UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY AND BIOLOGY OF NORTH ATLANTIC DEEP-SEA CORES

PART 8. ORGANIC MATTER CONTENT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 196-E

UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Professional Paper 196–E

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

PART 8. ORGANIC MATTER CONTENT

BY

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1942

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - Price 20 cents

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SUMMARY OF THE REPORT

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

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

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

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

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

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

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

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

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

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

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

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

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

The term globigerina ooze is used loosely in this report to designate sediment, half or more than half of which, by weight, consists of Foraminifera. This usage accords more closely with

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

FOREWORD

By C. S. Piggot [1]

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

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

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

[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]

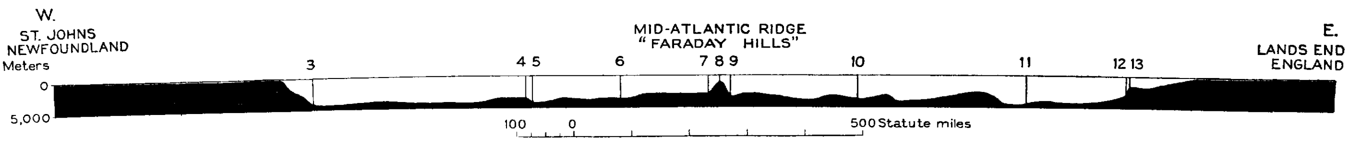


FIGURE 1.—Profile across the North Atlantic Ocean along the line of the numbered core stations shown on plate 1.

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.

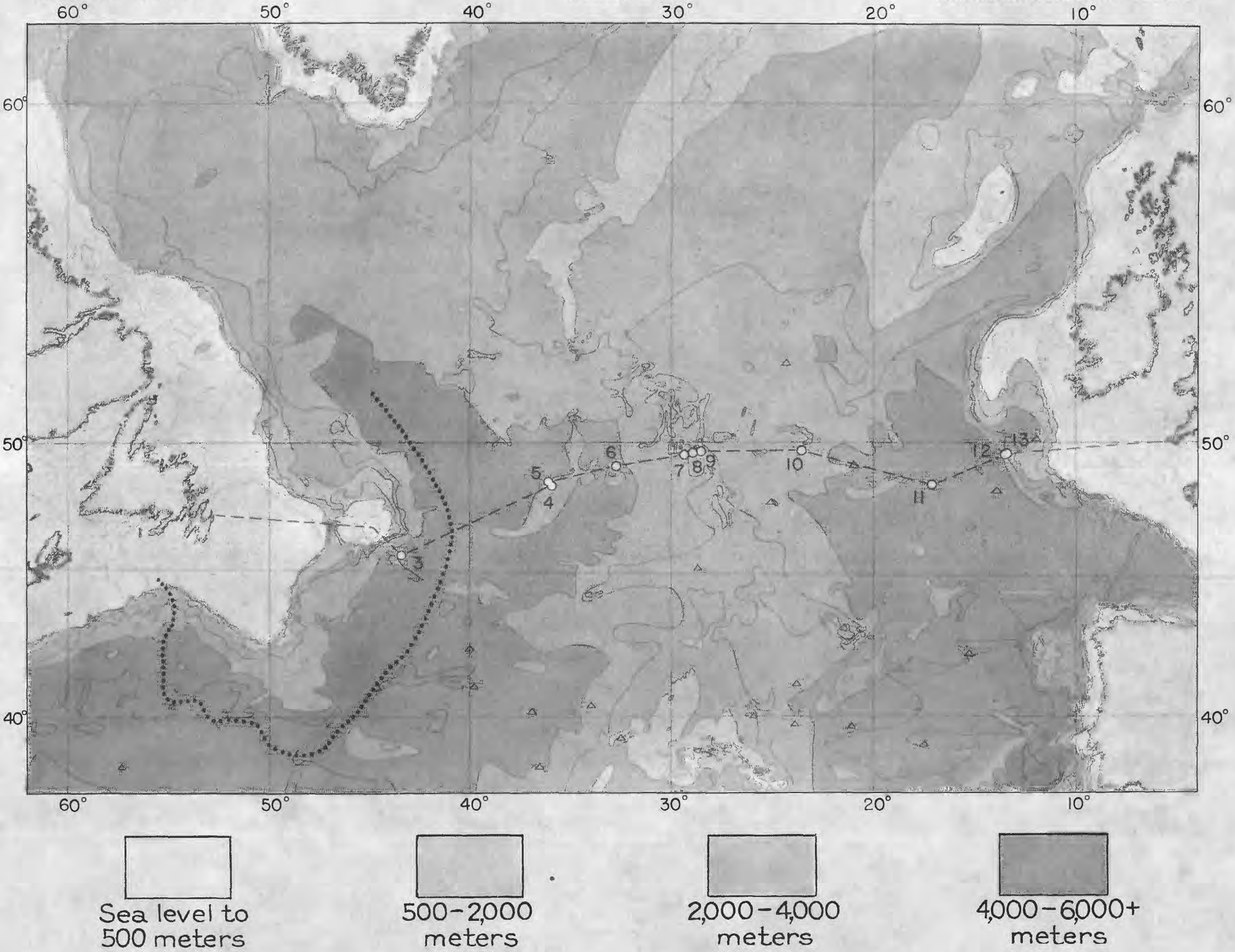
[12] Piggot, C. S., Apparatus to secure core samples from the ocean bottom: Geol. Soc. America Bull., vol., 47, pp. 675-684, 1936.

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.

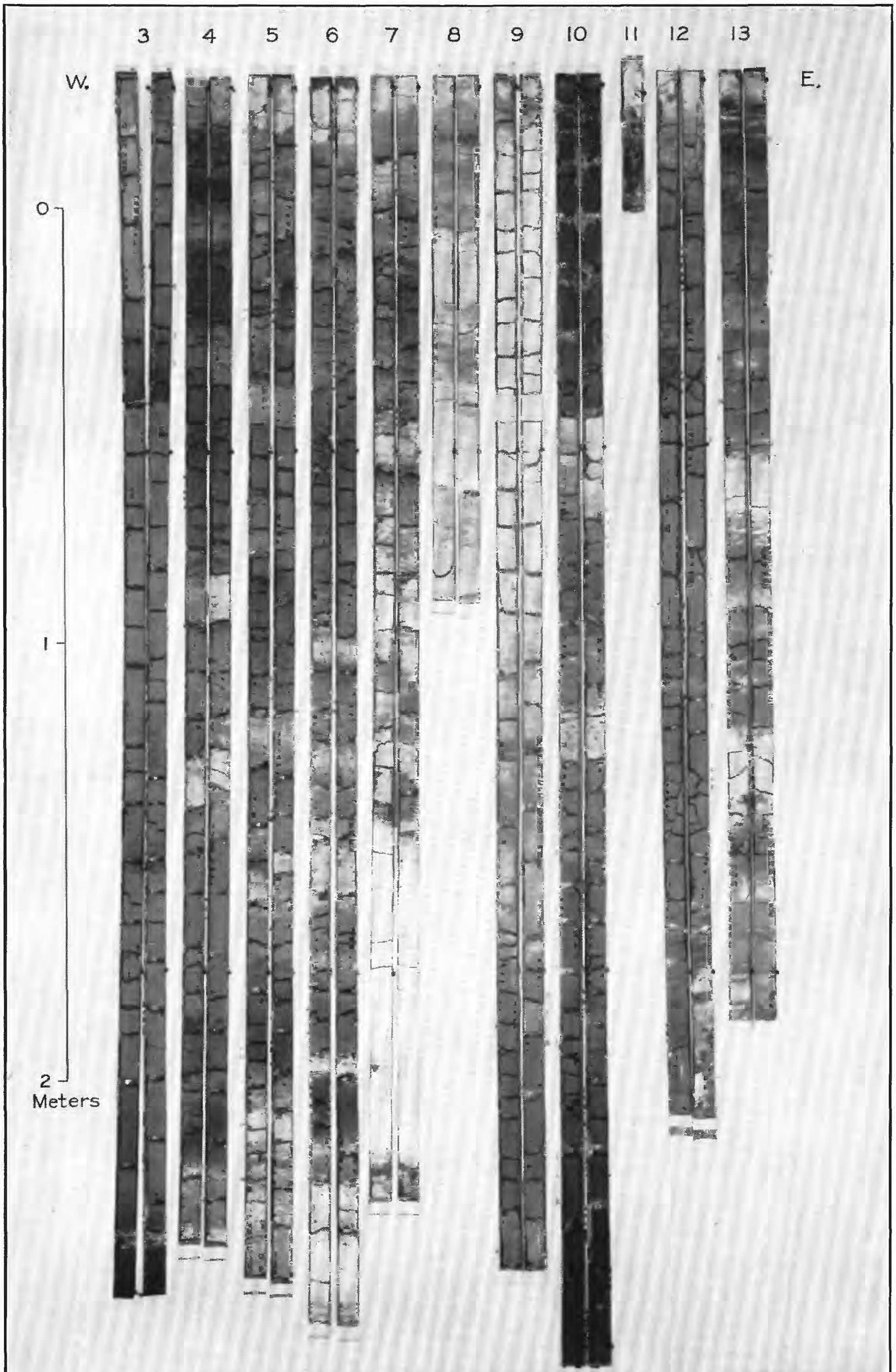
Samples for all phases of this investigation were taken from only one half of each core, the other half being held intact in the Geophysical Laboratory.



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.

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

PART 8. ORGANIC MATTER CONTENT

By P. D. TRASK, H. W. PATNODE, J. L. STIMSON, and J. R. GAY

INTRODUCTION

This report presents the results of a study of the organic constituents of samples of deep-sea sediments collected in 1936 in the North Atlantic Ocean by Dr. C. S. Piggot of the Geophysical Laboratory of the Carnegie Institution of Washington with his gun core sampler. The investigation was undertaken at the request of the Geological Survey and is the joint work of the Geological Survey and the American Petroleum Institute. Mr. Trask is a member of the staff of the Geological Survey, and Messrs. Patnode, Stimson, and Gay, at the time the investigation was made, were members of the staff of American Petroleum Institute Research Project 4 on the Origin and Environment of Source Sediments of Petroleum.

Mr. Trask wrote the report and, with Mr. Patnode, organized the general program of work. Mr. Patnode compiled the data and prepared the charts and tables. Messrs. Stimson and Gay made the chemical analyses. The chemical work was done in a laboratory placed at the disposal of Project 4 by the Division of Industrial Farm Products Research of the Bureau of Chemistry and Soils of the United States Department of Agriculture.

METHODS OF STUDY

This investigation is based on the determination of the nitrogen content and reduction number, as defined later, of 123 samples from 11 cores. Owing to the program of the regular work of Project 4 at the time the samples were being studied time and facilities did not permit a detailed study of the organic content of these samples, and the work was therefore limited to the determination of the nitrogen content and reduction number. Neither the nitrogen content nor reduction number is an exact measure of the quantity of organic matter in sediments; at best these properties are only crude approximations. Their significance with respect to the organic content is discussed elsewhere.[1]

[1] Trask, P. D., Inferences about the origin of oil as indicated by the composition of the organic constituents of sediments: U. S. Geol. Survey Prof. Paper 186-H pp. 149-154, 1937; Organic content of recent marine sediments, in Recent marine sediments, pp. 428-453, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1939.

A final report by P. D. Trask and H. W. Patnode embodying the results of the extensive research program carried out by the American Petroleum Institute and the United States Geological Survey is being prepared for publication by the American Association of Petroleum Geologists under the title "Source beds of petroleum."

NITROGEN CONTENT

Nitrogen was determined by a slight modification of the Kjeldahl-Arnold-Gunning method,[2] which consists of converting the nitrogen compounds to ammonia by digestion with sulfuric acid, making the solution alkaline with sodium hydroxide, distilling, catching the ammonia in hydrochloric acid, and titrating with sodium hydroxide. All the determinations were duplicated and many were made in triplicate. The results are presented in terms of the arithmetic average or mean of the results obtained. They are given to two significant figures, but the second figure is of doubtful value. The average (median) deviation of individual determinations from the means, which are reported in table 30, is 0.0012 percent of the total weight of the sediments. As the average nitrogen content is 0.022 percent of the weight of the sediments, the average deviation of the individual samples from the mean is 0.0012/0.022, or 5.5 percent. When averages of several samples are considered this quantity is reduced approximately as the inverse of the square root of the number of samples considered. Thus the probable error of an average based on 10 samples is $5.5/\sqrt{10}$ or 1.7 percent, which, for the purpose of this investigation, is a relatively insignificant quantity.

The nitrogen content in some ways seems to be a more suitable index of the organic content of sediments than is the reduction number, but on the whole it probably is not materially superior. The main advantage of nitrogen is its restriction almost entirely to the organic constituents, whereas the reduction number is influenced to some extent by the inorganic substances. Nitrogen, however, represents only a small part of the organic matter, thus necessitating the use of a large factor for estimating the organic content. Moreover, the percentage of nitrogen in the organic constituents of different sediments varies, thus introducing errors in the calculation of the organic content when a constant factor is used.

The nitrogen content of the organic constituents of recent marine sediments has not yet been studied adequately, but the available evidence seems to indicate

[2] Official Methods, Assoc. Official Agr. Chem., 2d ed., p. 81, 1925. Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

that on the average nitrogen forms about 5.5 percent of the weight of the organic matter and in most sediments ranges between 4.5 and 7 percent; however, in some deposits it may be as low as 3 percent and in others as high as 10 percent.[3]

If nitrogen forms 5.5 percent of the organic matter, the organic content of the sediments would be 100/5.5, or 18 times the nitrogen; that is, the organic content could be estimated by multiplying the nitrogen content by a factor of 18. Similarly nitrogen contents of 4.5 and 7.0 percent correspond to factors of 22 and 14, respectively, and contents of 3 and 10 percent are equivalent to factors of 33 and 10, respectively. Thus, if a single factor of 18 is used for determining the organic content, for most sediments the figure obtained will be within 4/18 or about 20 percent of the true quantity, but for some sediments it may be in error by as much as 50 percent.

The significance of the organic content as estimated in this way, therefore, must be interpreted with due consideration of the degree of reliability of the data. Small differences in nitrogen content, such as 5 percent or less, without supporting evidence from another source, cannot be considered as indicating any distinctive difference in organic content, but if the difference in nitrogen content between two or more sediments is considerable, that is 30 percent or more, the organic content of the sediments in all probability is different. If the averages of several sediments are considered, the chance for anomalous interpretations decreases more or less inversely as the square root of the number of sediments averaged. Therefore, if the chance for error is 20 percent for an individual sediment, it would be of the order of $20/\sqrt{10}$, or 6.3 percent, for an average based on 10 samples; also, if the averages of two series of 10 samples differ by as much as 10 percent the chances are greatly in favor of their content of organic matter being different. However, in view of the uncertainty as to the actual factor to use for estimating the organic content from nitrogen, the variations in organic matter have been discussed in this paper in terms of variations in nitrogen content (or reduction number, which varies in essentially the same way as the nitrogen content), rather than in terms of variation in organic content. Only when the differences between the nitrogen content or reduction number of individual sediments or groups of sediments are distinctly different have the results been interpreted as suggesting real differences in organic content.

REDUCTION NUMBER

The reduction number, like the nitrogen content, is only a crude index of the organic content. The reduction number is defined as the number of cubic centimeters of 0.4 normal chromic acid that can be reduced by 100 milligrams of dried sediment under certain standard conditions of heating.[4] Formerly it was called the reducing power, but in view of the fact that it is a relative rather than an absolute measure of the reducing power of the sediments it subsequently was designated as the reduction number.[5]

The method of determination is a modification of the Schollenberger [6] method of chromic acid titration for soil organic matter. It consists of adding a known amount of 0.4 normal chromic acid to a given quantity of sediment, heating it at such a rate that the temperature within the mixture of chromic acid and sediment reaches 145° C. at the end of 6 minutes, cooling, and titrating with 0.2 normal ferrous ammonium sulfate.[7] In the present investigation, samples of 0.5 gram were used for the determination of the reduction number. The method, when the time and rate of heating are controlled, gives results that can be duplicated readily. The average deviation of duplicate samples from the mean of the determinations for individual samples studied for this report is .0069. As each drop of ferrous ammonium sulfate used in the titration corresponds to .005 unit of reduction number, this deviation for duplicate samples amounts to only a little more than one drop in the titration, which indicates that the results as expressed to two significant figures are reliable insofar as errors in the method of determination are concerned. Since the average reduction number of the sediments is 0.25, the mean deviation of individual samples from the mean is 0.0069/0.25, or 2.7 percent.

Each unit of reduction number in recent marine sediments seems to be equivalent to approximately 2 percent organic matter. This relation of reduction number to organic content in recent sediments has been investigated relatively little, but in the experience of the writers each unit of reduction number on the average corresponds to approximately 1.1 percent of organic carbon in the sediments.[8] As the average ratio of organic matter to carbon in recent marine deposits seems to be about 1.8,[9] it follows that the percentage of organic matter in the sediments would be roughly equivalent to two times the reduction number. The ratio of organic matter to carbon in such deposits, however, is not constant. Moreover, the figures of 1.8 for the ratio of organic matter to carbon, and of 1.1 for the ratio of reduction number to carbon may not be correct. In addition, the ratio of carbon to reduction number is known to be variable. These variations in the ratio of carbon to reduction number are caused by the fact that the quantity of organic matter in the sediments is not the only factor influencing the reduction

[3] Trask, P. D., Organic content of recent marine sediments, p. 431, 1939.

[4] Trask, P. D., and Patnode, H. W., Means of recognizing source beds: Am. Petroleum Inst., Drilling and Production Practice, 1936, p. 369, 1937.

[5] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

[6] Schollenberger, C. J., A rapid approximate method for determining soil organic matter: Soil Science, vol. 24, pp. 65–68, 1928; The determination of soil organic matter: Soil Science, vol. 31, pp. 483–486, 1931.

[7] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

[8] Trask, P. D., Organic content of recent marine sediments, in Recent marine sediments, pp. 430–433, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1939.

[9] Idem., p. 430.

of chromic acid during the process of determining the reduction number. Chromic acid is reduced by certain inorganic constituents, such as iron sulfide; the extent to which the organic substances are oxidized by the chromic acid during the process of analysis varies among different sediments; and the degree of oxidation or nature of the organic material affects the reduction of chromic acid. If the organic substances are in a high state of oxidation, relatively little chromic acid is reduced and if they are in a low state of oxidation, that is, have a high degree of reduction, relatively much chromic acid is reduced.

In ancient or lithified sediments, three factors, the quantity of oxidizable inorganic substances, the degree of completeness of combustion by the chromic acid, and the state of oxidation of the organic matter, cause the majority of sediments to deviate 20 percent or less from the average ratio of carbon to reduction number, though in some sediments they may cause variations of as much as 50 percent.[10] Presumably similar variations apply to recent deposits, as is attested by the similarity in relationship of nitrogen and reduction number shown by figure 23. Both the nitrogen content and reduction number are independent measures of the organic content, yet when one is plotted against the other a moderately constant relationship is observed. Consequently, it seems to follow that the reduction number is of about the same order of reliability as an index of the organic content as is nitrogen; namely, only a crude approximation, which for most samples is probably within 20 or 25 percent of the true figure, but in some samples may deviate as much as 50 percent from the correct figure. Estimation of the quantity of organic matter in the sediments by the use of the reduction number, therefore, should be interpreted with due consideration of the uncertainties involved.

The foregoing discussion of the probable error of the determination of the organic content by multiplying the reduction number by a factor of 2, refers to calculations based on individual samples. When groups of samples are considered, the probable error is reduced. However, certain basic uncertainties are still involved, namely, the correctness of the ratio of organic matter to carbon, and of the ratio of carbon to reduction number. Therefore, in view of these uncertainties, the variations of reduction number among the different sediments studied in this report, wherever practicable, have been discussed in terms of reduction number, which is an empirical quantity, rather than in terms of organic content, which is an interpretation. Nevertheless, when averages of groups of samples show similar and consistent differences for both nitrogen content and reduction number, the inference is strong that the quantity of organic matter in the groups of sediments is different.

NITROGEN-REDUCTION RATIO

The ratio of the nitrogen content to the reduction number of ancient sediments, which is called the nitrogen-reduction ratio, has been interpreted as a crude index of the state of reduction of the organic constituents of the sediments.[11] The line of reasoning that leads to this conclusion is based on the inferences that the nitrogen content is a rough measure of the organic content of the sediments and the ratio of the organic content to the reduction number is a crude index of the state of reduction of the organic substances. If the organic constituents are in a high state of oxidation they can reduce relatively little chromic acid, and the reduction number will be comparatively small. As the reduction number forms the denominator of the nitrogen-reduction ratio, a small reduction number would make the quotient relatively large. If the state of oxidation is low, the reduction number would be high and the ratio of organic matter to reduction number would be low. That is, large numbers would indicate a high state of oxidation, and low numbers would indicate a low state of oxidation.

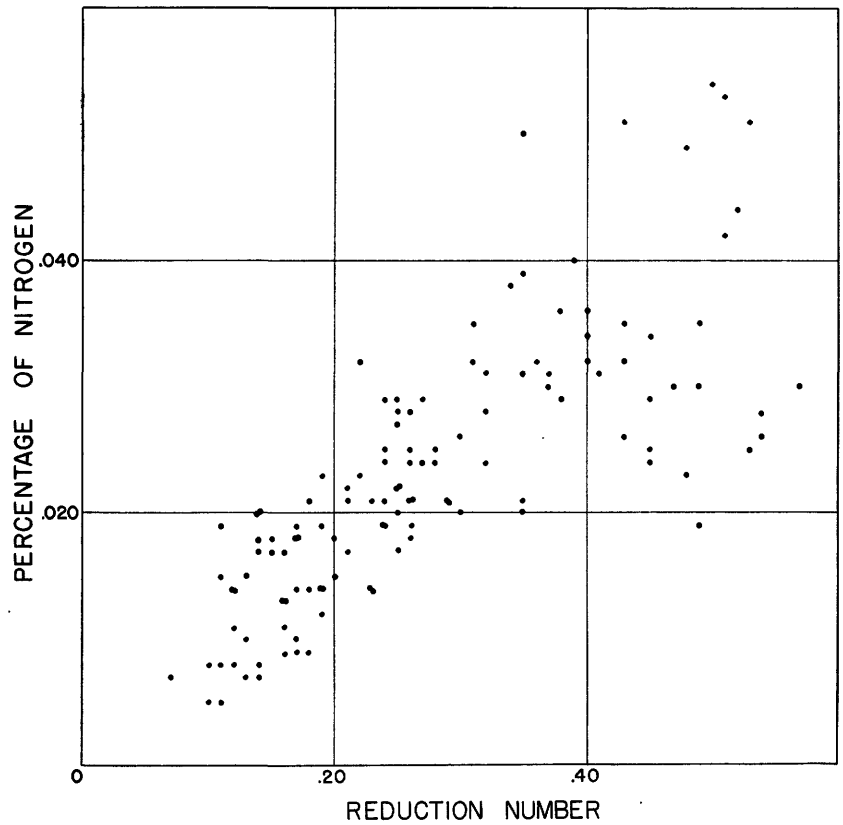


FIGURE 23.—Relation of nitrogen content to reduction number in the samples studied.

[10] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

[11] Trask, P. D., and Patnode, H. W., Means of recognizing source beds: Am. Petroleum Inst., Drilling and Production Practice, 1936, p. 371, 1937.

The relationship, however, is not as definite as the above line of reasoning would seem to indicate. The nitrogen content is not an exact measure of the organic content, because, as already indicated, the proportion of nitrogen varies in different sediments. Moreover, the effect of oxidizable inorganic substances in the sediments and the effect of the completeness of combustion by the chromic acid upon the reduction number have not been considered. The influence of these three factors upon the significance of the nitrogen-reduction ratio as an index of the state of reduction of the organic matter has been discussed in detail in another publication, and the conclusion was reached that, in general, their effect is not large.[12] Insufficient data are at hand, however, to warrant any definite statement as to the actual magnitude of their effect; moreover, the influence of these factors on recent marine sediments has been studied relatively little, but presumably it is not materially different from what it is in ancient deposits. In view of the uncertainties involved, the significance of the nitrogen-reduction ratio of recent sediments must, therefore, be interpreted with caution. About all that is safe to infer is that relatively low ratios suggest a low state of oxidation of the sediments and relatively high ratios suggest a high state of oxidation.

DESCRIPTION AND LOCATION OF SAMPLES

A proper description of the results of the work should include an account of the general nature of the samples, but as this subject has been discussed in detail in other parts of this professional paper only a brief summary is included here. The samples were collected in the spring of 1936 by C. S. Piggot (see Foreword, pp. xi–xii) with his gun sampler, which can take cores as much as 10 feet in length. Samples were obtained at fairly regular intervals along a nearly straight line about latitude 49° N., between the Grand Banks, Newfoundland, and Lands End, at the southwest end of England. The actual locations are indicated in plate 1 of the introductory chapter. Their general position is also indicated on the profile shown in figure 27 of this report. Eleven cores were obtained. They were taken in water that ranges from 1,280 to 4,800 meters (700 to 2,640 fathoms) in depth. Most of them came from water more than 3,000 meters deep, but one, number 8, was procured from the crest of the mid-Atlantic ridge, in water only 1,280 meters deep. The core material obtained ranged from 30 to 300 centimeters in length. At locality 10, the coring device buried itself in the mud, and an unknown quantity of the sediment was lost through the water ports at the top of the device.

As indicated by the work of Bramlette and Bradley on the lithologic character and geologic interpretations of the cores (see pt. 1, pl. 3), the samples are nearly all rich in calcium carbonate, and many are classified as foraminiferal marl and globigerina ooze. One core, number 3, taken from near the edge of the Grand Banks, contains considerable terrigenous debris, and another, number 11, encountered altered basalt at a depth of 30 centimeters below the top of the core. West of the mid-Atlantic ridge, two volcanic ash horizons were recognized, one at a depth that ranged between 10 and 50 centimeters beneath the surface of the deposits and the other at a depth of about 2 meters. East of the mid-Atlantic ridge only the upper of these two ash horizons has been recognized. These ash zones are particularly helpful in correlating the sediments in the different cores.

In addition to the ash horizons noted, pebbles and rock fragments are present in definite zones of sandy or silty sediment that contains relatively little carbonate. Bramlette and Bradley have recognized four such zones and regard them as of glacial or ice raft origin. Cushman and Henbest record (see pt. 2, figs. 11–21) the occurrence of cold-water Foraminifera in these pebbly zones, and this corroborates the concept of glacial origin. These zones, characterized by pebbles, rock fragments, sand, and silt, are designated in this paper as cold zones. The zones between the cold zones are called warm zones. These zones have been recognized in all the cores west of the mid-Atlantic ridge, but east of the ridge only the uppermost cold zone has been recognized. In core 3, near the edge of the Grand Banks, the uppermost cold zone has not been reached even at the bottom of the core at a distance of nearly 3 meters beneath the surface of the deposits. For convenience, the zones are numbered consecutively from the top downward. (See table 31.)

The general distribution of these cold zones is indicated on figure 24. The consistency with which they may be traced from core to core affords a means of correlating sediments of similar age and thus aids in the investigation of the lateral variation in the deposits at different depths.

The sediments in general contain about 50 percent calcium carbonate, though the quantity ranges from 10 to 90 percent. Some of the samples are sandy, particularly those from core 8 on the crest of the mid-Atlantic ridge.

The positions of the samples that were selected for study are shown in figure 24. In all, 123 samples were chosen. Samples were procured first from places near the top, middle, and bottom of each core, except the one (core 11) that penetrated the basalt. The results of the analyses of these first samples did not indicate any consistent trend with depth, but by the time they were analyzed the temperature zones had been recognized. Consequently, it seemed worth while to analyze samples in each core from each of the 9 temperature zones. Also, it was desirable to ascertain whether or not there was any change with depth in the individual warm and cold zones. Accordingly, an attempt was made to procure at least two samples from each of the

[12] Trask, P. D., and Patnode, H. W., Source beds of petroleum (see footnote 1).

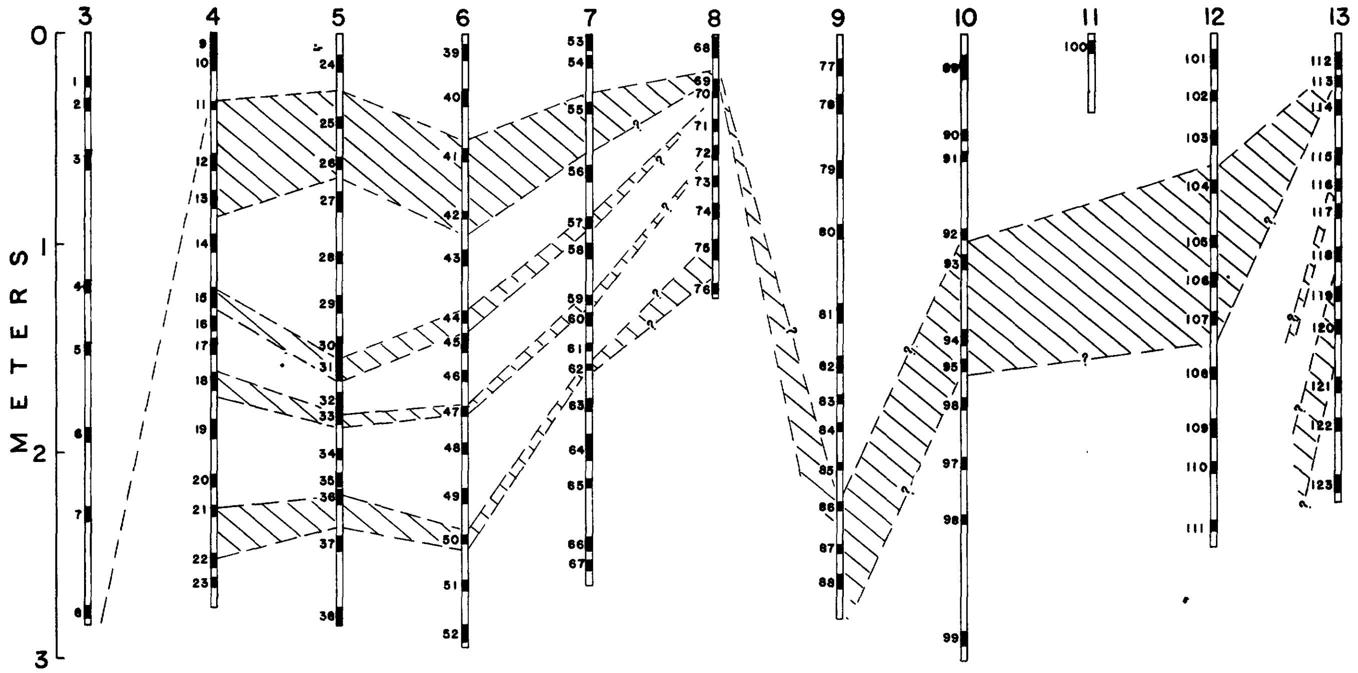


FIGURE 24.—Location of samples in cores. Vertical columns represent the numbered cores. (For location of cores see pl. 1 and fig. 1.) Black rectangular blocks represent position of samples studied; numbers opposite these blocks are the numbers of the samples. Diagonally ruled bands extending across the figure represent cold zones. Warm zones lie between the cold zones.

nine stratigraphic zones. However, by this time considerable material had already been removed from certain parts of the cores, and it was not possible to obtain some of the samples desired. Special effort was made to procure samples from the surface of the sediments in each core. However, top material could be obtained only from cores, 4, 7, and 8. In all other cores, except cores 3 and 10, the uppermost sample came from within 10 centimeters of the top of the core. In core 3 the first sample was taken 20 centimeters below the top, and in core 10 an unknown amount of the uppermost part of the core had been lost at the time the core was taken.

RESULTS

BASIC DATA

The results of the analyses are presented in table 30. This table contains the average of the determinations of the nitrogen and reduction number of each sample and the nitrogen-reduction ratios based on these average values. The table includes two forms of averages for the samples for each of the 11 cores, namely, the mean and median. The mean represents the sum of the determinations for the individual samples divided by the total number of samples. The median represents the middle determination with respect to all samples considered for the individual cores. Half the samples in any individual core have values larger than the median, and half have values smaller than the median. The median is particularly significant for ratios, such as the nitrogen-reduction ratio, and also for size distributions in which most of the samples have about the same average value, but a few are very much larger or smaller than the others.[13]

TABLE 30.—*Average values of the nitrogen content, reduction number, and nitrogen-reduction ratio*

Sample number	Nitrogen (percent)	Reduction number	Nitrogen-reduction ratio
Core 3			
T-1	0. 051	0. 43	11. 8
T. 2	. 054	. 50	10. 8
T-3	. 044	. 52	8. 5
T-4	. 042	. 51	8. 2
T-5	. 035	. 43	8. 1
T-6	. 034	. 40	8. 5
T-7	. 031	. 35	8. 9
T-8	. 034	. 45	7. 6
Mean	. 041	. 45	9. 1
Median	. 039	. 44	8. 5
Core 4			
T-9	0. 014	0. 23	6. 1
T-10	. 021	. 24	8. 7
T-11	. 013	. 16	8. 1
T-12	. 020	. 25	8. 0
T-13	. 035	. 31	11. 3
T-14	. 023	. 22	10. 5
T-15	. 017	. 16	10. 6
T-16	. 025	. 24	10. 4
T-17	. 024	. 24	10. 0
T-18	. 014	. 17	8. 2
T-19	. 039	. 35	11. 1
T-20	. 031	. 32	9. 7
T-21	. 036	. 40	9. 0
T-22	. 017	. 25	6. 8
T-23	. 021	. 23	9. 1
Mean	. 023	. 25	8. 9
Median	. 021	. 24	9. 1

[13] For further details on the respective values of the mean and median, see any text book of statistics, such as Chaddock, R. E., Principles and methods of statistics, pp. 81-124, New York, Houghton Mifflin Co., 1925.

TABLE 30.—*Average values of the nitrogen content, reduction number, and nitrogen-reduction ratio*—Continued

Sample number	Nitrogen (percent)	Reduction number	Nitrogen-reduction ratio
Core 5			
T-24	0.029	0.25	11.6
T-25	.024	.26	9.2
T-26	.014	.18	7.8
T-27	.010	.13	7.7
T-28	.020	.30	6.7
T-29	.024	.32	7.5
T-30	.022	.25	8.8
T-31	.011	.16	6.9
T-32	.021	.26	8.1
T-33	.018	.17	10.6
T-34	.017	.21	8.1
T-35	.021	.29	7.2
T-36	.021	.26	8.1
T-37	.018	.26	6.9
T-38	.015	.20	7.5
Mean	.019	.23	8.2
Median	.020	.25	7.8
Core 6			
T-39	0.028	0.25	11.2
T-40	.022	.25	8.8
T-41	.028	.26	10.8
T-42	.030	.37	8.1
T-43	.028	.32	8.7
T-44	.010	.17	5.9
T-45	.024	.27	8.9
T-46	.021	.29	7.2
T-47	.009	.18	5.0
T-48	.026	.30	8.7
T-49	.031	.37	8.4
T-50	.025	.26	9.6
T-51	.019	.24	7.9
T-52	.023	.19	12.1
Mean	.023	.26	8.7
Median	.025	.26	8.7
Core 7			
T-53	0.018	0.17	10.6
T-54	.018	.20	9.0
T-55	.019	.24	7.9
T-56	.021	.21	10.0
T-57	.013	.16	8.1
T-58	.014	.23	6.1
T-59	.007	.13	5.4
T-60	.019	.17	11.2
T-61	.019	.19	10.0
T-62	.025	.28	8.9
T-63	.014	.19	7.4
T-64	.007	.14	5.0
T-65	.009	.16	5.6
T-66	.008	.14	5.7
T-67	.014	.19	7.4
Mean	.015	.19	7.9
Median	.014	.19	7.9
Core 8			
T-68	0.009	0.17	5.3
T-69	.005	.10	5.0
T-70	.008	.11	7.3
T-71	.005	.11	4.5
T-72	.008	.12	6.7
T-73	.011	.12	9.2
T-74	.008	.10	8.0
T-75	.017	.15	11.3
T-76	.007	.07	10.0
Mean	.009	.12	7.5
Median	.008	.11	7.3

TABLE 30.—*Average values of the nitrogen content, reduction number, and nitrogen-reduction ratio*—Continued

Sample number	Nitrogen (percent)	Reduction number	Nitrogen-reduction ratio
Core 9			
T-77	0.037	0.49	7.5
T-78	.026	.54	4.8
T-79	.031	.41	7.6
T-80	.024	.45	5.3
T-81	.051	.53	9.6
T-82	.019	.49	3.9
T-83	.028	.54	5.2
T-84	.030	.57	5.3
T-85	.025	.53	4.7
T-86	.029	.45	6.4
T-87	.025	.45	5.6
T-88	.032	.40	8.0
Mean	.030	.49	6.2
Median	.029	.49	5.5
Core 10			
T-89	0.032	0.43	7.4
T-90	.023	.48	4.8
T-91	.026	.43	6.0
T-92	.024	.28	8.6
T-93	.021	.35	6.0
T-94	.032	.31	10.3
T-95	.012	.19	6.3
T-96	.020	.35	5.7
T-97	.029	.27	10.7
T-98	.030	.47	6.4
T-99	.029	.38	7.6
Mean	.025	.36	7.3
Median	.026	.35	6.4
Core 11			
T-100	0.019	0.26	7.3
Core 12			
T-101	0.029	0.24	12.1
T-102	.050	.35	14.3
T-103	.053	.51	10.4
T-104	.032	.36	8.9
T-105	.035	.49	7.1
T-106	.049	.48	10.2
T-107	.036	.38	9.5
T-108	.040	.39	10.2
T-109	.038	.34	11.2
T-110	.027	.25	10.8
T-111	.032	.22	14.5
Mean	.038	.36	10.8
Median	.036	.36	10.4
Core 13			
T-112	0.019	0.11	17.3
T-113	.021	.18	11.7
T-114	.022	.21	10.5
T-115	.015	.13	11.5
T-116	.020	.14	14.3
T-117	.018	.14	12.9
T-118	.014	.12	11.7
T-119	.015	.11	13.6
T-120	.020	.14	14.3
T-121	.017	.14	12.1
T-122	.018	.15	12.0
T-123	.014	.12	11.7
Mean	.018	.14	12.8
Median	.018	.14	12.1
General mean	.023	.28	8.7
General median	.022	.25	8.6

The areal and vertical distribution of the data are indicated graphically in figures 25 and 26. All the samples contain little organic matter. The nitrogen content ranges from 0.005 to 0.054 percent, and the reduction number ranges from 0.07 to 0.57. The median nitrogen content is 0.022 percent, and the median reduction number is 0.25. The respective means are 0.023 and 0.28. These data indicate that the organic content of the sediments ranges from about 0.1 percent to 1.0 percent, and the average is approximately 0.5 percent. These quantities of organic matter are of the same order of magnitude as previously reported from deep-sea deposits [14] but are much less than for

[14] Trask, P. D., Origin and environment of source sediments of petroleum: pp. 116–118, Houston, Texas, Gulf Publishing Co., 1932. Correns, C. W., Die Sedimente des äquatorialen Atlantischen Ozeans: Wiss. Ergeb. Deutschen Atlantischen Exped. *Meteor*, 1925–27, Band 3, Teil 3, Lief. 2, p. 236, 1937.

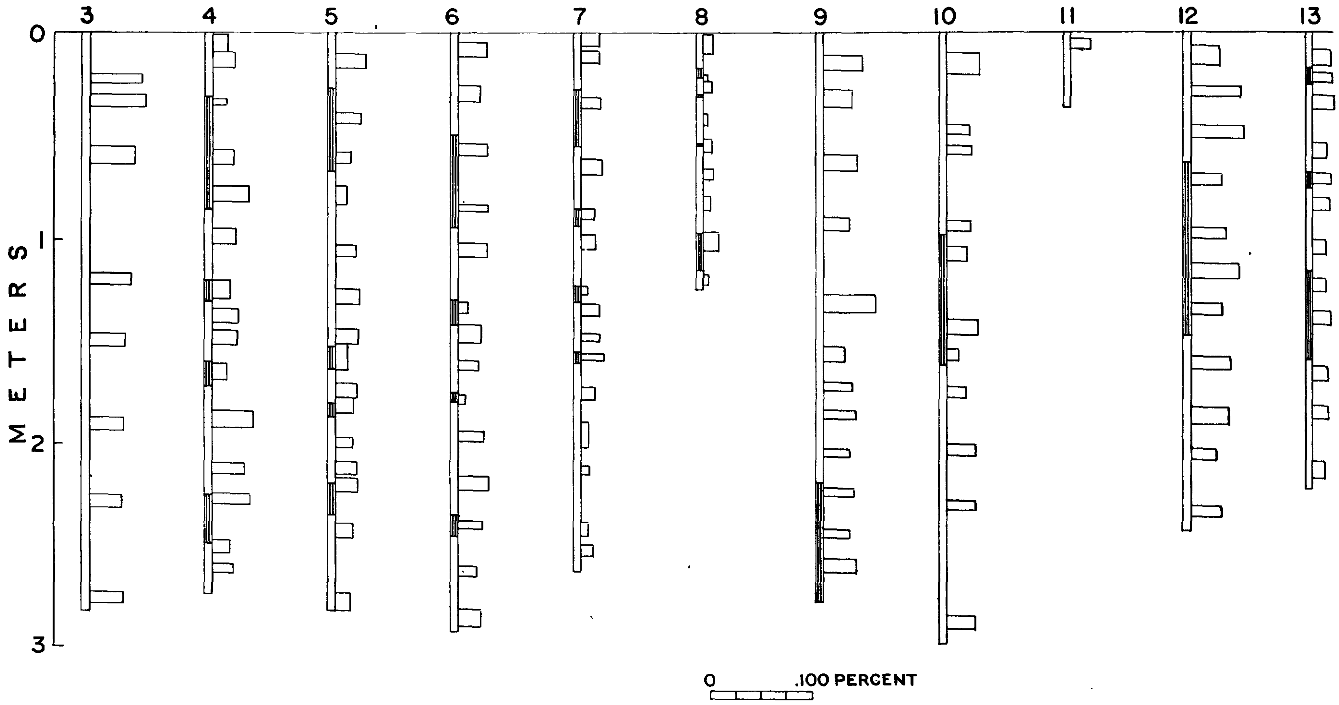


FIGURE 25.—Chart showing areal and vertical distribution of nitrogen in sediments in cores 3 to 13. Unshaded horizontal rectangular blocks indicate nitrogen content of samples. Position of these blocks indicates the respective location of samples in the cores. Vertical shading in core column represents limits of cold zones as determined by Bramlette and Bradley (see pt. 1 of this professional paper, pp. 2–7). Warm zones lie between the cold zones.

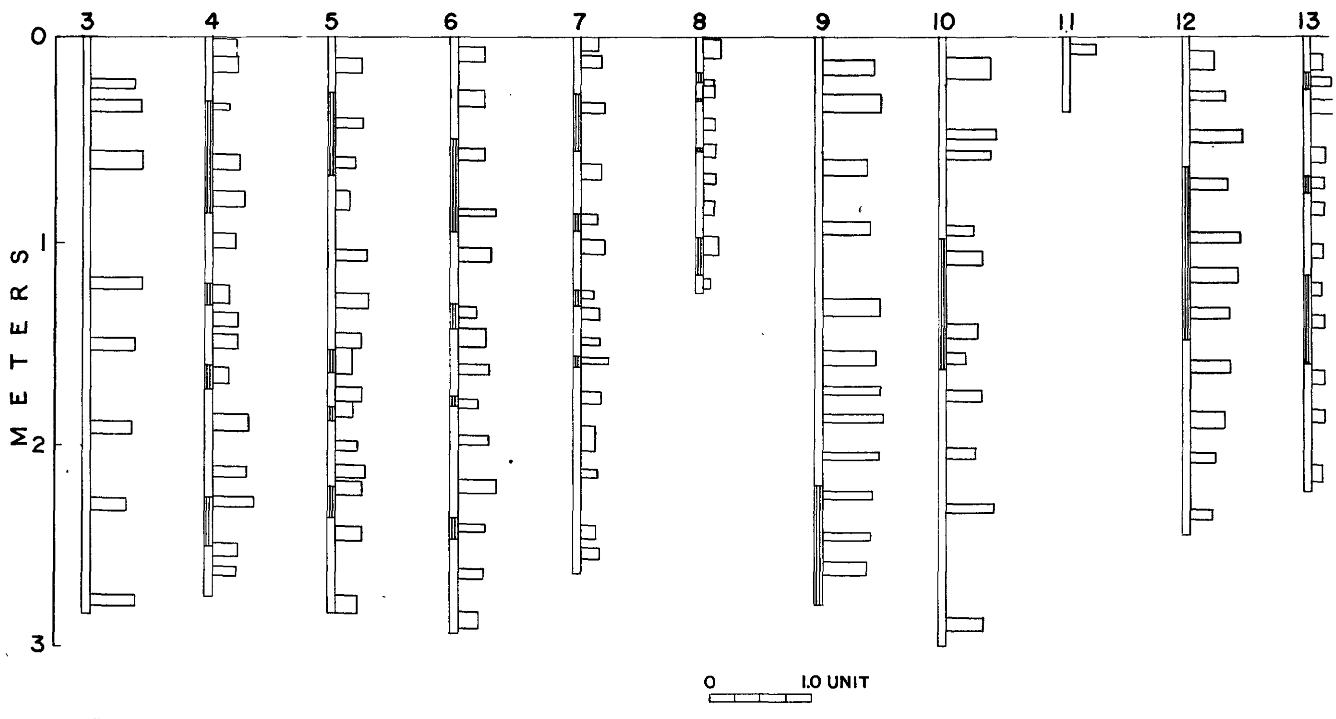


FIGURE 26.—Chart showing areal and vertical distribution of reduction number in sediments in cores 3 to 13. Unshaded horizontal rectangular blocks represent the reduction number of the samples. See figure 25 for description of other features of figure.

sediments deposited near shore, which ordinarily contain from 1 to 7 percent and have an average organic content of about 2.5 percent.[15]

RELATIONSHIPS

SURFACE LAYERS

The organic content of the sediments now forming on the sea floor as indicated by the uppermost samples procured from each core is clearly related to the configuration of the sea bottom (fig. 27). The sediments on exposed places on the sea floor, such as the sediments in core 8 on the mid-Atlantic ridge, and in core 13, on the edge of the ridge near the east end of the profile, contain distinctly less organic matter than the sediments in cores 3, 9, and 12, from the abyssal deeps. The organic content of the sediments on the ridges is 0.2 to 0.3 percent, compared with 0.3 to 1.0 percent in the deeps. Organic matter is relatively buoyant and is easily transported by currents. Consequently, if currents cross these ridges the sediments may be agitated, with the result that organic and fine-grained inorganic constituents will tend to be carried away and deposited in areas of quiet water. Evidence has been obtained from many other areas to the effect that sediments on ridges and exposed places on the sea floor, regardless of depth of water, are relatively coarse-grained and contain comparatively little organic matter.[16] The organic content of the sediments on the ridges in the Atlantic Ocean is small compared with that in the adjacent deeps.

The organic content of the sediments in the abyssal deeps varies somewhat, but owing to the small number of cores and to inadequate information on the submarine topography little can be inferred about the relation of the organic content to the configuration of the bottom along the part of this profile that represents the abyssal deeps. The sediments for a few hundred miles east of the mid-Atlantic ridge, however, seem to have a greater organic content than those for a similar distance to the west. The average nitrogen content of the uppermost samples contained from cores 9 and 10, east of the ridge, is 0.036 percent, compared with 0.022 percent for cores 4, 5, 6, and 7, west of the ridge. The corresponding averages for the reduction number are 0.46 and 0.23. The apparently greater organic content east of the ridge may perhaps be due to a greater supply of organic matter in the water.

SUBSURFACE LAYERS

The organic content of the sediments does not show any consistent decrease with depth of burial. In fact, as illustrated by table 30 and figures 25 to 27, the organic content is more or less constant throughout the length of the individual cores, except for core 3, in which it appears to diminish slightly with depth. These observations are not in accord with the common concept that the organic content of sediments decreases with the length of time the deposits have been buried. Loss of organic matter in the upper layers of sediments results mainly from decomposition caused by animals and microorganisms, which require a supply of oxygen in order to live. The source of oxygen is the water overlying the sediments. The more the sediments become removed from the overlying water by burial, the less is the supply of oxygen in the deposits. The available oxygen is probably used up rather rapidly in the surface layers of the sediments and at an increasingly slower rate with increasing depth of burial. Consequently, most of the loss in organic content due to microorganisms and animals seems to take place in the upper few inches of the deposits; in fact, observations on a considerable number of core samples of Recent near-shore sediments from many parts of the world suggest that the average loss in organic content is about 15 percent in the upper 12 inches (30 centimeters) of the deposits.[17]

The deep-sea sediments studied in this report, with the possible exception of core 3, were deposited so much more slowly than most near-shore sediments that in order to detect any decrease in organic content it probably would be necessary to analyze several samples from the upper few centimeters or millimeters of the deposits. As most of the samples considered in this report were taken at intervals of several centimeters, perhaps no detectable decrease in organic content should be expected. Moreover, the problem of loss in organic content with burial is complicated by the uncertainty as to how much organic matter was in the sediments at the time they were deposited. The different subsurface layers may have had different organic contents at time of deposition.

The sediments in core 3, as described below, probably accumulated at a more rapid rate than the others, and the apparent decrease in organic content may actually represent loss with burial. A decrease in organic content with depth in core 3, though suggested, is not certain, even granting that the organic content of all the layers of sediment was the same at time of deposition. The nitrogen content decreases from 0.051 percent in sample T–1, near the surface of the deposits, to 0.035 percent in sample T–5, about the middle of the core, below which it is more or less constant. The reduction number, on the other hand, varies irregularly between samples T–1 and T–5 and does not indicate a consistent decrease. Both the nitrogen content and reduction number are rough measures of the organic content, and one can take his choice as to which he thinks is the more significant. The nitrogen content, as mentioned above, is affected less by the inorganic constituents and possibly is the more reliable.

Though the sediments do not seem to show any general change for depth of burial, the organic content of the sediments in cores 8 and 13, taken near the crests

[15] Trask, P. D., op. cit., pp. 118–120.
[16] Trask, P. D., op. cit., pp. 83–95, 110–172.
[17] Trask, P. D., op. cit., pp. 205–208.

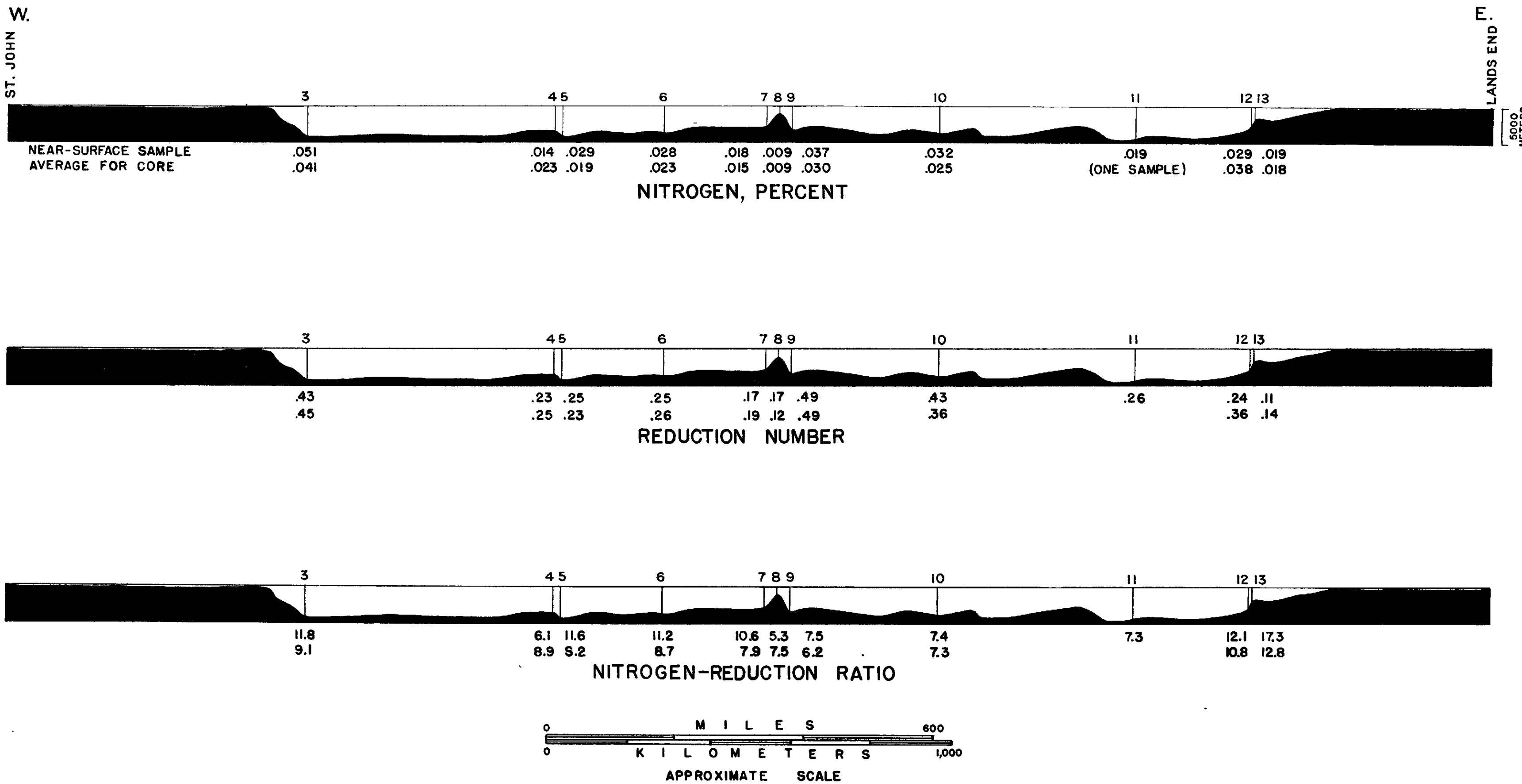


FIGURE 27.—Vertical profiles across the North Atlantic Ocean about latitude 49° N. between Grand Banks, Newfoundland, and Lands End, England, showing relation of submarine topography to nitrogen content, reduction number, and nitrogen-reduction ratio of sediments. Vertical lines represent position of cores, and the numbers above them indicate core numbers. In the first profile, the numbers immediately beneath the vertical lines representing the position of the cores indicate percentage of nitrogen in uppermost layers of the sediments, and the numbers beneath these numbers refer to average percentage of nitrogen in all the samples analyzed from the respective cores. In the second profile, the upper numbers refer to reduction number of the uppermost layers, and lower numbers refer to the average reduction number of all the samples studied in the respective cores. In the third profile, the upper numbers refer to the nitrogen-reduction ratio of the uppermost layers and the lower numbers refer to the average nitrogen-reduction ratio of all the samples studied in the respective cores.

of ridges, is consistently lower throughout the cores than it is in adjacent cores taken in deeper water. The older sediments in the cores, therefore, seem to have the same relationship to the submarine configuration as do the sediments near the surface of the deposits. Accordingly, it appears as if the mid-Atlantic ridge and the ridge west of Lands End, England, have been in existence during the deposition of the sediments, which, according to Bramlette and Bradley (see pt. 1 of this professional paper, pp. 10, 11), probably represents a considerable part of Quaternary time.

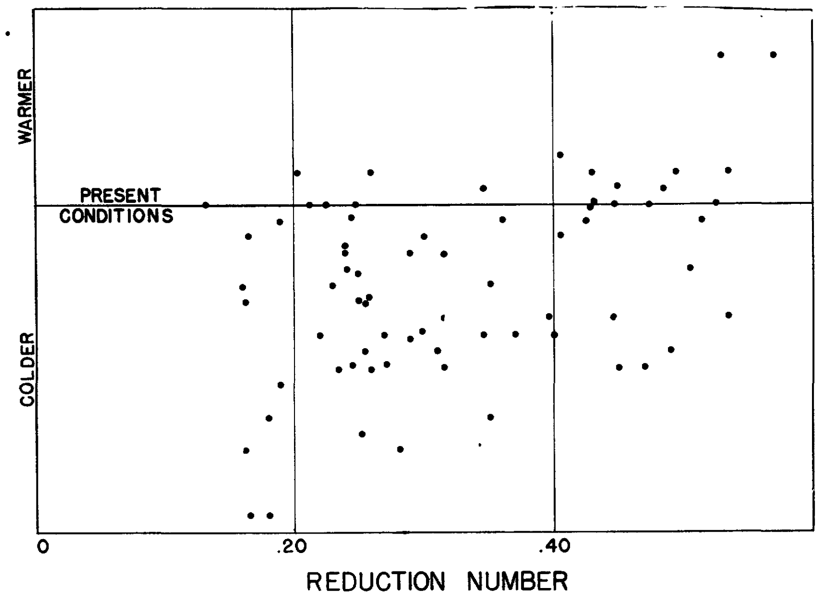


FIGURE 28.—Relation of reduction number of sediments to temperature of surface water as indicated by the pelagic Foraminifera in the sediments. The grades of temperature that form the ordinates of the figure represent relative deviations from the temperature of the surface water at the present time, as indicated by the types of Foraminifera in the sediments. These grades are based on data given by Cushman and Henbest (see pt. 2 of this professional paper, figs. 11-21).

TEMPERATURE

Although depth of burial does not seem to affect the organic content of the sediments appreciably, the different temperature zones apparently do have a slight effect. The average reduction number of the five warm and four cold zones encountered in the cores is given in table 31. The average (mean) of the five warm zones is 0.28 and of the five cold zones 0.25. As some of the temperature zones are not represented in the cores the means of the individual zones in cores 4, 5, 6, and 7, which penetrated all nine zones, were also determined. The average of the warm zones on this basis is 0.25 and of the cold zones 0.22. A compilation of the nitrogen content shows similar results.

This difference is hardly great enough to be distinctive, but it suggests a slight tendency for higher organic content under warm conditions. In order to test this possible relationship in another way, the reduction number was plotted against the temperature of the surface water as indicated by the pelagic Foraminifera found in the samples.

The results of this compilation are shown in figure 28 and indicate that the organic content, as indicated by the reduction number, seems to increase as the temperature of the surface water increases. The scatter of data on the chart, however, is great and the relationship at best is slight.

The relationship perhaps is contrary to what some might expect, because decomposition of organic matter is likely to progress at a more rapid rate in relatively warm water than in relatively cold water. Consequently less organic matter might be deposited in warm zones than in cold zones. However, even though the actual amount of organic matter deposited in a given unit of time may be less in the warm zones, the amount of inorganic material laid down in the cold zones may be so much greater than that deposited in the warm zones that the proportion of organic matter deposited in the cold zones may be less than what accumulates in the warm zones. The cold zones discussed in this paper contain relatively large amounts of material that seem to be of glacial or ice-raft origin. Consequently, the supply of inorganic debris during the

TABLE 31.—*Average reduction number of warm and cold zones*

	Core number									Mean	Median	Mean 4–7
	4	5	6	7	8	9	10	12	13			
1st warm zone	0.24	0.25	0.25	0.19	0.17	0.51	0.45	0.37	0.11	0.28	0.25	0.23
1st cold zone	.24	.22	.32	.24	.10	.43	.28	.43	.18	.27	.24	.26
2d warm zone	.22	.25	.32	.21	.11	------	.37	.30	.17	.24	.24	.25
2d cold zone	.16	.16	.17	.16	------	------	------	------	.14	.16	.16	.16
3d warm zone	.24	.26	.28	.23	.11	------	------	------	.13	.21	.24	.25
3d cold zone	.17	.17	.18	.13	.12	------	------	------	.12	.15	.15	.16
4th warm zone	.34	.25	.34	.18	.11	------	------	------	.14	.23	.17	.28
4th cold zone	.40	.26	.26	.28	.15	------	------	------	------	.27	.26	.30
5th warm zone	.24	.23	.22	.17	.07	------	------	------	------	.19	.22	.22
Median warm	.24	.25	.28	.19	.11	.51	.41	.34	.14	.27	.24	.24
Median cold	.21	.20	.22	.20	.12	.43	.28	.43	.14	.25	.21	.21
Mean warm	.26	.25	.28	.20	.11	.51	.41	.34	.14	.28	.26	.25
Mean cold	.24	.20	.23	.21	.12	.43	.28	.43	.15	.25	.23	.22

deposition of the sediments in the cold zones should be much greater than during the formation of the warm zones, especially as the sediments are so far from land. The apparently slightly greater organic content of the warm zones may possibly be due to such a cause. The sediments of the cold zones, moreover, are coarser than those in the warm zones and therefore may contain less organic matter, owing to the prevalence of conditions that favored the deposition of relatively coarse sediments. In fact, the organic content of all the sediments considered in this report seems to be related to the texture.

TEXTURE

The relation of the organic content to the texture of the sediments is illustrated by figure 29. In this figure the reduction number has been plotted against the percentage of material in the sediment finer than 74 microns, which corresponds roughly to the silt and clay content. This method of representing the texture is crude, but in general the greater the percentage of silt and clay in a sediment the finer is the texture. The data as plotted in this way exhibit a very definite increase in organic content as the percentage of clay and silt increases. The general trend is indicated by the heavy line through the samples. The scatter of the points on each side of this line is considerable, but the relationship of organic matter to texture is obvious.

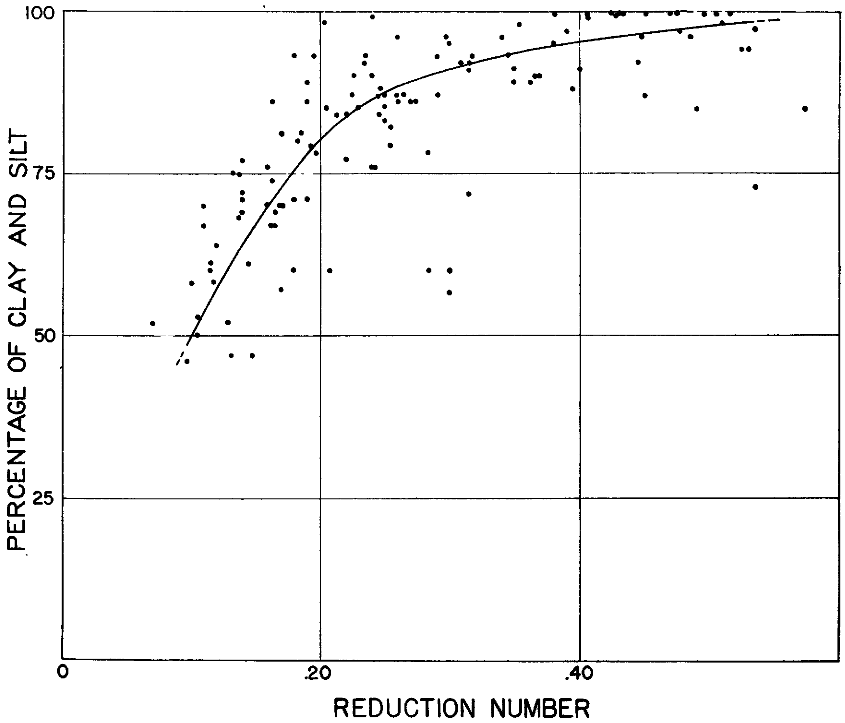


FIGURE 29.—Relation of reduction number to texture of sediments. The texture is represented by the percentage of silt and clay in the sample. The data on the silt and clay content of the sediments are taken from Bramlette and Bradley (see pt. 1 of this professional paper, pl. 3).

The relationship between the texture and organic content probably is not one of cause and effect. Instead, they both seem to vary with respect to some third factor, which presumably is the movement of water in which the sediments are deposited. If currents are relatively strong, little organic matter and few fine particles can accumulate, and if currents are weak, the content of organic matter and fine particles is apt to be high. In order to ascertain from the organic content what the relative supply of organic matter in the overlying water was at the time the sediments were deposited, it is, therefore, necessary to have a means of comparing the organic content of sediments of the same texture; that is, to have some way of ascertaining whether the sediments of any given texture, such as silts or clays, contain more or less organic matter than other sediments of the same texture. In this way, the effect of the motion of the water on the deposition of the organic matter is largely counterbalanced.

In near-shore sediments, this organic content relative to the fineness of the sediments has been determined by dividing the reduction number by a factor for the texture,[18] but the large percentage of calcium carbonate in these deep-sea deposits and the lack of adequate data on the texture complicate the application of such a factor to them. It seems more practicable to calculate the reduction number upon a carbonate- and sand-free basis. The estimate of the organic content as calculated in this way can conveniently be designated as the "comparative organic content," because it is a measure of the organic content compared with the percentage of fine-grained constituents in sediments that are deposited under conditions similar to those for organic matter.

To illustrate the method of calculation on this basis, take a sample in which the reduction number is 0.3, the carbonate content is 50 percent, and the percentage of sand is 10 percent. The percentage of noncalcareous fine-grained constituents would therefore be $100-(50+10)$, or 40 percent, and the reduction number divided by this fine fraction would be 0.3/0.4, or 0.75.

COMPARATIVE ORGANIC CONTENT

The comparative organic content of the sediments in the nine temperature zones, as calculated in this way, is given in table 32. The main features indicated by this table are the general uniformity in organic content throughout the areal extent of the individual zones, the general decrease downward from the surface to the second cold zone, and the greater content for

[18] Trask, P. D., and Hammar, H. E., Organic content of sediments: Am. Petroleum Inst., Drilling and Production Practice, 1934, p. 120, 1935.

the warm zones compared with the cold zones. The effect of the ridges is largely eliminated. Nevertheless, the comparative organic content of core 9, just east of the mid-Atlantic ridge, as determined in this way, is distinctly greater than that of core 8, on the crest of the ridge. This greater comparative organic content of core 9 perhaps might be due to a greater production of organic matter in the overlying water but is probably due to enrichment from material swept off the ridge to the west.

The uppermost samples in cores 7, 8, and 9, in the vicinity of the mid-Atlantic ridge, have a relatively large comparative organic content. Though this may be due to a greater production of organic matter, it might also represent improper compensation for the texture. Core 11, in the eastern part of the basin, likewise has a relatively high content, which, coupled with the richness of core 9, suggests that the rate of production of organic matter is greater east of the mid-Atlantic ridge than west of it, but core 10, between cores 9 and 11, has a relatively low content. The coring device at this locality buried itself in the mud, and an unknown amount of the upper part of the core was lost. The sediments encountered, therefore, represent material some distance beneath the surface, and the lower content in the upper part of this core might possibly be due to a decrease in organic content while the sediments have been buried. On the other hand, according to Bramlette and Bradley (see pt. 1, pp. 32–34), the upper and lower parts of core 10 are anomalous and consist of a mixture of basaltic debris and clay, perhaps derived from a submarine volcanic vent. Furthermore, the comparative organic content is too indefinite a measure of the supply of organic matter in the overlying water to be considered very seriously. All that can be inferred is that the data for the uppermost zone suggest that the supply of organic matter in the eastern part of the Atlantic Ocean might be greater than in the western part.

TABLE 32.—*Comparative organic content of the sediments*

	Core number											
	3	4	5	6	7	8	9	10	11	12	13	Mean
1st warm zone	0.86	0.83	0.63	0.86	1.10	1.13	1.35	0.65	1.30	0.71	0.31	0.89
1st cold zone		.48	.47	.54	.59	.33	.79	.64		.65	.33	.52
2d warm zone		.39	.46	.49	.39	.42		.51		.57	.53	.47
2d cold zone		.32	.33	.30	.36						.28	.32
3d warm zone		.54	.43	.49	.38	.42					.41	.45
3d cold zone		.37	.33	.40	.27	.39					.24	.33
4th warm zone		.67	.44	.61	.44	.47					.40	.51
4th cold zone		.62	.33	.40	.46	.49						.46
5th warm zone		.44	.93	.57	.65	.20						.56
Mean of warm zones	.86	.57	.58	.60	.59	.53	1.35	.58	1.30	.64	.41	.57
Mean of cold zones		.45	.37	.41	.42	.40	.79	.64		.65	.28	.41

Similarly, it is hard to explain the decrease in comparative organic content from the surface downward through the first four temperature zones. This decrease may represent a smaller supply of organic matter at the time the deeper sediments were deposited; it may represent a loss of organic matter while these sediments are buried; it may be only an apparent decrease resulting from the method of compensating for the texture; or it may reflect the influence of the calcium carbonate content. The sediments in the cold zones contain less carbonate than those in the warm zones; consequently, as the calcium carbonate is not considered in the method of calculation, the organic content might be proportionately greater in samples that have a large carbonate content. However, if calcium carbonate is the cause, it is difficult to understand why the organic content should be less in the second warm zone than in the overlying first cold zone. Moreover, as shown below, the organic content does not seem to have any general relationship to the carbonate content.

The same difficulties arise in trying to account for the greater comparative organic content of the warm zones compared with the cold zones. The mean of the four cold zones is 0.41 and of all five warm zones is 0.57. If the first warm zone is not considered, the mean of the other four warm zones is 0.50 This slight difference between the warm and cold zones, considering the method of calculation, probably is not large enough to be distinctive, but it does suggest that the organic content when compensated for the texture is greater in the warm zones than in the cold zones. As mentioned above, the organic content of the entire sediment tends to show the same relationship to the temperature zones. Perhaps the supply of organic matter actually is greater during the deposition of the warm-zone sediments.

The most noteworthy thing about the comparative organic content, however, is the uniformity throughout the individual zones. The consistency, except for the upper zone, seems too striking to be accidental. The rate of sedimentation differs in different areas, yet the comparative organic content is essentially the same. Therefore, in order for the quantity of organic matter per unit of silt and clay to be the same for sediments deposited at different rates, either the supply of organic matter must differ in different areas, or in places where deposition is slow the decomposition of organic matter must be somewhat greater.

RATE OF DEPOSITION OF ORGANIC MATTER

In order to ascertain the actual quantity of organic matter that was deposited in given units of time in different areas, the average quantity of organic matter in each zone in each core was multiplied by the number of cubic centimeters of sediment in each zone. The organic matter was calculated on the basis of the entire sediment, and the deepest zone penetrated in each core was neglected in the computations, as the thickness of that particular zone in each core is unknown. The results are presented in table 33. On the assumptions that the correlation of the zones is correct, that the averages indicate the proper organic content, and that the thickness of the zones represents the true thickness, the data represent relative measures of the quantity of organic matter that accumulated in each zone. However, as the length of time represented by the different zones is different, it is not possible to compare the rates of deposition of organic matter in one zone with that in other zones, unless the interval of time represented by each zone is known.

TABLE 33.—*Relative quantity of organic matter per zone, indicating relative rate of its deposition*

	Core number									
	3	4	5	6	7	8	9	10	12	13
1st warm zone	240	13	15	26	11	5	180	69	52	5
1st cold zone	-----	25	14	28	12	0.5	42	33	70	3
2d warm zone	-----	16	39	22	13	1	-----	88	64	16
2d cold zone	-----	3	2	3	3	0.2?	-----	-----	-----	3
3d warm zone	-----	14	10	18	11	4	-----	-----	-----	11
3d cold zone	-----	4	2	1	2	0.4	-----	-----	-----	11
4th warm zone	-----	37	14	36	12	9	-----	-----	-----	20
4th cold zone	-----	18	7	4	3	5	-----	-----	-----	-----
Total of first seven zones	-----	112	96	134	64	20	-----	-----	-----	69

The data presented in table 33 indicate definitely that the rate of deposition of organic matter is greatest at the foot of the east slope of the ridges, as indicated by the first warm zone in cores 3 and 9. On the other hand, the rate is low on the ridges, as illustrated by cores 8 and 13. The organic content of sediments in the basins just east of the ridges, therefore, seems to be enriched at the expense of organic matter derived from the vicinity of the ridges. The rate of deposition of organic matter in the basin is greater for several hundred miles east of the mid-Atlantic ridge than for a similar distance west of it. According to table 33, the average for the first warm zone for cores 9, 10, and 12, east of the ridge, is 100 units, compared with 16 units for cores 4, 5, 6, and 7, west of the ridge. Even if the enrichment of organic matter in core 9 is discounted, the rate of accumulation is greater east of the ridge, as the average of cores 10 and 12 is 60, which is much greater than the average of cores 4 to 7, inclusive. Similarly, the rate of accumulation in the subsurface zones is greater east of the ridge than west of it.

This greater accumulation of organic matter east of the mid-Atlantic ridge could be caused by a greater supply of organic matter in the water, by a slower rate of decomposition, by a combination of these two factors, or by a smaller supply of inorganic detritus. The quantity of organic matter in the water is related to the supply of plankton. However, as adequate data on the plankton content of the water along this profile in the North Atlantic are not available, it is impossible to estimate the extent to which the rate of accumulation of organic matter in the sediments is affected by the supply of organic matter in the water. The rate of accumulation is so much greater east of the ridge than west of it that the greater content of organic matter in the individual zones probably cannot all be due to a slower rate of decomposition of the organic matter after it reaches the sediments. The nitrogen-reduction ratio of the deposits, which is discussed below, tends to be lower east of the ridge and, therefore, suggests a higher state of reduction of the sediments. If the sediments are more reduced, the rate of decomposition probably would be slower,[19] but whether or not it is sufficiently slow east of the ridge to account for the greater preservation of organic matter in the sediments is problematical. It seems probable that the greater rate to the east is partly due to a greater supply of plankton. Future oceanographic investigations will determine whether this is so or not.

NITROGEN-REDUCTION RATIO

The nitrogen-reduction ratio suggests that the sediments east of the mid-Atlantic ridge are more reduced than those west of it. As mentioned above, this ratio is a rough measure of the state of reduction or oxidation of the organic compounds. The results of the determination of the ratio are given in table 30 and in figure 27. As illustrated by figure 27, the nitrogen-reduction ratio of the uppermost samples in the cores near the surface of deposits in general is lower east of the mid-Atlantic ridge than west of it. This lower ratio on the east side suggests a greater degree of reduction. The ratio, however, is low in core 6, west of the ridge, and is high in cores 12 and 13, near the east end of the profile on the continental slope; consequently the relationship is not entirely definite. As indicated by table 30, the ratio in the abyssal deeps in general also tends to be lower east of the ridge in the individual stratigraphic or temperature zones. The state of reduction of the sediments, therefore, may have been

[19] Trask, P. D., Inferences about the origin of oil as indicated by the composition of the organic constituents of sediments: U. S Geol. Survey Prof. Paper 186-H, pp 148-149, 1937.

greater east of the ridge during and since the later part of the Pleistocene.

This apparently greater state of reduction of the sediments east of the ridge could be caused by a lower degree of saturation of the deep water with oxygen. Data on the oxygen content of the water along this profile across the North Atlantic, however, are not available, but by analogy with determinations from other areas in the North Atlantic it seems probable that the oxygen content of the deep water east of the ridge is lower than that west of the ridge along this profile.[20]

The nitrogen-reduction ratio indicates few other relationships. It seems to be slightly larger in the uppermost sample in the individual cores than in the samples just below, which suggests an increase in degree of reduction a short distance beneath the surface of the deposits. The ratio does not seem to have any relationship to the warm and cold zones.

The sediments in core 13, on the ridge near the east end of the profile, have a relatively high ratio, and according to Bramlette and Bradley (see pt. 1, p. 15), the sediments are stained with iron oxide, which suggests oxidizing conditions. The sediments on the mid-Atlantic ridge likewise are stained with iron oxide, but the nitrogen-reduction ratio is low. The rusty color of the sediments seems a more reliable measure of the state of oxidation than the nitrogen-reduction ratio. Consequently, the low ratio of the sediments on the mid-Atlantic ridge is probably due to some cause other than the state of oxidation of the sediment, such as a relatively low percentage of nitrogen in the organic matter. The position of the sediments on a comparatively exposed place on the top of this ridge might be a favorable environment for the decomposition of the nitrogen compounds, but if so, then one would expect a similar decomposition at the site of core 13. The relations of the nitrogen-reduction ratio in cores 8 and 13 at best seem anomalous.

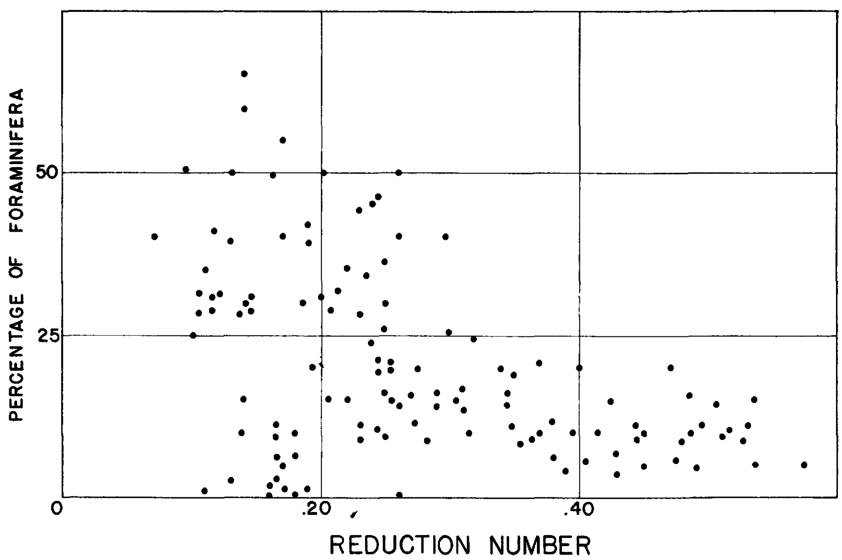


FIGURE 30.—Relation of reduction number to percentage of Foraminifera in sediments. Percentage of Foraminifera is based on data given by Bramlette and Bradley (see pt. 1 of this professional paper, pl. 3).

FORAMINIFERA

In order to ascertain whether or not the organic content might be related to the quantity of Foraminifera in the sediments, the reduction number of each sample was plotted against the percentage of Foraminifera in the samples. The results are indicated in figure 30. This figure indicates that the sediments having the greatest organic content contain the fewest Foraminifera. However, for any given percentage of Foraminifera the organic content varies widely. In all probability therefore, the organic content is not derived mainly from the Foraminifera. The inverse relationship to the Foraminifera presumably is caused largely by the relatively great bulk per unit of weight of the Foraminifera shells in the sediments. If sediments are composed largely of remains of Foraminifera, they contain relatively few fine ingredients, with which the organic matter generally is associated, but if they contain a small percentage of Foraminifera the proportion of fine ingredients is high, with the result that the organic content likewise should be comparatively high. However, even when the organic matter is compensated for the effect of Foraminifera, a uniform organic content is not obtained. For example, the average (median) reduction number of samples containing from 10 to 15 percent Foraminifera is 0.38. If none of the organic matter is assumed to be in the foraminiferal shells, then this 0.38 unit occurs in the nonforaminiferal constituents, or in 88 percent of the sediment. That is, these nonforaminiferal substances have a reduction number of 0.38/0.88 or 0.43 unit. Similarly, the average (median) reduction number of the nonforaminiferal constituents in the sediments that contain between 40 and 45 percent Foraminifera is 0.16/0.58, or 0.28 unit. Thus, even after the effect of the Foraminifera shells has been discounted, the organic content of the sediments is greater for sediments that contain few Foraminifera than it is for those that contain many, provided, of course, the two examples that were chosen indicate the general trend. This line of reasoning, too, suggests even more strongly than was indicated above that the organic content of the sediments is not related to the percentage of Foraminifera in the sediments, and hence presumably is not derived to any considerable extent from Foraminifera. However, Foraminifera tend to be plentiful in samples that contain the most sand. Consequently, the low organic

[20] Wattenberg, H., Die Durchlüftung des Atlantischen Ozeans: Internat. Council Exploration of the Sea Jour., vol. 4, No. 1, pp. 68-69, 1929.

content of those samples that are richest in Foraminifera perhaps may be due more to the physical conditions of sedimentation than to whether or not the organic matter is derived to a significant extent from Foraminifera.

The nitrogen content exhibits the same inverse relationship to the percentage of Foraminifera as does the reduction number. The nitrogen-reduction ratio, however, when similarly plotted, shows no relationship.

CALCIUM CARBONATE

The calcium carbonate content of the sediments does not seem to be related to the organic content or to the nitrogen-reduction ratio. The reduction number, when plotted against the calcium carbonate content of these sediments, gives a random distribution in which no definite trends are apparent. The nitrogen content and nitrogen-reduction ratio, when similarly plotted against the calcium carbonate, give equally random distributions. The inference follows that the organic content of the sediments is not related to the carbonate content.

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