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GEOLOGY AND BIOLOGY OF NORTH ATLANTIC DEEP-SEA CORES

PART 4. OSTRACODA

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

PART 4. OSTRACODA

BY

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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 considera-able 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

[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-

[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]

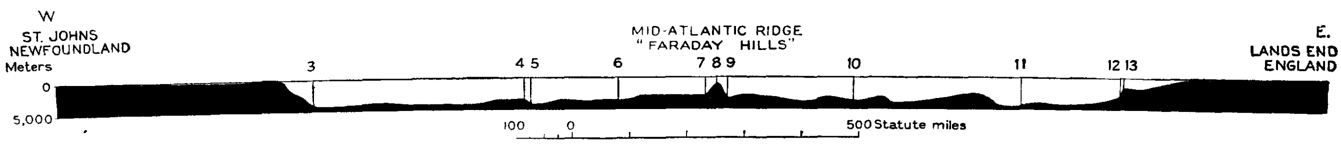


FIGURE 1.—Profile across the North Atlantic Ocean along the line of the numbered core stations shown on plate 1.

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.

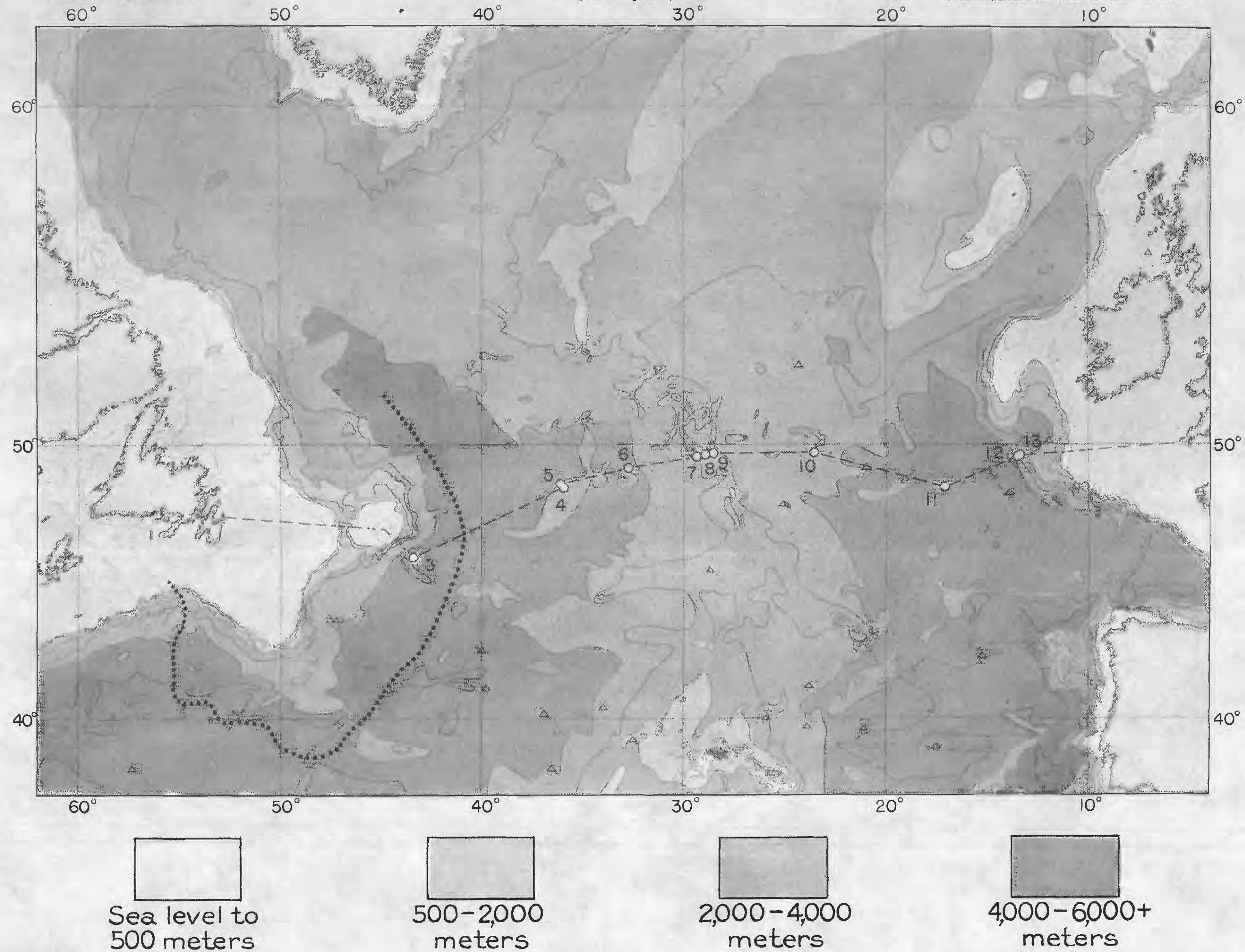
As part of a comprehensive research project on the distribution of selenium in marine sediments and the soils derived from them Dr. H. G. Byers and Mr. Glen Edgington, of the Bureau of Chemistry and Soils, United States Department of Agriculture, made complete chemical analyses of 20 samples from these 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.

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

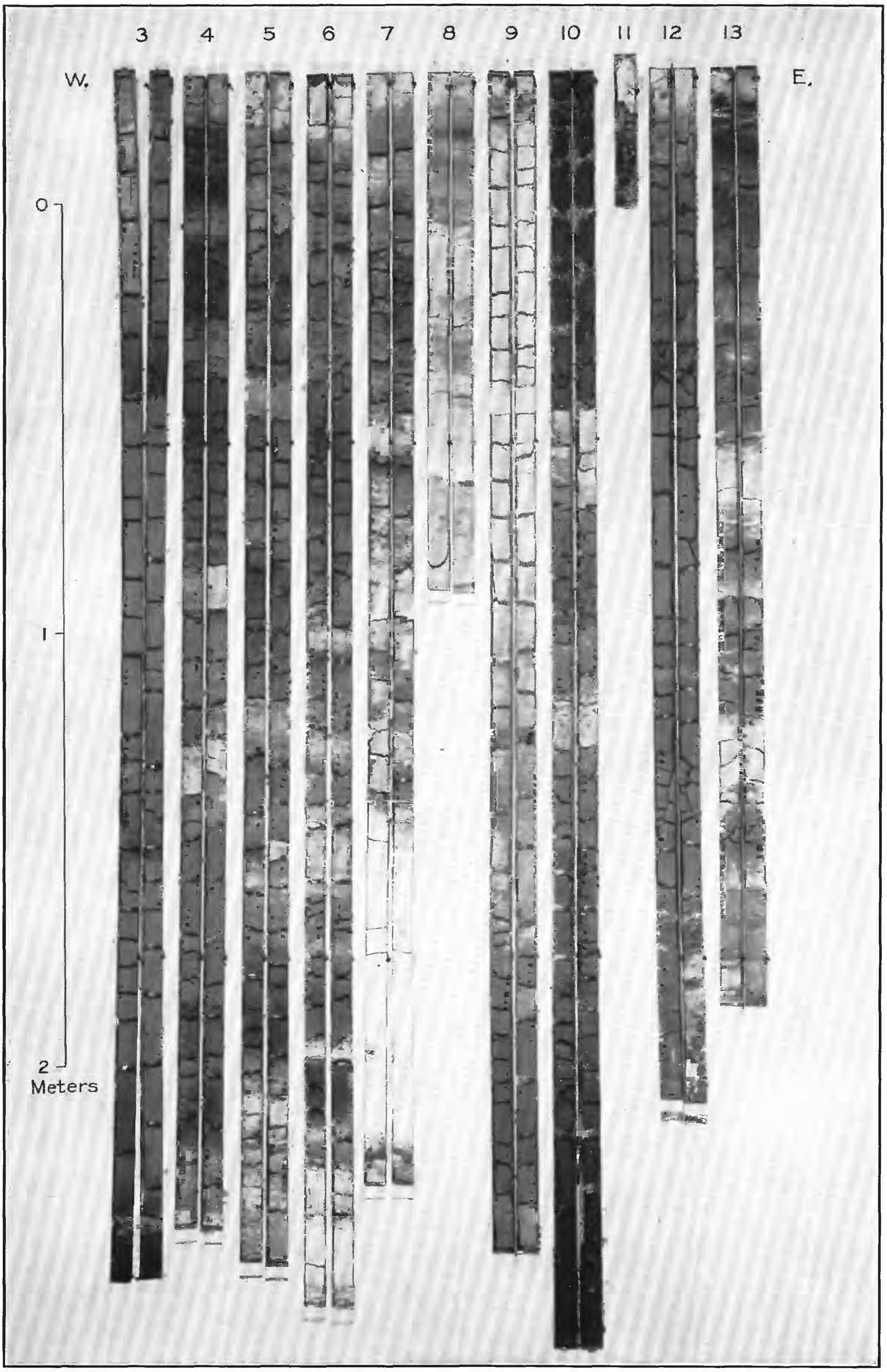
[12] Piggot, C. S., Apparatus to secure core samples from the ocean bottom: Geol. Soc. America Bull. vol. 47, pp. 675-684, 1936.



BATHYMETRIC CHART OF A PART OF THE NORTH ATLANTIC OCEAN.

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

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



LONGITUDINAL SECTIONS OF THE AIR-DRIED CORES.

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

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

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

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

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

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

PART 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

[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 fresh-water 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-

[5] Müller, G. W., Fauna und flora des Golfes von Neapel; Ostracoden: Zool. sta. Neapel, Mon. 21, pp. 173-387, 1894.

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.

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					
Sample, H-series	158	20	21	30	35	38	40	42	46	47	48	49a	54a	61a	62	64	68	69	71
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
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											●								
C. sp																			
Cytheropteron alatum	●											●						●	
C. hamatum																●			
C. inflatum																			
C. mucronalatum																			
C. (sp. a)					●									●					
C. (sp. b)																			●
Bythocythere constricta																●			●
Pseudocythere caudata														●	●	●	●	●	●
Paracytherois flexuosa														●				●	
P. producta																●		●	●
Paradoxstoma ensiforme																			●

Core	9	10	12											13												
Sample, H-series	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	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									●																	
C. sp														●												
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

[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.

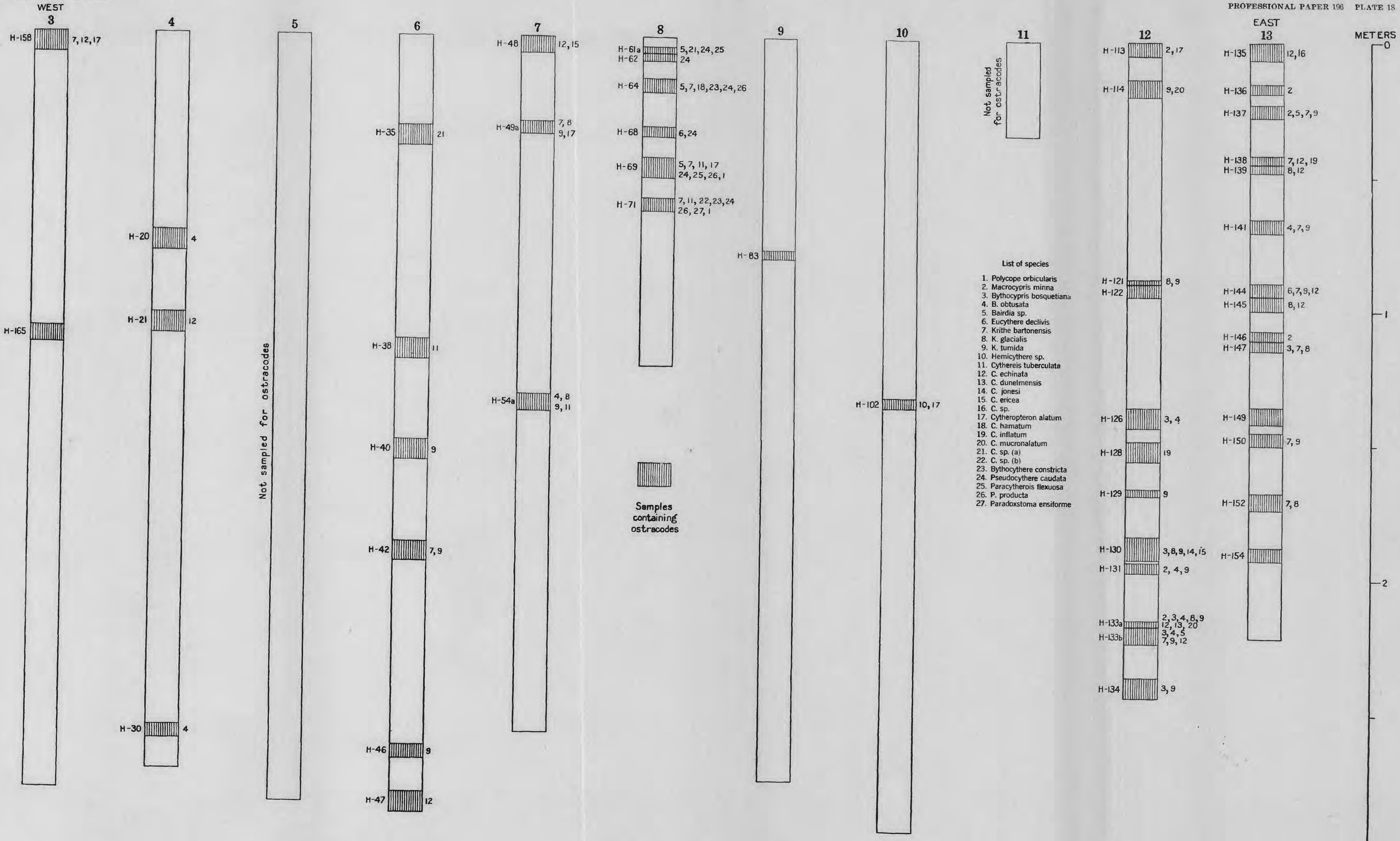


CHART SHOWING POSITION OF THE OSTRACODE-BEARING SAMPLES IN THE CORES AND THE DISTRIBUTION OF SPECIES.

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

[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 distributed 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 *Bythocythere*. 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

[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.

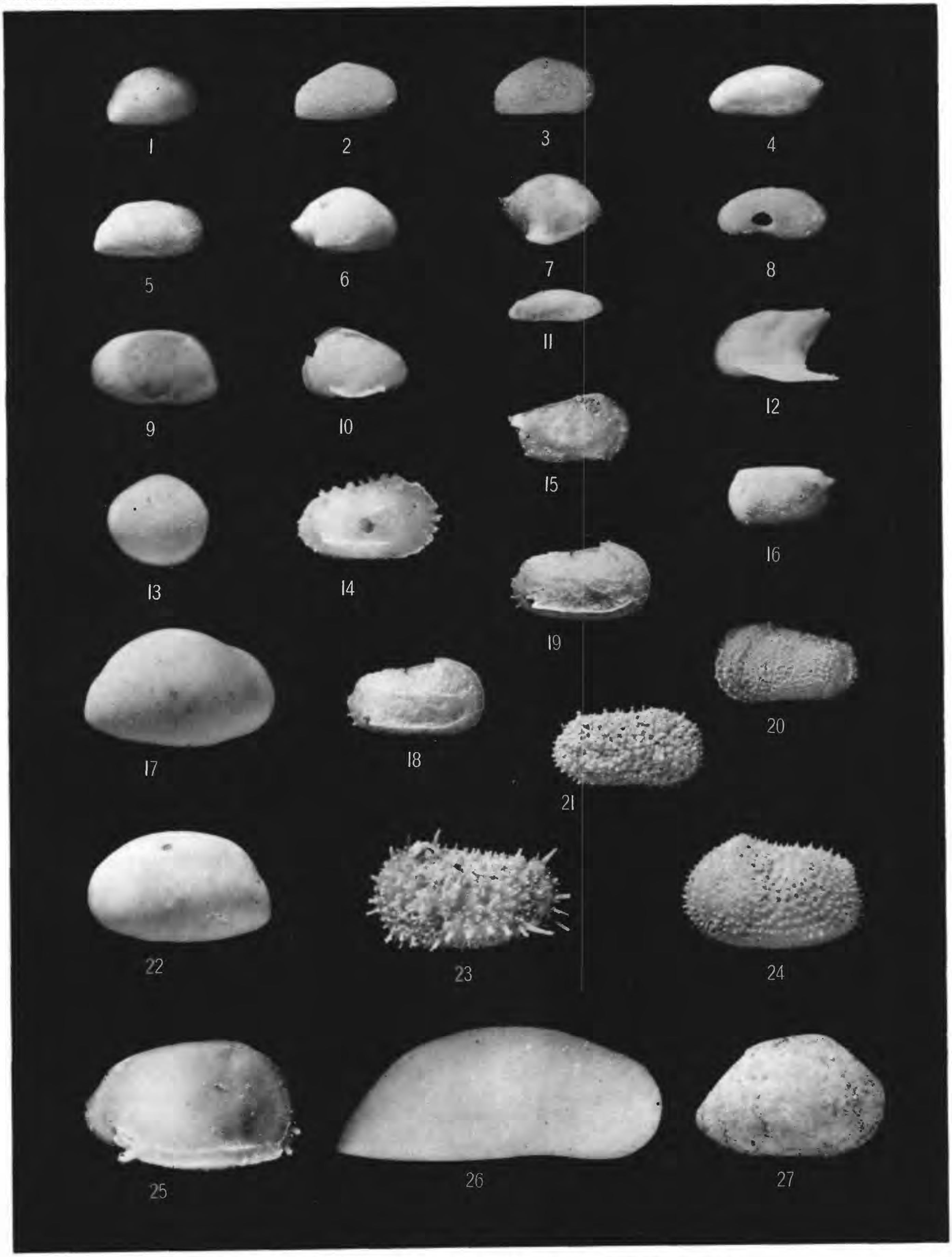
geologic interpretations) and by the pelagic Foraminifera. (See part 2, Foraminifera.) But the ostracodes in these cores are all bottom dwellers that lived 1,280 meters or more below the surface, and consequently there seems little reason to expect that they would be as sensitive to changes in surface-water 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.



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