar. It occurred commonly to rarely in the upper half of core 3, rarely in the lower third of core 9, and nowhere else. The geologic distribution of this species is equally erratic. It occurs commonly in the Calvert formation, of middle Miocene age, in Maryland and Virginia, but has not been found in the Temblor formation, of the same age, in the Coast Ranges in California, although a very large percentage of the species in each are common to the two formations.[35] By upper Miocene time it had become rare on the Atlantic Coast[36] and common on the coast of southern California.[37] It is also a common species in upper Pliocene rocks in the Kettleman Hills, Calif.[38] Diatoms have not been recorded from definitely dated Pliocene rocks along the Atlantic Coastal Plain. During the Pleistocene, however, *C. asteromphalus* appears to have become more widely distributed, and at present it is practically world-wide, although rarely abundant at any one locality. According to Hendey,[39] it is "a neritic diatom, favoring a fairly high salinity."

Diameter of figured specimen (U. S. G. S. diatom catalog no. 2004–2), 198μ. From sample L–2 (U. S. G. S. diatom locality 2864), 40–48 cm. below top of core 3.

Found rarely in samples L–4, L–54, L–55, and L–56, frequently in sample L–3, and commonly in sample L–2.

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[33] Reinhold, Th., Fossil diatoms of the Neogene of Java and their zonal distribution: Nederland en Koloniën Geol.-Mijnbouwk. Genootschap Verh., Geol. ser., Deel 12, p. 93, pl. 10, fig. 11, 1937.

[34] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 422, 1928.

[35] Lohman, K. E., Comparison of the diatom floras from the Calvert formation (middle Miocene) of Maryland and Virginia with those from the Temblor formation (middle Miocene) of California. (In preparation.)

[36] Henbest, L. G., Lohman, K. E., and Mansfield, W. C., Foraminifera, diatoms, and mollusks from test wells near Elizabeth City, N. C.: U. S. Geol. Survey Prof. Paper 189–G, p. 222, 1939.

[37] Lohman, K. E., in Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California: U. S. Geol. Survey Prof. Paper 165–C, p. 114, 1931.

[38] Lohman, K. E., Pliocene diatoms from the Kettleman Hills, California: U. S. Geol. Survey Prof. Paper 189–C, p. 82, pl. 21, fig. 3, 1938.

[39] Hendey, N. I., The plankton diatoms of the southern seas: Discovery Repts., vol. 16, p. 244, 1937.

Coscinodiscus convexus Schmidt

Plate 13, figure 9

Coscinodiscus convexus Schmidt, Atlas der Diatomaceenkunde, pl. 60, fig. 15, 1878.
Rattray, Royal Soc. Edinburgh Proc. vol. 16, p. 552, 1889.
Heiden and Kolbe, deutsche Südpolar-Expedition 1901–1903, Band 8, Botanik, Heft 5, p. 497, 1928.
Hanna, California Acad. Sci. Proc., 4th ser., vol. 20, No. 6, p. 179, pl. 6, figs. 2, 3; pl. 7, fig. 1, 1931.

The specimens found in the cores have coarser areolation than Schmidt's specimens, but the difference is too slight to warrant making a new species. The aerolation ranged from 1½ to 4 in 10μ in two individuals otherwise identical. The size and degree of convexity ranged between wide limits also, but, with the large number of specimens available, many of which formed gradational series, it appears wiser to refer them all to this species. One of the least convex specimens was chosen for the photomicrograph, as the more convex individuals are extremely difficult to focus all over simultaneously.

Schmidt's type came from the Springfield deposit, Barbados (probably Eocene in age), and Hanna's material (last citation above) came from the middle Miocene Temblor formation, Sharktooth Hill, Kern County, Calif. Heiden and Kolbe (3d citation above) reported this species from Observatory Bay, Kerguelen, but did not give its abundance nor state whether or not it was in the living state when found. It is entirely possible and certainly not improbable that this is another extinct species, which may have been redeposited from beds of Miocene age. It is an exceedingly robust, highly silicified species and would be able to withstand transportation over great distances.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1970–6), 178μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below the top of core 9.

Found rarely in samples L–4, L–5, L–49, L–54, and L–56, frequently in samples L–50, L–51, L–59, and L–62, and commonly in sample L–52.

Coscinodiscus decrescens Grunow

Plate 13, figure 6

Coscinodiscus decrescens Grunow, in Schmidt, Atlas der Diatomaceenkunde, pl. 61, figs. 8, 9, 10 (?), 1878.
Grunow, Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 48, p. 80, 1884.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 525, 1889.
De Toni, Sylloge algarum omnium hucusque cognitarum, vol. 2, p. 1252, 1894.
Van Heurck, Expédition Antarctique Belge, Botanique, p. 47, 1909.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 430, fig. 233, 1928.
Hendey, Discovery Repts., vol. 16, p. 245, 1937.

Reinhold[40] has reported this species from rocks of middle Miocene age in Java. The original type (see 1st citation above) came from Eocene rocks in Barbados, and I[41] have found it in the Modelo formation, of upper Miocene age, in the Santa Monica mountains, Los Angeles County, Calif. It is frequently found in European waters both in plankton and in littoral floras. Hendey (see last citation above) found it only in the plankton off south Georgia at water temperatures averaging 0° C. Although it has not been reported from the North Atlantic, it might be indigenous in that region.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1947–1), 39μ. From sample L–33 (U. S. G. S. diatom locality 2841), 118–122 cm. below the top of core 6.

Found rarely in samples L–33 and L–50.

Coscinodiscus kurzii Grunow

Plate 13, figure 5

Coscinodiscus kurzii Grunow, in Schmidt, Atlas der Diatomaceenkunde, pl. 11, fig. 17, 1888.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 564, 1889.
Lohman, U. S. Geol. Survey Prof. Paper 189–C, pl. 20, fig. 1; pl. 21, fig. 2, 1938.

This species has not been reported living. Grunow's original specimen (see 1st citation above) came from Elephant Point, and I have found it occurring commonly in the Etchegoin and San Joaquin formations, of upper Pliocene age, in the Kettleman Hills, Calif. (see last citation above). All of the specimens found in the cores were broken, and this, together with the fact that this species has never been reported definitely as living, invites the speculation that the forms found in the cores had been reworked from some fossil outcrop and redeposited on the ocean floor.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1951–1), 62μ. From sample L–10 (U. S. G. S. diatom locality 2854), 74–79 cm. below the top of core 4.

Found rarely in sample L–52 and frequently in sample L–10.

Coscinodiscus marginatus Ehrenberg

Plate 14, figures 1, 6

Coscinodiscus marginatus Ehrenberg, K. Akad. Wiss. Berlin, Physikal. Abh. 1841, p. 142, 1843.
Ehrenberg, Mikrogeologie, pl. 18, fig. 44; pl. 33, group 12, fig. 13; pl. 38B, group 22, fig. 8, 1854.
Schmidt, Atlas der Diatomaceenkunde, pl. 62, figs. 1–5, 9, 11, 12, 1878.

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[40] Reinhold, Th., Fossil diatoms of the Neogene of Java and their zonal distribution: Nederland en Koloniën Geol.-Mijnbouwk. Genootschap Verh., Geol. ser., Deel 12, p. 94, pl. 10, fig. 9, 1937.

[41] Lohman, K. E., in Hoots., H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California: U. S. Geol Surv. Prof. Paper 165–C, p. 114, pl. 28, fig. 5, 1931.

Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 509, 1889.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 416, fig. 223, 1928.
Hendey, Discovery Repts., vol. 16, p. 248, 1937.
Coscinodiscus limbatus Ehrenberg, K. Akad. Wiss. Berlin, Monatsber., 1840, p. 206, 1841.
Coscinodiscus fimbriatus-limbatus Ehrenberg, Mikrogeologie, pl. 19, fig. 4, 1854.
Coscinodiscus radiatus forma *heterosticta* Grunow, in Pantocsek, Beiträge zur Kenntnis der fossilen Bacillarien Ungarns, Teil 1, p. 70, pl. 20, fig. 184, 1886.
Coscinodiscus subconcavus forma *major* Schmidt, Atlas der Diatomaceenkunde, pl. 62, fig. 7, 1878.

For the differences between this species and *Endictya robusta* (Greville) Hanna and Grant, see discussion under the latter on p. 66 of this report. It is also sometimes confused with *C. radiatus* Ehrenberg, from which it differs in having coarser areolation, longer and coarser marginal striae, and much greater convexity. *C. radiatus* is usually quite flat. The convexity of *C. marginatus* is not so evident in plate 14, figure 1 (taken with a 16-mm. apochromat) but is very well shown in plate 14, figure 6 (taken with an 8-mm. apochromat).

This species has had a widespread distribution since early Miocene time and occurs today in all warm to temperate seas. According to Hendey [42] it is "probably a bottom form, meroplanktonic, but sometimes observed a considerable distance from land." It is one of the most common species found in the cores.

Measurements of figured specimens

U. S. G. S. diatom catalog no.	Diameter	Areolae near center	Areolae near margin	Marginal striae
1967–17	115μ	1½–2 in 10μ	3 in 10μ	5½ in 10μ
1967–19	97μ	2 in 10μ	3½ in 10μ	5 in 10μ

Both from sample L–3 (U. S. G. S. diatom locality 2857, 81–89 cm. below the top of core 3.

Found rarely in samples L–1, L–7, L–8, L–10, L–20, L–58, and L–60, frequently in samples L–2, L–3, L–4, L–31, L–33, L–51, L–52, L–54, L55, and L–56, and commonly in samples L–19, L–32, and L–59.

Coscinodiscus nodulifer Schmidt

Plate 14, figures 3, 5

Coscinodiscus nodulifer Schmidt, Atlas der Diatomaceenkunde, pl. 59, figs. 21–23, 1878.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 520, 1889.
De Toni, Sylloge algarum omnium hucusque cognitarum, vol. 2, p. 1249, 1894.
Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, supplement, p. 55, 1926.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 426, fig. 229, 1928.

Schmidt in his original illustration of this distinctive species included a form with prominent marginal apiculi,[43] which Rattray [44] subsequently described as var. *apiculata*. Mann [45] casually and Hustedt [46] definitely disregarded Rattray's variety and included it with the species. This does not appear to have been the wisest choice for the following reasons: The apiculi are shown quite definitely on Schmidt's figure and are good morphological characters used without question elsewhere; the variety *apiculata* has been recorded from only two localities,[47] both in warm tropical waters, and both occurrences were presumably in a living state. The type species has never been recorded from the same localities but has been found widely scattered over the globe, both living and from fossil deposits as old as middle Miocene. It seems possible, therefore, that var. *apiculata* may represent a particular ecologic condition, such as that found in Campeche Bay, and may prove useful as an ecologic indicator when and if found in sediments.

C. nodulifer has been reported from neritic zones of tropical and subtropical seas by various oceanographic expeditions but never in latitudes as high as those of the cores (lat. 46° to 49° N.), and it may, therefore, be regarded as a warm-water or warm-temperate-water species. Hendey [48] found it in only one sample, at latitude 38°27′30″ S. at a water temperature of 14.8° C. The presence of this species in the cores at higher latitude and in much colder water suggests transportation by the Gulf Stream.

Diameter of figured specimens, plate 14, figure 5 (U. S. G. S. diatom catalog no. 1967–6), 83μ; plate 14, figure 3 (U. S. G. S. diatom catalog no. 1967–9), 51μ. Both from sample L–51 (U. S. G. S. diatom locality 2857), 108–114 cm. below top of core 9.

Found rarely in samples L–6, L–31, L–52, L–55, L–59, and L–65 and frequently in samples L–2, L–4, and L–51.

Coscinodiscus oculus-iridis var. borealis (Bailey) Cleve

Plate 14, figure 2

Coscinodiscus borealis Bailey, Am. Jour. Sci., ser. 2, vol. 22, p. 3, 1856.
Schmidt, Atlas der Diatomaceenkunde, pl. 63, fig. 11, 1878.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 558, 1889.
Coscinodiscus oculus-iridis var. *borealis* (Bailey) Cleve, Vega-Exped. vetensk. Iakttagelser, Bandet 3, p. 483, 1883.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 456, fig. 253, 1928.

The large robust areolae and the raised zone about one-fifth the radius in from the margin distinguish this variety from *C. oculus-iridis* Ehrenberg. In the early

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[42] Hendey, N. I., The plankton diatoms of the southern seas: *Discovery* Repts., vol. 16, p. 248, 1937.

[43] Schmidt, Adolf, Atlas der Diatomaceenkunde, pl. 59, fig. 20, 1878.

[44] Rattray, John, A revision of the genus *Coscinodiscus* and some allied genera: Royal Soc. Edinburgh Proc., vol. 16, p. 520, 1889.

[45] Mann, Albert, Diatoms of the *Albatross* voyages: Contr. U. S. Nat. Herbarium, vol. 10, part 5, p. 255, 1907.

[46] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 427, 1928.

[47] Rattray, op. cit., p. 520.

[48] Hendey, N. I., The plankton diatoms of the southern seas: *Discovery* Repts., vol. 16, p. 248, 1937.

stages of the present investigation many individuals were tentatively identified as *C. oculus-iridis*, but, when large numbers of the variety *borealis* were found, the ones previously identified as typical were re-examined more critically, and all were assigned to the variety. Although this variety is very distinct, its close affinity to the type make specific separation unwise. Hustedt (last citation above) says, "Für die spezifische Abtrennung dieser Form liegt kein Grund vor."

It occurred in greater abundance than any other diatom in cores 3 and 9. Three other cores contained it rarely to frequently.

This is a definitely cold-water form and is common in most diatom floras from Arctic waters.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1965–1), 214μ. From sample L–3 (U. S. G. S. diatom locality 2865), 81–89 cm. below the top of core 3.

Found rarely in samples L–16, L–31, L–33, L–49, L–58, L–60, and L–62, frequently in samples L–1, L–7, L–10, L–19, L–32, L–37, L–51, and L–59, commonly in sample L–6, and abundantly in samples L–2, L–3, L–4, L–52, and L–54.

Coscinodiscus radiatus Ehrenberg

Plate 14, figures 7, 8

Coscinodiscus radiatus Ehrenberg, K. Akad. Wiss. Berlin, Physikal. Abh. 1839, p. 148, pl. 3, figs. 1a-c, 1841.
Schmidt, Atlas der Diatomaceenkunde, pl. 60, figs. 5, 6, 9, 10, 1878.
Van Heurck, Synopsis diatomées Belgique, pl. 129, fig. 1, 1883.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 514, 1889.
Hustedt, Die Kieselalgen Deutschlands, Österrichs, und der Schweiz, Teil 1, p. 420, fig. 225, 1928.
Hendey, Discovery Repts., vol. 16, p. 250, 1937.
Coscinodiscus caspius Ehrenberg, K. Akad. Wiss. Berlin, Physikal. Abh. 1872, p. 394, pl. 12, group 1, fig. 14, 1873.
Coscinodiscus borealis Ehrenberg, K. Akad. Wiss. Berlin, Monatsber. 1861, p. 294, 1862.
Coscinodiscus fallax Schumann, Königsberg K. physikal.-ökonomischen Gesell., Schr., Jahrg. 8, p. 62, pl. 3, fig. 76, 1867.

Hustedt [49] has recently included a great many varieties of *C. radiatus* with the species, and it appears to have been a wise course. Most of the varieties have been based on minor differences in areolation and size. In a variable species such as this, minor differences quickly lead to absurdities if new varieties are erected for each departure from the norm. In the material studied for this report, many variations of this species were found, with practically infinitesimal gradations between. The two extremes of such a series are here illustrated, one (pl. 14, fig. 7) a large form with areolae 2 to 2½ in 10μ, outer quarter of valve convex, and the other a smaller form (pl. 14, fig. 8) less than half the diameter of the former, with areolae 4 to 5 in 10μ, and flat from center to margin. In general the smaller forms are flat, and many of those with diameters greater than 100μ are convex. Although a great many individuals were found, nearly every one was damaged in some way.

This species has a world-wide distribution in warm to temperate seas and is probably encountered as often as any marine diatom. It is one of the species found most frequently in the cores. It has a long geologic history and has been found in many marine diatomites of Eocene and later ages.

Diameters of figured specimens: Plate 14, figure 7 (U. S. G. S. diatom catalog no. 1967–2), 158μ; plate 14, figure 8 (U. S. G. S. diatom catalog no. 1967–10), 71μ. Both from sample L–51 (U. S. G. S. diatom locality 2857), 108–114 cm. below top of core 9.

Found rarely in samples L–2, L–3, L–5, L–16, L–23, L–44, L–49, L–55, and L–58, frequently in samples L–4, L–6, L–7, L–10, L–19, L–30, L–31, L–32, L–33, L–37, L–52, L–56, L–62, and L–65, and commonly in samples L–54 and L–59.

Section FASCICULATAE Rattray

Coscinodiscus bicurvulatus Lohman, n. sp.

Plate 15, figure 5

Valve circular, flat, without rosette or central space; hexagonal areolae in indefinite fasciculi, occasionally straight but usually curved in either clockwise or counterclockwise direction; areolae near center, 7 to 8 in 10μ; at semi radius, 6 in 10μ; near margin, 8 to 9 in 10μ. Margin narrow with short radial striae, 18 in 10μ; stout rounded marginal apiculi, 10μ apart. Diameter 60–80μ.

Holotype: U. S. G. S. diatom catalog no. 1967–12, diameter, 67μ. U. S. G. S. diatom locality 2857. Sample L–52, from 108–114 cm. below the top of core 9, taken at a depth of 2,050 fathoms in lat. 49°40′00″ N., and long. 28°29′00″ W., by C. S. Piggot, 1936.

Reinhold [50] has recently published a figure of this species and confused it with *C. normani* Gregory. He published two figures (pl. 11, figs. 4 and 9), which he called *C. normani.* Figure 4 is not entirely clear, but appears to be *C. normani*, but figure 9, which is an excellent photomicrograph, is clearly not *C. normani* but identical with the present species. In *C. normani* the fasciculi are straight, with the rows of areolae parallel to the center row in each fasciculus, and the narrow zone between the apiculi and the margin is covered with very fine decussate markings. Both these features are exhibited in Reinhold's figure 4 but not in his figure 9.

This species is somewhat similar to *C. curvatulus* var. *odontodiscus* (Grunow) Hustedt,[51] from which it differs in having smaller areolae, particularly near the center and margin, and in not having the irregular hyaline

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[49] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 420, 1928.

[50] Reinhold, Th., Fossil diatoms of the Neogene of Java and their zonal distribution: Nederland en Koloniën Geol.-Mijnbouwk. Genootschap Verh., Geol. ser., Deel 12, pl. 11, fig. 9, 1937.

[51] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 408, fig. 215, 1928.

ring at the center. This ring is well shown in Grunow's original figure.[52]

More than a dozen individuals were found in the cores, all of which were consistent with the description and figure here given. No perfect individual was found; the holotype has the margin broken away from half of the valve but is otherwise intact. In view of the fact that many perfect specimens of more fragile diatoms were found, it is entirely possible that this species has been reworked from older material.

Found rarely in samples L-2, L-4, L-30, L-51, L-52, L-54, L-59, and L-60.

Coscinodiscus crenulatus Grunow var. nodulifer Lohman, n. var.

Plate 14, figure 4; plate 15, figure 1

Valve circular, flat, without rosette but occasionally with a small, irregular central space; polygonal areolae, 7 to 8 in 10µ at the semiradius, usually constant over the entire valve, but occasionally somewhat closer toward the margin; areolae arranged in definite fasciculi; initial and longest row of areolae in each fasciculus sometimes radial but more often tangent to an imaginary circle at the center of the valve and one-tenth to one-twelfth its diameter; initial row usually straight but occasionally slightly curved; remaining rows in each fasciculus parallel to the initial one. A single nodule 1µ to 1.5µ in diameter is always present, although not always obvious, and is always slightly excentric and usually surrounded by a narrow irregular space. Marginal apiculi 6µ to 9µ apart with identation at each apiculus giving a crenulate appearance to the margin. Marginal striae, short and robust, 14 to 16 in 10µ. Diameter of valve, 30µ to 40µ.

Holotype: U. S. G. S. diatom catalog no. 1970-3 (pl. 15, fig. 1); paratype: U. S. G. S. diatom catalog 1957-11 (pl. 14, fig. 4). U. S. G. S. diatom locality 2858. Sample L-52, from 142-151 cm. below the top of core 9, taken at a depth of 2,050 fathoms in lat. 49°40′00″ N. and long. 28°29′00″ W., by C. S. Piggot, 1936.

Measurements of figured specimens

Specimen	Diameter	Areolae in 10 µ	Marginal striae in 10 µ	Apiculi, distance apart
	µ			µ
Holotype, 1970-3	40	7-8	15-16	9
Paratype, 1957-11	37	7-8	14	6

This variety differs from *C. crenulatus* Grunow[53] principally in the presence of the small excentric nodule. This nodule is not present in any published figures or descriptions of *C. crenulatus*. In the type, the fasciculi are more definitely curved than in the variety, and, according to Hustedt,[54] who has given the best description of the species, the marginal striae are more closely spaced (20 in 10 µ) in the type than in the variety. Rattray's description[55] of *C. crenulatus* is very confusing, as, according to Hustedt,[56] he made his measurements on Schmidt's figure[57] rather than on an actual specimen and failed to notice that this particular figure was drawn at a magnification of 990 diameters, whereas the magnification for the balance of the plate was 660 diameters. Rattray used the smaller enlargement in computing his measurements.

The type is a littoral form from southern seas, and it is possible that the habitat of the variety was similar.

Found rarely in samples L-30, L-51, and L-52.

Coscinodiscus curvatulus Grunow

Plate 15, figure 8

Coscinodiscus curvatulus Grunow, in Schmidt, Atlas der diatomaceenkunde, pl. 57, fig. 33, 1878.
Grunow, Akad. Wiss. Wien, Math-naturwiss. Kl., Denkschr., Band 48, p. 82, pl. D, figs. 11-15, 1884.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 486, 1889.
Hustedt, Die Kieselalgen Deutschlands, Osterreichs, und der Schweiz, Teil 1, p. 406, fig. 214, 1928.

In the figured specimen the extreme margin is lacking, and the marginal apiculi so well illustrated by Hustedt in the figure cited above are not prominent, but careful focusing on the margin reveals them. Schmidt's original figure[58] shows the apiculi about as strongly developed as those in Hustedt's figure. Rattray[59] on the other hand, says, "apiculi absent." It is obvious that the apiculi represent a variable feature and one not to be taken too seriously, at least as far as this species is concerned. Another variable feature is the degree of curvature of the fasciculi. In most published figures of this species a pronounced curvature of the fasciculi is shown. In the specimens found in the cores, the curvature is real and constant as to direction but very slight. Mann[60] observed the same lack of pronounced curvature in his specimens from Bering Sea.

This species is known from the whole Tertiary, the earliest occurrence being recorded by Reinhold,[61] who found it in rocks of probable lower Eocene age near Maastricht, Netherlands.

Its present distribution is widespread in oceanic plankton, but is more abundant in cold northern waters.

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[52] Grunow, Albert, Die Diatomeen von Franz Josefs-Land: Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 48, p. 81, pl. 3 (C), fig. 23, 1884.

[53] Idem, p. 83, pl. 4 (D), fig. 17.

[54] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 411, fig. 219, 1928.

[55] Rattray, John, A revision of the genus *Coscinodiscus* and some allied genera: Royal Soc. Edinburgh Proc., vol. 16, p. 489, 1889.

[56] Hustedt, Friedrich, op. cit., p. 412.

[57] Schmidt, Adolf, Atlas der Diatomaceenkunde, pl. 57, fig. 33, 1878.

[58] Idem, fig. 33.

[59] Rattray, John, op. cit., p. 486.

[60] Mann, Albert, Diatoms of the *Albatross* voyages: Contr. U. S. Nat. Herbarium, vol. 10, part 5, p. 250, 1907.

[61] Reinhold, Th., Diatoms from rocks, possibly belonging to the Danian (or Lower Eocene), near Maastricht, Netherlands: Nederland. Geol. Bur. Jaarv., 1930, p. 15, pl. 1, figs. 2, 4-8, 1931.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1960–3), 91μ. From sample L–54 (U. S. G. S. diatom locality 2860), 206–213 cm. below top of core 9.

Found rarely in samples L–2 and L–31 and frequently in samples L–52 and L–54.

Coscinodiscus curvatulus var. minor (Ehrenberg) Grunow

Plate 15, figure 3

Coscinodiscus minor Ehrenberg, K. Akad. Wiss. Berlin, Physikal. Abh. 1838, p. 129, pl. 4, fig. 12e, 1840.

Coscinodiscus curvatulus var. ? *minor* (Ehrenberg) Grunow, Akad. Wiss. Wien. Math.-naturwiss. Kl., Denkschr., Band 48, p. 83, pl. 4 (D), figs. 8–10, 1884.

Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 487, 1889.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 409, fig. 217, 1928.

The curved fascicles immediately distinguish this small variety from small forms of *Coscinodiscus excentricus*, with which it is frequently confused. Ehrenberg's earliest figure of this diatom (see first citation above) left much to be desired. Many subsequent authors have combined Ehrenberg's *C. minor* with *C. excentricus*, whereas Grunow saw the curved fasciculate arrangement of the markings and hence realized its relationship to *C. curvatulus*. The doubtful accuracy of the original figure (now 100 years old) and the various interpretations that have been placed on it by other authors have confused the true position of this tiny diatom. Grunow entertained and recorded a doubt as to whether or not *C. minor* should be made a variety of *C. curvatulus* or combined with it. I agree with Rattray and Hustedt (see above synonymy) that the forms Grunow figured were certainly related to *C. curvatulus*. The specimens from the cores are more finely marked than the one figured by Hustedt (see last citation above) and approach *C. divisus* Grunow, which, however, is larger and has a zone of very fine decussate markings between the apiculi and the margin.

This variety is frequently found with small forms of *C. excentricus*, pelagic in all seas, but is more abundant in colder waters.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1957–1), 29μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below top of core 9.

Found rarely in sample L–4, and frequently in sample L–52.

Coscinodiscus denarius Schmidt

Plate 15, figure 6.

Coscinodiscus denarius Schmidt, Atlas der Diatomaceenkunde, pl. 57, figs. 19–21, 1878.

Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 504, 1889.

Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, supplement, p. 51, 1926.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 399, fig. 210, 1928.

Specimens assigned to this species have polygonal areolae, 8 in 10μ, which decrease in size very slightly toward the margin. In the photomicrograph the reduction in size of the areolae toward the margin is exaggerated on account of the change in focus from center to margin caused by the convexity of the valve. The number of rows of areolae in each fasciculus is greater than that usually given by various authors, but the difference does not appear to warrant specific separation, as the size of the fasciculi differs between different valves and even in a single valve.

This species is frequently confused with *C. subtilis* Ehrenberg, from which it differs in having coarser areolation and more definite fasciculi.

Schmidt's original specimens came from Eocene rocks on the island of Barbados,[62] and it has since been reported from Campeche Bay in the Gulf of Mexico,[63] and from the Antarctic Ocean.[64] Hustedt [65] states that except for a report by Peragallo of its occurrence living in the Bay of Villefranche, it is not known in European waters. It occurred in nearly half the samples from the cores but never in large numbers. As far as can be determined from available data it is not at all critical regarding temperature.

Measurements of figured specimen (U. S. G. S. diatom catalog no. 1968–4): Diameter, 76μ; areolae, 8 in 10μ; marginal striae, 13 in 10μ. From sample L–51 (U. S. G. S. diatom locality 2857), 108–114 cm. below the top of core 9.

Found rarely in samples L–2, L–3, L–7, L–16, L–19, L–20, L–31, L–32, L–51, L–54, and L–61, and frequently in samples L–4, L–33, and L–37.

Coscinodiscus divisus Grunow

Plate 15, figure 7

Coscinodiscus divisus Grunow, in Schneider, Naturwiss. Beitr. zur Kenntniss der Kaukasusländer, p. 125, 1878.

Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 499, 1889.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 410, fig. 218, 1928.

Coscinodiscus (*curvatulus* var.?) *divisus* Grunow, Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 48, p. 83, pl. 4 (D), fig. 16, 1884.

On purely morphologic grounds this species is closely related to both *C. curvatulus* Grunow and *C. rothii* (Ehrenberg) Grunow, having the curved fascicles (with rows of areolae parallel to a marginal row in each fascicle) of the former, and the band of fine, decussate markings between the apiculi and the margin of the latter. If the phylogenies of all three species were better known, it seems probable that *C. divisus* might be the intermediate form. On ecologic grounds the relationship is, perhaps, less evident but at least

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[62] Schmidt, Adolf, Atlas der Diatomaceenkunde, pl. 57, figs. 19–21, 1878.

[63] Rattray, John, A revision of the genus *Coscinodiscus* and some allied genera: Royal Soc. Edinburgh Proc., vol. 16, p. 504, 1889.

[64] Heiden, Heinrich, and Kolbe, R. W., Die marinen Diatomeen, in Von Drygalski, E., Die deutschen Südpolar-Expedition, 1901–1903, Band 8, Botanik, Heft 5, p. 490, 1928.

[65] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Osterreichs, und der Schweiz, Teil 1, p. 400, 1928.

not contradictory. According to Hendey,[66] *C. curvatulus* is "an oceanic species having a wide distribution in temperate seas." *C. divisus* is, according to Hustedt,[67] "Wahrscheinlich neritisch oder litoral." Regarding the occurrence of *C. rothii* and its varieties, the same author[68] states: "Die Art ist in allen Meeren verbreitet und meist häufig. Die Varietäten finden sich besonders im Brackwasser der Flussmündungen, zum Teil auch in Binnenseen mit reinem Süsswasser." Thus, assuming for the moment that the oceanic *C. curvatulus* was the earlier form, the neritic or litoral *C. divisus* the intermediate form and *C. rothii* var. *normani* the end product, we have a gradual transition from oceanic through littoral to brackish-water and even fresh-water conditions. The geologic evidence, as far as known, does not bear this out. Both *C. curvatulus* and *C. rothii* are known from the Eocene, whereas the oldest recorded occurrence for *C. divisus* is from the upper Pliocene of Java.[69] It is entirely possible, however, that some of the diatoms identified as *C. curvatulus* in earlier rocks were really *C. divisus.*

This species was well represented in the cores and occurred in nearly half of the samples studied.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1970–11), 57μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below top of core 9.

Found rarely in samples L–6, L–20, L–49, L–52, L–56, and L–60, and frequently in samples L–4, L–10, L–30, L–31, L–33, L–37, L–51, L–54, L–59, and L–65.

Coscinodiscus subtilis Ehrenberg

plate 15, figure 4

Coscinodiscus subtilis Ehrenberg, K. Akad. Wiss. Berlin, Physikal. Abh. 1841, p. 412, pl. 1, group 3, fig. 18; pl. 3, group 7, fig. 4, 1843.
Schmidt, Atlas der Diatomaceenkunde, pl. 57, figs. 11–16. 1878.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 494, 1889.
Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 259, 1907.
Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, suppl., p. 50, 1926.
Hendey, Discovery Repts., vol. 16, p. 254, 1937.

The diatoms referred to this species agree more closely with Ehrenberg's original description than with some descriptions published in later years. Most authors give from 6 to 10 areolae per 10μ, whereas these have 12 in 10μ, as did Ehrenberg's. The marginal striae, 16 in 10μ, are finer than usual and are of unequal length, giving the appearance of apiculi when viewed under medium magnifications, but none of the specimens found exhibit true apiculi.

C. subtilis has become somewhat of a catch-all for finely marked coscinodiscoid forms having fasciculi of varying degrees of distinctness and, undoubtedly, has been most frequently confused with *C. denarius* Schmidt and *C. rothii* (Ehrenberg) Grunow. Hustedt[70] has recently reviewed the situation and concluded that the name *C. subtilis* Ehrenberg should be abandoned and that forms referred to this species should be included in the "Formenkreis" of *C. rothii.* Although Hustedt's conclusion has much in its favor, it appears best to continue to recognize the species *C. subtilis* until a definite and thorough revision is made of the whole group.

This species has an almost universal distribution, occuring in marine, brackish, and fresh waters, and most abundantly today in cold subpolar waters, but also along the shores of most continents, in the mud of estuaries and in fresh water. Boyer[71] reports it as, "Very common in the water supply of Philadelphia and Camden, where the diameter seldom exceeds 40μ and the markings on the semiradius are 10 in 10μ." It occurs in many marine fossil deposits from Miocene to Recent,[72] and it is abundant in some Miocene fresh-water diatomites in the Otis Basin, Harney County, Oreg.[73]

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1972–8), 48μ. From sample L–4 (U. S. G. S. diatom locality 2866), 130.5–137 cm. below the top of core 3.

Found rarely in samples L–3 and L–6, and frequently in sample L–54.

Genus ACTINOCYCLUS Ehrenberg, 1838

Actinocyclus curvatulus Janisch

Plate 15, figure 2

Actinocyclus curvatulus Janisch, in Schmidt, Atlas der Diatomaceenkunde, pl. 57, fig. 31, 1878.
Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 261, 1907.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 538, 1929.
Coscinodiscus curvatulus var. *subocellatus* Grunow, Akad. Wiss. Wien, Math.-naturwiss Kl., Denkschr., Band 48, p. 83, pl. 4 (D), fig. 15, 1884.
Rattray, Royal Soc. Edinburgh Proc., vol. 16, p. 488, 1889.
Actinocyclus subocellatus (Grunow) Rattray, Quekett Micr. Club. Jour., ser. 2, vol. 4, p. 145, 1890.
Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, supplement, p. 81, 1926.

The indefiniteness of the pseudonodule on this diatom has resulted in much confusion. In view of the fact that the most fundamental difference between the gen-

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[66] Hendey, N. I., The plankton diatoms from the south seas: *Discovery* Repts., vol. 16, p. 252, 1937.

[67] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 411, 1928.

[68] Idem, p. 404.

[69] Reinhold, Th., Fossil diatoms of the Neogene of Java and their zonal distribution: Nederland en Koloniën Geol.-Mijnbouwk. Genootschap, Verh., Geol. ser., Deel 12, p. 94, 1937.

[70] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 404, 1928.

[71] Boyer, C. S., The diatomaceae of Philadelphia and vicinity, p. 22, 1916.

[72] Rattray, John, op. cit., p. 495.

[73] Lohman, K. E., in Moore, B. N., Nonmetallic mineral resources of eastern Oregon: U. S. Geol. Survey Bull. 875, p. 105, 1937.

era *Coscinodiscus* and *Actinocyclus* is the presence of a pseudonodule on the latter, the present species must go into *Actinocyclus*, even though the pseudonodule is not always obvious. The distinctness of the pseudonodule among the members of this species found in the cores ranged through wide limits. Most of the individuals were damaged, and the one figured represents the only whole specimen found. The dark radial streak near the top of the figure is due to a fragment of a diatom girdle that is firmly attached. The pseudonodule in this particular specimen (shown near the margin at the bottom of the figure) is rather faint, but may be seen clearly by proper focusing. It has exactly the same appearance as the one in the excellent drawing of *A. curvatulus* by Hustedt (3d citation above).

The distribution of this species is very imperfectly known, but appears to be fairly widespread, although Hustedt [74] notes that it has not been found in European seas. Doubtless it has been confused frequently with *Coscinodiscus curvatulus.*

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1957–2), 66μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below the top of core 9.

Found rarely in samples L–30, L–49, L–50, L–52, L–58, L–60 and L–65 and frequently in sample L–51.

Actinocyclus octonarius Ehrenberg

Plate 16, figure 4

Actinocyclus octonarius Ehrenberg, Die Infusionsthierchen als vollkommene Organismen, p. 172, pl. 21, fig. 7, 1838.
Hendey, Discovery Repts., vol. 16, p. 262, 1937.
Actinocyclus ehrenbergii Ralfs, in Pritchard, A history of Infusoria, 4th ed. p. 834, 1861.
Van Heurck, Synopsis diatomées Belgique, pl. 123, fig. 7, 1883; p. 215, 1885.
Rattray, Quekett Micr. Club Jour., ser. 2, vol. 4, p. 171, 1890.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 525, fig. 298, 1929.
Hanna, California Acad. Sci. Proc., 4th ser., vol. 20, p. 168, pl. 2, figs. 1, 2, 3, 1932.
Lohman, U. S. Geol. Survey Prof. Paper 189–C, p. 83, pl. 22, fig. 1, 1938.

The synonymy of this well-known species could be extended almost indefinitely, but this has already been done so often that nothing would be gained here by repeating it.

Hendey (see 2d citation above), has invoked the rule of strict priority and thus revived Ehrenberg's hundred-year-old original name from oblivion. Although Ralfs' name has been hallowed by long usage, it is, as Hendey has ably demonstrated, invalid. Ralfs, possibly thinking to appease Ehrenberg's displeasure, caused by throwing 118 of his names into synonymy, named the whole group *Actinocyclus ehrenbergii* instead of using *octonarius*, the earliest name. It is with some misgiving that I agree with Hendey in this matter, as common sense would appear to dictate that Ralfs name be retained, even though invalid, on the grounds of long and universal usage. However, the plea of "common-sense usage" might better be reserved for doubtful cases and not be applied in such clearly unequivocal ones as the present. It seems necessary, therefore, to follow Hendey and return to Ehrenberg's original name, although those who are inclined to use the common-sense plea in all cases may call it sheer pedantry.

The specimens found in the cores are all smaller than typical ones but differ in no other respect. They range from 34μ to 50μ in diameter, but the radial beads on each specimen are but 7 in 10μ, the mean for the type.

At the present time this neritic diatom has a world-wide distribution in temperate seas. Its known geologic range is middle Miocene [75] to Recent.

Measurements of figured specimen (U. S. G. S. diatom catalog no. 1971–1): diameter, 35μ; radial beads, 7 in 10μ. From sample L–3 (U. S. G. S. diatom locality 2865), 81–89 cm. below the top of core 3.

Found rarely in samples L–54 and L–66, frequently in L–2, L–3, L–10, and L–51, and commonly in L–4.

Genus ROPERIA Grunow, 1883

Roperia tessellata (Roper) Grunow

Plate 16, figure 3

Eupodiscus tessellatus Roper, Quart. Jour. Micr. Sci., vol. 6, p. 19, pl. 3, fig. 1, 1858.
Roperia tessallata (Roper) Grunow, in Van Heurck, Synopsis diatomées Belgique, pl. 118, figs. 6, 7, 1883.
Rattray, Royal Micr. Soc. Jour., vol. 8, p. 917, 1888.
Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, supplement, p. 88, 1926.
Heiden and Kolbe, Deutsche Südpolar Expedition 1901–1903, Band 8, Botanik, Heft 5, p. 507, 1928.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 523, fig. 297, 1929.
Actinocyclus tessellatus Ralfs, in Pritchard, History of the Infusoria, 4th Ed., p. 835, 1861.
Mann, U. S. Nat. Herbarium Contr., vol. 10, pt. 5, p. 264, 1907.

This pelagic diatom is found frequently in the central Pacific Ocean, off Rio de Janeiro, and along the coast of Europe. It is apparently a temperate to warm water form and may have been brought to the North Atlantic by the Gulf Stream. Lebour [76] has recorded it from (presumably) the North Atlantic but gives no information regarding locality or relative abundance.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1967–7), 62 μ. From sample L–51 (U. S. G. S. diatom locality 2857), 108–114 cm. below the top of core 9.

Found rarely in samples L–2, L–6, L–10, L–51, and L–52 and frequently in samples L–4, L–30, and L–65.

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[74] Hustedt, Friedrich, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 539, 1929.

[75] Hanna, G. D., The diatoms of Sharktooth Hill, Kern County, California: California Acad. Sci. Proc., 4th ser., vol. 20, No. 6, p. 168, 1932.

[76] Lebour, M. V., The planktonic diatoms of northern seas, p. 55, 1930.

Family HEMIDISCACEAE
Subfamily HEMIDISCOIDEAE
Genus HEMIDISCUS Wallich, 1860

Hemidiscus cuneiformis Wallich, *s. l.*

Plate 16, figures 1, 2, 5

Hemidiscus cuneiformis Wallich, London Micr. Soc. Trans., new ser., vol. 8, p. 42, pl. 2, figs. 3, 4, 1860.
  Ralfs, in Pritchard, History of the Infusoria, 4th ed., p. 853, pl. 6, fig. 14, 1861.
  Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 316, 1907.
  Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 904, fig. 542, 1930.
  Hendey, Discovery Repts., vol. 16, p. 264, 1937.
Euodia gibba Bailey. Ralfs, in Pritchard, History of the Infusoria, 4th ed., p. 852, pl. 8, fig. 22, 1861.
  Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, supplement, p. 87, 1926.
Euodia cuneiformis (Wallich) Schütt, in Engler and Prantl, Natürliche Pflanzenfamilien, Teil 1, Abteilung 16, p. 100, 1896.
  Gran, Nordisches Plankton, Lief. 3, p. 45, 1905.
Euodia inornata Castracane, Challenger Repts., Botany, vol. 2, p. 149, pl. 12, fig. 1, 1886.

Different authors have expressed very decided and diverse views regarding the disposition of this species and its varieties. Mann (3d citation above) could see no reason for making certain "species" such as *Hemidiscus rectus* (Castracane) Mann and *H. ventricosa* (Castracane) Mann varieties of *H. cuneiformis*. With considerable justification he says, "On the other hand, it should be here noted that the striking build of the members of this genus leads to the too easy conclusion that all cuneiform frustules bearing a reasonably close resemblance to the original species, *Hemidiscus cuneiformis* Wall, must be mere varieties of it." Hustedt (4th citation above), on the other hand, after a careful study of the situation, recognized four varieties of *H. cuneiformis*, namely, *gibba*, *recta*, *ventricosa*, and *orbicularis*, all as members of a closely related group or "*formenkreis*."

Hendey (5th citation above), finding himself unable to accept either of these alternatives, referred all his forms to *H. cuneiformis*. He says:

> Much variation in outline has been observed, and many species and varieties have been created upon such variable characters as the ratio between the apical and transapical axes, the degree of gibbosity displayed upon the ventral side, the convexity of the dorsal side, and the development of the marginal spinulae and pseudo-ocellus. From the vast amount of material examined from such widespread areas as the waters around the Cape of Good Hope, the west coast of Africa, the mid-Atlantic, and the Humbolt current in the Pacific, specimens were obtained forming a series of intermediate forms that made it impossible to recognize the value of the nomenclatorial species and varieties. All of the specimens observed have been referred to *H. cuneiformis* Wallich.

My own experience in dealing with a fairly large number of forms from the cores has caused me to agree with Hendey, although I believe it safer to add *sensu lato* to the name when so used.

The forms found in the cores and referred to this species were quite variable in size and shape, but the two figured forms were the most common. My figures 1 and 5 would be Hustedt's variety *ventricosa*, and figure 2 would be near his variety *orbicularis*.

This is an oceanic species with a wide distribution in tropical and subtropical seas, although it is occasionally found in the North Atlantic as an introduced species.[77]

Dimensions of figured specimens

Figure	U. S. G. S. diatom catalog number	U. S. G. S diatom locality number	Sample number	Length	Width
				μ	μ
1	1970–2	2858	L–52	114	74
2	1967–15	2857	L–51	49	43
5	1970–13	2858	L–52	69	51

Found rarely in samples L–1, L–49, L–52, and L–54, frequently in samples L–2, L–6, L–30, L–51, and L–59, and commonly in samples L–4 and L–65.

Family ACTINODISCEAE
Subfamily ASTEROLAMPROIDEAE
Genus ASTEROMPHALUS Ehrenberg, 1844

Asteromphalus roperianus var. atlanticus Castracane

Plate 16, figure 6

Asteromphalus roperianus var. *atlanticus* Castracane, Challenger Repts., Botany, vol. 2, p. 133, pl. 5, fig. 3, 1886
  De Toni, Sylloge algarum omnium hucusque cognitarum, vol. 2, p. 1411, 1894.

Castracane's original figure of this diatom is drawn with more geometric precision than similitude; otherwise the specimen found in the core agrees perfectly. The two characteristics which Castracane used in his description to differentiate his variety from the species, the straight inner edge of the sectors and the failure of the hyaline rays to reach the margin, are well exhibited in the present specimen. Unfortunately, the convexity of the valve is so great that the margin is out of focus in my photomicrograph and the latter characteristic is not shown clearly. The validity of the variety depends on the constancy of these characteristics, but this could not be tested in the present case, as only one specimen was found. Rattray[78] says in his description of *A. roperianus*, " * * * the intervals broad, their edges parallel, the outer ends sometimes slightly expanded, not reaching the border." On the other hand, Hendey,[79] who had a great many specimens of *A. roperianus* at his disposal says in his excellent description, "Hyaline rays proceed from the central area to the periphery." If Hendey's diagnosis of the species is correct, and I feel sure that it is, then Castracane's variety is a

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[77] Lebour, M. V., The planktonic diatoms of northern seas, p. 56, 1930.

[78] Rattray, John, A revision of the genus *Coscinodiscus* and some allied genera: Royal Soc. Edinburgh Proc., vol. 16, p. 657, 1889.

[79] Hendey, N. I., The plankton diatoms of the southern seas: *Discovery* Repts., vol. 16, p. 270, 1937.

valid one. In my specimen the margin is very narrow and the hyaline rays stop 2 to 3μ from the periphery. Hexagonal areolae continuous with those on each sector fill the space between the end of the ray and the periphery.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1960–1), 71μ. From sample L–54 (U. S. G. S. diatom locality 2860), 206–213 cm. below the top of core 9.

Found rarely in sample L–54.

Subfamily ACTINOPTYCHOIDEAE
Genus ACTINOPTYCHUS Ehrenberg, 1843

Actinoptychus bipunctatus Lohman n. sp.

Plate 16, figures 7, 10–12

Valve discoid, divided into 10 sectors, alternately raised or depressed. Central area indefinite in outline, sometimes hyaline, but usually covered with fine, scattered punctae in no definite arrangement. Raised[80] sectors covered with large rounded polygonal markings, 7 to 8 in 10μ, which appear round under medium or low magnification. Depressed sectors covered with similar markings overlain by fine puncta, 19 to 20 in 10μ, arranged in rows parallel to the center, radial row in each sector. Narrow, hyaline space occasionally across outer ends of raised sectors only. Marginal apiculi usually opposite the center of all sectors, occasionally only in depressed (bipunctate) sectors. Occasional valves have one to three apiculi perpendicular to the plane of the valve and in the sectors about one-fifth to one-fourth of the radius away from the margin. Margin narrow, 0.7 to 1.0μ wide, covered with fine decussate puncta, 20 to 22 in 10μ. Diameter, 25 to 35μ.

Holotype: U. S. G. S. diatom catalog no. 2000–1 (figs. 10–12), diameter, 34μ. Paratype: U. S. G. S. diatom catalog no. 1970–10 (fig. 7), diameter 26μ. Both from U. S. G. S. diatom locality 2858. Sample L–52 from 142–151 cm. below the top of core 9, taken at a depth of 2,050 fathoms in lat. 49°40′00″ N. and long. 28°29′00″ W. by C. S. Piggot, 1936.

The fine puncta on the depressed sectors can be seen with difficulty with a 4-mm. apochromat used at nearly full aperture and are quite obvious under a 2-mm. oil immersion apochromat. When a dry objective is used with an effective numerical aperture of around 0.50, the fine puncta on the depressed sectors are not visible, and the diatom somewhat resembles *A. parvus* Mann.[81] Mann's species, however, in addition to having identical markings on all sectors, is much less undulate and never has a hyaline space across the outer ends of any sectors. In the present species, the narrow hyaline space across the outer ends of the raised sectors is definitely seen with some difficulty and is never present across the ends of the depressed bipunctate sectors. The fine puncta in the bipunctate depressed sectors extend into and become continuous with the marginal puncta, but the coarser markings in the same sectors stop about 1μ short of the margin, giving the appearance of a hyaline space when viewed with objectives of insufficient aperture to resolve the finer puncta. These obviously illusory spaces in the depressed sectors are more visible under low and medium magnifications than the real spaces in the raised sectors.

Hanna and Grant[82] have figured a 10-sectored specimen of *A. maculatus* Grove and Sturt, of about the same size as the present species which might be confused with it. *A. bipunctatus* has a narrower margin with the same type of markings throughout, whereas *A. maculatus*[83] has the symmetrical group of coarse marginal puncta opposite each bipunctate sector, has coarse markings (maculations) in alternate sectors and fine markings throughout (the reverse is true in the present species), and has a prominent hyaline space opposite the sectors with fine markings only.

A large number of individuals of this species were found in the cores, and the characters as given above were remarkably constant, with the following exceptions: The scattered puncta in the central area ranged from prominent in most specimens to absent in a few; the marginal apiculi were present on all sectors in most cases and on alternate sectors in a few specimens. The number of sectors, usually considered to be a feature of minor importance in this genus, was uniformly 10 in all specimens observed.

Found rarely in samples L–30, L–50, L–51, and L–59, and frequently in samples L–31, L–52, and L–54.

Actinoptychus campanulifer Schmidt

Plate 16, figure 8

Actinoptychus campanulifer Schmidt, Atlas der Diatomaceenkunde, pl. 29, figs. 13–15, 1875.

The occurrence of this diatom in the cores is the first known to me since its original discovery by Schmidt from Rio Brasil in 1875. The broad hyaline submarginal space on alternate sectors, with pronounced marginal apiculi on intervening sectors, are distinguishing features that are constant among the specimens studied.

The specimen figured is the best one found, and unfortunately it was tilted somewhat in mounting, so that only half of the valve is in focus.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1984–5), 33μ. From sample L–65 (U. S. G. S. diatom locality 2878), 0–7 cm. below the top of core 13.

Found rarely in samples L–62 and L–65.

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[80] The terms "raised" and "depressed" may be interchanged if the valve is viewed from the opposite side.

[81] Mann, Albert, Marine diatoms of the Philippine Islands: U. S. Nat. Mus. Bull. 100, vol. 6, part 1, p. 15, pl. 1, fig. 8, 1925.

[82] Hanna, G. D., and Grant, W. M., Miocene marine diatoms from Maria Madre Island, Mexico: California Acad. Sci., 4th ser., vol. 15, no. 2, p. 122, pl. 11, figs. 8, 9, 1926.

[83] Grove, Edmund, and Sturt, Gerald, On a fossil marine diatomaceous deposit from Oamaru, Otago, New Zealand: Quekett Micr. Club Jour., ser. 2, vol. 3, p. 64, pl. 5, fig. 5, 1887.

Actinoptychus senarius (Ehrenberg) Ehrenberg

Plate 16, figure 9

Actinocyclus senarius Ehrenberg, Die Infusionsthierchen als vollkommene Organismen, p. 172, pl. 21, fig. 6, 1838.

Actinoptychus senarius (Ehrenberg) Ehrenberg, Berlin K. Akad. Wiss. Physikal. abh., 1841, p. 400, pl. 1, fig. 27, 1843.

Hendey, Discovery Repts., vol. 16, p. 271, 1937.

Actinocyclus sp. Bailey, Am. Jour. Sci., 1st ser. vol. 42, pl. 2, fig. 11, 1842.

Actinocyclus undulatus Kützing, Die kieselchaligen Bacillarien oder Diatomeen, p. 132, pl. 1, fig. 44, 1844.

Omphalopelta areolata Ehrenberg, K. akad. Wiss. Berlin, Ber. 1844, p. 270, 1845.

Ehrenberg, Mikrogeologie, pl. 33, group 13, fig. 17; pl. 35A, group 18, fig. 2, 1854.

Actinoptychus undulatus (Kützing) Ralfs, in Pritchard, A history of Infusoria, 4th ed., p. 839, pl. 5, fig. 88, 1861.

Actinoptychus omphalopelta Grunow, in Fenzl, Reise der Österreichischen Fregatte Novara um die Erde in Jahren 1857, 1858, 1859, Bot. Theil, Band 1, p. 25, 1870.

Actinoptychus undulatus Kützing. Grunow, idem, p. 25, 1870.

Actinoptychus undulatus var. *senarius* Grunow, idem, p. 25, 1870.

Actinoptychus undulatus Ehrenberg. Schmidt, Komm. zur Untersuchung der deutschen Meer in Kiel, p. 94, pl. 3, figs. 29, 30, 1874.

Schmidt, Atlas der Diatomaceenkunde, pl. 1, figs. 1–4, 1875; pl. 109, fig. 1, 1886; pl. 132, fig. 16, 1888.

Van Heurck, Synopsis diatomées Belgique, pl. 22B, fig. 14, 1880; pl. 122, figs. 1, 3, 1883; p. 210, 1885.

Actinoptychus undulatus var. *microsticta* Grunow, in Van Heurck, Synopsis diatomées Belgique, pl. 122, figs. 2, 4, 1883.

Actinoptychus undulatus Ehrenberg. Van Heurck, Treatise on the Diatomaceae, p. 493, fig. 232; p. 494, fig. 234; p. 496, pl. 22, fig. 648, 1896.

Actinoptychus undulatus (Bailey) Ralfs. Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 272, 1907.

Actinoptychus undulatus (Kützing) Ralfs. Boyer, The Diatomaceae of Philadelphia and vicinity, p. 24, pl. 4, figs. 1, 2, 4, 6, 1916.

Actinoptychus undulatus (Bailey?) Ralfs. Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 78, supplement, p. 64, 1926.

Actinoptychus undulatus (Bailey). Hanna and Grant, California Acad. Sci. Proc., 4th ser., vol. 15, no. 2, p. 124, pl. 12, fig. 4, 1926.

Actinoptychus undulatus Ehrenberg. Hanna, Jour. Paleontology, vol. 1, no. 2, p. 108, 1927.

Actinoptychus undulatus Ralfs. Karsten, in Engler, Die naturlichen Pflanzenfamilien, Band 2, Bacillariophyta, p. 219, fig. 236, a, b, 1928.

Coupin, Album général des Diatomées, pl. 294, fig. H, 1930.

Actinoptychus undulatus (Bailey) Ralfs. Hustedt, Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 475, fig. 264, 1929.

Hanna, California Acad. Sci. Proc. 4th ser., vol. 20, No. 6, p. 172, 1932.

Mills, An Index to the Genera and Species of the Diatomaceae, vol. 1, p. 117, 1933.

Actinoptychus undulatus Ehrenberg. Lohman, U. S. Geol. Survey Prof. Paper 189–C, p. 82, pl. 20, fig. 8; pl. 22, fig. 3, 1938.

Although the above list may seem unnecessarily long and detailed, it is only a fragment of the available synonymy of this species. The present synonymy has been given in considerable detail to show the uncertainty with which the name *Actinoptychus undulatus* has been used in the past by different authors and to justify Hendey's action [84] in invoking the rule of strict priority by returning to Ehrenberg's original name, *Actinoptychus senarius.* In each of the citations the authorship of the species is given, exactly as it appears in the paper cited. The synonymy itself presents such a graphic picture of the uncertainty with which the name *Actinoptychus undulatus* has been used by different authors (occasionally even by the same author in different works) that the point hardly needs elaboration here.

As Hendey's excellent volume on the planktonic diatoms of the southern seas may not be available to many, his argument for changing the name of this well-known diatom deserves to be repeated here. He says: [85]

> It has been often said that there existed in the minds of early diatomists a confusion between *Actinoptychus* and *Actinocyclus.* Although this has now been settled, the following notes are included in order to make clear the reasons which have led to changes being made in the names of some well-known species. Ehrenberg (1838, p. 171) [86] established the genus *Actinocyclus.* Two species were described and figured, *A. senarius* and *A. octonarius.* Later, other forms were added, and Ehrenberg, realizing that the genus contained more than one group, desired to make a separation. Ehrenberg (1840a) [87] introduced a subgenus in the following manner:
>
> "*Actinocyclus* (*Actinoptychus*) *senarius,* synonym *Actinocyclus senarius* 1838." Later Ehrenberg ((1841) 1843, p. 400) [88] established the genus *Actinoptychus.* On a previous page (p. 328), and in the description of the plates, the combination *Actinoptychus senarius* was used, and there is reason to believe from the similarity of the figures provided that *Actinoptychus senarius* Ehrenberg was based on *Actinocyclus senarius* (1838). Ehrenberg (1843, p. 400) explained that the separation was necessary on account of structural differences that existed in *Actinocyclus* (1838) and continued at some length to explain the differences upon which the separation was made. *Actinocyclus octonarius* (1838) was retained as the type species of *Actinocyclus.* The species *Actinoptychus senarius* is often attributed to Bailey in the following manner: "*Actinoptychus undulatus* Bailey," but there appear to be no grounds for this. Bailey (1842) [89] mentioned the occurrence of a number of species of *Actinocyclus* in fossil material from Richmond, Virginia, and provided figures which undoubtedly represented the species under consideration here, but the figures were unnamed. Ehrenberg (1843, p. 328) accepted Bailey's figure as being equal to his *Actinoptychus senarius.* Kützing (1844) [90] took Bailey's illustration as a type illustration and described *Actinocyclus undulatus.* Ralfs (1861) [91] placed this species in

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[84] Hendey, N. I., The plankton diatoms of the southern seas: *Discovery* Repts., vol. 16, p. 271, 1937.

[85] Hendey, N. I., idem., p. 271.

[86] Ehrenberg, C. G., Die Infusionsthierchen als volkommene Organismen, p. 171, 1838.

[87] Ehrenberg, C. G., Über noch jetzt zahlreich lebende Thierarten der Kreidebildung und den Organismus der Polythalmien: K. Akad. Wiss. Berlin, Physikal. Abh. 1839, p. 137, pl. 4, fig. 1a-e, 1841.

[88] Ehrenberg, C. G., Verbreitung und Einfluss des mikroskopischen Lebens in Sud- und Nord-Amerika: Berlin K. Akad. Wiss. Physikal. Abh., 1841, p. 400, 1843.

[89] Bailey, J. W., A sketch of the infusoria of the family Bacillaria, with some account of the most interesting species which have been found in a recent or fossil state in the United States: Am. Jour. Sci., vol. 42, p. 93, pl. 2, fig. 11, 1842.

[90] Kützing, F. T., Die kieselschaligen Bacillarien oder Diatomeen, p. 132, pl. 1, fig. 44, 1844.

[91] Ralfs, John, in Pritchard, Andrew, A history of Infusoria, 4th ed., p. 839, pl. 5, fig. 88, 1861.

the genus *Actinoptychus*, but accepted Kützing's epithet. Ehrenberg's epithet is used here to satisfy claims of priority.

This is another case (see *Actinocyclus octonarius* Ehrenberg, p. 77) where there is no choice between the claims of strict priority and the "common sense" view of allowing a well-established name to stand.

This neritic species is common in subtropical seas, and Lebour[92] has reported it from "all parts of the North Sea, Norwegian Seas, Danish Seas, Skaggerak, Baltic, North Atlantic, Finland, English Channel, West Coast of France, Mediterranean, Atlantic and Pacific American coasts." Its geologic range is Eocene[93] to Recent.

Diameter of figured specimen (U. S. G. S. diatom catalog no. 1958–1): 39μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below the top of core 9.

Found rarely in samples L–23, L–31, L–32, L–37, and L–52 and frequently in sample L–10.

Suborder BIDDULPHINEAE
Family CHAETOCERACEAE
Subfamily CHAETOCEROIDEAE
Genus CHAETOCEROS Ehrenberg, 1844
Subgenus PHAEOCEROS Gran, 1897

Chaetoceros atlanticum Cleve

Plate 17, figure 1

Chaetoceros atlanticum Cleve, K. svenska vetensk. akad. Handl., Band 1, no. 13, p. 11, pl. 2, fig. 8, 1873.
Gran, Nordisches Plankton, Lief. 3, p. 64, fig. 74, 1905.
Hustedt, in Schmidt, Atlas der Diatomaceenkunde, pl. 337, fig. 1, 2, 1921.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 641, fig. 363, 1930.
Hendey, Discovery Repts., vol. 16, p. 290, 1937.
Chaetoceros dispar Castracane, Challenger Repts., Botany, vol. 2, p. 76, pl. 8, fig. 6, 1886.
Chaetoceros audax Schütt, Deutsche bot. Gesell. Ber., Band 13, p. 47, pl. 5, fig. 25, 1895.
Chaetoceros polygonum Schütt, Deutsche bot. Gesell. Ber., Band 13, p. 46, pl. 5, fig. 24, 1895.

This oceanic species is common in north polar and North Atlantic waters and is frequently found in European seas farther south. Hendey (5th citation above) notes that it prefers a high salinity and although common in south temperate seas is seldom found in Antarctic waters.

Major axis of valve in specimen figured (U. S. G. S. diatom catalog no. 1957–4), 27μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below the top of core 9.

Found rarely in sample L–30 and frequently in sample L–52.

Suborder SOLENIINEAE
Family RHIZOSOLENIACEAE
Subfamily RHIZOSOLENIOIDEAE
Genus RHIZOSOLENIA Ehrenberg, 1843, emend. Brightwell, 1858

Rhizosolenia bergonii H. Peragallo

Plate 17, figure 2

Rhizosolenia bergonii H. Peragallo, Le Diatomiste, vol. 1, p. 110. pl. 15, fig. 5, 1892.
Gran, Nordisches Plankton, Lief. 3, p. 51, fig. 60, 1905.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 575, fig. 327, 1929.
Lebour, The planktonic diatoms of northern seas, p. 102, fig. 74b, 1930.
Rhizosolenia amputata Ostenfeld, in Schmidt, Bot. Tidsskrift., Band 25, p. 227, fig. 4, 1902.
Hustedt, in Schmidt, Atlas der Diatomaceenkunde, pl. 318, fig. 1–3, 1920.

Only the spines of this oceanic species were found and these rarely. The characteristic canal, cup-shaped at the apex and inflated at the base, and the fine markings on the shoulder serve to identify these fragments.

It is usually found in tropical and subtropical seas. Lebour (4th citation above) gives the northerly limit of this species as lat. 48° N.

Length of fragment figured (U. S. G. S. diatom catalog no. 1961–1), 88μ. From sample L–55 (U. S. G. S. diatom locality 2861), 246–250 cm. below the top of core 9.

Found rarely in sample L–55.

Rhizosolenia styliformis Brightwell

Plate 17, figures 3, 4

Rhizosolenia styliformis Brightwell, Quart. Jour. Micr. Sci., vol. 6, p. 95, pl. 5, fig. 5, 1858.
Peragallo, H., Le Diatomiste, vol. 1, p. 111, pl. 17, fig. 5, 1892.
Van Heurck, Treatise on the Diatomaceae, p. 415, fig. 137; pl. 17, fig. 601, 1896.
Gran, Nordisches Plankton, Lief. 3, p. 54, 1905.
Hustedt, in Schmidt, Atlas der Diatomaceenkunde, pl. 316, figs. 1–4, 8–11, 1914.
Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 1, p. 584, fig. 333, 1929.
Hendey, Discovery Repts., vol. 16, p. 320, pl. 11, figs. 15–17, 1937.

Kain and Schultze[94] have reported this species from beds that are probably equivalent to the Calvert formation (middle Miocene) of Maryland, from a depth of 387–638 feet in a well at Atlantic City, N. J. Brun and Tempère[95] also reported this species as abundant in a calcareous shale of probable upper Miocene age in Sendai, Japan. Its occurrence in these older rocks is particularly interesting, as the cell wall in this species is usually much less highly silicified than in other diatoms. Many specimens were found in the cores, but

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[92] Lebour, M. V., The planktonic diatoms of northern seas, p. 51, fig. 27, 1930.

[93] Hanna, G. D., The lowest known tertiary diatoms in California: Jour. Paleontology, vol. 1, no. 2, p. 108, 1927. (From Kreyenhagen shale in Phoenix Canyon, Fresno County, California, then considered by Hanna to be Lower Miocene in age, but now thought to be Upper Eocene.)

[94] Kain, C. H., and Schultze, E. A., On a fossil marine diatomaceous deposit from Atlantic City, N. J.: Torrey Bot. Club Bull., vol. 16, p. 76, 1889.

[95] Brun, J., and Tempère, J., Diatomées fossiles du Japon: Genève Soc. Phys. Hist. Nat. Mém., tome 30, No. 9, p. 73, 1889.

in each case only the apical spines and small portions of the valve were preserved. The winglike projections near the base of the spine are clearly shown in figure 3.

This is an oceanic species of world-wide distribution, common in both tropical seas and in the colder sub-Arctic and sub-Antarctic waters.

Over-all lengths of fragments figured

Figure	U. S. G. S. diatom catalog number	U. S. G. S. diatom locality number	Sample number	Length in μ
4	1960–2	2860	L–54	92
3	1964–5	2864	L–2	75

Found rarely in samples L–3, L–6, L–31, and L–54 and frequently in samples L–2, L–4, L–30, and L–37.

Suborder ARAPHIDINEAE
Family FRAGILARIACEAE
Subfamily FRAGILARIOIDEAE
Genus RHAPHONEIS Ehrenberg, 1844

Rhaphoneis surirella (Ehrenberg) Grunow

Plate 17, figure 6

Zygoceros surirella Ehrenberg, K. Akad. Wiss. Berlin Abh., pl. 4, fig. 12, 1840.[96]

Ralfs, in Pritchard, History of the Infusoria, 4th ed., p. 850, pl. 11, figs. 50, 51, 1861.

Rhaphoneis surirella (Ehrenberg) Grunow, in Van Heurck, Synopsis diatomées Belgique, pl. 36, fig. 26, 27a, 1881.

De Toni, Sylloge algarum omnium hucusque cognitarum, vol. 2, p. 712, 1892.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 2, p. 173, fig. 679 a–c, 1931.

Dimerogramma surirella Grunow, K. svenska vetensk. akad. Handl., Band 5, no. 8, p. 11, 1878.

Fragilaria surirella Schönfeldt, Die deutschen Diatomeen des Süsswassers und des Brackwassers, p. 103, 1907.

Rhaphoneis surirella Ehrenberg. Hustedt, in Schmidt, Atlas der Diatomaceenkunde, pl. 267, figs. 47–49, 1911.

The pseudoraphe in this species is frequently expanded near the apices. In the specimen found in the core, the pseudoraphe was parallel-sided throughout its length. Hustedt (5th citation above) has figured both forms.

This species lives in brackish and salt water and is frequently found in brackish estuaries and along the coast of southern Europe.

Length of figured specimen (U. S. G. S. diatom catalog no. 1984–4), 36μ. From sample L–66 (U. S. G. S. diatom locality 2878), 0–7 cm. below the top of core 13.

Found rarely in sample L–66.

Genus THALASSIOTHRIX Cleve and Grunow, 1880

Thalassiothrix longissima Cleve and Grunow

Plate 17, figure 5

Synedra thalassiothrix Cleve, K. svenska vetensk. akad. Handl., Bihang, Band 1, no. 13, p. 22, pl. 4, fig. 24, 1873.

Thalassiothrix longissima Cleve and Grunow, K. svenska vetensk. akad. Handl., Band 17, no. 2, p. 108, 1880.

Heiden and Kolbe, Deutsche Südpolar-Expedition, Band 8, Botanik, Heft 5, p. 565, pl. 6, fig. 123, 1928.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 2, p. 247, fig. 726, 1932.

Hendey, Discovery Repts., vol. 16, p. 336, 1937.

This diatom, the longest known, attains a length of 4 mm. with an average width of only 3 to 4μ. As only fragments of varying length are found in anything but recent material, it is easily confused with *Thalassionema nitzschioides* (Grunow) Hustedt, which has somewhat similar markings. The latter species, however, grows in stellate or zigzag clusters, and individual frustules rarely attain a length of 100μ.

It occurs commonly to frequently in middle Miocene[97] and later rocks in California. In general the forms assigned to this species from the cores are somewhat heavier-walled that the California forms; otherwise they are identical. In the Upper Miocene Monterey formation in California, concentrations of this diatom occur in the form of thin partings in shale up to beds several inches thick, in which it forms a very large percentage of the material present. No such concentrations were observed in the cores.

Brun and Tempère[98] found it in considerable abundance in Japan in what are now considered to be upper Miocene rocks. In my report on the Pliocene diatoms from the Kettleman Hills, Calif.,[99] I erroneously assigned this diatom to *Thalassionema nitzschioides* Grunow.

It is a true pelagic marine cold-water diatom and is very common in the Arctic seas, the North Atlantic, along the European coasts, and in the South Atlantic and South Pacific.

Although one of the most abundant species found in the cores, no whole specimens were found. The fragments ranged from 3μ to 6μ in width, and 30μ to 165μ in length.

Dimensions of figured specimen (fragment) (U. S. G. S. diatom catalog no. 1957–9): Length, 165μ; maximum width, 6μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below the top of core 9.

Found rarely in sample L–6, L–7, L–8, L–16, L–49, L–53, L–59, and L–61, frequently in samples L–1, L–2, L–3, L–20, L–23, L–33, L–50, and L–55, commonly in samples L–10, L–19, L–32, L–37, L–51, L–52, L–54, and L–56, and abundantly in samples L–4, L–30 and L–31.

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[96] This citation is doubtful, as I have been unable to find the original. Reference here taken from Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 2, p. 173, 1931.

[97] Lohman, K. E., Comparison of the diatom floras from the Temblor formation (middle Miocene) in California with those from the Calvert (middle Miocene) in Maryland and Virginia: MS. (Report in preparation).

[98] Brun, Jacques and Tempère, J., Diatomées fossiles du Japon. Espèces marines et nouvelles des calcaires argileux de Sendai et de Yedo: Genève Soc. Physique Hist. Nat. Mém., tome 30, no. 9, p. 74, 1889.

[99] Lohman, K. E., Pliocene diatoms from the Kettleman Hills, California: U. S. Geol. Survey Prof. Paper 189–C, p. 83, 1937.

Suborder RAPHIDIOIDINEAE
Family EUNOTIACEAE
Genus EUNOTIA Ehrenberg, 1837

Eunotia praerupta Ehrenberg var. bidens (W. Smith) Grunow

Plate 17, figure 7

Himantidium bidens Ehrenberg. W. Smith, Synopsis of the British Diatomaceae, vol. 2, p. 13, pl. 33, fig. 284, 1854.

Eunotia praerupta Ehrenberg var. *bidens* (W. Smith) Grunow, in Van Heurck, Synopsis diatomées Belgique, pl. 34, figs. 20, 21, 1881.

Grunow, Akad. Wiss. Wien, Math.-naturwiss. Kl., Denkschr., Band 48, p. 48, pl. 2 (B), fig. 12, 1884.

Hustedt, in Schmidt, Atlas der Diatomaceenkunde, pl. 273, figs. 26–28, 32, 33, 1911.

Hustedt, in Pascher, Die Süsswasser-flora Mitteleuropas, Heft 10, p. 174, fig. 213, 1930.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 2, p. 281, figs. 747A, i-m, 1932.

Eunotia bigibba Gregory (not Kützing), Quart. Jour. Micr. Sci., 1854, p. 95, pl. 4, fig. 3.

William Smith, in his original (?) description of *Himantidium bidens* cited Ehrenberg as the author, but no one has since been able to discover where or when Ehrenberg described it. The authority is, therefore, attributed to Smith.

This is another fresh-water diatom that must have been transported many miles to be deposited on a mid-Atlantic sea bottom.

Length of figured specimen (U. S. G. S. diatom catalog no. 1987–1), 69μ. From sample L–39 (U. S. G. S. diatom locality 2894), 275–281 cm. below the top of core 6.

Found rarely in sample no. L–39.

Genus PSEUDOEUNOTIA Grunow, 1881

Pseudoeunotia doliolus (Wallich) Grunow

Plate 17, figure 12, 13

Synedra doliolus Wallich, Micr. Soc. London Trans., new ser., vol. 8, p. 48, pl. 2, fig. 19, 1860.

Pseudoeunotia doliolus (Wallich) Grunow, in Van Heurck, Synopsis diatomées Belgique, pl. 35, fig. 22, 1881.

Mann, U. S. Nat. Mus. Bull. 100, vol. 6, pt. 1, p. 140, pl. 30, figs. 7–8, 1925.

Heiden and Kolbe, Deutsche Südpolar-Expedition 1901–1903, Band 8, Botanik, Heft 5, p. 558, 1928.

Hustedt, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Teil 2, p. 259, fig. 737, 1932.

Himantidium? doliolus Grunow, Zool.-bot. Gesell. Wien Verh., Band 12, p. 342, 1862.

Hustedt's figure (5th citation above) is somewhat misleading, as he does not show the heavy, double-beaded margin that is clearly shown in Grunow's figures (2d citation above) and in Mann's figures (3d citation above). It is very prominent on the forms found in the cores. My specimens have the same slender, produced apices shown in Mann's figures, and not the broader apices shown by Hustedt.

This is a littoral, warm-water species found along the coast of southern Europe and around the Philippine Islands. It has never been reported from the North or West Atlantic, and its presence in the cores suggests long travel before deposition.

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 2000–2): Length, 75μ; width, 8μ. From sample L–52 (U. S. G. S. diatom locality 2858), 142–151 cm. below top of core 9.

Found rarely in samples L–10, L–37, L–51, and L–52.

Suborder MONORAPHIDINEAE
Family ACHNANTHACEAE
Subfamily ACHNANTHOIDEAE
Genus RHOICOSPHENIA Grunow, 1860

Rhoicosphenia curvata (Kützing) Grunow

Plate 17, figure 8

Gomphonema curvatum Kützing, Linnaea, vol. 8, p. 567, pl. 16, fig. 51, 1833.

Rhoicosphenia curvata (Kützing) Grunow, in Fenzl, Reise der Österreichischen Fregatte Novara um die Erde, Bot. Theil, Band 1, Algen, p. 8, 1870.

Van Heurck, Synopsis diatomées Belgique, p. 127 (1885), pl. 26, fig. 1–3, 1880.

Schmidt, Atlas der Diatomaceenkunde, pl. 213, figs. 1–5, 1899.

Pantocsek, Die Kieselalgen oder Bacillarien des Balaton, p. 60, pl. 7, figs. 155, 156, 1901.

Boyer, Diatomaceae of Philadelphia and vicinity, p. 56, pl. 19, figs. 25–27, 1916.

Hustedt, in Pascher, Die Süsswasser-flora Mitteleuropas, Heft 10, p. 211, fig. 311, 1930.

Hustedt, Die Kieselalgen, Deutschlands, Österreichs, und der Schweiz, Teil 2, p. 431, fig. 879, 1933.

Gomphonema fractum Schumann, Königsberg physikal.-ökonomische Gesell. Schr., Band 3, p. 187, pl. 9, fig. 32, 1863.

Rhoicosphenia fracta Rabenhorst, Flora Europaea algarum, p. 292, 1864.

Rhoicosphenia curvata var. *fracta* Cleve, K. svenska vetensk. akad. Handl., Band 27, no. 3, p. 166, 1895.

Rhoicosphenia linearis Östrup, Danske Diatomeer, p. 120, pl. 3, fig. 74, 1910.

This widely distributed fresh-water and brackish-water form was probably introduced into the basin of deposition by currents.

Dimensions of specimen figured (U. S. G. S. diatom catalog no. 1951–2): Length (as shown), 68μ; maximum width, 14μ. From sample L–10 (U. S. G. S. diatom locality 2854), 74–79 cm. below the top of core 4.

Found rarely in sample L–10.

Suborder BIRAPHIDINEAE
Family NAVICULACEAE
Subfamily NAVICULOIDEAE
Genus NAVICULA Bory, 1822

Navicula pennata Schmidt

Plate 17, figure 14

Navicula pennata Schmidt, Atlas der Diatomaceenkunde, pl. 48, fig. 41–43, 1876.

Cleve, K. svenska vetensk. akad. Handl., Band 27, no. 3, p. 32, 1895.

Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 349, 1907.

Boyer, Diatomaceae of Philadelphia and vicinity, p. 96, pl. 27, fig. 22, 1916.
Lohman, U. S. Geol. Survey Prof. Paper 189–C, p. 84, pl. 22, fig. 16, 1938.

Mann (see 3d citation above) has listed as synonyms of this species, *N. kinkeri* Pantocsek,[1] *N. pinnata* Pantocsek,[2] and *Scoliopleura szakalensis* Pantocsek,[3] which for several reasons does not appear to have been a wise choice. The type of *N. pennata* Schmidt came from the Mediterranean Sea and has since been found living in several other localities. Neither *N. kinkeri* or *N. pinnata* have been found living and hence may be of value in stratigraphy if kept separate from *N. pennata*. Cleve [4] combined *Scoliopleura szakalensis* and *Navicula kinkeri* as *Navicula pennata* var. *kinkeri*, which appears to be a satisfactory solution of the difficulty. Cleve retained *N. pinnata* Pantocsek as a separate species, and several other authors have followed.[5]

This is a warm-water species of wide distribution at present and is known from the Pliocene [6] to the Recent.

Dimensions of figured specimen (fragment) (U. S. G. S. diatom catalog no. 1964–1): Length, 75μ; width, 17μ; costae, 4–5 in 10μ. From sample L–2 (U. S. G. S. diatom locality 2864), 40–48 cm. below the top of core 3.

Found rarely in samples L–2 and L–66.

Genus DIPLONEIS Ehrenberg, 1844

Diploneis interrupta (Kützing) Cleve

Plate 17, figure 15

Navicula interrupta Kützing, Die kieselschaligen Bacillarien oder Diatomeen, p. 100, pl. 29, fig. 93, 1844.
Diploneis interrupta (Kützing) Cleve, K. svenska vetensk. akad. Handl., Band 26, no. 2, p. 84, 1894.
Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 79, supplement, p. 348, 1927.
Hustedt, in Pascher, Süsswasser-flora Mitteleuropas, Heft 10, p. 252, fig. 400, 1930.
Navicula interrupta Kützing. Donkin, The natural history of the British Diatomaceae, pt. 1, p. 47, pl. 7, fig. 2, 1870.
Schmidt, Atlas der Diatomaceenkunde, pl. 12, figs. 3–11, 1875; pl. 69, fig. 24, 1881.
Van Heurck, Synopsis diatomées Belgique, p. 89, 1885; pl. 9, figs. 7, 8, 1880.
Navicula interrupta var. *novae-seelandiae* Schmidt, Atlas der Diatomaceenkunde, pl. 12, fig. 12, 1875.
Diploneis didyma Ehrenberg, K. Akad. Wiss. Berlin, Physikal. Abh., 1870, pl. 2, fig. 13, 1871.
Navicula puella Schmidt, Atlas der Diatomaceenkunde, pl. 69, fig. 25, 1881.

This brackish-water and marine species is one of the most tolerant diatoms known. It occurs in brackish to almost fresh water, under truly marine conditions, and under an equally wide variety of temperatures. Cleve[7] listed the following habitats for this diatom:

Spitzbergen, Beeren Eiland (Lagst.), Kara, Finmark, North Sea, Baltic (Tornea to Rügen), Mediterranean Sea, Red Sea (Grun.), Java, Samoa, Australia, Aukland (Grun.), Cape Good Hope (Atl.), Atlantic Coast of America, Greenland, Arctic America, Franzenbad, Halle, Great Salt Lake.

The reference to Great Salt Lake above is misleading, as it implies that *Diploneis interrupta* is living in the highly saline water of the Great Salt Lake. In 1870 Ehrenberg[8] published a paper on diatoms from California in which he lists *D. didyma* (= *D. interrupta*) from three samples of "Sehr weisse, mehlartige, leichte Erde" cataloged as "Salt Lake Nr. 6550, Nr. 6551, and Nr. 6559," on pages 14, 15, and 16 respectively. In his checklist, facing page 68, the same samples are again listed by "Salt Lake Nr. 6550" etc., but without the lithologic description given in the text. It appears that Cleve, in making his list of habitats, used the checklist and thought that Ehrenberg's material from Salt Lake was living in the lake water. Patrick,[9] who studied the diatoms in mud samples around the shores of the Great Salt Lake, says, "No diatom flora is found living in the lake proper today."

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 1986–1): Length, 33μ; maximum width, 13μ; width at constriction, 7μ; costae, 11 in 10μ. From sample L–37 (U. S. G. S. diatom locality 2893), 226–230 cm. below the top of core 6.

Found rarely in sample L–37.

Diploneis smithii (Brébisson) Cleve

Plate 17, figure 18

Navicula smithii Brébisson, in Smith, Wm., Synopsis of the British Diatomaceae, vol. 2, p. 92, 1856.
Diploneis smithii (Brébisson) Cleve, K. svenska vetensk. akad. Handl., Band 26, No. 2, p. 96, 1894.
Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 79, supplement, p. 354, 1927.
Hustedt, in Pascher, Die Süsswasser-flora Mitteleuropas, Heft 10, p. 253, fig. 402, 1930.
Lohman, U. S. Geol. Survey Prof. Paper 189–C, p. 84, pl. 23, fig. 10, 1938.
Navicula smithii Brébisson. Schmidt, Atlas der Diatomaceenkunde, pl. 7, figs. 14–20, 1875.
Van Heurck, Synopsis diatomées Belgique, p. 91, 1885; pl. 9, fig. 12, 1880; supplement, pl. B, fig. 23, 1884.
Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 354, 1907.
Hanna and Grant, California Acad. Sci. Proc., ser. 4, vol. 15, No. 2, p. 155, pl. 19, fig. 1, 1926.

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[1] Pantocsek, Josef, Beitrage zur Kenntnis der fossilen Bacillarien Ungarns, Teil 2, p. 50, pl. 9, fig. 169, 1889.
[2] Idem, Teil 2, p. 54, pl. 20, fig. 308.
[3] Idem, Teil 2, p. 57, pl. 8, fig. 154.
[4] Cleve, P. T., A synopsis of the naviculoid diatoms, part 2: K. svenska vetensk. akad. Handl., Band 27, no. 3, p. 33, 1895.
[5] Mills, F. W., An index to the genera and species of the Diatomaceae, part 15, p. 1120, 1934.
[6] Lohman, K. E., Pliocene diatoms from Kettleman Hills, California: U. S. Geol. Survey Prof. Paper 189–C, p. 84, pl. 22, fig. 16, 1938.
[7] Cleve, P. T., Synopsis of the naviculoid diatoms: K. svenska vetensk. akad. Handl., Band 26, no. 2, p. 84, 1894.
[8] Ehrenberg, C. G., Über die wachsende Kenntniss des unsichtbaren Lebens als felsbildende Bacillarien in Californien: K. Akad. Wiss. Berlin Physikal. Abh. 1870, No. 1, pp. 1–74, pls. 1–3, 1871.
[9] Patrick, Ruth, Some diatoms of Great Salt Lake: Torrey Bot. Club Bull., vol. 63, p. 165, 1936.

Hanna and Grant, Jour, Paleontology, vol. 3, no. 1, p. 98, pl. 13, fig. 5, 1929.

Navicula elliptica W. Smith, Synopsis of the British Diatomaceae, vol. 1, p. 48, pl. 17, fig. 152a, 1853.

Navicula doczyi Pantocsek, Beiträge zur Kenntniss der fossilen Bacillarien Ungarns, Teil 2, p. 45, pl. 14, fig. 247, 1889.

Navicula (*Diploneis*) *smithii* (Brébisson) Cleve. Reinhold, Nederland en Koloniën Geol.-Mijnbouwk. Genootschap, Verh., geol. ser., Deel 12, p. 112, pl. 14, fig. 11, 1937.

This diatom has a world-wide distribution in marine and brackish waters in warm, temperate, and cold zones. The specimen figured is an elongate, elliptical form, but others in the same sample were somewhat more angular, approaching the one illustrated in plate 7, figure 18, of Schmidt's Atlas.

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 1981–1): Length, 81μ; width, 39μ. From sample L–60 (U. S. G. S. diatom locality 2873), 233–237 cm. below the top of core 10.

Found rarely in samples L–51 and L–60.

Diploneis weissflogii (Schmidt) Cleve

Plate 17, figure 16

Navicula weissflogii Schmidt, Gesell. Naturwiss. Zeitschr., Band 41, p. 406, pl. 6, figs. 3, 4, 1873.

Diploneis weissflogii (Schmidt) Cleve, K. svenska vetensk. akad. Handl., Band 26, No. 2, p. 91, 1894.

Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 79, supplement, p. 351, 1927.

Navicula weissflogii Schmidt. Van Heurck, Synopsis diatomées Belgique, p. 90, supplement, pl. A, fig. 21, 1885.

Van Heurck, Treatise on the Diatomaceae, p. 194, pl. 3, fig. 148, 1896.

Reinhold, Nederland en Koloniën, Geol.-Mijnbouwk, Genootschap, Verh., geol. ser., Deel 12, p. 112, pl. 13, fig. 7, 1937.

Cleve[10] has included *Navicula diversa* Greville[11] in the synonymy of this species with a query. If Greville's description and figure are accurate, the query should stand, as his species is much less constricted, the central transverse bars have the small nodules at the outer ends rather than towards the center, and the markings are much finer, with a stauriform central space. Greville's species should, therefore, not be combined with *Diploneis weissflogii*, although Peragallo[12] and Mills[13] (possibly ignoring Cleve's query) have done so.

This is a temperate to warm water species with a known geologic range of upper Miocene[14] to Recent.

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 1972–3): Length, 36μ; maximum width, 16μ; width at constriction, 11μ. From sample L–4 (U. S. G. S. diatom locality 2866), 130–137 cm. below top of core 3.

Found rarely in sample L–4.

Genus PLEUROSIGMA Wm. Smith, 1852

Pleurosigma naviculaceum Brébisson

Plate 17, figure 17

Pleurosigma naviculaceum Brébisson, Cherbourg Soc. Sci. Nat. Mém., tome 2, p. 17, fig. 7, 1854.

Cleve and Grunow, K. svenska vetensk. akad. Handl., Band 17, no. 2, p. 51, 1880.

Van Heurck, Synopsis diatomées Belgique, p. 116, supplement, pl. C, fig. 35, 1885.

Peragallo, Le Diatomiste, vol. 1, p. 11, pl. 4, figs. 19, 23, 1891.

Cleve, K. svenska vetensk. akad. Handl., Band 26, No. 2, p. 36, 1894.

Boyer, Diatomaceae of Philadelphia and vicinity, p. 74, pl. 22, fig. 6, 1916.

Pleurosigma transversale W. Smith, Synopsis of the British Diatomaceae, vol. 2, p. 96, 1856.

Pleurosigma japonicum Castracane, Challenger Repts., Botany, vol. 2, p. 38, pl. 29, fig. 14, 1886.

This species is most frequently found in tropical waters, although Cleve[15] has reported it from the North Sea and Boyer[16] has reported it from Long Island Sound. In the material studied for this report it was found only in the two easternmost cores.

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 1984–1): Length, 87μ; width, 21μ. From sample L–66 (U. S. G. S. diatom locality 2878), 0–7 cm. below the top of core 13.

Found rarely in sample L–62 and frequently in sample L–66.

Family BACILLARIACEAE
Subfamily NITZSCHIOIDEAE
Genus NITZSCHIA Hassall, 1845

Nitzschia marina Grunow

Plate 17, figure 10, 11

Nitzschia marina Grunow, in Cleve and Grunow, K. svenska vetensk akad. Handl., Band 17, No. 2, p. 70, 1880.

Grunow, in Van Heurck, Synopsis diatomées Belgique, pl. 57, fig. 26–27, 1881.

De Toni, Sylloge algarum omnium hucusque cognitarum, vol. 2, Bacillarieae, p. 500, 1891.

Mann[17] erroneously combined this species with *Nitzschia angustata* (Wm. Smith) Grunow. The differences between the two are as follows:

	N. angustata	*N. marina*
Length	25–110μ	95–165μ
Width	5–10μ	8–9. 5μ
Length-width ratio	5–11	12–17
Longitudinal fold	Usually present	Never present
Transverse striae	8–13 in 10μ	12 in 10μ
Puncta in transverse striae.	18–20 in 10μ	19 in 10μ
Arrangement of puncta in transverse striae.	Single rows	Double, staggered rows.

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[10] Cleve, P. T., Synopsis of the naviculoid diatoms, part 1: K. svenska vetensk. akad. Handl., Band 26, no. 2, p. 91, 1894.

[11] Greville, R. K., Descriptions of new genera and species of diatoms from the South Pacific: Edinburgh New Philos. Jour., new ser., vol. 18, p. 186, pl. 4, fig. 14, 1863.

[12] Peragallo, M., Catalogue général des Diatomées, p. 313, 1897.

[13] Mills, F. W., An index to the genera and species of the Diatomaceae, part 9, p. 628, 1934.

[14] Reinhold, Th., Nederland en Koloniën, Geol.-Mijnbouwk. Genootschap, Verh., geol. ser., Deel 12, p. 72, 1937.

[15] Cleve, P. T., Synopsis of the naviculoid diatoms, part 1: K. svenska vetensk. akad. Handl., Band 26, no. 2, p. 36, 1894.

[16] Boyer, C. S., The Diatomaceae of Philadelphia and vicinity, p. 74, 1916.

[17] Mann, Albert, Diatoms of the *Albatross* voyages: Contr. U. S. Nat. Herbarium, vol. 10, part 5, p. 379, 1907.

The most significant difference is the last one in the table, namely the arrangement of the puncta in the transverse striae. In *N. angustata* the puncta are arranged in single rows; in *N. marina* the puncta are arranged in double rows, with the puncta in any one row opposite the space between puncta in the adjacent row. Furthermore, the puncta in each pair are closer together than those in adjacent pairs, which is very well shown on the lower part of plate 17, figure 11. When viewed with a high-power dry objective the doubling is extremely difficult to see, and the transverse striae appear to be composed of a single row of pucta. Under the increased resolving power of an oil-immersion objective of N. A. 1.30, however, the staggered double rows are very easily observed. The much greater length-width ratio of *N. marina* is another consistent difference.

This species has a wide geographic distribution, from the Mediterranean Sea to the North Atlantic, off Lower California, and in the Arctic Ocean. It has not been reported as abundant in any locality, and the ecologic data in the literature is very sketchy. After a careful review of the literature the most reasonable conclusion appears to be that it is a marine neritic species inhabiting cold to warm waters, with a preferance for cold waters. For the purpose of computing the distribution of the temperature facies of the diatoms from the cores (see table 13 and plate 11) this species has been considered to be a cold-water, neritic one.

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 1942–1): Length, 139μ; maximum width, 9.5μ; transverse striae, 12 in 10μ; puncta, 19 in 10μ. From sample L–30 (U. S. G. S. diatom locality 2838), 0–4.5 cm. below the top of core 6.

Found rarely in samples L–51, L–54, L–59, and L–65 and frequently in samples L–10, L–30, L–31, and L–37.

Nitzschia panduriformis Gregory

Plate 17, figure 9

Nitzschia panduriformis Gregory, Royal Soc. Edinburg Trans., vol. 21, p. 529, pl. 14, fig. 102, 1857.
Van Heurck, Synopsis diatomées Belgique, p. 172, 1885; pl. 58, figs. 1–4, 1881.
Wolle, Diatomaceae of North America, pl. 44, figs. 3, 4, 9, 1894.
Mann, Contr. U. S. Nat. Herbarium, vol. 10, pt. 5, p. 380, 1907.
Hustedt, in Schmidt, Atlas der Diatomaceenkunde, pl. 331, figs. 19–21, 1921.
Boyer, Acad. Nat. Sci. Philadelphia Proc., vol. 79, supplement, p. 497, 1927.
Nitzschia latestriata var. *panduriformis* Rabenhorst, Flora Europaea algarum, Sectio I, p. 154, 1864.
Tryblionella panduriformis (Gregory) Pelletan, Les diatomées, histoire naturelle, p. 29, fig. 284, 1891.

My specimens agree in shape and structure with the form figured by Hustedt in Schmidt's Atlas, plate 331, figure 20, but are somewhat smaller. Hustedt's specimen is 126μ long and 31μ wide, whereas the one here figured is 89μ long and 20μ wide; in both the transverse rows of dots are 15 in 10μ, and the other features are similar. Hustedt labeled his figure *Nitzschia panduriformis* Gregory, which is here considered correct. Mills[18] has referred Hustedt's figure 20 (only) to *N. panduriformis* var. *lata* (Witt) Grunow, which must have been a mistake. Grunow[19] in defining his variety *lata*, says:

> Schaale breiter mit mehr abgerunden Enden, sonst ganz ähnlich und durch zahlreiche Mittelformen welche grösser oder kleiner und in der Mitte mehr oder weniger eingeschnürt sind, mit der Hauptart zusammenhängend. Querstreifen 13–18 in 0.01 mm. (*Tryblionella lata* O. Witt).

Grunow's description, obviously does not agree with Hustedt's figure 20, which differs from the type only in having a slightly higher length-width ratio. This ratio is not constant in *N. panduriformis* and varies materially in the specimens from the core. I have referred my specimens to Gregory's species as interpreted by Hustedt.

This marine and brackish-water species is found along both the Atlantic and Pacific coasts, usually in temperate waters.

Dimensions of figured specimen (U. S. G. S. diatom catalog no. 1982–3): Length, 89μ; maximum width, 20μ; width at constriction, 17μ; transverse and oblique rows of dots, 15 in 10μ; keel puncta, 6 in 10μ. From sample L–61 (U. S. G. S. diatom locality 2874), 258–263 cm. below the top of core no. 10.

Found rarely in sample L–61.

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[18] Mills, F. W., An index to the genera and species of the Diatomaceae, part 16, p. 1225, 1934.

[19] Grunow, Albert, in Cleve, P. T., and Grunow, Albert, Beitrage zur Kenntniss der arctischen Diatomeen: K. svenska vetensk. akad. Handl., Band 17, no. 2, p. 71, 1880.

PLATES 12–17

PLATE 12

FIGURE 1. *Melosira sulcata* (Ehrenberg) Kützing. U. S. G. S. diatom catalog no. 1983–1, locality 2876. Diameter, 32μ. × 1600.

2. *Stephanodiscus astraea* (Ehrenberg) Grunow. U. S. G. S. diatom catalog no. 1962–1, locality 2862. Diameter, 38μ. × 1000.

3. *Endictya oceanica* Ehrenberg. U. S. G. S. diatom catalog no. 1970–16, locality 2858. Diameter, 84μ. × 700.

4. *Endictya robusta* (Greville) Hanna and Grant. U. S. G. S. diatom catalog no. 1958–2, locality 2858. Diameter, 108μ. × 475.

5. *Podosira stelliger* (Bailey) Mann. U. S. G. S. diatom catalog no. 1984–2, locality 2878. Diameter, 56μ. × 770. Focused on margin.

6. *Podosira stelliger* (Bailey) Mann. U. S. G. S. diatom catalog no. 1984–2, locality 2878. Diameter, 56μ. × 770. Focused on central portion.

7. *Coscinodiscus excentricus* Ehrenberg. U. S. G. S. diatom catalog no. 1968–8, locality 2857. Diameter, 45μ. × 980.

8. *Thalassiosira decipiens* (Grunow) Joergensen. U. S. G. S. diatom catalog no. 1970–4, locality 2858. Diameter, 30μ × 1370.

9. *Melosira granulata* (Ehrenberg) Ralfs. U. S. G. S. diatom catalog no. 1928–1, locality 2817. Length, 20μ; diameter, 7μ. × 1280.

10. *Coscinodiscus lineatus* Ehrenberg. U. S. G. S. diatom catalog no. 1967–5. locality 2857. Diameter, 89μ. × 670.

11. *Thalassiosira baltica* (Grunow) Ostenfeld. U. S. G. S. diatom catalog no. 1965–4, locality 2865. Diameter, 27μ. × 1000.

12. *Coscinodiscus circumdatus* Schmidt. U. S. G. S. diatom catalog no. 1941–2, locality 2838. Diameter, 62μ. × 970.


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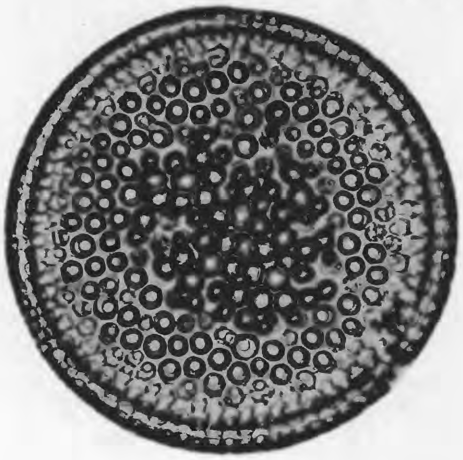
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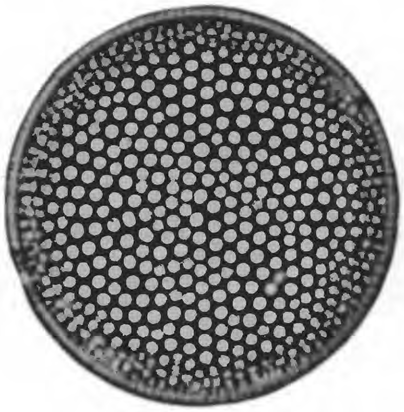
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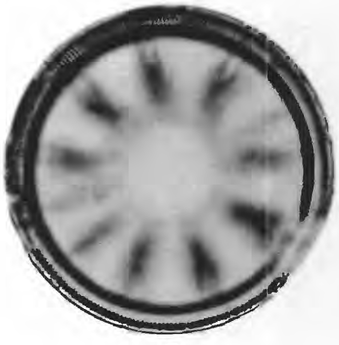
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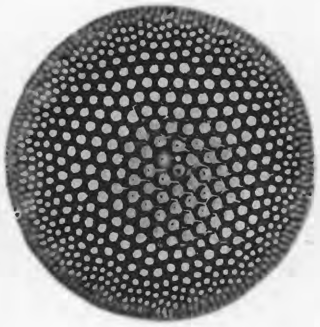
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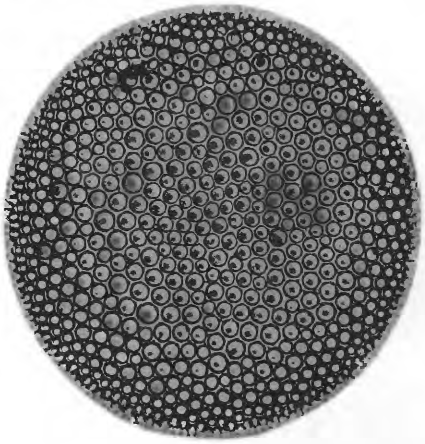
DIATOMS FROM THE NORTH ATLANTIC DEEP SEA CORES.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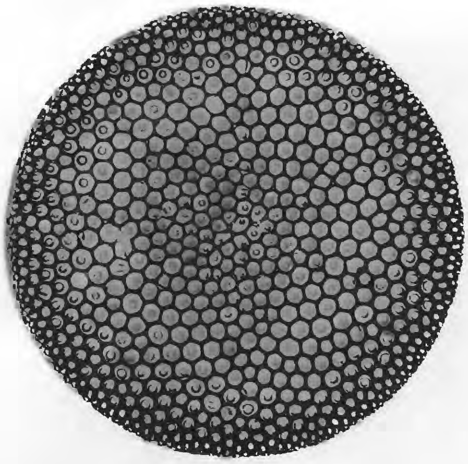
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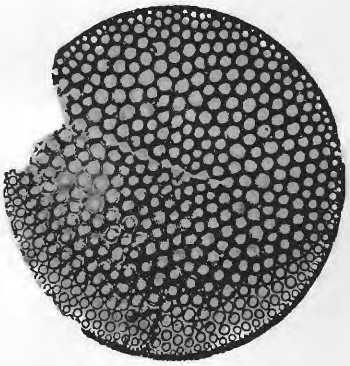
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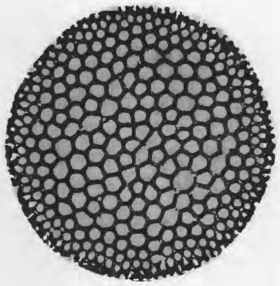
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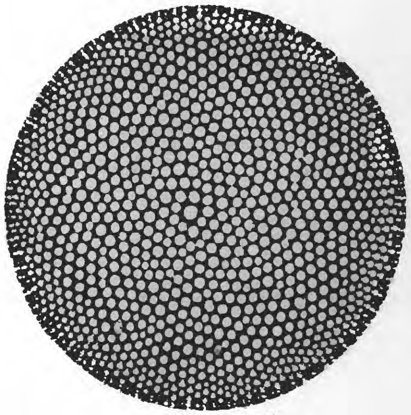
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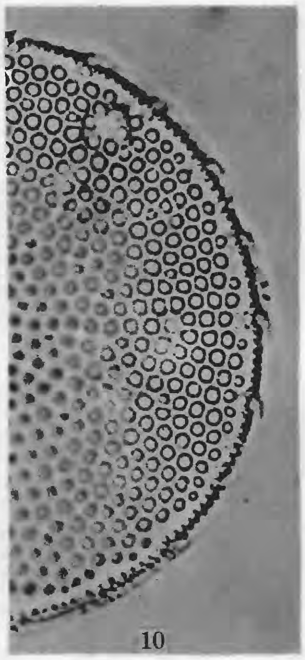
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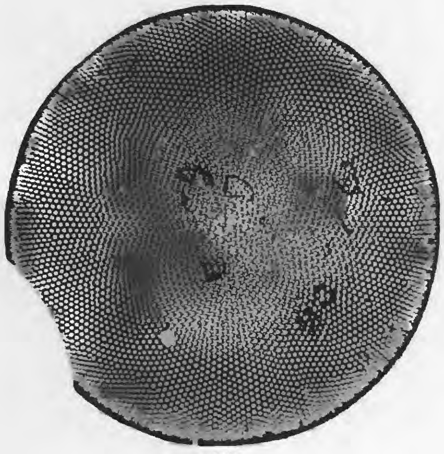
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DIATOMS FROM THE NORTH ATLANTIC DEEP SEA CORES.

PLATE 13

FIGURE 1. *Coscinodiscus argus* Ehrenberg. U. S. G. S. diatom catalog no. 1968–2, locality 2857. Diameter, 71μ. × 780.
2. *Coscinodiscus stellaris* Roper. U. S. G. S. diatom catalog no. 1970–14, locality 2858. Diameter, 62μ. × 640.
3. *Coscinodiscus argus* Ehrenberg. U. S. G. S. diatom catalog no. 1968–3, locality 2857. Diameter, 77μ. × 760.
4. *Coscinodiscus africanus* Janisch. U. S. G. S. diatom catalog no. 1972–1, locality 2866. Diameter, 41μ. × 1230.
5. *Coscinodiscus kurzii* Grunow. U. S. G. S. diatom catalog no. 1951–1, locality 2854. Diameter, 62μ. × 750.
6. *Coscinodiscus decrescens* Grunow. U. S. G. S. diatom catalog no. 1947–1, locality 2841. Diameter, 39μ. × 930.
7 *Coscinodiscus africanus* Janisch. U. S. G. S. diatom catalog no. 1972–1, locality 2866. Diameter, 41μ. × 1050.
8. *Coscinodiscus excentricus* Ehrenberg. U. S. G. S. diatom catalog no. 2000–3, locality 2858. Diameter, 39μ. × 900.
9. *Coscinodiscus convexus* Schmidt. U. S. G. S. diatom catalog no. 1970–6, locality 2858. Diameter, 178μ. × 295.
10. *Coscinodiscus africanus* Janisch. U. S. G. S. diatom catalog no. 1972–1, locality 2866. Diameter, 41μ. × 1900.
11. *Coscinodiscus asteromphalus* Ehrenberg. U. S. G. S. diatom catalog no. 2004–2, locality 2864. Diameter, 198μ. × 293.

PLATE 14

FIGURE 1. *Coscinodiscus marginatus* Ehrenberg. U. S. G. S. diatom catalog no. 1967–17, locality 2857. Diameter, 115μ. × 474.

2. *Coscinodiscus oculus-iridis* Ehrenberg var. *borealis* (Bailey) Cleve. U. S. G. S. diatom catalog no. 1965–1, locality 2865. Diameter, 214. × 295.

3. *Coscinodiscus nodulifer* Schmidt. U. S. G. S. diatom catalog no. 1967–9, locality 2857. Diameter, 51μ. × 1050.

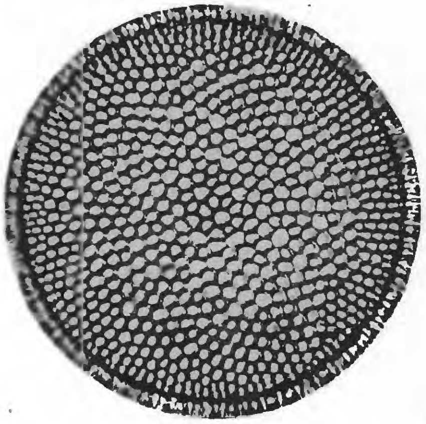
4. *Coscinodiscus crenulatus* Grunow var. *nodulifer* Lohman, n. var. Paratype. U. S. G. S. diatom catalog no. 1957–11, locality 2858. Diameter, 37μ. × 1320.

5. *Coscinodiscus nodulifer* Schmidt. U. S. G. S. diatom catalog no. 1967–6, locality 2857. Diameter, 83μ. × 660.

6. *Coscinodiscus marginatus* Ehrenberg. U. S. G. S. diatom catalog no. 1967–19, locality 2857. Diameter, 97μ. × 485.

7. *Coscinodiscus radiatus* Ehrenberg. U. S. G. S. diatom catalog no. 1967–2, locality 2857. Diameter, 158μ. × 425.

8. *Coscinodiscus radiatus* Ehrenberg. U. S. G. S. diatom catalog no. 1967–10, locality 2857. Diameter, 71μ. × 880.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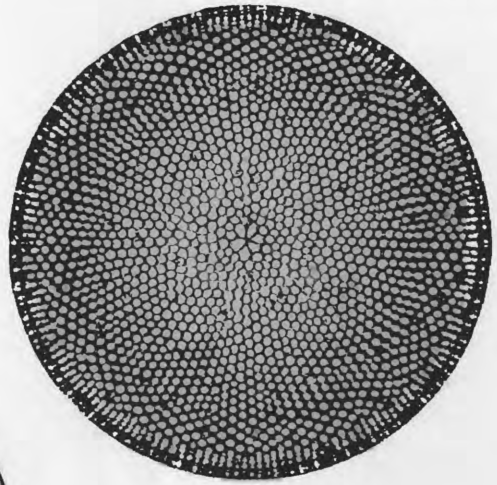
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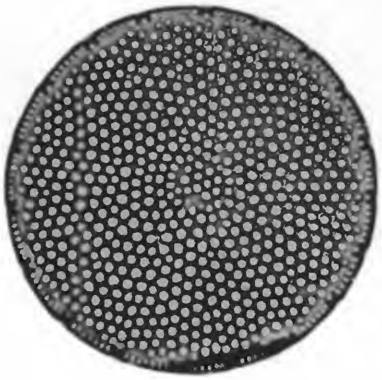
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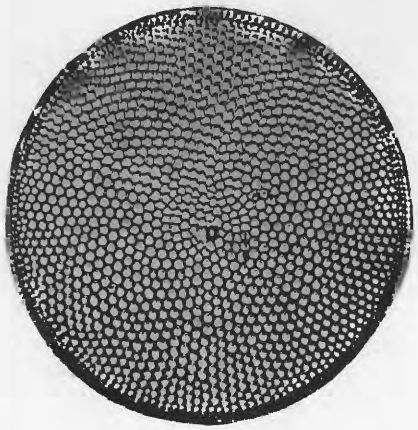
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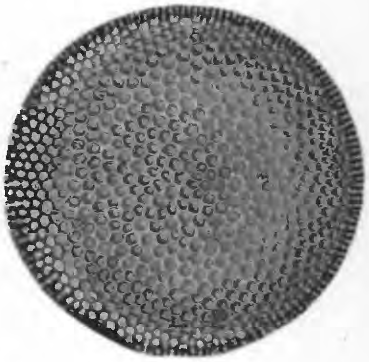
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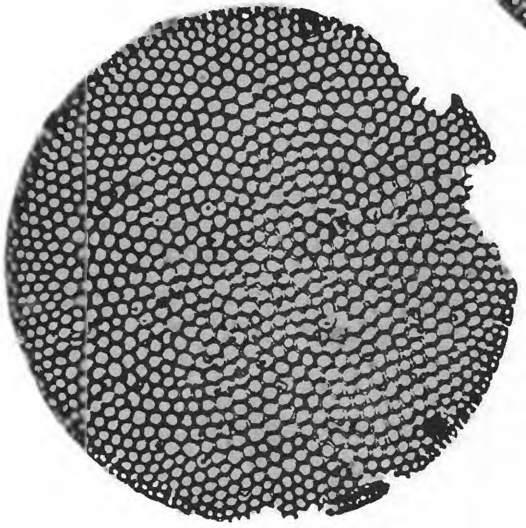
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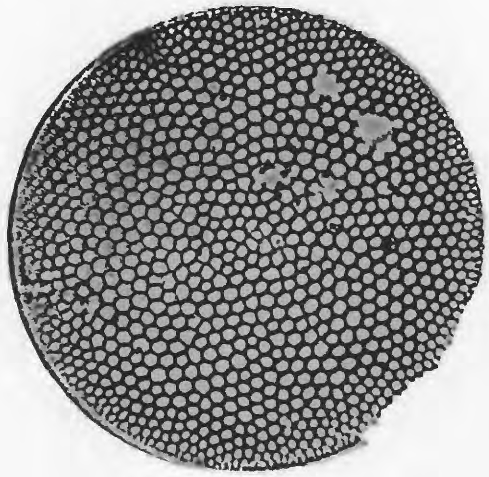
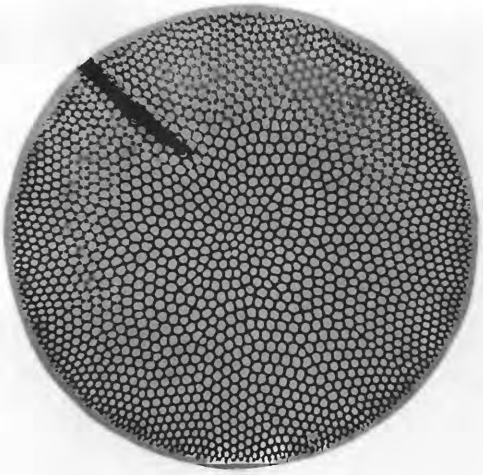

8

DIATOMS FROM THE NORTH ATLANTIC DEEP SEA CORES.


1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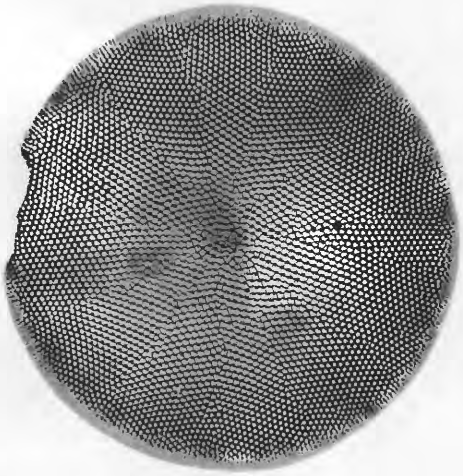
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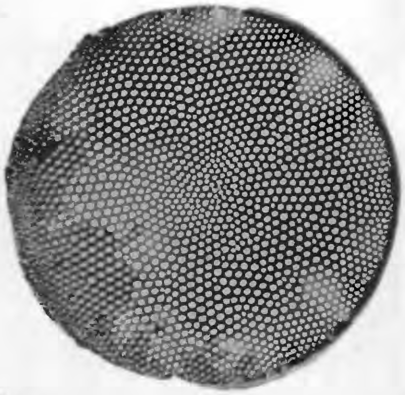
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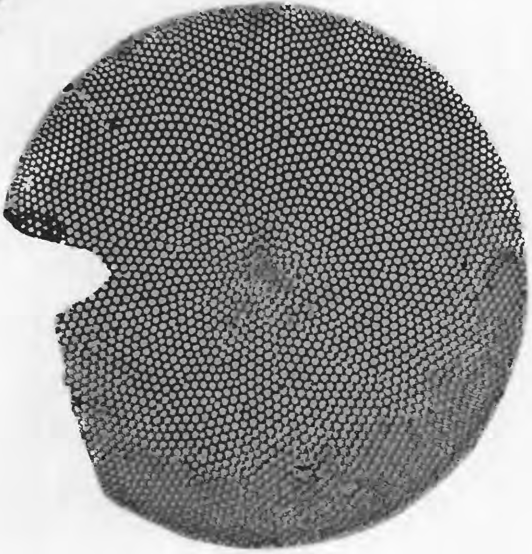
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DIATOMS FROM THE NORTH ATLANTIC DEEP SEA CORES.

PLATE 15

FIGURE 1. *Coscinodiscus crenulatus* Grunow var. *nodulifer* Lohman, n. var. Holotype. U. S. G. S. diatom catalog no. 1970–3, locality 2858. Diameter, 40μ. ×1410.

2. *Actinocyclus curvatulus* Janisch. U. S. G. S. diatom catalog no. 1957–2, locality 2858. Diameter, 66μ. × 930.
3. *Coscinodiscus curvatulus* Grunow var. *minor* (Ehrenberg) Grunow. U. S. G. S. diatom catalog no. 1957–1, locality 2858. Diameter, 29μ. × 1000.
4. *Coscinodiscus subtilis* Ehrenberg. U. S. G. S. diatom catalog no. 1972–8, locality 2866. Diameter, 48μ. × 1110.
5. *Coscinodiscus bicurvatulus* Lohman, n. sp. Holotype. U. S. G. S. diatom catalog no. 1967–12, locality 2857. Diameter, 67μ. × 780.
6. *Coscinodiscus denarius* Schmidt. U. S. G. S. diatom catalog no. 1968–4, locality 2857. Diameter, 76μ. × 790.
7. *Coscinodiscus divisus* Grunow. U. S. G. S. diatom catalog no. 1970–11, locality 2858. Diameter, 57μ. × 1150.
8. *Coscinodiscus curvatulus* Grunow. U. S. G. S. diatom catalog no. 1960–3, locality 2860. Diameter, 91μ. × 780.

PLATE 16

FIGURE 1. *Hemidiscus cuneiformis* Wallich, *s. l.* U. S. G. S. diatom catalog no. 1970–2, locality 2858. Length, 114μ; width, 74μ. × 635.

2. *Hemidiscus cuneiformis* Wallich, *s. l.* U. S. G. S. diatom catalog no. 1967–15, locality 2857. Length, 49μ; width, 43μ. × 1000.

3. *Roperia tessellata* (Roper) Grunow. U. S. G. S. diatom catalog no. 1967–7, locality 2857. Diameter, 62μ. × 940.

4. *Actinocyclus octonarius* Ehrenberg (=*A. ehrenbergii* Ralfs). U. S. G. S. diatom catalog no. 1971–1, locality 2865. Diameter, 35μ. × 915.

5. *Hemidiscus cuneiformis* Wallich, *s. l.* U. S. G. S. diatom catalog no. 1970–13, locality 2858. Length, 69μ; width, 51μ. × 697.

6. *Asteromphalus roperianus* var. *atlanticus* Castracane. U. S. G. S. diatom catalog no. 1960–1, locality 2860. Diameter, 71μ. × 715.

7. *Actinoptychus bipunctatus* Lohman, n. sp. Paratype. U. S. G. S. diatom catalog no. 1970–10, locality 2858. Diameter, 26μ. × 1770.

8. *Actinoptychus campanulifer* Schmidt. U. S. G. S. diatom catalog no. 1984–5, locality 2878. Diameter, 33μ. × 1030.

9. *Actinoptychus senarius* Ehrenberg (=*A. undulatus* of authors). U. S. G. S. diatom catalog no. 1958–1, locality 2858. Diameter, 39μ. × 1020.

10. *Actinoptychus bipunctatus* Lohman, n. sp. Holotype. U. S. G. S. diatom catalog no. 2000–1, locality 2858. Diameter, 34μ. × 1530.

11. *Actinoptychus bipunctatus* Lohman, n. sp. Holotype. U. S. G. S. diatom catalog no. 2000–1, locality 2858. Diameter, 34μ. × 1530.

12. *Actinoptychus bipunctatus* Lohman, n. sp. Holotype. U. S. G. S. diatom catalog no. 2000–1, locality 2858. Diameter, 34μ. × 1530.

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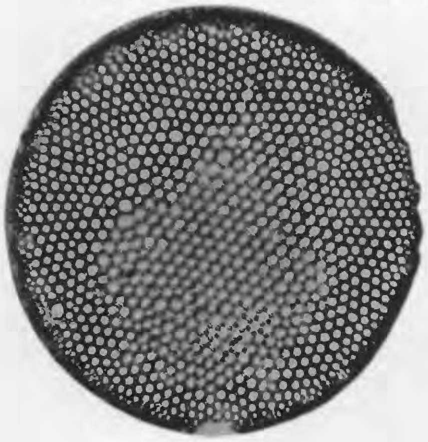

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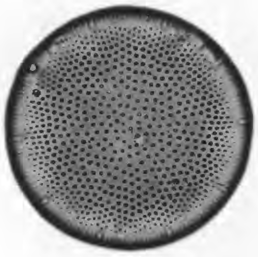

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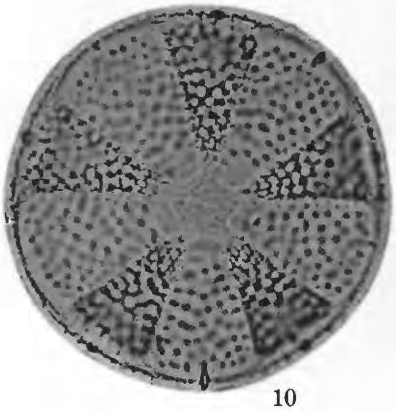

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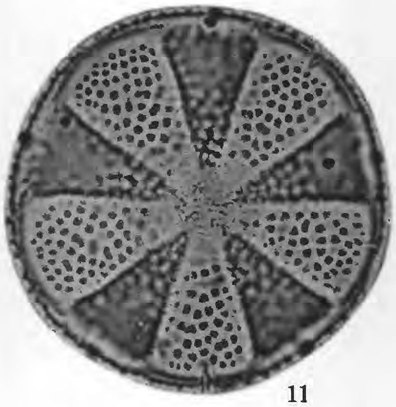

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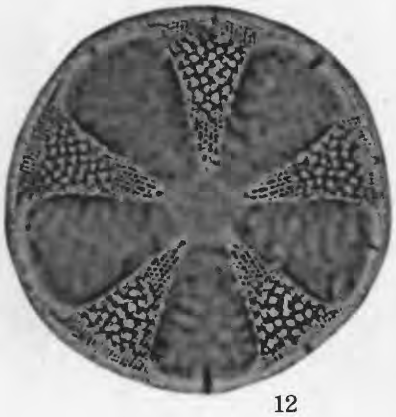

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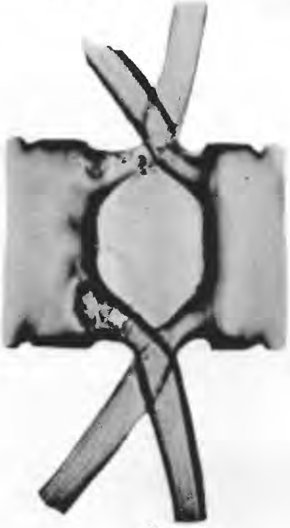
DIATOMS FROM THE NORTH ATLANTIC DEEP SEA CORES.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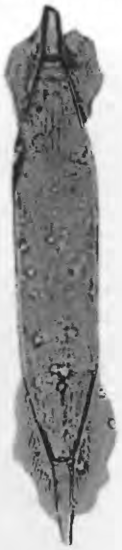
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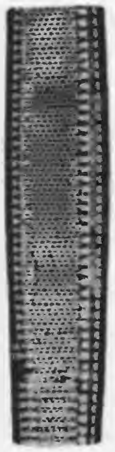
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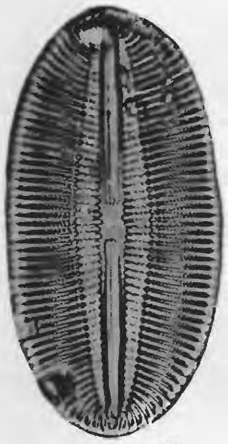
18

DIATOMS FROM THE NORTH ATLANTIC DEEP SEA CORES.

PLATE 17

FIGURE 1. *Chaetoceros atlanticum* Cleve. U. S. G. S. diatom catalog no. 1957–4, locality 2858. Major axis, 27μ. × 1000.

2. *Rhizosolenia bergonii* H. Peragallo. U. S. G. S. diatom catalog no. 1961–1, locality 2861. Length of fragment, 88μ. × 670.

3. *Rhizosolenia styliformis* Brightwell. U. S. G. S. diatom catalog no. 1964–5, locality 2864. Length of fragment, 75μ. × 1000.

4. *Rhizosolenia styliformis* Brightwell. U. S. G. S. diatom catalog no. 1960–2, locality 2860. Length of fragment, 92μ. × 784.

5. *Thalassiothrix longissima* Cleve and Grunow. U. S. G. S. diatom catalog no. 1957–9, locality 2858. Length of fragment, 165μ. × 520.

6. *Rhaphoneis surirella* (Ehrenberg) Grunow. U. S. G. S. diatom catalog no. 1984–4, locality 2878. Length, 36μ. × 1020.

7. *Eunotia praerupta* Ehrenberg var. *bidens* (W. Smith) Grunow. U. S. G. S. diatom catalog no. 1987–1, locality 2894. Length, 69μ. × 790.

8. *Rhoicosphenia curvata* (Kützing) Grunow. U. S. G. S. diatom catalog no. 1951–2, locality 2854. Length of fragment, 68μ; width (max.), 14μ. × 760.

9. *Nitzschia panduriformis* Gregory. U. S. G. S. diatom catalog no. 1982–3, locality 2874. Length, 89μ. × 590.

10. *Nitzschia marina* Grunow. U. S. G. S. diatom catalog no. 1942–1, locality 2838. Length, 139μ; width, 9.5μ. × 545.

11. *Nitzschia marina* Grunow. U. S. G. S. diatom catalog no. 1942–1, locality 2838. Central portion only. × 1480.

12. *Pseudoeunotia doliolus* (Wallich) Grunow. U. S. G. S. diatom catalog no. 2000–2, locality 2858. Length, 75μ. × 1060.

13. *Pseudoeunotia doliolus* (Wallich) Grunow. U. S. G. S. diatom catalog no. 2000–2, locality 2858. Enlarged to show structure. × 1830.

14. *Navicula pennata* Schmidt. U. S. G. S. diatom catalog no. 1964–1, locality 2864. Length of fragment, 75μ. × 1000.

15. *Diploneis interrupta* (Kützing) Cleve. U. S. G. S. diatom catalog no. 1986–1, locality 2893. Length, 33μ. × 970.

16. *Diploneis weissflogii* (Schmidt) Cleve. U. S. G. S. diatom catalog no. 1972–3, locality 2866. Length, 36μ. × 850.

17. *Pleurosigma naviculaceum* Brébisson. U. S. G. S. diatom catalog no. 1984–1, locality 2878. Length, 87μ. × 1030.

18. *Diploneis smithii* (Brébisson) Cleve. U. S. G. S. diatom catalog no. 1981–1, locality 2873. Length, 81μ. × 716.

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

PART 4. OSTRACODA

By WILLIS L. TRESSLER [1]

INTRODUCTION

The material described in this report was obtained in 1936 in the North Atlantic Ocean with the Piggot deep-sea core sampler [2] on board the Western Union cable ship *Lord Kelvin*. While looking over the samples for Foraminifera, L. G. Henbest of the Federal Geological Survey, found a few ostracodes, which were picked out and sent to me for identification. Some 175 ostracodes belonging to 13 genera and 27 species were identified and are discussed in the following pages. Photographs of specimens of all but two of the species were made by Mr. Henbest and are reproduced here as plate 19, figures 1 to 27. I am greatly indebted to Mr. Henbest and to W. H. Bradley, also of the Geological Survey, for much helpful criticism and assistance. Because few ostracodes have previously been described from marine core samples, this material is of particular interest.

ECOLOGY OF THE OSTRACODES

In his treatise on sedimentation, Twenhofel [3] says of the planktonic Arthropoda (phyllopods, copepods, and ostracodes) that "As they belong to the plankton, their distribution at all times has been independent of the character of the bottom, and they lend little to evaluation of conditions of the environment." This statement is certainly correct for the first two groups of planktonic Arthropoda, but it is not entirely true for the ostracodes.

The great majority of ostracodes are strictly bottom-dwelling organisms; indeed many are entirely incapable of swimming. A brief review of the various groups of the Ostracoda will bear this out. The suborder Myodocopa includes both pelagic and benthonic forms. In some genera the females are confined to the bottom although the males are active swimmers and may be taken at the surface. The family Conchoecidae is entirely pelagic. The suborder Platycopa contains strictly benthonic forms, which are confined to the deeper parts of the ocean. The Cladocopa are good swimmers, but most of them live on the bottom. *Polycope orbicularis*, the only representative of this suborder found in the core samples, swims along the bottom at depths of 10 to 35 meters. The largest of the suborders, the Podocopa, contains representatives of both pelagic and benthonic forms. Of the Cypridae, one genus, *Pontocypris*, contains active swimmers, but these forms rarely leave the bottom. The other marine genera are either poor swimmers and never leave the bottom or are without swimming organs. *Macrocypris*, *Bythocypris*, and *Bairdia*, genera which were found in the core samples, are distinctly bottom-dwelling forms. The family Cytheridae, to which all except four of the genera found in the core samples belong, is entirely restricted to the bottom. All 13 genera from the core samples, therefore, are known to be bottom-living forms. Although some forms are widely distributed in the oceans, many have a very restricted range, and all seem to be confined to fairly limited environmental conditions. In many of their relations to environment they resemble the Foraminifera.[4] Both Foraminifera and ostracodes that are found at extreme depths in tropical climates are found in much shallower water in northern regions; for both classes of organisms cold water is an environmental factor limiting the distribution of the species. As an illustration of the distribution of present-day Ostracoda I shall cite two examples. *Pseudocythere caudata* occurs at the present time along the Norwegian coast at a depth of about 75 meters, whereas off Buenos Aires it was found at 3,480 meters where the bottom temperature was 0.0° C. *Macrocypris minna* occurs along the Norwegian coast at depths ranging from 35 to 550 meters, whereas off the coast of Morocco it is found at depths ranging from 640 to 1,350 meters. In a series such as this, which includes so few ostracodes, it is impossible to make any general statement regarding the correlation of the present distribution of living

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[1] Zoology Department, University of Maryland, College Park, Md.

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

[3] Twenhofel, W. H., Treatise on sedimentation, 2d ed., p. 182, 1933.

[4] Cushman, J. A., Geology and paleontology of the Georges Bank Canyons, Part IV. Cretaceous and late Tertiary Foraminifera: Geol. Soc. America, Bull. vol. 47, pp. 413–440, 1936.

forms with respect to depth as compared with that distribution observed in the several cores.

From the foregoing statements it will be evident, I believe, that marine ostracodes may be used as an aid in determining environmental conditions of the past. As fossils they have long been used as horizon indicators and particularly in the correlation of oil-bearing strata. The principal difficulty in using ostracodes as horizon indicators is that all identification must, of necessity, be made from the shell alone, and this is often very difficult, even with the diverse forms of marine ostracodes. It would be impossible to identify most freshwater forms from an examination of the shell without further aid from internal anatomy.

Plate 18 shows in graphic form the positions at which ostracode-bearing samples were taken and the distribution of the species in the cores. The numbers at the right of each sample correspond to species which are listed on plate 18.

A large proportion of the ostracodes found were in cores 8, 12, and 13, which were taken at shallower depths than the others. Very few were found in the cores taken at depths greater than 3,230 meters. At these greater depths the thin calcium carbonate shells of the ostracodes are presumably dissolved by the greater quantities of carbon dioxide that the cold deep water holds in solution. In a total of some 1,175 species described, Müller [5] lists only 4 that were taken below a depth of 4,200 meters. Of these, 3 were found at about 5,000 meters and 1 was doubtful. Only 12 species were recorded from depths greater than 3,200 meters, and only 24 had been found deeper than 2,000 meters. The greatest depth at which a core was taken that contained ostracodes was 4,700 meters, this was core 3. The greater abundance of ostracodes found in the cores taken at depths of less than 3,250 meters is thus easily explained.

In core 8, which was taken on top of the Faraday Hills, a narrow part of the mid-Atlantic ridge, several ostracodes (*Cytheropteron* sp. (b), *Bythocythere constricta*, *Pseudocythere caudata*, *Paracytherois flexuosa*, and *P. producta*) were found, which appeared nowhere else in the cores. Three of these, *B. constricta*, *P. caudata*, and *P. flexuosa*, are forms that are at present found in the Arctic seas as well as on the western coast of the Atlantic. They are also, however, rather widely distributed elsewhere but are decidedly cold-water forms. *Pseudocythere caudata*, the most widely distributed of the group, both in the core samples and in present-day seas, is an unmistakable species. *Pseudocythere* is closely related to another member of the group, *Bythocythere constricta*. Although these data are insuf-

TABLE 14.—*Geographic distribution and depth and temperature ranges of the ostracodes*

	Mid-Atlantic	North Atlantic	British Isles	Norway	Arctic Ocean	Baffin Bay	Gulf of St. Lawrence	Cape Breton	South Atlantic	South Pacific	North Pacific	Indian Ocean	Mediterranean	Fossil [1]	Temperature [2]		Depth [3]	
															Warm	Cold	Shallow	Deep
Polycope orbicularis			X	X	X					X		X				X	X	X
Macrocypris minna		X		X										X		X	X	X
Bythocypris bosquetiana		X		X					X				X		X	X		X
B. obtusata			X	X							X			X		X	X	X
Bairdia sp																		
Eucythere declivis	X	X	X	X	X		X					X	X		X	X	X	X
Krithe bartonensis	X	X	X	X								X		X		X	X	X
K. glacialis		X												X		X		X
K. tumida									X	X						X		X
Hemicythere sp. (?)																		
Cythereis tuberculata	X	X		X	X	X			X	X			X	X	X	X	X	X
C. echinata		X		X					X							X	X	X
C. dunelmensis		X	X	X	X	X	X							X		X	X	X
C. jonesi	X		X	X	X								X	X	X		X	X
C. ericea									X	X		X				X		X
C. sp																		
Cytheropteron alatum		X	X	X						X						X	X	?
C. hamatum		X		X	X	X								X		X		X
C. inflatum			X	X		X								X		X	X	X
C. mucronalatum	X									X	X					X		X
C. sp. (a)																		
C. sp. (b)																		
Bythocythere constricta	X		X	X	X			X						X		X	X	?
Pseudocythere caudata	X	X	X	X	X			X	X				X	X	X	X	X	X
Paracytherois flexuosa	X		X	X	X			X					X		X	X		X
P. producta				X									X		X	X	X	
Paradoxstoma ensiforme	X		X	X								X	X	X	?	X	X	X

[1] Reported in sediments of Pleistocene age or older.
[2] Previous record of species. The present marine climate is taken as the mean temperature.
[3] Previous record of species. The 100-fathom (183-meter), or Murray's line, is taken as the boundary between shallow and deep water.

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[5] Müller, G. W., Fauna und flora des Golfes von Neapel; Ostracoden: Zool. sta. Neapel, Mon. 21, pp. 173-387, 1894.

ficient to warrant more than a general statement, they seem to suggest colder water on the Faraday Hills at the periods represented by the various samples in this core. Besides the three Arctic species mentioned, all the other ostracodes found in core 8 are cold-water forms; *Polycope orbicularis* was found only in this core.

The present geographic distribution of all the species found in the cores is given in table 14, page 96, but the environmental factors are given in the systematic description of the individual species that follows. A column in table 14 summarizes the available information on bathymetric distribution. These data are inconclusive, however, because the records of depth ranges are either too scarce or too uncertain to place much confidence in them. The data in the column of table 14 giving present water temperatures in which these species have been found are also very general. In addition, the samples generally do not contain a sufficient number and variety of ostracode species to obtain the advantages of multiple evidence that a whole fauna would offer. These data, however, are of sufficient interest to be presented, whether they agree or disagree with other information.

The distribution of each species in the core samples is given in table 15. It is greatly to be hoped that more extensive core sampling will be possible in the future, so that a much more complete picture of conditions may be obtained.

SYSTEMATIC DESCRIPTIONS OF THE SPECIES

I follow G. O. Sars' classification in the treatment of the ostracodes here discussed.

Suborder CLADOCOPA Sars

Family POLYCOPIDAE Sars

Genus POLYCOPE Sars

The genus *Polycope* includes several species, all of which are remarkable for the more or less orbicular shape of the shells as seen from the side. The valves are quite thin and are ordinarily smooth, although in some species they may be closely punctate or reticulate.

Polycope orbicularis Sars

Plate 19, figure 13

Four specimens of this peculiar ostracode were obtained from samples H–69 and H–70, about 0.5 meter below the top of core 8. Length 0.74 millimeter, height 0.61 millimeter. Core 8 was taken at a depth of 1,280 meters (700 fathoms), whereas the present distribution of this species seems to be confined to much shallower seas; it has never been recorded from water more than 290 meters deep. It is a common form along the coasts of Norway, where it is found at very moderate depths, 11 to 36 meters, on a sandy bottom covered with a thin layer of mud. It swims

TABLE 15.—*Distribution of the ostracodes in the core samples*

Core	3	4			6						7			8						9	10	12											13												
Sample, H-series	158	20	21	30	35	38	40	42	46	47	48	49a	54a	61a	62	64	68	69	71	83	102	113	114	121	126	128	129	130	131	133a	133b	134	135	136	137	138	139	141	144	145	146	147	149	150	152
Position of sample, in centimeters, below top of core	0–5	74–82	104–112	258–262	34–42	114–121	152–158	189–195	265–270	282–290	0–7	32–36	133–139	6–8	8–10	17–21	35–38	45–52	60–64	79–82	136–139	0–5	15–20	89–90	137–142	149–154	165–168	183–191	193–195	216–217	217–223	236–243	0–5	15–19	23–27	41–42	42–47	66–70	89–94	94–100	108–112	112–115	135–141	145–150	169–173
Polycope orbicularis																		●	●																										
Macrocypris minna																						●							●	●				●	●						●				
Bythocypris bosquetiana																									●			●		●	●	●										●			
B. obtusata		●		●									●												●				●	●	●							●							
Bairdia sp														●		●		●													●				●										
Eucythere declivis																	●																						●						
Krithe bartonensis	●							●				●				●		●	●												●				●	●		●	●			●		●	●
K. glacialis												●	●											●				●		●							●			●		●			●
K. tumida							●	●	●			●	●										●	●			●	●	●	●	●	●			●			●	●					●	
Hemicythere ? sp																				●																									
Cythereis tuberculata						●							●					●	●																										
C. echinata	●		●							●	●																			●	●		●			●	●		●	●					
C. dunelmensis																														●															
C. jonesi																												●																	
C. ericea											●																	●																	
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Cytheropteron alatum	●											●						●			●	●																							
C. hamatum																●																													
C. inflatum																										●										●									
C. mucronalatum																							●							●															
C. (sp. a)					●									●																															
C. (sp. b)																			●																										
Bythocythere constricta																●			●																										
Pseudocythere caudata														●	●	●	●	●	●																										
Paracytherois flexuosa														●				●																											
P. producta																●		●	●																										
Paradoxstoma ensiforme																			●																●										

rapidly along the bottom but evidently is restricted to a benthonic existence. The present distribution of this form includes the British Isles, Spitzbergen, Cape of Good Hope, and the Torres Straits. At the Cape of Good Hope and at Torres Straits it was captured at a depth of about 275 meters (150 fathoms) on a sandy bottom by the *Challenger* Expedition.[6] The temperature at 275 meters at the Cape of Good Hope was 8.3° C.

Suborder PODOCOPA Sars

Family CYPRIDAE Baird

Genus MACROCYPRIS Brady

Macrocypris includes several species having very solid shells, which are rather elongate and which are acutely produced at the posterior end. The inner duplicatures of the shells are broad and have a narrow marginal zone with transverse striations. Scars of muscle attachments are arranged in a circular pattern.

Macrocypris minna (Baird)

Plate 19, figure 26

Ten specimens of this large creamy white form were obtained from cores 12 and 13. Most of the individuals were immature, but three adults were obtained from sample H–137, about 0.2 meter below the top of core 13. Length 2.12 millimeters, height 0.83 millimeter. The immature specimens came from samples H–113, H–131, and H–133a in core 12, and H–136 in core 13. Core 12 was taken at a depth of 3,230 meters (1,770 fathoms) and core 13 at 1.955 meters (1,070 fathoms). This ostracode, by far the largest and finest of the marine Cypridae, is strictly a bottom-dwelling form. On the bottom it crawls slowly. It is at present a common form along the Norwegian coast but is found at much shallower depths than those at which the cores were taken. Along the Norwegian coast and also off the Shetland Islands it is found at depths ranging from 35 to 550 meters. Off the coast of Morocco, however, it has been obtained at depths ranging from 640 to 1,350 meters. *Macrocypris minna* is known as a fossil from post-Tertiary beds in Calabria.

Genus BYTHOCYPRIS Brady

The shell in this genus is more or less oval, without hairs, and somewhat compressed, and the sides are entirely unarmed. *Bythocypris* is closely allied to the genus *Bairdia*, although the two genera may easily be distinguished by the difference in the shape of the shell. The genus is composed entirely of bottom-dwelling forms.

Bythocypris bosquetiana (Brady)

Plate 19, figure 22

Six specimens, five of which were mature individuals, were found in samples H–126, H–130, H–133a, H–133b, and H–134 in core 12. One adult was found in sample H–147, 1.1 meters below the top of core 13. Length 1.19 millimeters, height 0.74 millimeter. This species is found along the Norwegian coast at the present time at a depth of 275 meters. It has also been taken in the Atlantic at a depth of 860 meters, in the Mediterranean at 1,280 meters, in Bass Straits (between Australia and Tasmania), and in the waters of the West Indies. G. O. Sars[7] includes *B. reniformis* as a synonym, which would increase somewhat the range of distribution, but I am inclined to follow Müller's synonomy[8] and consider *B. reniformis* as a distinct species. The shape of the shell of *B. reniformis* is quite different from that of the shells found in the core samples. *B. bosquetiana* is a bottom-living ostracode.

Bythocypris obtusata (Sars)

Plate 19, figure 17

Three adult and five immature specimens of this species were found in samples H–20, and H–30 in core 4; H–54a in core 7; H–126, H–131, H–133a, and H–133b in core 12; and H–141 in core 13. An adult form in core 4, sample H–30, was found 2.5 meters below the top of the core; one immature specimen was found in the top layer of core 7, sample H–54a; and the individuals in each of cores 12 and 13 were found between 1.3 and 1.9 meters below the top. Core 4 was taken at a depth of 3,955 meters (2,165 fathoms) and core 7 at 3,250 meters (1,780 fathoms). Length of specimen 1.26 millimeters, height 0.80 millimeter. At present this species is found at a depth of 145 to 165 meters along the Norwegian coast. It is also found in the waters adjacent to the British Isles and near the Kerguelen Islands, where it was found at a depth of 1,490 meters. Fossil forms have been reported from post-Tertiary deposits in Calabria.

Genus BAIRDIA M'Coy

Bairdia includes ostracodes with rhomboidal shells of comparatively great height and somewhat attenuated extremities that are usually denticulate at the edges of the valves. In the living state they are covered with coarse recurved hairs. This genus was described by M'Coy in 1844 and has been confused by many authors

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[6] Brady, G. S., Report on the Ostracoda dredged by the H. M. S. *Challenger* during the years 1873–1876, *Challenger* Rept., Zoology, vol. 1, pp. 16, 21, 169–170, 1880.

[7] Sars, G. O., An account of the Crustacea of Norway, vol. 9, Ostracoda, pp. 64–65, Bergen, Bergen Museum, 1928.

[8] Müller, G. W., Das Tierreich. Lief. 31, Ostracoda: K. preuss. Akad. Wiss., p. 250, 1912.

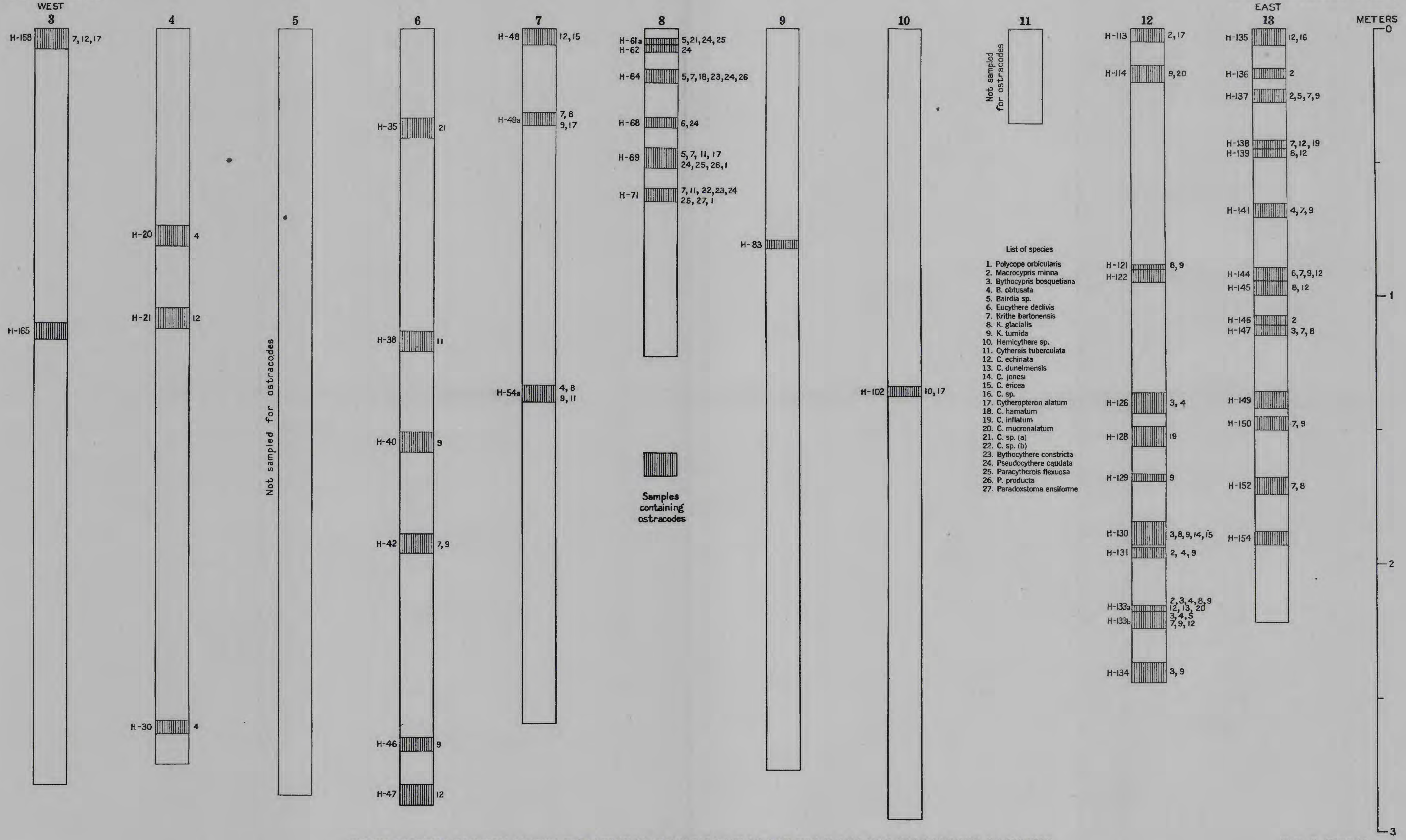

CHART SHOWING POSITION OF THE OSTRACODE-BEARING SAMPLES IN THE CORES AND THE DISTRIBUTION OF SPECIES.

with *Nesidea*. I shall use the genus in the restricted sense employed by G. O. Sars. *Bairdia* includes ostracodes that are strictly bottom-dwelling forms and that are widely dispersed at the present time. The genus is most abundantly distributed in tropical and southern waters, where in many places it is the dominant genus.

Bairdia sp.

Plate 19, figure 27

Seven individuals of an ostracode referable to this genus were found in cores 8, 12, and 13. Four immature specimens were found within 0.4 meter of the top of core 8 in samples H–61a, H–64, and H–69, one immature specimen was found in core 13, sample H–133b, 0.3 meter below the top of the core; and an adult was found 2.1 meters below the top of core 12, sample H–137. The anterior end of the shell of the adult specimen was broken off, but it was clearly identical with the immature forms. Length of adult 1.50 millimeters, height 0.96 millimeter. The figured specimen is an immature form from core 8, sample H–61a, just beneath the top layer of the core. Length of figured specimen 1.26 millimeters, height 0.82 millimeter. I have been unable to identify this species with any described in the available literature. It is undoubtedly of Recent age.

Family CYTHERIDAE Baird

Genus EUCYTHERE Brady

This genus contains species that are characterized by a triangular shell, which is compressed in front and much higher at the anterior end than at the posterior. The valves are thin and pellucid and possess wide marginal zones, which are crossed by pore channels. The edges are smooth with few scattered hairs. This genus has only two species.

Eucythere declivis (Norman)

Plate 19, figures 2–3

Two adult specimens of this unmistakable species were found in core 8, sample H–68, and core 13, sample H–144, 0.3 and 0.8 meter, respectively, below the tops of the cores. Length 0.67 millimeter, height 0.41 millimeter. This species is at present distributed along the Norwegian coast, the British Isles, the Gulf of St. Lawrence, Franz Joseph Land, the Mediterranean, and along the European coast. In the Indian Ocean it was found at a depth of 358 meters. Cores 8 and 13 were taken at 1,280 and 1,955 meters (700 and 1,070 fathoms). *Eucythere declivis,* like the other Cytheridae, is a form that crawls slowly along the bottom.

Genus KRITHE Brady and Norman

The genus *Krithe* includes ostracodes with a thin and pellucid shell, which has a smooth, polished surface with marginal zones that contain scattered pore canals rather irregularly arranged. At the anterior extremity is a thin hyaline border. Three species were found in the cores.

Krithe bartonensis (Jones)

Plate 19, figure 5

Numerous specimens of this species were found in most of the cores. The locations are given in table 16.

TABLE 16.—*Distribution of* Krithe bartonensis (*Jones*) *in the cores*

Core number	Sample number	Distance below top of core, in meters	Number of specimens	Core number	Sample number	Distance below top of core, in meters	Number of specimens
3	H–158	0. 0	1	13	H–137	0. 3	2
6	H–42	1. 8	1	13	H–138	. 4	1
7	H–49a	. 2	1	13	H–141	. 6	1
8	H–64	. 2	2	13	H–144	. 8	1
8	H–69	. 4	2	13	H–147	1. 1	1
8	H–71	. 6	4	13	H–150	1. 4	1
12	H–133b	2. 1	1	13	H–153	1. 7	1

Length 0.75 millimeter, height 0.37 millimeter. Core number 3 was obtained at a depth of 4,700 meters (2,575 fathoms) and core 6 at 4,125 meters (2,260 fathoms). At the present time this species is common along the Norwegian coast, where it is found at depths ranging between 35 and 90 meters on a muddy bottom. It is strictly a bottom-dwelling form. Its present distribution also includes the British Isles, Iceland, the Bay of Biscay, the European coast, and Kerguelen Island. At Kerguelen Island it was found at a depth of 3,210 meters. It is known as a fossil from Tertiary and post-Tertiary deposits in Scotland, England, and Norway.

Krithe glacialis Brady, Crosskey, and Robertson

Plate 19, figure 9

Twenty individuals of this species, which is very closely allied to *K. bartonensis*, were taken from cores 7, 12, and 13. In core 7, samples H–49a and H–54a, it was found at 0.3 and 1.3 meters below the top of the core; in core 12, samples H–121, H–130, and H–133a, at 0.8, 1.7, and 2.1 meters; and in core 13, samples H–139, H–145, H–147, and H–152 at 0.4, 1.0, 1.1, and 1.7 meters. Length of figured specimen 0.83 millimeter, height 0.48 millimeter, *K. glacialis* was known as a fossil in post-Tertiary beds in Scotland and Norway for some time before it was taken in dredge samples in the North Atlantic. It is not known from any other localities and apparently is another of the northern ostracodes.

Krithe tumida Brady

Plate 19, figure 1

A large number of specimens of this species were found in cores 6, 7, 12, and 13, the distribution of which is given in table 17.

TABLE 17.—*Distribution of* Krithe tumida *Brady in the cores*

Core number	Sample number	Distance below top of core, in meters	Number of specimens	Core number	Sample number	Distance below top of core, in meters	Number of specimens
6	H-40	1.5	1	12	H-130	1.8	1
6	H-42	1.8	1	12	H-131	1.9	1
6	H-46	2.6	1	12	H-133a	2.1	4
7	H-49a	.2	2	12	H-133b	2.4	2
7	H-54a	1.3	1	13	H-137	.3	1
12	H-114	.2	1	13	H-141	.6	1
12	H-121	.8	1	13	H-144	.8	3
12	H-129	1.6	1	13	H-150	1.4	1

This ostracode is a southern form in its present known distribution, having been found living at great depths in the South Atlantic and at 3,470 meters at Funafuti but so far it has not been reported from the Northern Hemisphere. It is significant, however, that in southern waters it is found only at great depths, where cold water prevails the year around. For example, off Buenos Aires, members of the *Challenger* Expedition found it living on the bottom in gray mud at a temperature of 0.0° C. Length of figured specimen 0.61 millimeter, height 0.37 millimeter.

Genus HEMICYTHERE Sars

Hemicythere includes forms that have a heavy calcareous shell somewhat resembling that of *Cythere* in shape. The valves are rather unequal and have much-pitted outer surfaces. This genus is in an intermediate position between *Cythere* and *Cythereis*. Eight species have been reported from Norway.

Hemicythere sp. (?)

The posterior third of a shell fragment which seems to agree most closely with a species of *Hemicythere*, was found in core 9, sample H-83, at 0.8 meter below the top of the core. Several species of this genus live in the North Atlantic and Arctic Oceans, whereas fossil forms are known from Scotland, Norway, and Germany. Some of the species are littoral and others live in deep water. It is possible that this species belongs to the deep-water northern group.

Genus CYTHEREIS Sars

This very large genus contains ostracodes whose shells have uneven surfaces, variously formed spines or projections, and denticulated anterior and posterior extremities. The sculpturing of the valves is usually less coarse than in *Hemicythere* and in some species it may be quite inconspicuous.

Cythereis tuberculata (Sars)

Plate 19, figure 20

Six specimens of this species were found in cores 6, 7, and 8. In core 6 the ostracodes were located in sample H-38 and in core 7 in sample H-54a, both 1.2 meters below the top of the core, and in core 8, samples H-69 and H-71, at about 0.5 meter below the top. Length 0.92 millimeter, height 0.52 millimeter. This is one of the commonest and most widely distributed of ostracodes living in British waters. It is also common along the Norwegian coast. In both regions it is now found at depths of 18 to 55 meters. It is further distributed in the waters near Iceland, and Spitzbergen, in the Bay of Biscay, the Mediterranean, and Baffin Bay, near the West Indies, and in the South Pacific, where it was found at 358 meters. It is also found in the deep cold waters of Vineyard Sound off the Massachusetts coast.[9] Fossils of this species have been found in the post-Tertiary beds of Scotland, England, Ireland, and Norway.

Cythereis echinata Sars

Plate 19, figure 24

Numerous specimens of this distinctive species were found in cores 3, 4, 6, 7, 12, and 13. Their distribution is given in table 18.

TABLE 18.—*Distribution of* Cythereis echinata *Sars in the cores*

Core number	Sample number	Distance below top of core, in meters	Number of specimens	Core number	Sample number	Distance below top of core, in meters	Number of specimens
3	H-158	0.0	1	12	H-133b	2.2	1
4	H-21	1.1	1	13	H-135	.0	2
6	H-47	2.8	1	13	H-138	.4	2
7	H-48	.0	1	13	H-139	.8	1
12	H-133a	2.1	3	13	H-144-5	.9	2

Length 1.19 millimeters, height 0.75 millimeter. At the present time this is a common form along the Norwegian coast, where it is found on a muddy bottom at depths of 55 to 90 meters. It is also found near the Lofoten Islands at 550 meters, and the *Challenger* Expedition found it in the abyssal parts of the North Atlantic and South Atlantic at depths ranging from 1,825 to 2,600 meters. North of Tristan d'Acunha it was taken at 2,600 meters in globigerina ooze, where the bottom temperature was 2.3° C.

Cythereis dunelmensis Norman

Plate 19, figure 21

Only one specimen of this highly ornamented ostracode was found, and that was in sample H-133a, 2.1 meters below the top of core 12. Length 0.99 millimeter, height 0.48 millimeter. *C. dunelmensis* is decidedly a northern form at the present time. It is common along the coast of Norway, where it is found

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[9] Cushman, J. A., Marine Ostracoda of Vineyard Sound and adjacent waters: Boston Soc. Nat. Hist., Proc. vol. 32, no. 10. p. 376, 1906.

at depths of 18 to 90 meters on a muddy bottom, in the waters around the British Isles, Iceland and Spitzbergen and in Baffin Bay and the Gulf of St. Lawrence. As a fossil it is known from the post-Tertiary beds of Scotland, England, and Ireland.

Cythereis jonesi Baird

Plate 19, figure 14

A single specimen of this species was found in core 12, sample H–130, at 1.8 meters below the top of the core. Length 0.92 millimeter, height 0.54 millimeter. This is a more widely distributed species than *C. dunelmensis*, although it too appears to be a northern cold-water form. In upper Oslo Fjord it lives on a muddy bottom at depths ranging from 55 to 90 meters. It has also been found in the waters adjacent to the British Isles and Spitzbergen and in the Bay of Biscay and the Mediterranean. Fossil forms have been found in the post-Tertiary beds of Ireland, in Pliocene deposits in England, and in Eocene beds in Belgium and France. This species and *Krithe bartonensis* are the only ostracodes found in the present series of cores that have also been found as fossils which antedate the Pleistocene.

Cythereis ericea (G. Brady)

Plate 19, figure 23

Two specimens of this very spiny ostracode were found in cores 7 and 12. In core 7, sample H–48, the figured specimen was at the very upper level of the core, whereas in core 12, sample H–130, an immature form, evidently of the same species, was found at 1.8 meters below the top. Length 1.29 millimeters, height 0.71 millimeter. This species appears to be a southern form at the present time and has to date not often been encountered in dredged samples. It was discovered by the members of the *Challenger* Expedition off the coast of Brazil, near Pernambuco, at a depth of 1,235 meters on a mud bottom. Since then it has been reported, but with some uncertainty, from two other localities, one off the southern tip of Africa and the other in the Indian Ocean off the northwestern coast of Australia. Both these collections were made in deep water, 2,630 and 3,125 meters, respectively, so that *C. ericea* is evidently a cold-water species.

Cythereis sp.

Plate 19, figures 18–19

One specimen of this distinctive species was found in core 13, sample H–135, at the very top of the core. I have not been able to identify it definitely with any described species of *Cythereis* in the available literature. Length 0.88 millimeter, height 0.49 millimeter.

Genus CYTHEROPTERON Sars

This genus is composed of ostracodes possessing more or less prominent lateroventral alaeform projections on each valve. The shape of the shell shows much variation, although it is generally thin, pellucid, and unsculptured. *Cytheropteron* is definitely a northern genus, its range extending into the Arctic seas on both sides of the Atlantic. Six species were found in the core samples.

Cytheropteron alatum Sars

Plate 19, figure 12

Eight individuals of this species were found in core 3, sample H–158; core 7, sample H–49a; core 8, sample H–69; core 10, sample H–102; and core 12, sample H–113. In all the cores except 10 the ostracodes were found within 0.4 meter of the top of the core. In core 10, taken at 4,190 meters, a single specimen of this species was found 1.3 meters below the top. This was the only ostracode found in core 10. Length 0.78 millimeter, height 0.41 millimeter. *C. alatum* is another form found principally in northern waters, but it is also found in southern waters. Its present distribution includes the southern coast of Norway and upper Oslo Fjord, where it occurs at 55 meters, the waters of the British Isles, and the Shetland Islands. It has been reported at Funafuti, but at what depth I am unable to determine with certainty (3,470 meters?)

Cytheropteron hamatum Sars

Plate 19, figure 7

One specimen was found 0.2 meter below the top of core 8 in sample H–64. Length 0.69 millimeter, height 0.41 millimeter. Another northern form, this species is at present distributed along the Norwegian coast and the Lofoten Islands at depths of 220 to 550 meters on muddy bottoms. It has also been taken near Spitzbergen and in Davis Strait. It is known as a fossil in post-Tertiary beds in Scotland.

Cytheropteron inflatum Crosskey

Plate 19, figure 6

Two specimens were found, in core 12, sample H–128, and core 13, sample H–138, at 1.5 and 0.4 meters, respectively, below the tops of the cores. Length 0.70 millimeter, height 0.48 millimeter. Also a northern form, it is at present found along the coast of Norway at depths of 55 meters on muddy sand, near the British Isles, and in the Arctic Ocean (Baffin Bay). It occurs as a fossil in Scotland in post-Tertiary deposits and also in post-Tertiary deposits in Canada.

Cytheropteron mucronalatum Brady

Plate 19, figure 25

Two specimens of this striking form were found in core 12, samples H–114 and H–133a, at 0.2 and 2.1 meters below the top of the core. Length 1.39 millimeters, height 0.85 millimeter. *C. mucronalatum* is decidedly a cold, deep-water species. It is widely distirbuted in the Pacific Ocean from Patagonia to Japan and in the Atlantic has been taken between the Azores Islands and the Bay of Biscay (slightly south of core 12 at a depth of 3,060 meters in globerigina ooze. This had previously been its most northern record in the Atlantic. The *Challenger* Expedition recorded this species in globigerina ooze at a depth of 3,420 meters off the Caroline Islands, near the equator, where the bottom temperature was 1.3° C. In the North Pacific it was found at latitude 36° N. in gray ooze at a depth of 3,740 meters, where the bottom temperature was 1.3° C. Again, off the coast of Chile near the Juan Fernandez Islands, it was found on red clay at a depth of 3,330 meters, where the bottom temperature was 1.2° C.

Cytheropteron sp. (a)

Plate 19, figure 10

Two evidently immature specimens were found 0.3 meter below the top of core 6, sample H–35, and at the top of core 8, sample H–61a. The shape of the shell and the rounded processes lead me to believe that these are immature forms, but of what species I have been unable to determine. Length 0.68 millimeter, height 0.48 millimeter.

Cytheropteron sp. (b)

A broken right valve, which broke up further when handled, was found 0.6 meter below the top of core 8, sample H–71. The shell fragment of this truly remarkable ostracode showed two lateral processes, one behind the other, which were extremely serrated on their posterior edges.

Genus BYTHOCYTHERE Sars

This genus includes forms which have rather tumid shells, although the shape varies somewhat. They have lateral expansions of more or less prominence and the posterior end of the shell is obtusely pointed. The valves are comparatively thin and have a smooth or slightly punctate surface.

Bythocythere constricta Sars

Plate 19, figure 16

Two specimens of this species were obtained from samples H–64 and H–71 in core 8 at 0.2 and 0.6 meter, respectively, below the top. Length 0.68 millimeter, height 0.38 millimeter. This is also a northern ostracode; at present it is distributed along the Norwegian coast at depths of 55 to 73 meters on soft clay bottoms. It is also found in the waters of the British Isles, Spitzbergen, Fosse de Cap Breton, and in the Bay of Biscay. Fossil forms are known from the post-Tertiary deposits of Scotland and Netherlands.

Genus PSEUDOCYTHERE Sars

Pseudocythere is a very easily identified genus and may be recognized by the peculiar shape of the shells. The shells are compressed, lack lateral expansions, and their posterior extremities are produced into a taillike process. The surfaces of the valves are smooth, but they have wide marginal zones crossed by prominent pore channels. The genus is closely allied to *Pythocythere.* Four species are now known, three from southern waters and one from northern.

Pseudocythere caudata Sars

Plate 19, figure 15

Numerous specimens of this easily recognized species were found near the upper part of core 8 in samples H–61a, H–62, H–64, H–68, H–69, and H–71. These samples were found within 0.6 meter of the top of the core. Length 0.78 millimeter, height 0.37 millimeter. This is a widely distributed species. It is found in the Olso Fjord and other Norwegian fjords at a depth of 73 meters. It is also distributed around the British Isles, the Bay of Biscay, the Mediterranean, Fosse de Cap Breton, the North Atlantic as far as Franz Joseph Land, and the South Atlantic to the Kerguelen Islands. Near the Kerguelen Islands it was taken at depths ranging from 36 to 220 meters, whereas off the coast of Brazil (Buenos Aires) it was taken at 3,470 meters on a gray mud bottom, where the temperature was 0.0° C. It is found as a fossil in the post-Tertiary beds of Scotland and Ireland.

Genus PARACYTHEROIS Müller

This genus contains ostracodes with an elongate shell that is quite fragile. The marginal zones are comparatively broad and are crossed by irregular pore channels. *Paracytherois* was first found in the Mediterranean but has since then been taken in northern waters. Two species were found in the core samples.

Paracytherois flexuosa (Brady)

Plate 19, figure 11

Two specimens were found in core 8, samples H–61a and H–69, within 0.4 meter of the top of the core. Length 0.70 millimeter, height, 0.24 millimeter. At present this species is found off the western coast of Norway in deep water among hydroids. It has also been found in the waters off the British Isles, Netherlands, the Fosse de Cap Breton, Bay of Biscay, the Mediterranean, and as far north as Franz Joseph Land.

Paracytherois producta (Brady and Norman)

Plate 19, figure 8

Three specimens were found in core 8, samples H–64, H–69, and H–71, at 0.2 and 0.6 meter below the top. Length 0.70 millimeter, height 0.30 millimeter. Although the length of the ostracode found in the core sample is considerably greater than that given by Sars, the shape of the shell is very similar. *P. producta* is at present known only from Bergen Fjord and other places along the western coast of Norway and in the Mediterranean.

Genus PARADOXSTOMA Brady

This genus includes ostracodes with thin, fragile shells usually somewhat higher behind than in front. The valves have narrow inner duplicatures and narrow marginal zones with inconspicuous pore channels. The genus is distributed in both northern and southern waters.

Paradoxstoma ensiforme Brady

Plate 19, figure 4

Two specimens were found in core 8, sample H–71, 0.6 meter below the top and one in core 13, sample H–137, 0.3 meter below the top. Length 0.78 millimeter, height 0.43 millimeter. At present this form is found along the Norwegian coast, in the waters off the British Isles, and in the Bay of Biscay. The *Challenger* Expedition apparently found it in mud clinging to the anchor in Vigo Bay, Spain, at a depth of 20 meters. This is a rather doubtful record, however. In the Indian Ocean it has been found at a depth of 358 meters. It is known as a fossil in the post-Tertiary beds of the British Isles.

DISCUSSION

Brady, Crosskey, and Robertson [10] in 1874 found that in the postglacial beds in Scotland the fauna was the same as that inhabiting the adjacent seas, whereas in the glacial deposits the invertebrate fauna was mainly northern. The Mollusca of the glacial beds included some Arctic forms, which are absent from the neighboring seas. Moreover, some species that are now common in the Arctic were common in the glacial beds but are very rare in the seas adjacent to the British Isles. Of the ostracodes, 18 were either extinct or as yet unknown as living forms, and 10 were Arctic but still found in British waters. The fossil ostracodes from the glacial deposits of Scotland were found to be almost identical with those of Norway, and almost all were still living in neighboring seas. A great similarity between the fauna of the Scotch glacial beds and the fauna of the glacial beds of Canada was also observed.

It is of interest to note that northern forms predominate among the ostracodes from these North Atlantic cores. Only two of the species identified have not previously been known from northern waters, and 10 species are definitely Arctic forms. Furthermore, most of the species are decidedly cold-water forms and when found in tropical waters are confined to great depths where nearly freezing temperatures exist the year around. 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 water below about 230 meters in the Mediterranean maintains a yearly temperature between 13° and 14° C. Eight species are forms that are at present distributed on the western shores of the Atlantic, in Baffin Bay, Davis Straits, off Cape Breton, or in the Gulf of St. Lawrence.

The age of the ostracodes found in the core samples is difficult to estimate with any certainty. Those in the upper levels of the core samples certainly represent Recent forms (see plate 18). All the identified species are known as living forms today, whereas 12 of the 27 species are also known as fossils in the British Isles, Norway, Europe, and Canada. The sediments from which the core samples were obtained have been estimated from other evidence to be of Pleistocene and Recent age, and, as all except two of the species of ostracodes known as fossils have also been found in the Pleistocene beds in the above-mentioned countries, this seems quite reasonable. One ostracode, *Cythereis jonesi*, has been found as a fossil in Eocene deposits in France and in Pliocene deposits in England. However, it is at present represented by living forms in northern waters, the Bay of Biscay, and the Mediterranean.[11] One specimen of *Cythereis jonesi* was obtained from sample H–130, core 12, taken at 3,230 meters. *Krithe bartonensis* has also been found in Tertiary and post-Tertiary beds in Scotland, England, and Norway. Its present distribution includes northern waters, the mid-Atlantic, and great depths in the Indian Ocean off Kerguelen Island. Many specimens of this ostracode were found in the cores.

The predominance of distinctly cold-water ostracodes and the prevalence of Arctic forms suggest that the water temperatures in this part of the North Atlantic were formerly much lower. However, the distribution of the ostracodes in these cores shows no evident relationship to the cold and warm zones indicated by the lithology of the sediments (see part 1, Lithology and

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[10] Brady, G. S., Crosskey, H. W., and Robertson, D., A monograph of the post-Tertiary Entomostraca of Scotland: Paleontographical Soc. London, vol. 28, pp. 96–99, 1874.

[11] Brady, G. S., Crosskey, H. W., and Robertson, D., idem., pp. 171–172.

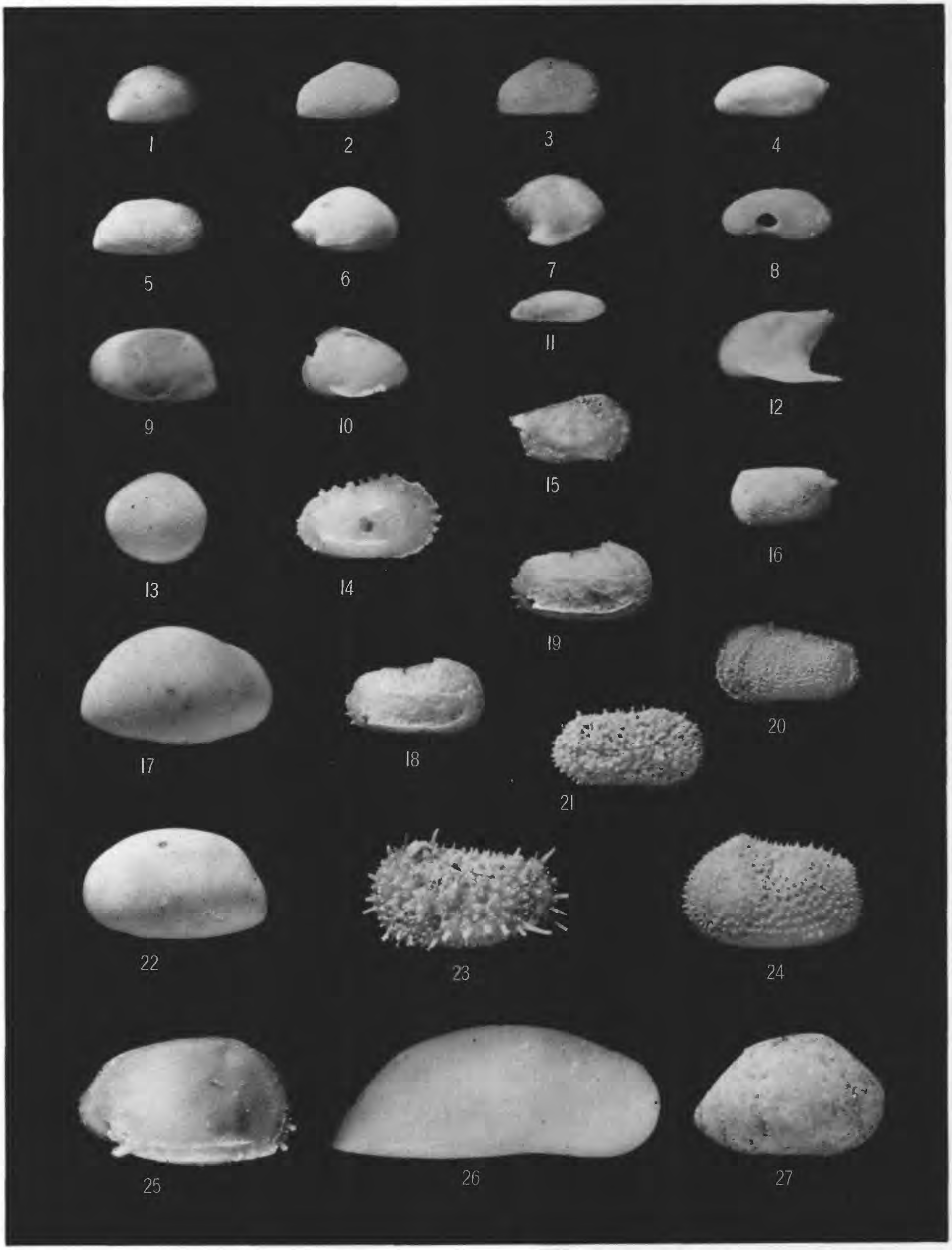
geologic interpretations) and by the pelagic Foraminifera. (See part 2, Foraminifera.) But the ostracodes in these cores are all bottom dwellers that lived 1,280 meters or more below the surface, and consequently there seems little reason to expect that they would be as sensitive to changes in surface-water temperatures as would strictly pelagic organisms. At depths of 1,280 meters or more the water temperatures probably were somewhat lower during the glacial stages of the Pleistocene than they are today, but it seems likely that any changes in temperature at those depths would have been so slow that they lagged far behind the climatic changes that produced them. Possibly the change was so slow that it masked the alternation of cold and warm epochs that left so clear an impress on the composition of the pelagic foraminiferal fauna.

PLATE 19

PLATE 19

[All figures magnified 30 diameters]

FIGURE 1. *Krithe tumida* Brady. Lateral view of right valve. North Atlantic deep-sea core 7, H–49a.
2–3. *Eucythere declivis* (Norman). Lateral views of right valve. North Atlantic deep-sea core 8, H–68.
4. *Paradoxstoma ensiforme* Brady. Lateral view of right valve. North Atlantic deep-sea core 8, H–71.
5. *Krithe bartonensis* (Jones). Lateral view of right valve. North Atlantic deep-sea core 7, H–49a.
6. *Cytheropteron inflatum* Crosskey. Lateral view of right valve. North Atlantic deep-sea core 13, H–138.
7. *Cytheropteron hamatum* Sars. Lateral view of right valve. North Atlantic deep-sea core 8, H–64.
8. *Paracytherois producta* (Brady and Norman). Lateral view of right valve. North Atlantic deep-sea core 8, H–71.
9. *Krithe glacialis* Brady, Crosskey, and Robertson. Lateral view of left valve. North Atlantic deep-sea core 13, H–147.
10. *Cytheropteron* sp. (a). Lateral view of left valve. North Atlantic deep-sea core 6, H–35.
11. *Paracytherois flexuosa* (Brady). Lateral view of right valve. North Atlantic deep-sea core 8, H–69.
12. *Cytheropteron alatum* Sars. Lateral view of left valve. North Atlantic deep-sea core 8, H–69.
13. *Polycope orbicularis* Sars. Lateral view of right valve. North Atlantic deep-sea core 8, H–69.
14. *Cythereis jonesi* Baird. Lateral view of right valve. North Atlantic deep-sea core 12, H–130.
15. *Pseudocythere caudata* (Sars). Lateral view of right valve. North Atlantic deep-sea core 8, H–61a.
16. *Bythocythere constricta* Sars. Lateral view of left valve. North Atlantic deep-sea core 8, H–71.
17. *Bythocypris obtusata* Sars. Lateral view of right valve. North Atlantic deep-sea core 4, H–30.
18–19. *Cythereis* sp. Lateral views of right valve. North Atlantic deep-sea core 13, H–135.
20. *Cythereis tuberculata* Sars. Lateral view of left valve. North Atlantic deep-sea core 8, H–71.
21. *Cythereis dunelmensis* Norman. Lateral view of right valve. North Atlantic deep-sea core 12, H–133a.
22. *Bythocypris bosquetiana* (Brady). Lateral view of left valve. North Atlantic deep-sea core 12, H–130.
23. *Cythereis ericea* (Brady). Lateral view of left valve. North Atlantic deep-sea core 7, H–48.
24. *Cythereis echinata* Sars. Lateral view of left valve. North Atlantic deep-sea core 7, H–48.
25. *Cytheropteron mucronalatum* Brady. Lateral view of right valve. North Atlantic deep-sea core 12, H–133a.
26. *Macrocypris minna* (Baird). Lateral view of right valve. North Atlantic deep-sea core 13, H–137.
27. *Bairdia* sp. Lateral view of right valve. North Atlantic deep-sea core 8, H–61a.



OSTRACODA FROM THE NORTH ATLANTIC DEEP-SEA CORES.

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

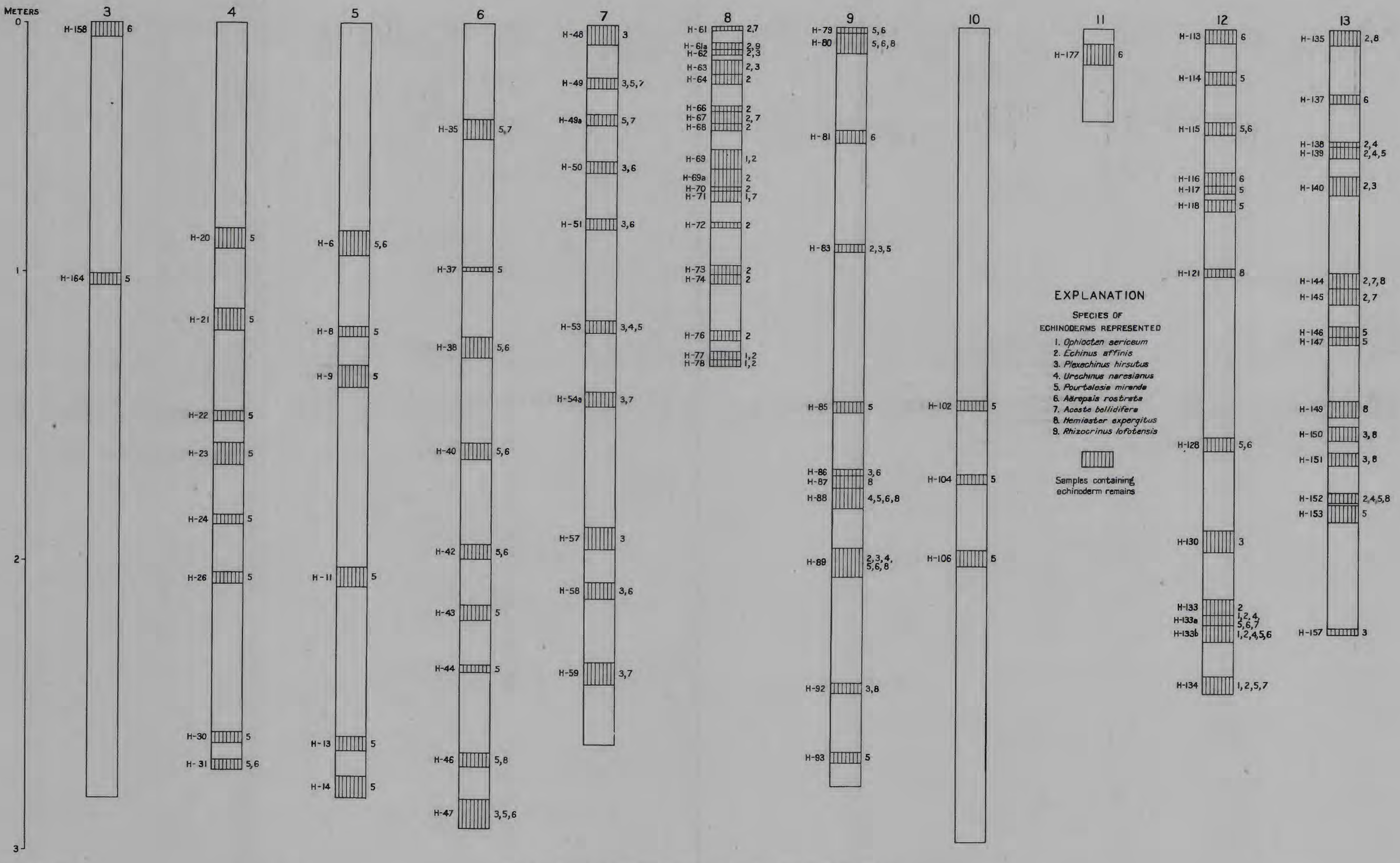
Geographic range: Off southern New England and Virginia, off the Azores, the eastern Atlantic, the Canary Islands, the Caribbean Sea, off Uruguay, off the coast of Peru, northwest of the Marquesas, the Hawaiian Islands, southern Japan, the Lesser Sunda Islands, and the Bay of Bengal. It is probably cosmopolitan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

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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., Échinodèrmes 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.

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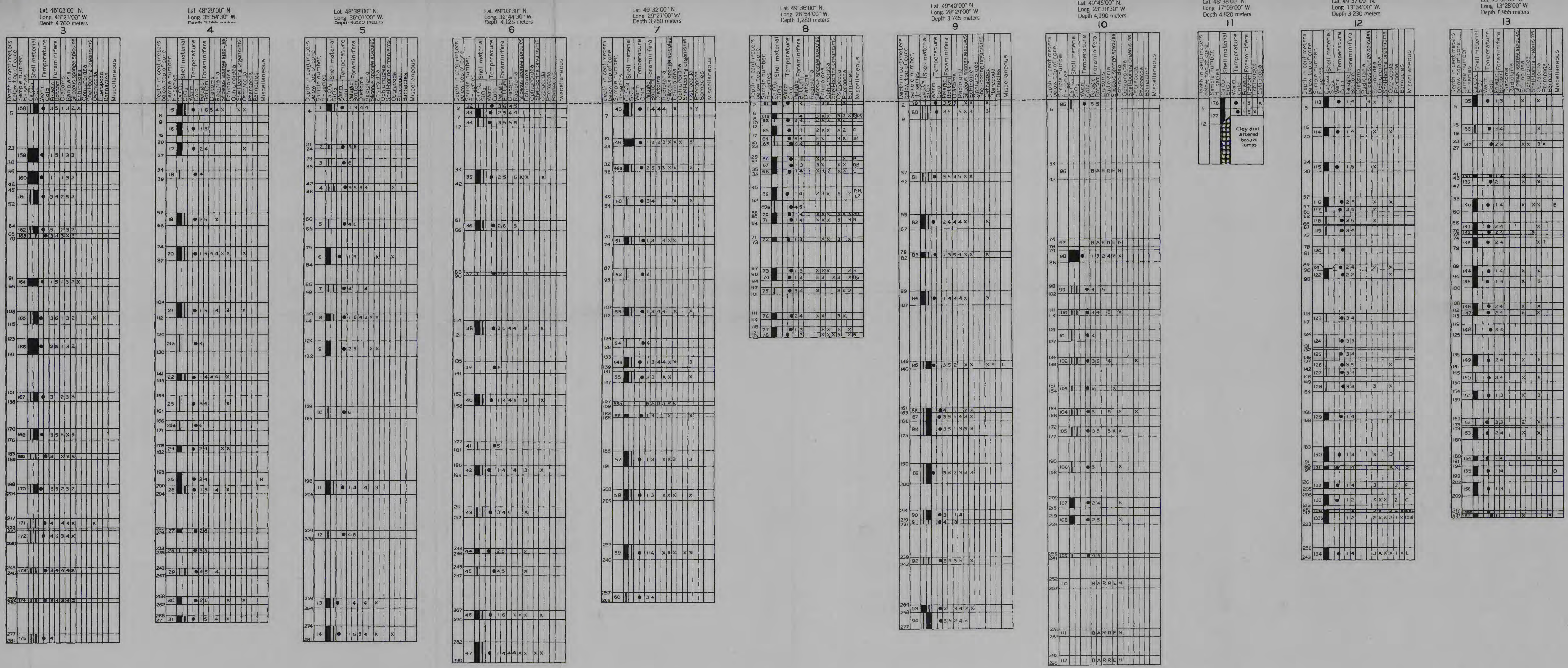
[1] For explanation of these temperature zones see part 2, Foraminifera, p. 48.

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



(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 X. 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.

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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 façies, 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. London, Macmillan Co., 1912.

PLATES 22–23

PLATE 22

Miscellaneous fossils

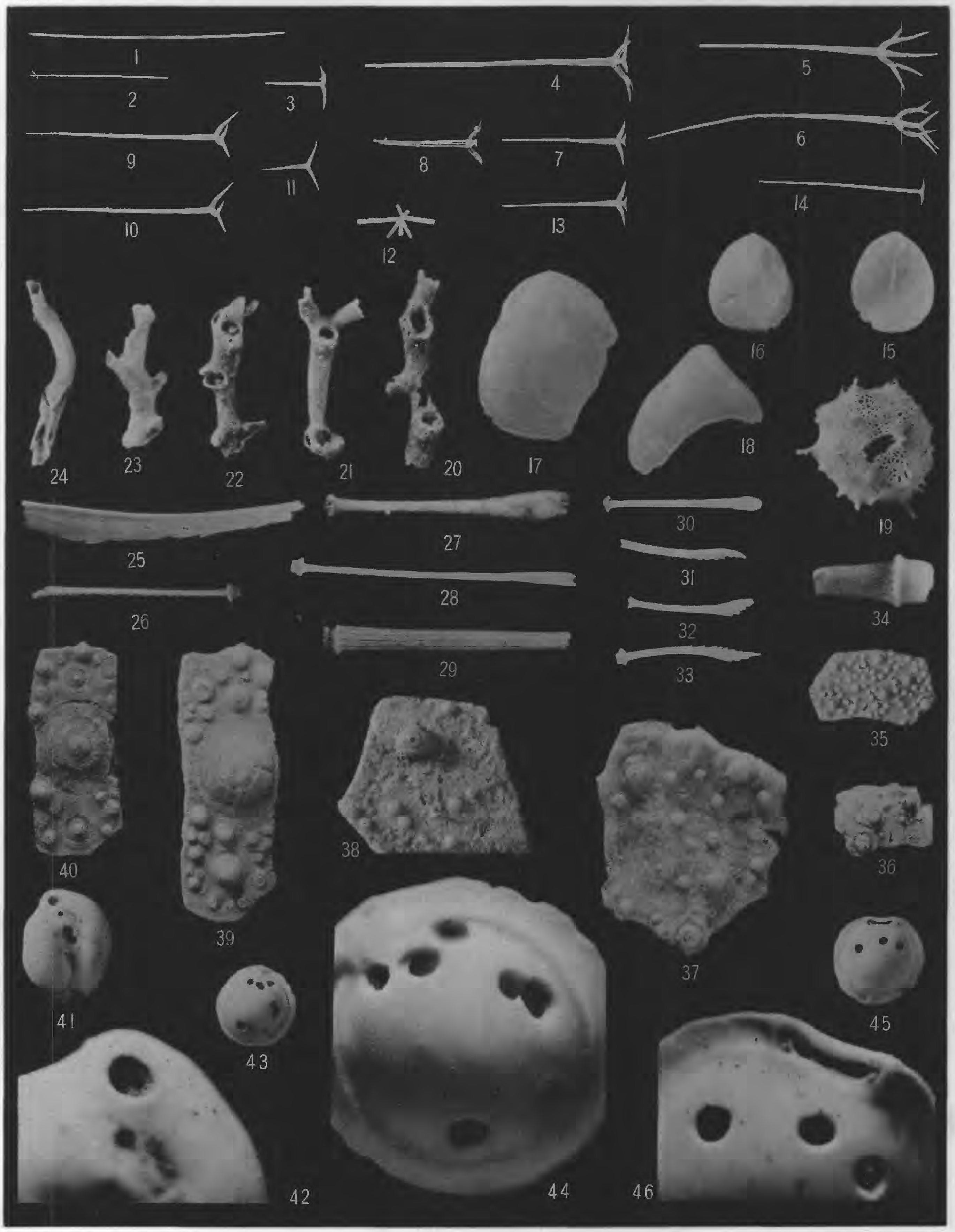
Figures 1–14. Siliceous sponge spicules. 1–11 and 13–14, × 10, core 8, H–63; 12, × 15, core 6, H–35.
15–16. Brachiopod. *Cryptopora gnomon* (Jeffreys). × 5. 15, Interior view; 16, exterior view. Core 12, H–133b.
17–18. Brachiopod. *Gryphus* sp. × 15. 17, Exterior view of dorsal valve; 18, exterior view 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

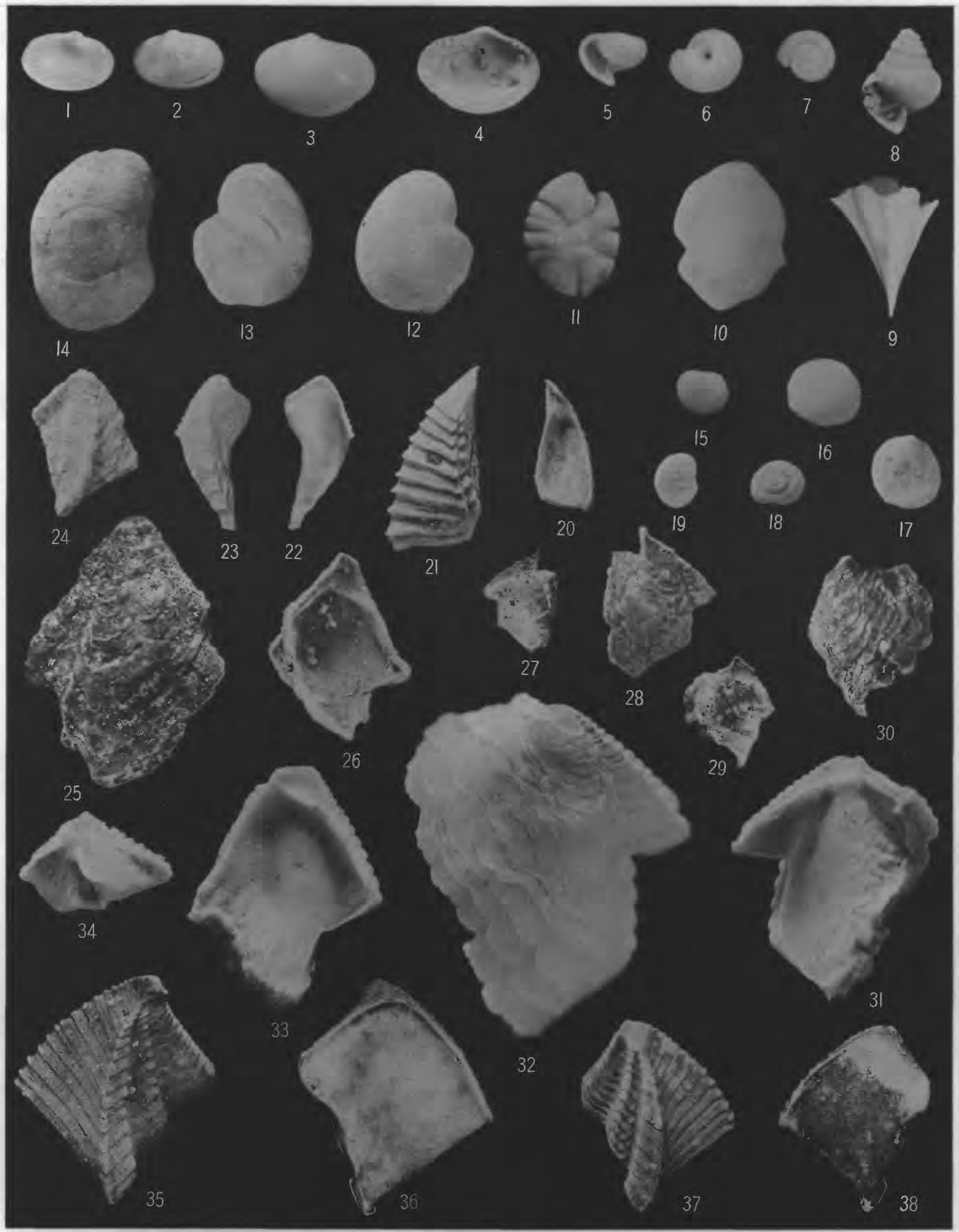
Figure 25. Echinoderm (?) spine. × 10. Core 12, H–133b.
26. *Pourtalesia miranda.* Primary spine. × 15. Core 12, H–117.
27. *Aceste bellidifera.* × 15. Core 12, H–35.
28. *Plexechinus hirsutus.* Primary spine. × 10. Core 12, H–47.
29. *Echinus affinis.* Base of a spine. × 10. Core 12, H–133b.
30. *Hemiaster 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.

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

PART 8. ORGANIC MATTER CONTENT

By P. D. TRASK, H. W. PATNODE, J. L. STIMSON, and J. R. GAY

INTRODUCTION

This report presents the results of a study of the organic constituents of samples of deep-sea sediments collected in 1936 in the North Atlantic Ocean by Dr. C. S. Piggot of the Geophysical Laboratory of the Carnegie Institution of Washington with his gun core sampler. The investigation was undertaken at the request of the Geological Survey and is the joint work of the Geological Survey and the American Petroleum Institute. Mr. Trask is a member of the staff of the Geological Survey, and Messrs. Patnode, Stimson, and Gay, at the time the investigation was made, were members of the staff of American Petroleum Institute Research Project 4 on the Origin and Environment of Source Sediments of Petroleum.

Mr. Trask wrote the report and, with Mr. Patnode, organized the general program of work. Mr. Patnode compiled the data and prepared the charts and tables. Messrs. Stimson and Gay made the chemical analyses. The chemical work was done in a laboratory placed at the disposal of Project 4 by the Division of Industrial Farm Products Research of the Bureau of Chemistry and Soils of the United States Department of Agriculture.

METHODS OF STUDY

This investigation is based on the determination of the nitrogen content and reduction number, as defined later, of 123 samples from 11 cores. Owing to the program of the regular work of Project 4 at the time the samples were being studied time and facilities did not permit a detailed study of the organic content of these samples, and the work was therefore limited to the determination of the nitrogen content and reduction number. Neither the nitrogen content nor reduction number is an exact measure of the quantity of organic matter in sediments; at best these properties are only crude approximations. Their significance with respect to the organic content is discussed elsewhere.[1]

NITROGEN CONTENT

Nitrogen was determined by a slight modification of the Kjeldahl-Arnold-Gunning method,[2] which consists of converting the nitrogen compounds to ammonia by digestion with sulfuric acid, making the solution alkaline with sodium hydroxide, distilling, catching the ammonia in hydrochloric acid, and titrating with sodium hydroxide. All the determinations were duplicated and many were made in triplicate. The results are presented in terms of the arithmetic average or mean of the results obtained. They are given to two significant figures, but the second figure is of doubtful value. The average (median) deviation of individual determinations from the means, which are reported in table 30, is 0.0012 percent of the total weight of the sediments. As the average nitrogen content is 0.022 percent of the weight of the sediments, the average deviation of the individual samples from the mean is 0.0012/0.022, or 5.5 percent. When averages of several samples are considered this quantity is reduced approximately as the inverse of the square root of the number of samples considered. Thus the probable error of an average based on 10 samples is $5.5/\sqrt{10}$ or 1.7 percent, which, for the purpose of this investigation, is a relatively insignificant quantity.

The nitrogen content in some ways seems to be a more suitable index of the organic content of sediments than is the reduction number, but on the whole it probably is not materially superior. The main advantage of nitrogen is its restriction almost entirely to the organic constituents, whereas the reduction number is influenced to some extent by the inorganic substances. Nitrogen, however, represents only a small part of the organic matter, thus necessitating the use of a large factor for estimating the organic content. Moreover, the percentage of nitrogen in the organic constituents of different sediments varies, thus introducing errors in the calculation of the organic content when a constant factor is used.

The nitrogen content of the organic constituents of recent marine sediments has not yet been studied adequately, but the available evidence seems to indicate

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[1] Trask, P. D., Inferences about the origin of oil as indicated by the composition of the organic constituents of sediments: U. S. Geol. Survey Prof. Paper 186-H pp. 149-154, 1937; Organic content of recent marine sediments, in Recent marine sediments, pp. 428-453, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1939.

A final report by P. D. Trask and H. W. Patnode embodying the results of the extensive research program carried out by the American Petroleum Institute and the United States Geological Survey is being prepared for publication by the American Association of Petroleum Geologists under the title "Source beds of petroleum."

[2] Official Methods. Assoc. Official Agr. Chem., 2d ed., p. 81, 1925. Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

that on the average nitrogen forms about 5.5 percent of the weight of the organic matter and in most sediments ranges between 4.5 and 7 percent; however, in some deposits it may be as low as 3 percent and in others as high as 10 percent.[3]

If nitrogen forms 5.5 percent of the organic matter, the organic content of the sediments would be 100/5.5, or 18 times the nitrogen; that is, the organic content could be estimated by multiplying the nitrogen content by a factor of 18. Similarly nitrogen contents of 4.5 and 7.0 percent correspond to factors of 22 and 14, respectively, and contents of 3 and 10 percent are equivalent to factors of 33 and 10, respectively. Thus, if a single factor of 18 is used for determining the organic content, for most sediments the figure obtained will be within 4/18 or about 20 percent of the true quantity, but for some sediments it may be in error by as much as 50 percent.

The significance of the organic content as estimated in this way, therefore, must be interpreted with due consideration of the degree of reliability of the data. Small differences in nitrogen content, such as 5 percent or less, without supporting evidence from another source, cannot be considered as indicating any distinctive difference in organic content, but if the difference in nitrogen content between two or more sediments is considerable, that is 30 percent or more, the organic content of the sediments in all probability is different. If the averages of several sediments are considered, the chance for anomalous interpretations decreases more or less inversely as the square root of the number of sediments averaged. Therefore, if the chance for error is 20 percent for an individual sediment, it would be of the order of $20/\sqrt{10}$, or 6.3 percent, for an average based on 10 samples; also, if the averages of two series of 10 samples differ by as much as 10 percent the chances are greatly in favor of their content of organic matter being different. However, in view of the uncertainty as to the actual factor to use for estimating the organic content from nitrogen, the variations in organic matter have been discussed in this paper in terms of variations in nitrogen content (or reduction number, which varies in essentially the same way as the nitrogen content), rather than in terms of variation in organic content. Only when the differences between the nitrogen content or reduction number of individual sediments or groups of sediments are distinctly different have the results been interpreted as suggesting real differences in organic content.

REDUCTION NUMBER

The reduction number, like the nitrogen content, is only a crude index of the organic content. The reduction number is defined as the number of cubic centimeters of 0.4 normal chromic acid that can be reduced by 100 milligrams of dried sediment under certain standard conditions of heating.[4] Formerly it was called the reducing power, but in view of the fact that it is a relative rather than an absolute measure of the reducing power of the sediments it subsequently was designated as the reduction number.[5]

The method of determination is a modification of the Schollenberger [6] method of chromic acid titration for soil organic matter. It consists of adding a known amount of 0.4 normal chromic acid to a given quantity of sediment, heating it at such a rate that the temperature within the mixture of chromic acid and sediment reaches 145° C. at the end of 6 minutes, cooling, and titrating with 0.2 normal ferrous ammonium sulfate.[7] In the present investigation, samples of 0.5 gram were used for the determination of the reduction number. The method, when the time and rate of heating are controlled, gives results that can be duplicated readily. The average deviation of duplicate samples from the mean of the determinations for individual samples studied for this report is .0069. As each drop of ferrous ammonium sulfate used in the titration corresponds to .005 unit of reduction number, this deviation for duplicate samples amounts to only a little more than one drop in the titration, which indicates that the results as expressed to two significant figures are reliable insofar as errors in the method of determination are concerned. Since the average reduction number of the sediments is 0.25, the mean deviation of individual samples from the mean is 0.0069/0.25, or 2.7 percent.

Each unit of reduction number in recent marine sediments seems to be equivalent to approximately 2 percent organic matter. This relation of reduction number to organic content in recent sediments has been investigated relatively little, but in the experience of the writers each unit of reduction number on the average corresponds to approximately 1.1 percent of organic carbon in the sediments.[8] As the average ratio of organic matter to carbon in recent marine deposits seems to be about 1.8,[9] it follows that the percentage of organic matter in the sediments would be roughly equivalent to two times the reduction number. The ratio of organic matter to carbon in such deposits, however, is not constant. Moreover, the figures of 1.8 for the ratio of organic matter to carbon, and of 1.1 for the ratio of reduction number to carbon may not be correct. In addition, the ratio of carbon to reduction number is known to be variable. These variations in the ratio of carbon to reduction number are caused by the fact that the quantity of organic matter in the sediments is not the only factor influencing the reduction

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[3] Trask, P. D., Organic content of recent marine sediments, p. 431, 1939.

[4] Trask, P. D., and Patnode, H. W., Means of recognizing source beds: Am. Petroleum Inst., Drilling and Production Practice, 1936, p. 369, 1937.

[5] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

[6] Schollenberger, C. J., A rapid approximate method for determining soil organic matter: Soil Science, vol. 24, pp. 65–68, 1923; The determination of soil organic matter: Soil Science, vol. 31, pp. 483–486, 1931.

[7] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

[8] Trask, P. D., Organic content of recent marine sediments, in Recent marine sediments, pp. 430–433, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1939.

[9] Idem., p. 430.

of chromic acid during the process of determining the reduction number. Chromic acid is reduced by certain inorganic constituents, such as iron sulfide; the extent to which the organic substances are oxidized by the chromic acid during the process of analysis varies among different sediments; and the degree of oxidation or nature of the organic material affects the reduction of chromic acid. If the organic substances are in a high state of oxidation, relatively little chromic acid is reduced and if they are in a low state of oxidation, that is, have a high degree of reduction, relatively much chromic acid is reduced.

In ancient or lithified sediments, three factors, the quantity of oxidizable inorganic substances, the degree of completeness of combustion by the chromic acid, and the state of oxidation of the organic matter, cause the majority of sediments to deviate 20 percent or less from the average ratio of carbon to reduction number, though in some sediments they may cause variations of as much as 50 percent.[10] Presumably similar variations apply to recent deposits, as is attested by the similarity in relationship of nitrogen and reduction number shown by figure 23. Both the nitrogen content and reduction number are independent measures of the organic content, yet when one is plotted against the other a moderately constant relationship is observed. Consequently, it seems to follow that the reduction number is of about the same order of reliability as an index of the organic content as is nitrogen; namely, only a crude approximation, which for most samples is probably within 20 or 25 percent of the true figure, but in some samples may deviate as much as 50 percent from the correct figure. Estimation of the quantity of organic matter in the sediments by the use of the reduction number, therefore, should be interpreted with due consideration of the uncertainties involved.

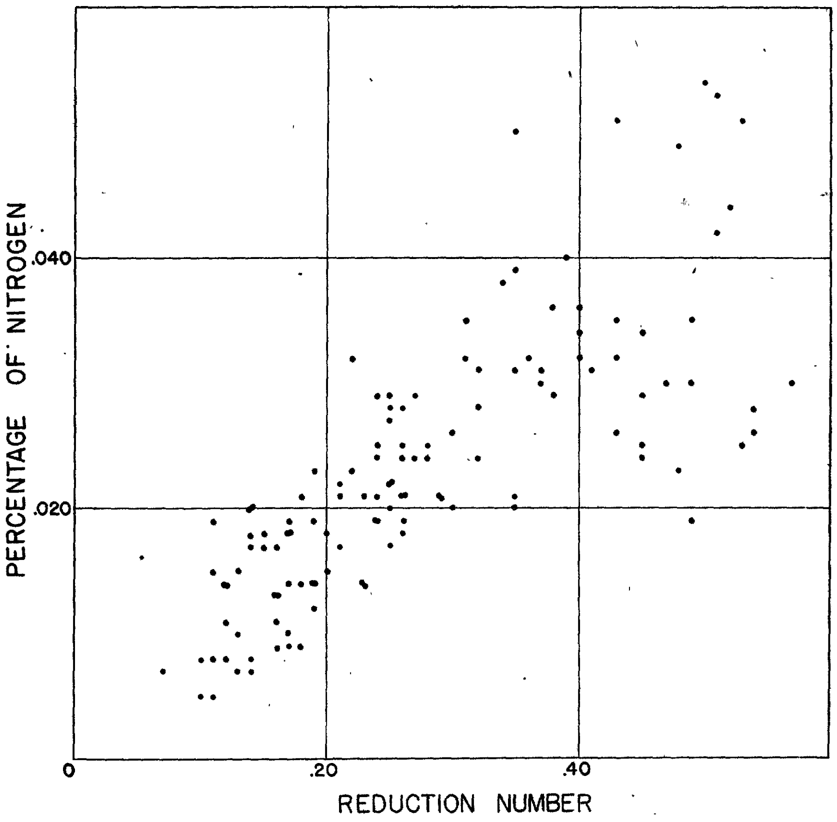

FIGURE 23.—Relation of nitrogen content to reduction number in the samples studied.

The foregoing discussion of the probable error of the determination of the organic content by multiplying the reduction number by a factor of 2, refers to calculations based on individual samples. When groups of samples are considered, the probable error is reduced. However, certain basic uncertainties are still involved, namely, the correctness of the ratio of organic matter to carbon, and of the ratio of carbon to reduction number. Therefore, in view of these uncertainties, the variations of reduction number among the different sediments studied in this report, wherever practicable, have been discussed in terms of reduction number, which is an empirical quantity, rather than in terms of organic content, which is an interpretation. Nevertheless, when averages of groups of samples show similar and consistent differences for both nitrogen content and reduction number, the inference is strong that the quantity of organic matter in the groups of sediments is different.

NITROGEN-REDUCTION RATIO

The ratio of the nitrogen content to the reduction number of ancient sediments, which is called the nitrogen-reduction ratio, has been interpreted as a crude index of the state of reduction of the organic constituents of the sediments.[11] The line of reasoning that leads to this conclusion is based on the inferences that the nitrogen content is a rough measure of the organic content of the sediments and the ratio of the organic content to the reduction number is a crude index of the state of reduction of the organic substances. If the organic constituents are in a high state of oxidation they can reduce relatively little chromic acid, and the reduction number will be comparatively small. As the reduction number forms the denominator of the nitrogen-reduction ratio, a small reduction number would make the quotient relatively large. If the state of oxidation is low, the reduction number would be high and the ratio of organic matter to reduction number would be low. That is, large numbers would indicate a high state of oxidation, and low numbers would indicate a low state of oxidation.

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[10] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

[11] Trask, P. D., and Patnode, H. W., Means of recognizing source beds: Am. Petroleum Inst., Drilling and Production Practice, 1936, p. 371, 1937.

The relationship, however, is not as definite as the above line of reasoning would seem to indicate. The nitrogen content is not an exact measure of the organic content, because, as already indicated, the proportion of nitrogen varies in different sediments. Moreover, the effect of oxidizable inorganic substances in the sediments and the effect of the completeness of combustion by the chromic acid upon the reduction number have not been considered. The influence of these three factors upon the significance of the nitrogen-reduction ratio as an index of the state of reduction of the organic matter has been discussed in detail in another publication, and the conclusion was reached that, in general, their effect is not large.[12] Insufficient data are at hand, however, to warrant any definite statement as to the actual magnitude of their effect; moreover, the influence of these factors on recent marine sediments has been studied relatively little, but presumably it is not materially different from what it is in ancient deposits. In view of the uncertainties involved, the significance of the nitrogen-reduction ratio of recent sediments must, therefore, be interpreted with caution. About all that is safe to infer is that relatively low ratios suggest a low state of oxidation of the sediments and relatively high ratios suggest a high state of oxidation.

DESCRIPTION AND LOCATION OF SAMPLES

A proper description of the results of the work should include an account of the general nature of the samples, but as this subject has been discussed in detail in other parts of this professional paper only a brief summary is included here. The samples were collected in the spring of 1936 by C. S. Piggot (see Foreword, pp. XI–XII) with his gun sampler, which can take cores as much as 10 feet in length. Samples were obtained at fairly regular intervals along a nearly straight line about latitude 49° N., between the Grand Banks, Newfoundland, and Lands End, at the southwest end of England. The actual locations are indicated in plate 1 of the introductory chapter. Their general position is also indicated on the profile shown in figure 27 of this report. Eleven cores were obtained. They were taken in water that ranges from 1,280 to 4,800 meters (700 to 2,640 fathoms) in depth. Most of them came from water more than 3,000 meters deep, but one, number 8, was procured from the crest of the mid-Atlantic ridge, in water only 1,280 meters deep. The core material obtained ranged from 30 to 300 centimeters in length. At locality 10, the coring device buried itself in the mud, and an unknown quantity of the sediment was lost through the water ports at the top of the device.

As indicated by the work of Bramlette and Bradley on the lithologic character and geologic interpretations of the cores (see pt. 1, pl. 3), the samples are nearly all rich in calcium carbonate, and many are classified as foraminiferal marl and globigerina ooze. One core, number 3, taken from near the edge of the Grand Banks, contains considerable terrigenous debris, and another, number 11, encountered altered basalt at a depth of 30 centimeters below the top of the core. West of the mid-Atlantic ridge, two volcanic ash horizons were recognized, one at a depth that ranged between 10 and 50 centimeters beneath the surface of the deposits and the other at a depth of about 2 meters. East of the mid-Atlantic ridge only the upper of these two ash horizons has been recognized. These ash zones are particularly helpful in correlating the sediments in the different cores.

In addition to the ash horizons noted, pebbles and rock fragments are present in definite zones of sandy or silty sediment that contains relatively little carbonate. Bramlette and Bradley have recognized four such zones and regard them as of glacial or ice raft origin. Cushman and Henbest record (see pt. 2, figs. 11–21) the occurrence of cold-water Foraminifera in these pebbly zones, and this corroborates the concept of glacial origin. These zones, characterized by pebbles, rock fragments, sand, and silt, are designated in this paper as cold zones. The zones between the cold zones are called warm zones. These zones have been recognized in all the cores west of the mid-Atlantic ridge, but east of the ridge only the uppermost cold zone has been recognized. In core 3, near the edge of the Grand Banks, the uppermost cold zone has not been reached even at the bottom of the core at a distance of nearly 3 meters beneath the surface of the deposits. For convenience, the zones are numbered consecutively from the top downward. (See table 31.)

The general distribution of these cold zones is indicated on figure 24. The consistency with which they may be traced from core to core affords a means of correlating sediments of similar age and thus aids in the investigation of the lateral variation in the deposits at different depths.

The sediments in general contain about 50 percent calcium carbonate, though the quantity ranges from 10 to 90 percent. Some of the samples are sandy, particularly those from core 8 on the crest of the mid-Atlantic ridge.

The positions of the samples that were selected for study are shown in figure 24. In all, 123 samples were chosen. Samples were procured first from places near the top, middle, and bottom of each core, except the one (core 11) that penetrated the basalt. The results of the analyses of these first samples did not indicate any consistent trend with depth, but by the time they were analyzed the temperature zones had been recognized. Consequently, it seemed worth while to analyze samples in each core from each of the 9 temperature zones. Also, it was desirable to ascertain whether or not there was any change with depth in the individual warm and cold zones. Accordingly, an attempt was made to procure at least two samples from each of the

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[12] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

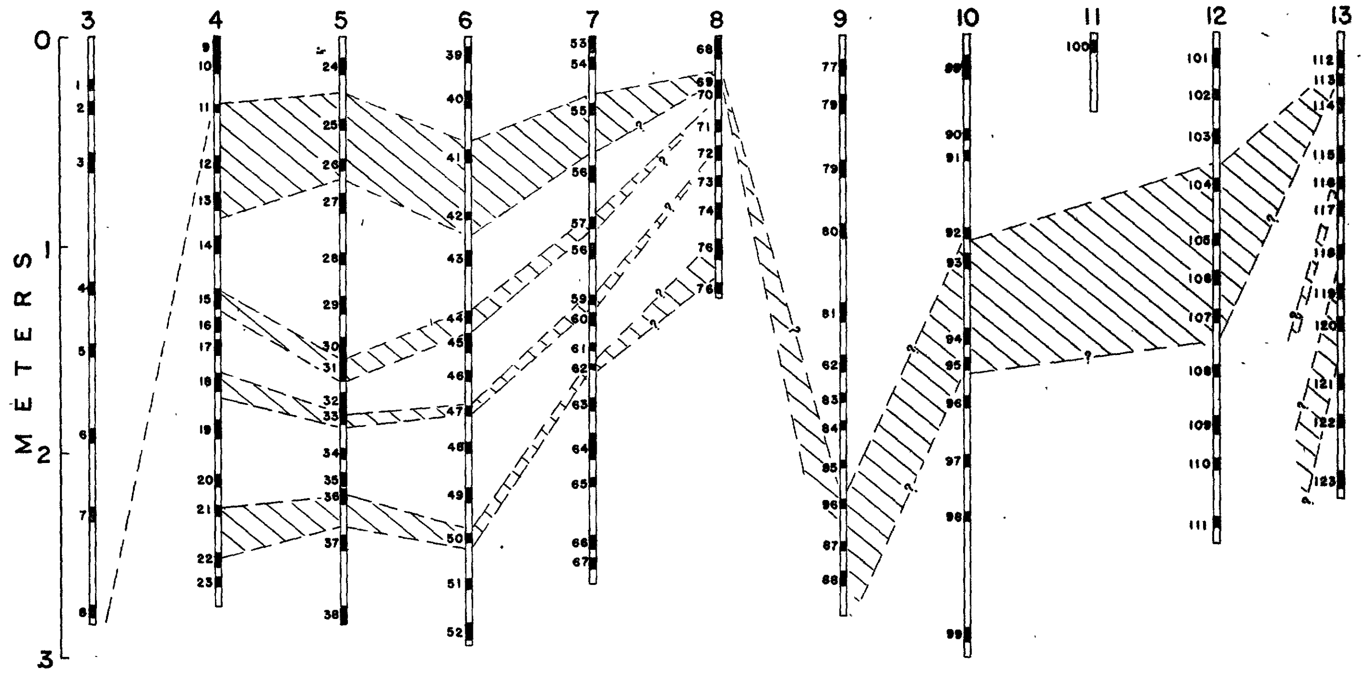

FIGURE 24.—Location of samples in cores. Vertical columns represent the numbered cores. (For location of cores see pl. 1 and fig. 1.) Black rectangular blocks represent position of samples studied; numbers opposite these blocks are the numbers of the samples. Diagonally ruled bands extending across the figure represent cold zones. Warm zones lie between the cold zones.

nine stratigraphic zones. However, by this time considerable material had already been removed from certain parts of the cores, and it was not possible to obtain some of the samples desired. Special effort was made to procure samples from the surface of the sediments in each core. However, top material could be obtained only from cores, 4, 7, and 8. In all other cores, except cores 3 and 10, the uppermost sample came from within 10 centimeters of the top of the core. In core 3 the first sample was taken 20 centimeters below the top, and in core 10 an unknown amount of the uppermost part of the core had been lost at the time the core was taken.

RESULTS

BASIC DATA

The results of the analyses are presented in table 30. This table contains the average of the determinations of the nitrogen and reduction number of each sample and the nitrogen-reduction ratios based on these average values. The table includes two forms of averages for the samples for each of the 11 cores, namely, the mean and median. The mean represents the sum of the determinations for the individual samples divided by the total number of samples. The median represents the middle determination with respect to all samples considered for the individual cores. Half the samples in any individual core have values larger than the median, and half have values smaller than the median. The median is particularly significant for ratios, such as the nitrogen-reduction ratio, and also for size distributions in which most of the samples have about the same average value, but a few are very much larger or smaller than the others.[13]

TABLE 30.—*Average values of the nitrogen content, reduction number, and nitrogen-reduction ratio*

Core 3

Sample number	Nitrogen (percent)	Reduction number	Nitrogen-reduction ratio
T-1	0. 051	0. 43	11. 8
T-2	. 054	. 50	10. 8
T-3	. 044	. 52	8. 5
T-4	. 042	. 51	8. 2
T-5	. 035	. 43	8. 1
T-6	. 034	. 40	8. 5
T-7	. 031	. 35	8. 9
T-8	. 034	. 45	7. 6
Mean	. 041	. 45	9. 1
Median	. 039	. 44	8. 5

Core 4

Sample number	Nitrogen (percent)	Reduction number	Nitrogen-reduction ratio
T-9	0. 014	0. 23	6. 1
T-10	. 021	. 24	8. 7
T-11	. 013	. 16	8. 1
T-12	. 020	. 25	8. 0
T-13	. 035	. 31	11. 3
T-14	. 023	. 22	10. 5
T-15	. 017	. 16	10. 6
T-16	. 025	. 24	10. 4
T-17	. 024	. 24	10. 0
T-18	. 014	. 17	8. 2
T-19	. 039	. 35	11. 1
T-20	. 031	. 32	9. 7
T-21	. 036	. 40	9. 0
T-22	. 017	. 25	6. 8
T-23	. 021	. 23	9. 1
Mean	. 023	. 25	8. 9
Median	. 021	. 24	9. 1

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[13] For further details on the respective values of the mean and median, see any text book of statistics, such as Chaddock, R. E., Principles and methods of statistics, pp. 81-124, New York, Houghton Mifflin Co., 1925.

TABLE 30.—*Average values of the nitrogen content, reduction number, and nitrogen-reduction ratio*—Continued

Sample number	Nitrogen (percent)	Reduction number	Nitrogen-reduction ratio
Core 5			
T-24	0. 029	0. 25	11. 6
T-25	. 024	. 26	9. 2
T-26	. 014	. 18	7. 8
T-27	. 010	. 13	7. 7
T-28	. 020	. 30	6. 7
T-29	. 024	. 32	7. 5
T-30	. 022	. 25	8. 8
T-31	. 011	. 16	6. 9
T-32	. 021	. 26	8. 1
T-33	. 018	. 17	10. 6
T-34	. 017	. 21	8. 1
T-35	. 021	. 29	7. 2
T-36	. 021	. 26	8. 1
T-37	. 018	. 26	6. 9
T-38	. 015	. 20	7. 5
Mean	. 019	. 23	8. 2
Median	. 020	. 25	7. 8
Core 6			
T-39	0. 028	0. 25	11. 2
T-40	. 022	. 25	8. 8
T-41	. 028	. 26	10. 8
T-42	. 030	. 37	8. 1
T-43	. 028	. 32	8. 7
T-44	. 010	. 17	5. 9
T-45	. 024	. 27	8. 9
T-46	. 021	. 29	7. 2
T-47	. 009	. 18	5. 0
T-48	. 026	. 30	8. 7
T-49	. 031	. 37	8. 4
T-50	. 025	. 26	9. 6
T-51	. 019	. 24	7. 9
T-52	. 023	. 19	12. 1
Mean	. 023	. 26	8. 7
Median	. 025	. 26	8. 7
Core 7			
T-53	0. 018	0. 17	10. 6
T-54	. 018	. 20	9. 0
T-55	. 019	. 24	7. 9
T-56	. 021	. 21	10. 0
T-57	. 013	. 16	8. 1
T-58	. 014	. 23	6. 1
T-59	. 007	. 13	5. 4
T-60	. 019	. 17	11. 2
T-61	. 019	. 19	10. 0
T-62	. 025	. 28	8. 9
T-63	. 014	. 19	7. 4
T-64	. 007	. 14	5. 0
T-65	. 009	. 16	5. 6
T-66	. 008	. 14	5. 7
T-67	. 014	. 19	7. 4
Mean	. 015	. 19	7. 9
Median	. 014	. 19	7. 9
Core 8			
T-68	0. 009	0. 17	5. 3
T-69	. 005	. 10	5. 0
T-70	. 008	. 11	7. 3
T-71	. 005	. 11	4. 5
T-72	. 008	. 12	6. 7
T-73	. 011	. 12	9. 2
T-74	. 008	. 10	8. 0
T-75	. 017	. 15	11. 3
T-76	. 007	. 07	10. 0
Mean	. 009	. 12	7. 5
Median	. 008	. 11	7. 3

TABLE 30.—*Average values of the nitrogen content, reduction number, and nitrogen-reduction ratio*—Continued

Sample number	Nitrogen (percent)	Reduction number	Nitrogen-reduction ratio
Core 9			
T-77	0. 037	0. 49	7. 5
T-78	. 026	. 54	4. 8
T-79	. 031	. 41	7. 6
T-80	. 024	. 45	5. 3
T-81	. 051	. 53	9. 6
T-82	. 019	. 49	3. 9
T-83	. 028	. 54	5. 2
T-84	. 030	. 57	5. 3
T-85	. 025	. 53	4. 7
T-86	. 029	. 45	6. 4
T-87	. 025	. 45	5. 6
T-88	. 032	. 40	8. 0
Mean	. 030	. 49	6. 2
Median	. 029	. 49	5. 5
Core 10			
T-89	0. 032	0. 43	7. 4
T-90	. 023	. 48	4. 8
T-91	. 026	. 43	6. 0
T-92	. 024	. 28	8. 6
T-93	. 021	. 35	6. 0
T-94	. 032	. 31	10. 3
T-95	. 012	. 19	6. 3
T-96	. 020	. 35	5. 7
T-97	. 029	. 27	10. 7
T-98	. 030	. 47	6. 4
T-99	. 029	. 38	7. 6
Mean	. 025	. 36	7. 3
Median	. 026	. 35	6. 4
Core 11			
T-100	0. 019	0. 26	7. 3
Core 12			
T-101	0. 029	0. 24	12. 1
T-102	. 050	. 35	14. 3
T-103	. 053	. 51	10. 4
T-104	. 032	. 36	8. 9
T-105	. 035	. 49	7. 1
T-106	. 049	. 48	10. 2
T-107	. 036	. 38	9. 5
T-108	. 040	. 39	10. 2
T-109	. 038	. 34	11. 2
T-110	. 027	. 25	10. 8
T-111	. 032	. 22	14. 5
Mean	. 038	. 36	10. 8
Median	. 036	. 36	10. 4
Core 13			
T-112	0. 019	0. 11	17. 3
T-113	. 021	. 18	11. 7
T-114	. 022	. 21	10. 5
T-115	. 015	. 13	11. 5
T-116	. 020	. 14	14. 3
T-117	. 018	. 14	12. 9
T-118	. 014	. 12	11. 7
T-119	. 015	. 11	13. 6
T-120	. 020	. 14	14. 3
T-121	. 017	. 14	12. 1
T-122	. 018	. 15	12. 0
T-123	. 014	. 12	11. 7
Mean	. 018	. 14	12. 8
Median	. 018	. 14	12. 1
General mean	0. 023	0. 28	8. 7
General median	. 022	. 25	8. 6

The areal and vertical distribution of the data are indicated graphically in figures 25 and 26. All the samples contain little organic matter. The nitrogen content ranges from 0.005 to 0.054 percent, and the reduction number ranges from 0.07 to 0.57. The median nitrogen content is 0.022 percent, and the median reduction number is 0.25. The respective means are 0.023 and 0.28. These data indicate that the organic content of the sediments ranges from about 0.1 percent to 1.0 percent, and the average is approximately 0.5 percent. These quantities of organic matter are of the same order of magnitude as previously reported from deep-sea deposits [14] but are much less than for

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[14] Trask, P. D., Origin and environment of source sediments of petroleum: pp. 116–118, Houston, Texas, Gulf Publishing Co., 1932. Correns, C. W., Die Sedimente des äquatorialen Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925-27, Band 3, Teil 3, Lief. 2, p. 236, 1937.

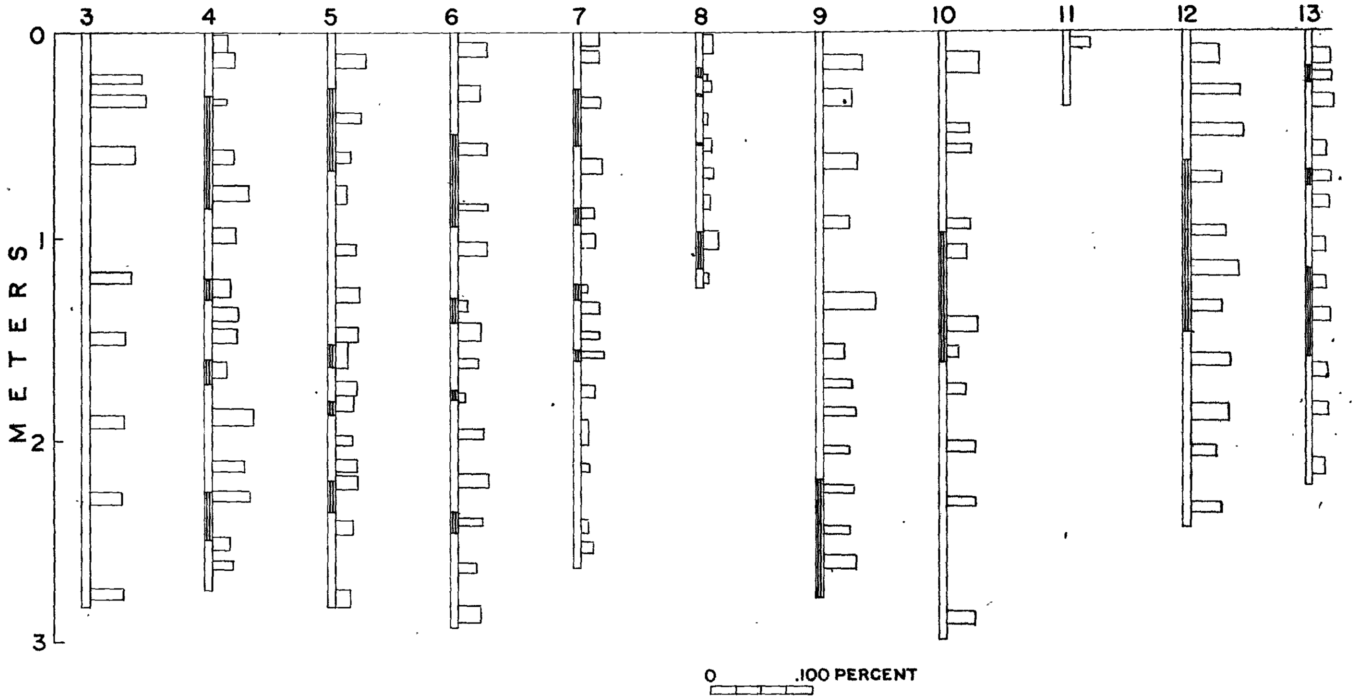

FIGURE 25.—Chart showing areal and vertical distribution of nitrogen in sediments in cores 3 to 13. Unshaded horizontal rectangular blocks indicate nitrogen content of samples. Position of these blocks indicates the respective location of samples in the cores. Vertical shading in core column represents limits of cold zones as determined by Bramlette and Bradley (see pt. 1 of this professional paper, pp. 2–7). Warm zones lie between the cold zones.

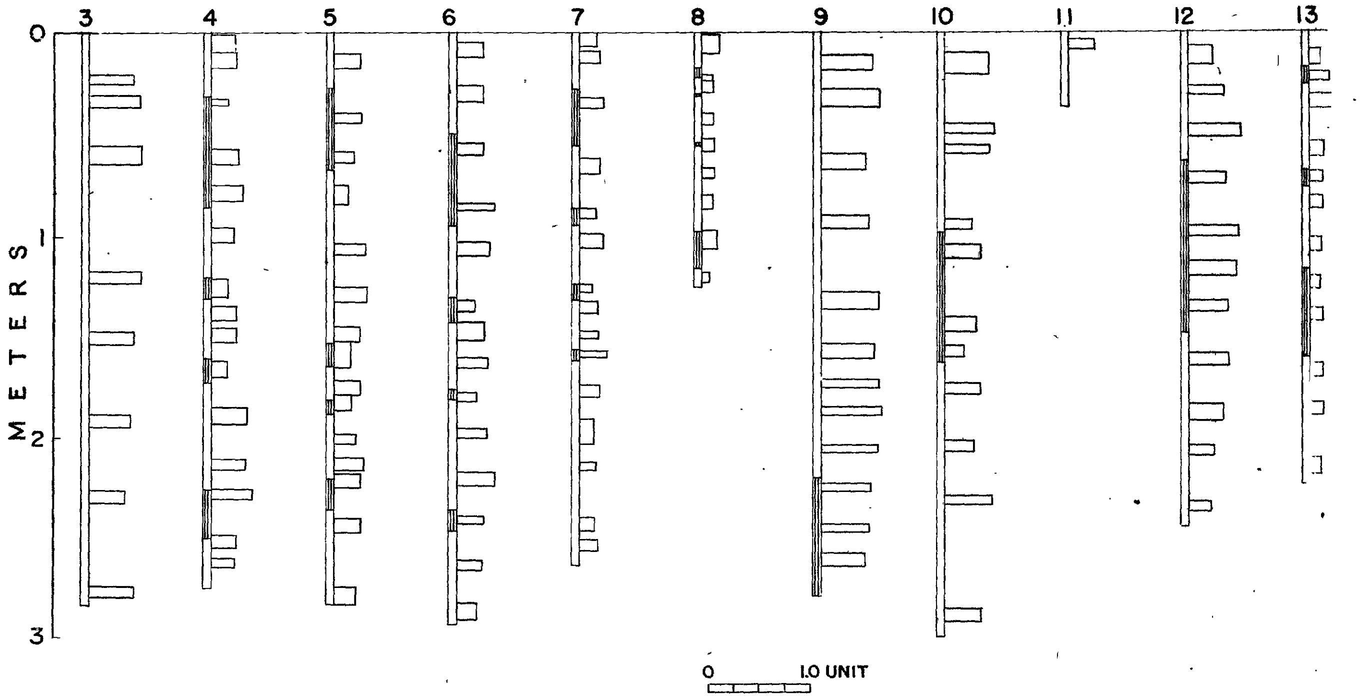

FIGURE 26.—Chart showing areal and vertical distribution of reduction number in sediments in cores 3 to 13. Unshaded horizontal rectangular blocks represent the reduction number of the samples. See figure 25 for description of other features of figure.

sediments deposited near shore, which ordinarily contain from 1 to 7 percent and have an average organic content of about 2.5 percent.[15]

RELATIONSHIPS

SURFACE LAYERS

The organic content of the sediments now forming on the sea floor as indicated by the uppermost samples procured from each core is clearly related to the configuration of the sea bottom (fig. 27). The sediments on exposed places on the sea floor, such as the sediments in core 8 on the mid-Atlantic ridge, and in core 13, on the edge of the ridge near the east end of the profile, contain distinctly less organic matter than the sediments in cores 3, 9, and 12, from the abyssal deeps. The organic content of the sediments on the ridges is 0.2 to 0.3 percent, compared with 0.3 to 1.0 percent in the deeps. Organic matter is relatively buoyant and is easily transported by currents. Consequently, if currents cross these ridges the sediments may be agitated, with the result that organic and fine-grained inorganic constituents will tend to be carried away and deposited in areas of quiet water. Evidence has been obtained from many other areas to the effect that sediments on ridges and exposed places on the sea floor, regardless of depth of water, are relatively coarse-grained and contain comparatively little organic matter.[16] The organic content of the sediments on the ridges in the Atlantic Ocean is small compared with that in the adjacent deeps.

The organic content of the sediments in the abyssal deeps varies somewhat, but owing to the small number of cores and to inadequate information on the submarine topography little can be inferred about the relation of the organic content to the configuration of the bottom along the part of this profile that represents the abyssal deeps. The sediments for a few hundred miles east of the mid-Atlantic ridge, however, seem to have a greater organic content than those for a similar distance to the West. The average nitrogen content of the uppermost samples contained from cores 9 and 10, east of the ridge, is 0.036 percent, compared with 0.022 percent for cores 4, 5, 6, and 7, west of the ridge. The corresponding averages for the reduction number are 0.46 and 0.23. The apparently greater organic content east of the ridge may perhaps be due to a greater supply of organic matter in the water.

SUBSURFACE LAYERS

The organic content of the sediments does not show any consistent decrease with depth of burial. In fact, as illustrated by table 30 and figures 25 to 27, the organic content is more or less constant throughout the length of the individual cores, except for core 3, in which it appears to diminish slightly with depth. These observations are not in accord with the common concept that the organic content of sediments decreases with the length of time the deposits have been buried. Loss of organic matter in the upper layers of sediments results mainly from decomposition caused by animals and microorganisms, which require a supply of oyxgen in order to live. The source of oxygen is the water overlying the sediments. The more the sediments become removed from the overlying water by burial, the less is the supply of oxygen in the deposits. The available oxygen is probably used up rather rapidly in the surface layers of the sediments and at an increasingly slower rate with increasing depth of burial. Consequently, most of the loss in organic content due to microorganisms and animals seems to take place in the upper few inches of the deposits; in fact, observations on a considerable number of core samples of Recent near-shore sediments from many parts of the world suggest that the average loss in organic content is about 15 percent in the upper 12 inches (30 centimeters) of the deposits[17]

The deep-sea sediments studied in this report, with the possible exception of core 3, were deposited so much more slowly than most near-shore sediments that in order to detect any decrease in organic content it probably would be necessary to analyze several samples from the upper few centimeters or millimeters of the deposits. As most of the samples considered in this report were taken at intervals of several centimeters, perhaps no detectable decrease in organic content should be expected. Moreover, the problem of loss in organic content with burial is complicated by the uncertainty as to how much organic matter was in the sediments at the time they were deposited. The different subsurface layers may have had different organic contents at time of deposition.

The sediments in core 3, as described below, probably accumulated at a more rapid rate than the others, and the apparent decrease in organic content may actually represent loss with burial. A decrease in organic content with depth in core 3, though suggested, is not certain, even granting that the organic content of all the layers of sediment was the same at time of deposition. The nitrogen content decreases from 0.051 percent in sample T–1, near the surface of the deposits, to 0.35 percent in sample T–5, about the middle of the core, below which it is more or less constant. The reduction number, on the other hand, varies irregularly between samples T–1 and T–5 and does not indicate a consistent decrease. Both the nitrogen content and reduction number are rough measures of the organic content, and one can take his choice as to which he thinks is the more significant. The nitrogen content, as mentioned above, is affected less by the inorganic constitutents and possibly is the more reliable.

Though the sediments do not seem to show any general change for depth of burial, the organic content of the sediments in cores 8 and 13, taken near the crests

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[15] Trask, P. D., op. cit., pp. 118–120.

[16] Trask, P. D., op. cit., pp. 83–95, 110–172.

[17] Trask, P. D., op. cit., pp. 205–208.

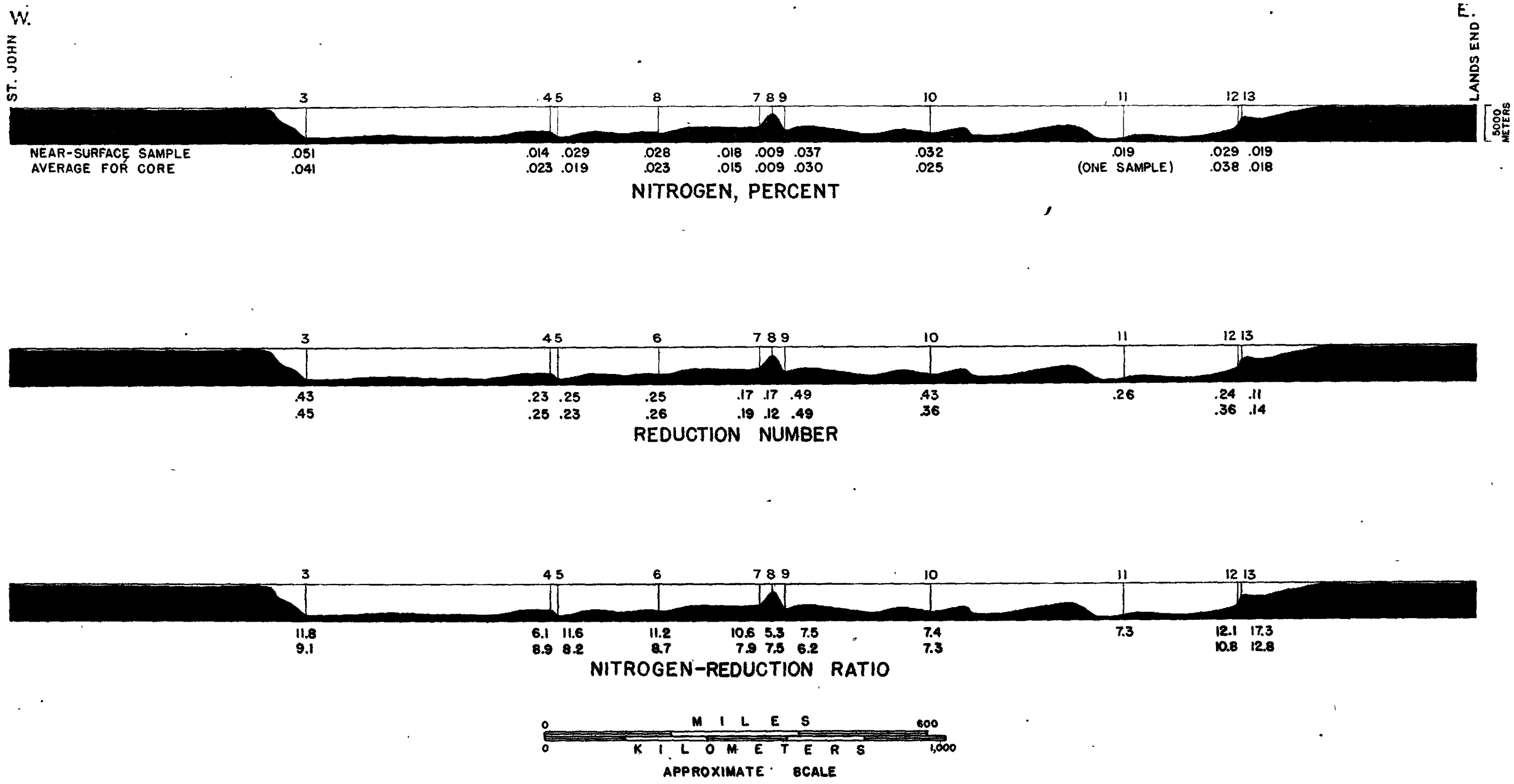

FIGURE 27.—Vertical profiles across the North Atlantic Ocean about latitude 49° N. between Grand Banks, Newfoundland, and Lands End, England, showing relation of submarine topography to nitrogen content, reduction number, and nitrogen-reduction ratio of sediments. Vertical lines represent position of cores, and the numbers above them indicate core numbers. In the first profile, the numbers immediately beneath the vertical lines representing the position of the cores indicate percentage of nitrogen in uppermost layers of the sediments, and the numbers beneath these numbers refer to average percentage of nitrogen in all the samples analyzed from the respective cores. In the second profile, the upper numbers refer to reduction number of the uppermost layers, and lower numbers refer to the average reduction number of all the samples studied in the respective cores. In the third profile, the upper numbers refer to the nitrogen-reduction ratio of the uppermost layers and the lower numbers refer to the average nitrogen-reduction ratio of all the samples studied in the respective cores.

of ridges, is consistently lower throughout the cores than it is in adjacent cores taken in deeper water. The older sediments in the cores, therefore, seem to have the same relationship to the submarine configuration as do the sediments near the surface of the deposits. Accordingly, it appears as if the mid-Atlantic ridge and the ridge west of Lands End, England, have been in existence during the deposition of the sediments, which, according to Bramlette and Bradley (see pt. 1 of this professional paper, pp. 10, 11), probably represents a considerable part of Quaternary time.

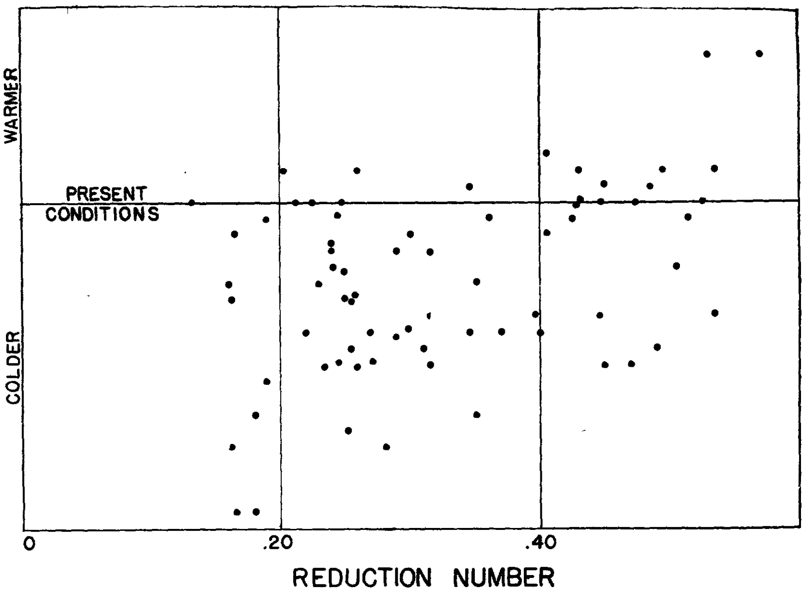

FIGURE 28.—Relation of reduction number of sediments to temperature of surface water as indicated by the pelagic Foraminifera in the sediments. The grades of temperature that form the ordinates of the figure represent relative deviations from the temperature of the surface water at the present time, as indicated by the type of Foraminifera in the sediments. These grades are based on data given by Cushman and Henbest (see pt. 2 of this professional paper, figs. 11-21).

TEMPERATURE

Although depth of burial does not seem to affect the organic content of the sediments appreciably, the different temperature zones apparently do have a slight effect. The average reduction number of the five warm and four cold zones encountered in the cores is given in table 31. The average (mean) of the five warm zones is 0.28 and of the five cold zones 0.25. As some of the temperature zones are not represented in the cores the means of the individual zones in cores 4, 5, 6, and 7, which penetrated all nine zones, were also determined. The average of the warm zones on this basis is 0.25 and of the cold zones 0.22. A compilation of the nitrogen content shows similar results.

This difference is hardly great enough to be distinctive, but it suggests a slight tendency for higher organic content under warm conditions. In order to test this possible relationship in another way, the reduction number was plotted against the temperature of the surface water as indicated by the pelagic Foraminifera found in the samples.

The results of this compilation are shown in figure 28 and indicate that the organic content, as indicated by the reduction number, seems to increase as the temperature of the surface water increases. The scatter of data on the chart, however, is great and the relationship at best is slight.

The relationship perhaps is contrary to what some might expect, because decomposition of organic matter is likely to progress at a more rapid rate in relatively warm water than in relatively cold water. Consequently less organic matter might be deposited in warm zones than in cold zones. However, even though the actual amount of organic matter deposited in a given unit of time may be less in the warm zones, the amount of inorganic material laid down in the cold zones may be so much greater than that deposited in the warm zones that the proportion of organic matter deposited in the cold zones may be less than what accumulates in the warm zones. The cold zones discussed in this paper contain relatively large amounts of material that seem to be of glacial or ice-raft origin. Consequently, the supply of inorganic debris during the

TABLE 31.—*Average reduction number of warm cold zones*

	Core number									Mean	Median	Mean 4–7
	4	5	6	7	8	9	10	12	13			
1st warm zone	0. 24	0. 25	0. 25	0. 19	0. 17	0. 51	0. 45	0. 37	0. 11	0. 28	0. 25	0. 23
1st cold zone	. 24	. 22	. 32	. 24	. 10	. 43	. 28	. 43	. 18	. 27	. 24	. 26
2d warm zone	. 22	. 25	. 32	. 21	. 11	-------	. 37	. 30	. 17	. 24	. 24	. 25
2d cold zone	. 16	. 16	. 17	. 16	-------	-------	-------	-------	. 14	. 16	. 16	. 16
3d warm zone	. 24	. 26	. 28	. 23	. 11	-------	-------	-------	. 13	. 21	. 24	. 25
3d cold zone	. 17	. 17	. 18	. 13	. 12	-------	-------	-------	. 12	. 15	. 15	. 16
4th warm zone	. 34	. 25	. 34	. 18	. 11	-------	-------	-------	. 14	. 23	. 17	. 28
4th cold zone	. 40	. 26	. 26	. 28	. 15	-------	-------	-------	-------	. 27	. 26	. 30
5th warm zone	. 24	. 23	. 22	. 17	. 07	-------	-------	-------	-------	. 19	. 22	. 22
Median warm	. 24	. 25	. 28	. 19	. 11	. 51	. 41	. 34	. 14	. 27	. 24	. 24
Median cold	. 21	. 20	. 22	. 20	. 12	. 43	. 28	. 43	. 14	. 25	. 21	. 21
Mean warm	. 26	. 25	. 28	. 20	. 11	. 51	. 41	. 34	. 14	. 28	. 26	. 25
Mean cold	. 24	. 20	. 23	. 21	. 12	. 43	. 28	. 43	. 15	. 25	. 23	. 22

deposition of the sediments in the cold zones should be much greater than during the formation of the warm zones, especially as the sediments are so far from land. The apparently slightly greater organic content of the warm zones may possibly be due to such a cause. The sediments of the cold zones, moreover, are coarser than those in the warm zones and therefore may contain less organic matter, owing to the prevalence of conditions that favored the deposition of relatively coarse sediments. In fact, the organic content of all the sediments considered in this report seems to be related to the texture.

TEXTURE

The relation of the organic content to the texture of the sediments is illustrated by figure 29. In this figure the reduction number has been plotted against the percentage of material in the sediment finer than 74 microns, which corresponds roughly to the silt and clay content. This method of representing the texture is crude, but in general the greater the percentage of silt and clay in a sediment the finer is the texture. The data as plotted in this way exhibit a very definite increase in organic content as the percentage of clay and silt increases. The general trend is indicated by the heavy line through the samples. The scatter of the points on each side of this line is considerable, but the relationship of organic matter to texture is obvious.

The relationship between the texture and organic content probably is not one of cause and effect. Instead, they both seem to vary with respect to some third factor, which presumably is the movement of water in which the sediments are deposited. If currents are relatively strong, little organic matter and few fine particles can accumulate, and if currents are weak, the content of organic matter and fine particles is apt to be high. In order to ascertain from the organic content what the relative supply of organic matter in the overlying water was at the time the sediments were deposited, it is, therefore, necessary to have a means of comparing the organic content of sediments of the same texture; that is, to have some way of ascertaining whether the sediments of any given texture, such as silts or clays, contain more or less organic matter than other sediments of the same texture. In this way, the effect of the motion of the water on the deposition of the organic matter is largely counterbalanced.

In near-shore sediments, this organic content relative to the fineness of the sediments has been determined by dividing the reduction number by a factor for the texture,[18] but the large percentage of calcium carbonate in these deep-sea deposits and the lack of adequate data on the texture complicate the application of such a factor to them. It seems more practicable to calculate the reduction number upon a carbonate- and sand-free basis. The estimate of the organic content as calculated in this way can conveniently be designated as the "comparative organic content," because it is a measure of the organic content compared with the percentage of fine-grained constituents in sediments that are deposited under conditions similar to those for organic matter.

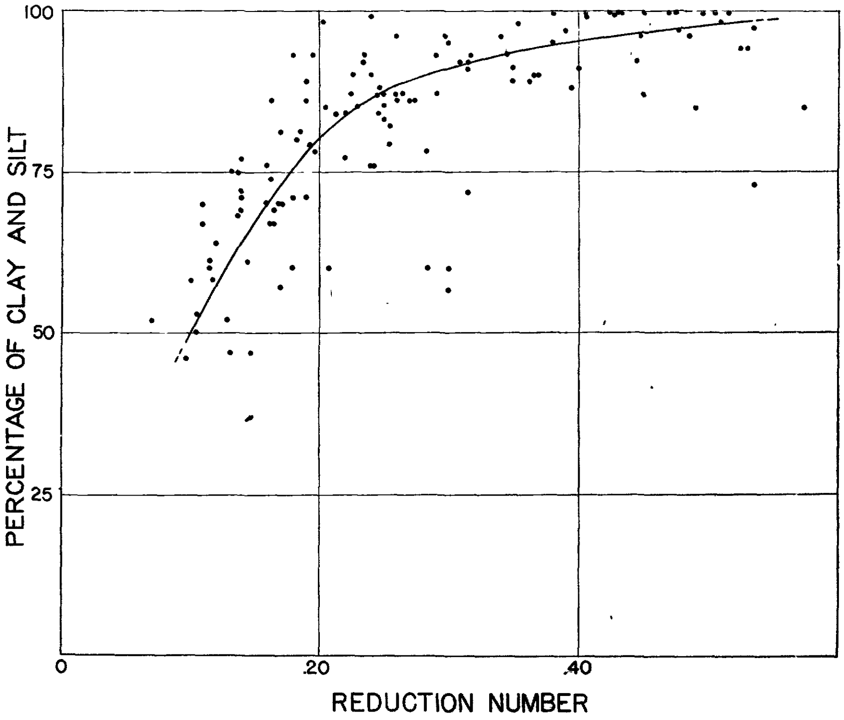

FIGURE 29.—Relation of reduction number to texture of sediments. The texture is represented by the percentage of silt and clay in the sample. The data on the silt and clay content of the sediments are taken from Bramlette and Bradley (see pt. 1 of this professional paper, pl. 3).

To illustrate the method of calculation on this basis, take a sample in which the reduction number is 0.3, the carbonate content is 50 percent, and the percentage of sand is 10 percent. The percentage of noncalcareous fine-grained constituents would therefore be 100—(50+10), or 40 percent, and the reduction number divided by this fine fraction would be 0.3/0.4, or 0.75.

COMPARATIVE ORGANIC CONTENT

The comparative organic content of the sediments in the nine temperature zones, as calculated in this way, is given in table 32. The main features indicated by this table are the general uniformity in organic content throughout the areal extent of the individual zones, the general decrease downward from the surface to the second cold zone, and the greater content for

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[18] Trask, P. D., and Hammar, H. E., Organic content of sediments: Am. Petroleum Inst., Drilling and Production Practice, 1934, p. 120, 1935.

the warm zones compared with the cold zones. The effect of the ridges is largely eliminated. Nevertheless, the comparative organic content of core 9, just east of the mid-Atlantic ridge, as determined in this way, is distinctively greater than that of core 8, on the crest of the ridge. This greater comparative organic content of core 9 perhaps might be due to a greater production of organic matter in the overlying water but is probably due to enrichment from material swept off the ridge to the west.

The uppermost samples in cores 7, 8, and 9, in the vicinity of the mid-Atlantic ridge, have a relatively large comparative organic content. Though this may be due to a greater production of organic matter, it might also represent improper compensation for the texture. Core 11, in the eastern part of the basin, likewise has a relatively high content, which, coupled with the richness of core 9, suggests that the rate of production of organic matter is greater east of the mid-Atlantic ridge than west of it, but core 10, between cores 9 and 11, has a relatively low content. The coring device at this locality buried itself in the mud, and an unknown amount of the upper part of the core was lost. The sediments encountered, therefore, represent material some distance beneath the surface, and the lower content in the upper part of this core might possibly be due to a decrease in organic content while the sediments have been buried. On the other hand, according to Bramlette and Bradley (see pt. 1, pp. 32–34), the upper and lower parts of core 10 are anomalous and consist of a mixture of basaltic debris and clay, perhaps derived from a submarine volcanic vent. Furthermore, the comparative organic content is too indefinite a measure of the supply of organic matter in the overlying water to be considered very seriously. All that can be inferred is that the data for the uppermost zone suggest that the supply of organic matter in the eastern part of the Atlantic Ocean might be greater than in the western part.

TABLE 32.—*Comparative organic content of the sediments*

	Core number											
	3	4	5	6	7	8	9	10	11	12	13	Mean
1st warm zone	0. 86	0. 83	0. 63	0. 86	1. 10	1. 13	1. 35	0. 65	1. 30	0. 71	0. 31	0. 89
1st cold zone	-------	. 48	. 47	. 54	. 59	. 33	. 79	. 64	-------	. 65	. 33	. 52
2d warm zone	-------	. 39	. 46	. 49	. 39	. 42	-------	. 51	-------	. 57	. 53	. 47
2d cold zone	-------	. 32	. 33	. 30	. 36	-------	-------	-------	-------	-------	. 28	. 32
3d warm zone	-------	. 54	. 43	. 49	. 38	. 42	-------	-------	-------	-------	. 41	. 45
3d cold zone	-------	. 37	. 33	. 40	. 27	. 39	-------	-------	-------	-------	. 24	. 33
4th warm zone	-------	. 67	. 44	. 61	. 44	. 47	-------	-------	-------	-------	. 40	. 51
4th cold zone	-------	. 62	. 33	. 40	. 46	. 49	-------	-------	-------	-------	-------	. 46
5th warm zone	-------	. 44	. 93	. 57	. 65	. 20	-------	-------	-------	-------	-------	. 56
Mean of warm zones	. 86	. 57	. 58	. 60	. 59	. 53	1. 35	. 58	1. 30	. 64	. 41	. 57
Mean of cold zones	-------	. 45	. 37	. 41	. 42	. 40	. 79	. 64	-------	. 65	. 28	. 41

Similarly, it is hard to explain the decrease in comparative organic content from the surface downward through the first four temperature zones. This decrease may represent a smaller supply of organic matter at the time the deeper sediments were deposited; it may represent a loss of organic matter while these sediments are buried; it may be only an apparent decrease resulting from the method of compensating for the texture; or it may reflect the influence of the calcium carbonate content. The sediments in the cold zones contain less carbonate than those in the warm zones; consequently, as the calcium carbonate is not considered in the method of calculation, the organic content might be proportionately greater in samples that have a large carbonate content. However, if calcium carbonate is the cause, it is difficult to understand why the organic content should be less in the second warm zone than in the overlying first cold zone. Moreover, as shown below, the organic content does not seem to have any general relationship to the carbonate content.

The same difficulties arise in trying to account for the greater comparative organic content of the warm zones compared with the cold zones. The mean of the four cold zones is 0.41 and of all five warm zones is 0.57. If the first warm zone is not considered, the mean of the other four warm zones is 0.50. This slight difference between the warm and cold zones, considering the method of calculation, probably is not large enough to be distinctive, but it does suggest that the organic content when compensated for the texture is greater in the warm zones than in the cold zones. As mentioned above, the organic content of the entire sediment tends to show the same relationship to the temperature zones. Perhaps the supply of organic matter actually is greater during the deposition of the warm-zone sediments.

The most noteworthy thing about the comparative organic content, however, is the uniformity throughout the individual zones. The consistency, except for the upper zone, seems too striking to be accidental. The rate of sedimentation differs in different areas, yet the comparative organic content is essentially the same. Therefore, in order for the quantity of organic matter per unit of silt and clay to be the same for sediments deposited at different rates, either the supply of organic matter must differ in different areas, or in places where deposition is slow the decomposition of organic matter must be somewhat greater.

RATE OF DEPOSITION OF ORGANIC MATTER

In order to ascertain the actual quantity of organic matter that was deposited in given units of time in different areas, the average quantity of organic matter in each zone in each core was multiplied by the number of cubic centimeters of sediment in each zone. The organic matter was calculated on the basis of the entire sediment, and the deepest zone penetrated in each core was neglected in the computations, as the thickness of that particular zone in each core is unknown. The results are presented in table 33. On the assumptions that the correlation of the zones is correct, that the averages indicate the proper organic content, and that the thickness of the zones represents the true thickness, the data represent relative measures of the quantity of organic matter that accumulated in each zone. However, as the length of time represented by the different zones is different, it is not possible to compare the rates of deposition of organic matter in one zone with that in other zones, unless the interval of time represented by each zone is known.

TABLE 33.—*Relative quantity of organic matter per zone, indicating relative rate of its deposition*

	Core number									
	3	4	5	6	7	8	9	10	12	13
1st warm zone	240	13	15	26	11	5	180	69	52	5
1st cold zone	----	25	14	28	12	0. 5	42	33	70	3
2d warm zone	----	16	39	22	13	1	----	88	64	16
2d cold zone	----	3	2	3	3	0. 2?	----	----	----	3
3d warm zone	----	14	10	18	11	4	----	----	----	11
3d cold zone	----	4	2	1	2	0. 4	----	----	----	11
4th warm zone	----	37	14	36	12	9	----	----	----	20
4th cold zone	----	18	7	4	3	5	----	----	----	----
Total of first seven zones	----	112	96	134	64	20	----	----	----	69

The data presented in table 33 indicate definitely that the rate of deposition of organic matter is greatest at the foot of the east slope of the ridges, as indicated by the first warm zone in cores 3 and 9. On the other hand, the rate is low on the ridges, as illustrated by cores 8 and 13. The organic content of sediments in the basins just east of the ridges, therefore, seems to be enriched at the expense of organic matter derived from the vicinity of the ridges. The rate of deposition of organic matter in the basin is greater for several hundred miles east of the mid-Atlantic ridge than for a similar distance west of it. According to table 33, the average for the first warm zone for cores 9, 10, and 12, east of the ridge, is 100 units, compared with 16 units for cores 4, 5, 6, and 7, west of the ridge. Even if the enrichment of organic matter in core 9 is discounted, the rate of accumulation is greater east of the ridge, as the average of cores 10 and 12 is 60, which is much greater than the average of cores 4 to 7, inclusive. Similarly, the rate of accumulation in the subsurface zones is greater east of the ridge than west of it.

This greater accumulation of organic matter east of the mid-Atlantic ridge could be caused by a greater supply of organic matter in the water, by a slower rate of decomposition, by a combination of these two factors, or by a smaller supply of inorganic detritus. The quantity of organic matter in the water is related to the supply of plankton. However, as adequate data on the plankton content of the water along this profile in the North Atlantic are not available, it is impossible to estimate the extent to which the rate of accumulation of organic matter in the sediments is affected by the supply of organic matter in the water. The rate of accumulation is so much greater east of the ridge than west of it that the greater content of organic matter in the individual zones probably cannot all be due to a slower rate of decomposition of the organic matter after it reaches the sediments. The nitrogen-reduction ratio of the deposits, which is discussed below, tends to be lower east of the ridge and, therefore, suggests a higher state of reduction of the sediments. If the sediments are more reduced, the rate of decomposition probably would be slower,[19] but whether or not it is sufficiently slow east of the ridge to account for the greater preservation of organic matter in the sediments is problematical. It seems probable that the greater rate to the east is partly due to a greater supply of plankton. Future oceanographic investigations will determine whether this is so or not.

NITROGEN-REDUCTION RATIO

The nitrogen-reduction ratio suggests that the sediments east of the mid-Atlantic ridge are more reduced than those west of it. As mentioned above, this ratio is a rough measure of the state of reduction or oxidation of the organic compounds. The results of the determination of the ratio are given in table 30 and in figure 27. As illustrated by figure 27, the nitrogen-reduction ratio of the uppermost samples in the cores near the surface of deposits in general is lower east of the mid-Atlantic ridge than west of it. This lower ratio on the east side suggests a greater degree of reduction. The ratio, however, is low in core 6, west of the ridge, and is high in cores 12 and 13, near the east end of the profile on the continental slope; consequently the relationship is not entirely definite. As indicated by table 30, the ratio in the abyssal deeps in general also tends to be lower east of the ridge in the individual stratigraphic or temperature zones. The state of reduction of the sediments, therefore, may have been

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[19] Trask, P. D., Inferences about the origin of oil as indicated by the composition of the organic constituents of sediments: U. S. Geol. Survey Prof. Paper 186–H, pp. 148–149, 1937.

greater east of the ridge during and since the later part of the Pleistocene.

This apparently greater state of reduction of the sediments east of the ridge could be caused by a lower degree of saturation of the deep water with oxygen. Data on the oxygen content of the water along this profile across the North Atlantic, however, are not available, but by analogy with determinations from other areas in the North Atlantic it seems probable that the oxygen content of the deep water east of the ridge is lower than that west of the ridge along this profile.[20]

The nitrogen-reduction ratio indicates few other relationships. It seems to be slightly larger in the uppermost sample in the individual cores than in the samples just below, which suggests an increase in degree of reduction a short distance beneath the surface of the deposits. The ratio does not seem to have any relationship to the warm and cold zones.

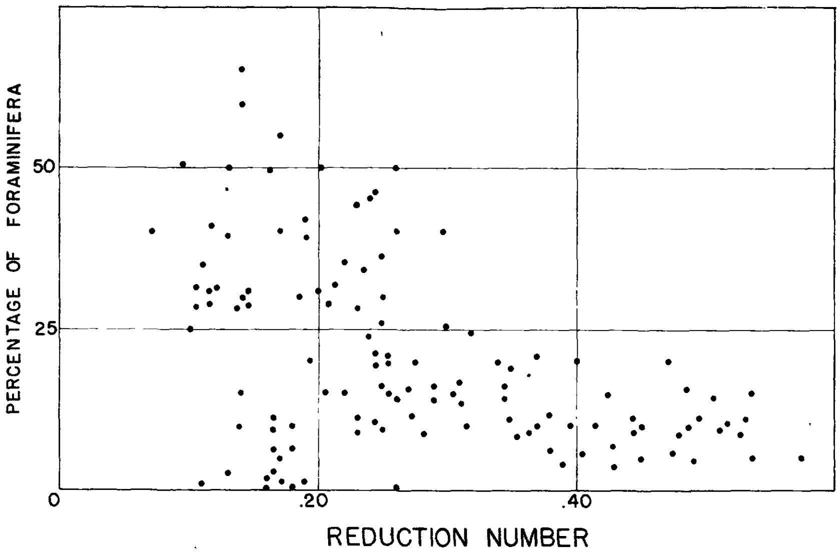

FIGURE 30.—Relation of reduction number to percentage of Foraminifera in sediments. Percentage of Foraminifera is based on data given by Bramlette and Bradley (see pt. 1 of this professional paper, pl. 3).

The sediments in core 13, on the ridge near the east end of the profile, have a relatively high ratio, and according to Bramlette and Bradley (see pt. 1, p. 15), the sediments are stained with iron oxide, which suggests oxidizing conditions. The sediments on the mid-Atlantic ridge likewise are stained with iron oxide, but the nitrogen-reduction ratio is low. The rusty color of the sediments seems a more reliable measure of the state of oxidation than the nitrogen-reduction ratio. Consequently, the low ratio of the sediments on the mid-Atlantic ridge is probably due to some cause other than the state of oxidation of the sediment, such as a relatively low percentage of nitrogen in the organic matter. The position of the sediments on a comparatively exposed place on the top of this ridge might be a favorable environment for the decomposition of the nitrogen compounds, but if so, then one would expect a similar decomposition at the site of core 13. The relations of the nitrogen-reduction ratio in cores 8 and 13 at best seem anomalous.

FORAMINIFERA

In order to ascertain whether or not the organic content might be related to the quantity of Foraminifera in the sediments, the reduction number of each sample was plotted against the percentage of Foraminifera in the samples. The results are indicated in figure 30. This figure indicates that the sediments having the greatest organic content contain the fewest Foraminifera. However, for any given percentage of Foraminifera the organic content varies widely. In all probability therefore, the organic content is not derived mainly from the Foraminifera. The inverse relationship to the Foraminifera presumably is caused largely by the relatively great bulk per unit of weight of the Foraminifera shells in the sediments. If sediments are composed largely of remains of Foraminifera, they contain relatively few fine ingredients, with which the organic matter generally is associated, but if they contain a small percentage of Foraminifera the proportion of fine ingredients is high, with the result that the organic content likewise should be comparatively high. However, even when the organic matter is compensated for the effect of Foraminifera, a uniform organic content is not obtained. For example, the average (median) reduction number of samples containing from 10 to 15 percent Foraminifera is 0.38. If none of the organic matter is assumed to be in the foraminiferal shells, then this 0.38 unit occurs in the nonforaminiferal constituents, or in 88 percent of the sediment. That is, these nonforaminiferal substances have a reduction number of 0.38/0.88 or 0.43 unit. Similarly, the average (median) reduction number of the nonforaminiferal constituents in the sediments that contain between 40 and 45 percent Foraminifera is 0.16/0.58, or 0.28 unit. Thus, even after the effect of the Foraminifera shells has been discounted, the organic content of the sediments is greater for sediments that contain few Foraminifera than it is for those that contain many, provided, of course, the two examples that were chosen indicate the general trend. This line of reasoning, too, suggests even more strongly than was indicated above that the organic content of the sediments is not related to the percentage of Foraminifera in the sediments, and hence presumably is not derived to any considerable extent from Foraminifera. However, Foraminifera tend to be plentiful in samples that contain the most sand. Consequently, the low organic

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[20] Wattenberg, H., Die Durchlüftung des Atlantischen Ozeans: Internat. Council exploration of the Sea Jour., vol. 4, No. 1, pp. 68-69, 1929.

content of those samples that are richest in Foraminifera perhaps may be due more to the physical conditions of sedimentation than to whether or not the organic matter is derived to a significant extent from Foraminifera.

The nitrogen content exhibits the same inverse relationship to the percentage of Foraminifera as does the reduction number. The nitrogen-reduction ratio, however, when similarly plotted, shows no relationship.

CALCIUM CARBONATE

The calcium carbonate content of the sediments does not seem to be related to the organic content or to the nitrogen-reduction ratio. The reduction number, when plotted against the calcium carbonate content of these sediments, gives a random distribution in which no definite trends are apparent. The nitrogen content and nitrogen-reduction ratio, when similarly plotted against the calcium carbonate, give equally random distributions. The inference follows that the organic content of the sediments is not related to the carbonate content.

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

PART 9. SELENIUM CONTENT AND CHEMICAL ANALYSES

By GLEN EDGINGTON and H. G. BYERS [1]

INTRODUCTION

For several years the Division of Soil Chemistry and Physics, formerly under the Bureau of Chemistry and Soils but now a part of the Bureau of Plant Industry, has been interested in analyses of profiles of soils and also in the origin and distribution of selenium in surface formations. For both these reasons the opportunity to examine chemically the sea-bottom cores, which were made available through the kindness of Dr. C. S. Piggot, was extremely welcome. These offer for the first time submarine profile samples for examination and comparison with samples of soil profiles, lacustrine deposits, and delta deposits. Though numerous samples of deep-sea deposits from various sources have been available, there is a singular absence of complete fusion analyses. These are virtually limited to analyses of a composite of 51 samples of red clay and of 52 samples of terrigenous clays by G. Steiger.[2] These samples are partly collections from the *Challenger* expedition and partly from other expeditions. There are also analyses by Brazier and by Hornung [3] of the acid-soluble and acid-insoluble portions of a considerable number of individual sediments; also 14 analyses by Caspari.[4] These may be combined to give the composition of the sediment as a whole.

Many partial analyses of samples of ocean sediments are available from various sources, such as those by Fairchild on samples from Pago Pago Harbor [5] and from the Gulf of Maine.[6] In addition, Twenhofel [7] has summarized numerous analyses of surface material, such as glacial, lacustrine, and delta deposits.

A great number of analyses of sedimentary deposits, which are now, or may become, parent material for soils, are also available.[8]

The analyses presented herewith include not only 20 samples selected by Dr. C. S. Piggot from the North Atlantic cores but also 3 samples from a core taken off Ocean City, Md., and 8 samples from 3 cores taken in the Bartlett Deep, in the Caribbean Sea. These additional samples offer some interesting relationships with those from the North Atlantic.

ANALYTICAL PROCEDURE

Our primary purpose in making these analyses was for comparison with soil and shale analyses. These comparisons will be more fully discussed elsewhere when more cores have been examined and especially when colloid data are available.

The cores from the sea bottom were prepared for analysis in accordance with the methods used by the United States Department of Agriculture in analyzing soils.[9] More extensive descriptions of the fundamental methods have been given by Hillebrand and Lundell.[10]

The dried salts from sea water were not removed from the samples before analysis. If these had been removed by leaching, the results would have more closely simulated the actual composition of the sediments. However, such leaching, especially if extended, may remove some material that should properly be regarded as a part of the sediment. The results as obtained are a combination of the actual insoluble material and the amount of sea-water salts held by the sediment on drying. The amount of salts held by the sediments varies of course with the size of the particles and perhaps with the composition of the material.

The chlorine determinations represent the total chlorine in the sample. Analyses were made on 10 ignited saline samples to determine to what extent

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[1] Glen Edgington, assistant chemist, and H. G. Byers, principal chemist, Division of Soil Chemistry and Physics, Bureau of Plant Industry.

[2] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 518, 1924.

[3] Murray, John, and Renard, A. F., *Challenger* Rept., Deep sea deposits, pp. 425-451, 1891.

[4] Caspari, W. A., Composition and character of oceanic red clay: Royal Soc. Edinburgh Proc., vol. 30, pp. 183-201, 1910.

[5] Bramlette, M. N., Some marine bottom samples from Pago Pago harbor, Samoa: Papers Dept. Marine Biol., Carnegie Inst. Washington, vol. 23, pp. 9-23, 1926.

[6] Wells, R. C., Analyses of rocks and minerals: U. S. Geol. Survey Bull. 878, p. 67, 1936.

[7] Twenhofel, W. H., Treatise on sedimentation, 2d. ed., pp. 3-32, 247-276, Williams and Wilkins, 1932.

[8] Clarke, F. W., op. cit., pp. 543-593.

[9] Robinson, W. O., Method and procedure of soil analysis used in the Division of Soil Chemistry and Physics: U. S. Dept. Agr. Circ. 139, pp. 1-20, 1930.

[10] Hillebrand, W. F., The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 700, pp. 1-285, 1919. Hillebrand, W. F., and Lundell, G. E. F., Applied inorganic analysis, with special reference to the analysis of metals, minerals, and rocks, pp. 645-849, New York, John Wiley and Sons, 1929.

the chlorine was lost by ignition. The results are given in table 34.

TABLE 34.—*Chlorine content of dry sample and chlorine lost by ignition*

Sample number	Chlorine in oven-dry sample (percent)	Chlorine in ignited sample (percent)
B22595	1. 55	0. 11
B22596	1. 84	. 26
C3938	1. 03	. 11
C3939	1. 03	. 09
C3940	1. 06	. 23
C3941	1. 26	. 25
C3942	1. 26	. 11
C3943	1. 42	. 23
C3944	1. 22	. 10
C3945	1. 11	. 24

It is evident that not all the chlorine was volatilized by heating to a constant weight at about 900° C. In determining the loss on ignition, some of the samples came to a constant weight by heating for 1 hour, whereas others required as much as 3 hours. Unfortunately, chlorine determinations were not made on all the samples analyzed.

The percentage of constituents is reported on the oven-dry basis. The inorganic constituents plus the ignition loss should equal very nearly 100 percent. The ignition loss includes constituents otherwise reported, such as nitrogen, carbon dioxide, organic matter, chlorine, and combined water.

ANALYTICAL RESULTS

All the analytical data obtained on the 31 samples examined are assembled in table 35. They include, in addition to the normal analytical data obtained in a so-called complete soil analysis by the fusion method, organic matter, nitrogen, chlorine, hygroscopic water, and selenium. No attempt has been made to determine the quantities of minor elements probably present in the material.

TABLE 35.—*Chemical analyses of samples from sea-bottom cores*[1]

[Composition expressed in percent, except for selenium, which is expressed in parts per million]

Field number	Laboratory number	Distance below top of core (centimeters)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Ignition loss	Total	Nitrogen	Carbon dioxide	Organic matter	Chlorine, oven-dry sample	Water at 105°-110° F.	Selenium
Ocean floor off Ocean City, Md.																					
1	B20610	Top	61.12	0.61	9.62	3.22	0.05	7.29	1.63	1.88	2.34	0.13	1.00	10.86	99.75	Not run	5.50	0.56	----------	1.50	0.6
2	B20611	100	58.45	.65	10.26	3.74	.06	7.46	1.88	2.07	2.29	.16	1.52	11.57	100.11	Not run	5.60	.92	----------	1.67	1.0
3	B20612	200	57.51	.70	9.72	3.74	.06	8.53	1.86	1.96	2.17	.18	1.75	11.88	100.06	Not run	6.47	.20	----------	1.67	2.0
Ocean floor of North Atlantic between Newfoundland and Ireland																					
3-A7[2]	B20639	Top	32.40	0.50	8.30	3.61	0.13	23.89	2.82	1.51	3.20	0.07	0.43	23.27	100.13	0.06	18.40	1.07	----------	1.62	0.15
3-A8	B20640	100	32.72	.48	7.90	3.58	.12	24.11	2.81	1.48	2.99	.11	.51	23.09	99.90	.06	18.73	.89	----------	1.45	.6
3-A9	B20641	200	36.62	.57	9.42	4.17	.15	20.51	3.34	1.64	3.00	.12	.42	19.66	99.62	.04	16.42	.73	----------	1.38	.6
4-A20	B22598	Top	32.65	.54	8.57	3.98	.14	25.04	2.74	1.54	2.07	.15	.31	22.52	100.25	.03	19.42	.17	1.50	1.51	<.1
5-A19	B22597	Top	29.52	.46	7.53	3.26	.12	28.04	2.28	1.37	2.07	.08	.23	25.19	100.15	.03	21.63	.16	1.48	1.31	.1
5-A11	B22589	110	46.01	.57	11.53	4.57	.09	14.96	2.44	2.12	2.45	.13	.25	14.97	100.09	.04	11.37	.36	1.39	1.62	.1
5-A12	B22590	155	45.99	.43	9.73	3.37	.09	15.59	3.72	1.94	2.18	.12	.16	16.88	100.20	.02	13.66	.28	.78	.93	.1
6-A18	B22596	Top	19.44	.32	5.71	2.37	.15	35.62	1.74	.91	2.06	.06	.30	31.74	100.42	.03	27.52	.70	1.84	1.35	.1
7-A17	B22595	Top	18.05	.26	3.97	1.72	.10	39.13	1.30	.66	1.71	.05	.30	33.21	100.46	.02	30.14	.45	1.55	1.05	<.1
7-A10	B22588	260	36.04	.46	7.67	3.33	.10	24.41	2.08	1.42	1.85	.11	.29	22.30	100.06	.02	19.08	.21	1.35	1.48	.1
8-A16	B22594	Top	38.94	.56	6.04	2.68	.07	25.92	1.63	.98	1.36	.05	.18	21.75	100.16	.01	19.99	.25	.70	.79	.1
9-A15	B22593	Top	15.34	.20	3.65	2.05	.28	38.96	1.26	.63	2.39	.15	.42	35.14	100.47	.06	30.02	.90	2.56	1.88	.2
9-A13	B22591	135	34.28	.52	8.05	4.04	.09	22.96	2.38	1.58	2.85	.11	.61	23.00	100.47	.07	17.48	1.02	2.34	2.37	.8
10-A4	B20636	Top	42.29	1.35	13.08	8.72	.16	9.42	4.00	1.86	4.67	.19	.72	13.16	99.62	.03	5.86	.47	----------	3.75	.8
10-A5	B20637	100	42.55	.55	8.54	3.38	.11	18.32	3.30	1.81	2.28	.13	.33	18.33	99.63	.01	15.18	.42	----------	1.38	.06
10-A6	B20638	200	53.83	.90	13.28	5.89	.10	7.30	2.92	2.68	2.82	.12	.33	9.73	99.90	.02	6.14	.07	----------	2.35	.06
12-A14	B22592	Top	17.98	.27	5.24	2.02	.08	37.42	1.29	.98	1.24	.13	.28	33.28	100.21	.05	29.44	.66	1.30	1.08	.1
13-A1	B20633	Top	38.18	.45	7.23	2.88	.10	24.50	1.76	1.38	1.52	.12	.25	21.19	99.56	.02	19.52	.23	----------	1.14	.06
13-A2	B20634	100	35.47	.35	6.58	2.44	.05	27.14	1.49	1.20	1.57	.12	.26	22.90	99.57	.02	21.24	.27	----------	.92	.06
13-A3	B20635	200	42.87	.44	6.46	2.86	.04	22.72	1.39	1.21	1.44	.09	.26	20.08	99.86	.02	18.69	.00	----------	1.06	.15
Floor of Caribbean Sea at Bartlett Deep																					
135-A1	C3938	6-10	33.16	0.51	11.64	5.72	0.24	21.34	3.21	1.10	2.30	0.13	0.21	20.82	100.38	0.04	15.28	0.18	1.03	3.09	0.2
135-A2	C3939	100	38.21	.64	12.97	6.56	.23	16.78	3.48	1.24	2.48	.12	.19	17.79	100.69	.04	11.43	.57	1.03	3.69	<.08
136-A1	C3940	Top	15.83	.31	6.86	2.94	.20	37.09	1.60	.58	1.48	.11	.29	32.46	99.75	.05	28.02	.59	1.06	1.98	<.08
136-A2	C3941	100	23.99	.44	9.38	4.31	.29	29.20	2.00	.86	1.86	.09	.29	27.49	100.20	.04	21.71	.28	1.26	2.95	<.08
136-A3	C3942	190	21.92	.42	8.70	4.05	.25	30.94	2.11	.71	1.72	.09	.26	28.58	99.75	.03	23.34	.31	1.26	2.72	<.08
137-A1	C3943	Top	20.72	.37	7.98	3.91	.17	32.29	2.17	.71	1.93	.10	.29	29.40	100.04	.05	23.85	.74	1.42	2.33	<.08
137-A2	C3944	100	25.89	.43	10.31	4.95	.24	27.70	2.50	.89	1.69	.12	.25	25.60	100.57	.06	20.10	.35	1.22	3.68	<.08
137-A3	C3945	190	23.91	.42	9.13	4.44	.18	29.57	2.64	.82	1.65	.10	.22	27.02	100.10	.06	21.64	.31	1.11	3.49	<.08

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[1] The geographic location of each of the cores is listed below:

OCEAN CITY, MD.

1-3	37°26′ N., 74°28′ W.

NORTH ATLANTIC BETWEEN NEWFOUNDLAND AND IRELAND

3-A7 to 3-A9	46°03′ N., 43°23′ W.
4-A20	48°29′ N., 35°54′30″ W.
5-A19, 5-A11, 5-A12	48°38′ N., 36°01′ W.
6-A18	49°03′30″ N., 32°44′30″ W.
7-A17, 7-A10	49°32′ N., 29°21′ W.
8-A16	49°36′ N., 28°54′ W.
9-A15, 9-A13	49°40′ N., 28°29′ W.
10-A4 to 10-A6	49°45′ N., 23°30′30″ W.
12-A14	49°37′ N., 13°34′ W.
13-A1 to 13-A3	49°38′ N., 13°28′ W.

CARIBBEAN SEA

135-A1, 135-A2	19°18′ N., 76°48′ W.
136-A1 to 136-A3	18°38′ N., 79°12′ W.
137-A1 to 137-A3	19°14′ N., 80°20′ W.

[2] The numbers in this column to the left of the letter A are the numbers used in the preceding chapters of this report to designate the cores taken between Newfoundland and Ireland.

DISCUSSION OF ANALYSES

The data presented in table 35 show that all the elements normally sought in soil analysis are present in these sea-bottom deposits. This fact lends color to the assumption that they are formed in part from material derived from land. The material from such sources may have been brought to the ocean by water currents, by wind, or by floating ice. The extent to which the land affects the composition of the sediments should be expected to vary with the distance from shore lines, the rate and direction of ocean currents, and the amount of material transported by ice. That other sources of material also contribute to the sediments seems certain. Among these the most important are wind-blown volcanic dust, the residues of animal and plant life, including Foraminifera, diatoms, and other forms, and precipitated salts representing the reactions between the sea and the fresh-water soluble materials. From these sources come silica, silicates, and carbonates, but in unknown relative amounts. These relations are of special interest in soil studies, because enormous areas of soils are derived from similar sea-bottom deposits of former, though probably shallower, seas.

It may be noted that all the deposits analyzed contain carbonates in quantities ranging from the equivalent of 5.5 percent carbon dioxide up to 30.14 percent. If all the carbon dioxide is combined with calcium, these values correspond to a range of 12.5 to 68.4 percent of calcium carbonate. There seems to be no definite relation between these quantities and either depth or distance from shore lines. It seems possible that the quantities of carbonate may in part depend upon the abundance of living organisms in relation to sea-water temperatures. Of course, the greater the contribution of inorganic material from land or volcanic matter, the less the relative amount of carbonates.

The fact that the chlorine content of the cores varies so widely is an indication of considerable variation in the porosity of the materials as they exist in the sea bottom. It should be noted also that as these cores were analyzed just as received the analyses include the bases of the soluble sea-water salts within the solid cores. No consistent relationship exists with respect to variation of composition with depth or within the cores, and perhaps none should be expected.

Indeed, complete analyses of this type are difficult to compare directly with each other or with other analyses, and the difficulties are increased when analyses are made by different methods and the results calculated on different bases. It seems desirable therefore to use as a basis of comparison the silica-sesquioxide and silica-alumina ratios for obtaining information concerning the purely inorganic portion of the sediments, because the aluminum ferric iron silicate appears to be the most important component of most clays. It is true that by no means all the sediment in these cores is to be considered as clay, but all of it contains clay. Approximately two-thirds of the samples of *Challenger* sediments examined by Robinson and Fry[11] were found to be colloidal. No colloid analytical data are available for the sediments in these cores.

Nevertheless, considerable interest attaches to the calculation of these ratios, as by this means all other constituents and components are excluded from the comparisons sought. Marbut[12] has made extensive use of the silica-alumina and other ratios for whole soils, and extensive use of various ratios has been made in the study of soil colloids. Examples of such use are given by Byers, Alexander, and Holmes[13] and by Robinson and Holmes.[14] The ratios are obtained by dividing the percentage amounts found by analysis by the respective formula weights and then making the desired comparison between the quotients so obtained. In the analyses reported here the silica quotient is divided by the quotient for alumina for the silica-alumina ratio and for the silica-sesquioxide ratio by the sum of the quotients for the iron-oxide and alumina. If free silica and unweathered minerals were absent these ratios would indicate the types of clay present. However, free silica and unweathered minerals are present in these samples; yet despite their presence the ratios indicate roughly the relative abundance of clay minerals, for the smaller the ratios the larger are the relative quantities of inorganic silicates of the clay-mineral type.

Table 36 gives the silica-sesquioxide and silica-alumina ratios for the sediments reported in table 35 and in addition the ratios for three composites of silt, red clay, and terrigenous clays. These last are from analyses given in The Data of Geochemistry.

TABLE 36.—*Silica-sesquioxide and silica-alumina ratios of sediments*

Ocean floor off Ocean City, Md.

Field number	Depth (meters)	Silica-sesquioxide ratio	Silica-alumina ratio
1	338	8.85	10.77
2		7.81	9.65
3		8.04	10.03
Ocean floor of North Atlantic between Newfoundland and Ireland			
3-A7[1]	4,700	5.17	6.61
3-A8		5.47	7.02
3-A9		5.14	6.54
4-A20	3,955	5.00	6.45
5-A19	4,820	5.24	6.70
5-A11		5.34	6.77
5-A12		6.55	8.02
6-A18	4,125	4.55	5.81
7-A17	3,250	6.03	7.70
7-A10		6.23	7.95
8-A16	1,280	8.52	10.93
9-A15	3,745	5.23	7.13
9-A13		5.44	7.21
10-A4	4,190	3.83	5.48
10-A5		6.70	8.41
10-A6		5.34	6.86
12-A14	3,230	4.60	5.81
13-A1	1,955	7.12	8.94
13-A2		7.38	9.13
13-A3		8.75	11.24

[1] The numbers in this column to the left of the letter A are the numbers used in the preceding chapters of this report to designate the cores taken between Newfoundland and Ireland.

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[11] Wells, R. C., op. cit., p. 71.

[12] Marbut, C. F., Soils of the United States: U. S. Dept. Agr., Atlas Am. Agriculture, pt. 3, Advance sheet 8, 1935.

[13] Byers, H. G., Alexander, L. T., and Holmes, R. S., The composition and constitution of the colloids of certain of the great groups of soils: U. S. Dept. Agr. Tech. Bull. 484, pp. 1-39, 1935.

[14] Robinson, W. O., and Holmes, R. S., The chemical composition of soil colloids: U. S. Dept. Agr. Bull. 1311, pp. 1-42, 1924.

TABLE 36.—*Silica-sesquioxide and silica-alumina ratios of sediments*—Continued

Floor of Caribbean Sea at Bartlett Deep

Field number	Depth (meters)	Silica-sesquioxide ratio	Silica-alumina ratio
135-A1	4,900	3.66	4.83
135-A2		3.77	4.99
136-A1	4,635	3.07	3.91
136-A2		3.33	4.33
136-A3		3.28	4.27
137-A1	4,880	3.33	4.40
137-A2		3.25	4.25
137-A3		3.38	4.44

Silt from Mississippi Delta [2]

Number of samples	Silica-sesquioxide ratio	Silica-alumina ratio
Composite of 235 samples	9.29	11.26

Marine clays [3]

[Percentages of iron oxide are calculated as if ferric oxide]

Number of samples	Silica-sesquioxide ratio	Silica-alumina ratio
Red clay, composite of 51 samples	4.19	6.00
Terrigenous clays, composite of 52 samples	4.40	5.61

[2] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 509, 1924.

[3] Idem, p. 518.

Examination of the data in table 36 reveals several interesting relations. If we recall that these silica ratios include any silica which is present as sand and silt as well as that which is present as a part of the clay proper, it ought to be expected that deposits near the shore line would have higher silica ratios than do the pelagic samples. The highest samples in respect to these ratios are presented by the relatively shallow core taken off Ocean City, Md., field numbers 1, 2, and 3, and by the uppermost part of core 8, field number 8-A16, and core 13, field numbers 13-A1, 13-A2, and 13-A3, taken from the ocean floor of the North Atlantic. It may be readily believed that in the first core, shore-derived silica and silicate minerals cause the high ratios. In the second core, which was taken from the top of the mid-Atlantic ridge, it may be that submarine erosion removed the finer particles (lower in silica) from the tops of the submarine mountains. The variation in the silica ratios of the cores from the North Atlantic may be occasioned by variations in the quantities of volcanic ash deposited at different time intervals as a result of the eruptions of volcanoes, or possibly submarine volcanic eruptions of past time, or by deposition of varying quantities of glacial material rafted by icebergs. The high ratios of the core nearest Ireland (field numbers 13-A1, 13-A2, and 13-A3) may reflect the influence of the shore or the proximity to sources of volcanic material.

The most striking relations are shown by cores from Bartlett Deep. These show the same low ratios both for sesquioxides and alumina as are shown by tropical soils. This is the more striking when we recall that in the tropical soils probably most of the iron oxide exists in the free state, whereas that in soils from the higher latitudes is probably a part of the aluminum-ferric iron complex. The Bartlett Deep cores have much lower ratios than the mean values of the red clay and terrigenous clays calculated from the data in Clark's geochemistry, and the coast samples off Ocean City and Ireland approximate the ratios shown for the Mississippi Delta silts. (See table 36.)

It would seem that much information respecting the character and sources of deep-sea deposits could be gained by a study of the complete analyses, but it is desirable to await additional analyses before attempting further discussion of the present data.

SELENIUM

The ocean-bottom core samples listed in table 35 were analyzed for selenium, because other investigations had shown that although sea water does not contain selenium [15] the sediments from Bearing Sea do.[16] Also it seemed worth while to analyze the sediments from the sea floor for selenium, because they contain volcanic ash, and it had already been found [17] that the soils from Hawaii contain selenium, which was probably derived from volcanic material.

From these investigations also it seemed probable that the accumulations of selenium in certain of the marine Cretaceous shales of the Great Plains area and the relatively small quantity of selenium in other shales might be associated with the ejection of seleniferous emanations from particular volcanic sources at the time the sediments were laid down. It seemed probable that analyses of sea-bottom sediments from various parts of the oceans might throw some light upon this question. Samples from too few localities are as yet available for any general deductions, but the following facts appear. The deposits from Bering Sea that were examined contain selenium ranging from 0.25 to 0.7 part per million. The core off Ocean City (table 35) contains quantities ranging from 0.6 to 2 parts per million. The samples from the North Atlantic range from less than 0.1 to 0.8 part per million, and all the Bartlett Deep samples contain less than 0.08 part per million, except sample 135A1, which contains 0.2 part per million.

No evidence of a relation between volcanic activity and selenium accumulation can be drawn from these data, but it is still possible that a large number of samples from widely distributed localities may throw some light on the conditions requisite for the formation of shale containing about 100 parts per million of selenium which quantities have been found in Cretaceous shales.[18]

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[15] Byers, H. G., Miller, J. T., Williams, K. T., and Lakin, H. W., Selenium occurrence in certain soils in the United States, with a discussion of related topics, third report: U. S. Dept. Agr. Tech. Bull. 601, p. 49, 1938.

[16] Williams, K. T., and Byers, H. G., Selenium in deep sea deposits: Ind. and Eng. chemistry, news ed., vol. 13, p. 353, 1935.

[17] Byers, H. G., Williams, K. T., and Lakin, H. W., Selenium in Hawaii and its probable source in the United States: Ind. and Eng. Chemistry, vol. 28, pp. 821-823, 1936.

[18] Byers, H. G., Selenium occurrence in certain soils in the United States, with a discussion of related topics: U. S. Dept. Agr. Tech. Bull. 482, pp. 1-48, 1935.

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