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Technical Report on Submarine Geology No. 1

Sediments of the Atlantic Ocean

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Sediments of the Atlantic Ocean

by

David B. Ericson

This report is a brief summary of the present status of research on deep-sea sediment cores and dredge samples from the Atlantic Ocean brought together at the core laboratory of Lamont Geological Observatory (Department of Geology, Columbia University). The research constitutes a part of geological investigations of the earth with the application of the methods of physics, chemistry, mathematics and engineering carried out by Dr. Maurice Ewing, Director of the Observatory, and his co-workers.

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November 1953

ACKNOWLEDGMENTS

The writer thanks Dr. Maurice Ewing, Director of Lamont Geological Observatory, for the opportunity to work on the unique collection of bottom sample which is the subject of this report.

He is grateful to Dr. Walter Bucher, Department of Geology, Columbia University for valuable advice and encouragement. He is in debt to Bruce C. Heezen, who by combining knowledge of ocean bottom topography with theories of sedimentation, has taken many particularly important cores and dredge samples.

Without the loyal help of my assistants Gösta and Janet Wollin this research could not have gone on. They have taken part in all aspects of the work from the construction of core racks to detailed analyses of foraminiferal assemblages and have supplied a multitude of invaluable ideas together with the energy and ingenuity to put them into effect.

To others associated with the Lamont Geological Observatory who have aided directly or indirectly in this study the writer gives his thanks.

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INTRODUCTION

A large collection of deep sea sediment cores has been brought together at the core laboratory of Lamont Geological Observatory, Columbia University. There are over 700 piston cores, 350 trigger-weight cores, and 250 camera cores. The total length of the cores is more than 2400 meters (7870 ft.), individual lengths varying from less than a meter (3 ft.) to 13 meters (42 ft.). The majority of the cores are raised from a depth of more than 2000 meters (1100 fms.) and some from such a great depth as 7970 meters (4360 fms.). The cores are obtained from all over the Atlantic -- from the northern part of Greenland Sea to south of the Tropic of Capricorn and from the Eastern Mediterranean to the western part of the Gulf of Mexico. Figure 1 shows the majority of core stations.

In addition to the collection of sediment cores there are about 100 dredge samples with a total weight of over 2 tons.

The core collection is unique in several aspects.

The cores have not been obtained at random during a single cruise. They are the product of 37 cruises* made at frequent intervals over the past six years. Therefore most of the cores have been raised with full benefit of the knowledge of local submarine topography acquired on earlier cruises. Several series of cores have been obtained particularly to test specific theories in regions known through previous coring to be critical.

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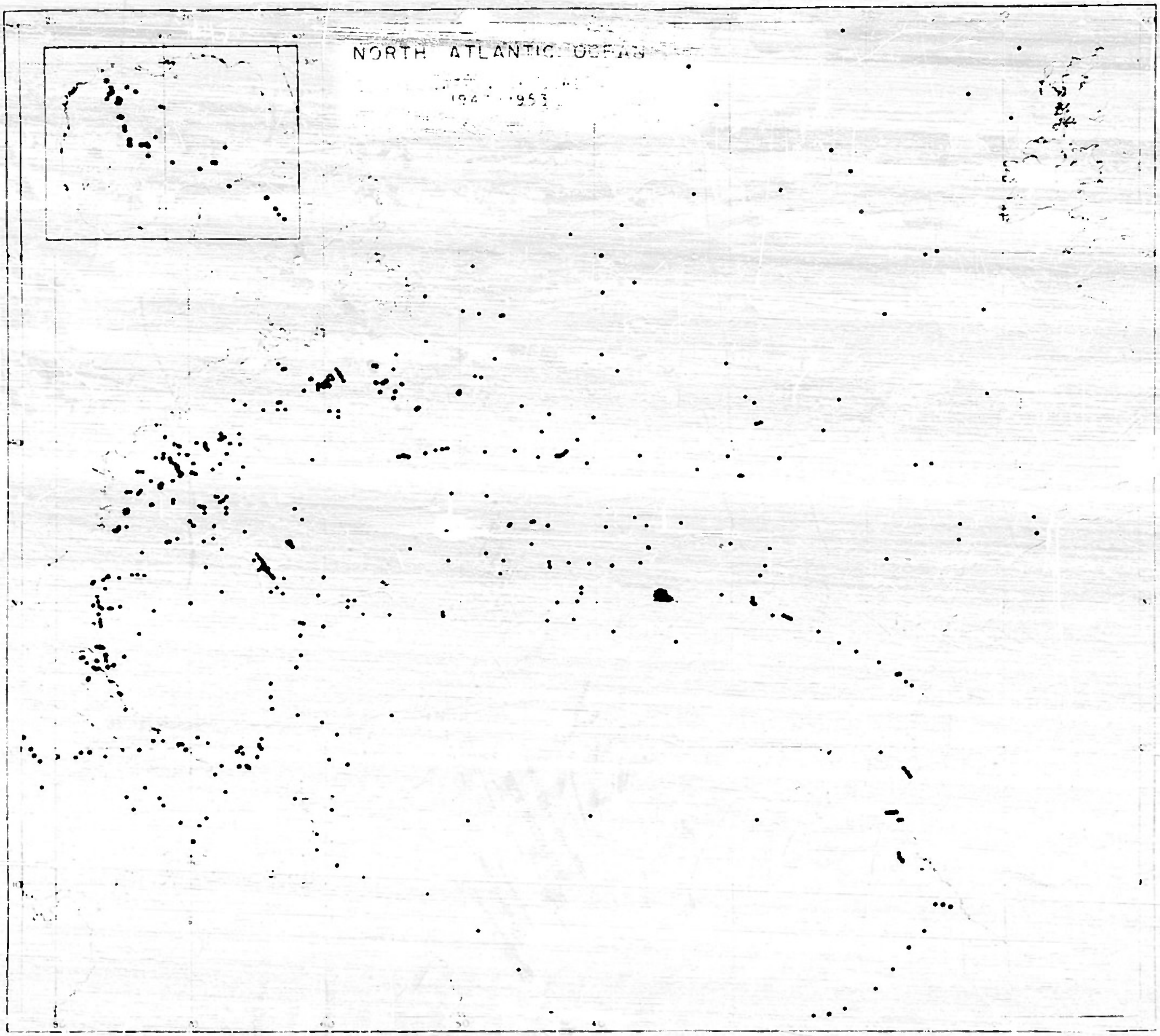
*The greatest number of cruises were carried out by Drs. M. Ewing, J. L. Worzel, and B. C. Heezen and their co-workers and were supported by contracts with the Office of Naval Research and the Bureau of Ships, U.S. Navy. Three cruises were sponsored by the National Geographic Society, the Woods Hole Oceanographic Institution, and Columbia University. From 13 cruises carried out by U.S. Navy Hydrographic Office 92 piston cores and 21 trigger-weight and camera cores have been obtained.

Many of the cores are from areas of rough topography. At these core stations the cores obtained were often short, the coring tubes were bent, and sometimes the coring apparatus was lost. The scientific information, however, from that type of coring is of outstanding value.

The collection is not a finished series. A campaign of coring has been tentatively planned for the coming year.

The research on the cores has led to several conclusions, previously published and summarized in this report, regarding the processes of sedimentation, the sediments themselves, Recent and Pleistocene stratigraphy, submarine erosion and the combined effect on ocean bottom topography. The importance of the nature of the sea bottom in relation to the transmission and reflection of sound which has significant Naval applications has also been shown.

It is hoped that the research on the present collection of cores and new material will also add to the knowledge of the structure of ocean basins, the origin of continents, the chronology of Pleistocene climatic changes, diagenesis, and the origin of petroleum. The results of this research will of course influence the concepts on sedimentation applied by geologists working in continental areas.



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PREPARATION AND STORING OF THE CORES

As soon as the cores arrive at the laboratory they are unpacked, extruded, split, photographed, labelled, sampled, and stored. From all the cores samples are taken for preliminary microscopic investigation, and from some cores samples are taken for density determinations, sound velocity measurements, C^{14} determinations, paleo-temperature determinations by the oxygen isotope method, $CaCO_3$ determinations, and other chemical analyses.

For the preliminary microscopic investigation 8 gm samples are taken from a quarter section of each core at 10 cm intervals down to 50 cm. Below 50 cm. samples are taken wherever there are changes in type of sediment. In cores of uniform lithology samples below 50 cm. are taken every 50 cm. The samples are dried, weighed, and washed on a 74 micron sieve. The fractions retained on the sieve are dried, weighed, and the percentage of material coarser than 74 microns is calculated. The coarse fractions so obtained are examined and then stored in vials for future research work.

Halves of the piston cores which are 2 1/2 in. in diameter are stored in rectangular 8 ft.-long metal trays. The quarter sections from which the first sampling is made are stored in cardboard boxes. In order to preserve a part of the cores in the original condition, quarters of the piston cores are stored in glass tubes. Formaldehyde is then dropped into the tubes to prevent moulding and the tubes are sealed with rubber stoppers.

The trigger-weight and camera cores (short gravity cores 1 1/4" in diameter) having been split and sampled are stored in the plastic liners in which they were raised from the ocean bottom.

PRELIMINARY INVESTIGATIONS

A general description of each core is made shortly after splitting, while it remains moist. This is in the form of a core log on which lithological changes are noted.

A preliminary microscopic investigation is made of all the washed coarse-fraction sediment samples obtained in the way already described. The samples are examined for foraminifera and other organic remains. Where possible climatic changes are inferred from the vertical sequence of foraminiferal assemblages, and these changes are plotted on the core log. An estimate of the relative abundance of mineral particles to organic remains is made as well as a rough description of the mineral species present. Further study of any particular core depends upon the information yielded by these preliminary examinations.

The main purpose of the preliminary investigations is to obtain a maximum of information with a minimum delay. The results are rapidly given to the expedition leaders so that various points which seem to be promising can be further explored by more intensive coring in certain areas.

The value of this method is well illustrated in case of the relationships of submarine topography and sediment type. Preliminary investigation of 2 cores from the Bermuda pedestal revealed tertiary sediment. On a subsequent cruise a number of cores were taken from the same general area and outcrops of other tertiary stages were found. (Ericson, Ewing, Heezen, 1952)

The probable importance of turbidity currents as transporter of sediment into deep water was first indicated by a study of the relationship between sediment type and topography in the Hudson submarine canyons region (Ericson, Ewing, Heezen, 1951). After a few cores indicated the probability that sands and gravel were limited to the canyon floor on the continental rise and that normal clays were found in the inter canyon areas, about 30 cores were taken at topographic locations selected so as to confirm or refute the prediction. These cores not only confirmed the predicted occurrence but of 20 cores, taken on the same cruise in order to determine the possible existence of a delta, 18 contained sands thus confirming this additional prediction.

The original purpose of most core studies was the determination of a Pleistocene stratigraphy in marine sediments beneath deep water where it was supposed that only slow deposition occurred without interference by erosion, slumping or periods of rapid deposition. The studies have demonstrated that while there are many areas where such undisturbed sedimentation occurs there are probably as many areas where it does not occur. Therefore in order to obtain cores suitable for study of Pleistocene chronology cores must be taken from areas which seem promising in the light of the analyses of cores from previous cruises.

Quick studies of a great number of cores make possible the gathering of material for a more detailed study of a specific problem. The relationship of deep-sea areas and the neighboring continental areas in selected regions can be studied in detail by a comparison of the sediments of both areas. The general horizontal and vertical distribution of a few selected species of foraminifera within a great number of cores combined with data on the ec ology of these planktonic animals gives the key to the lithogenetic interpretation of older foraminiferal sediments which is needed for every kind of continental survey in areas of sedimentary rocks.

Since generalized assumptions on the bottom sediments of the Atlantic Ocean based on incomplete data play a big role in numerous world-wide geologic problems, it is important to obtain more data as rapidly as possible to test these assumptions. A practical example has been furnished by the study of the cable break area south of Newfoundland (Heezen and Ewing, 1952; Ericson, Heezen and Ewing, 1953).

TRANSPORTATION AND DEPOSITION OF SEDIMENTS

Turbidity currents. It has been found that beds as much as 10 feet thick of fairly well sorted sand are of frequent occurrence in sediments at abyssal depths hundreds of miles from the continents. Evidence in the cores indicates that these sands have been laid down in water of essentially the same depth as that which now covers them.

Characteristic minerals and organic remains in the sands point to the continental shelf and slope as the sources from which the sands have been derived. The fact that sands and even gravels are found in the bed of canyons, but neither on the sides nor the divides, indicates that these coarse clastic sediments have been transported along the canyon beds by some kind of gravity induced flow.

Transportation by turbidity currents seems to account for all the observed facts. This evidence for transportation of large volumes of sediment by turbidity currents through the canyons gives strong support to the theory that the canyons themselves have been eroded by turbidity currents.

Cores from Puerto Rico Trough. Since the flow of turbidity currents is determined by bottom topography, it is becoming more and more possible to predict the nature of the sediment in a given area from a knowledge of the bottom topography.

One of the first of many examples for testing this theory was a series of cores taken in and about the Puerto Rico Trough. The result was a complete confirmation. Two cores, about 25 miles apart, were taken on the flat floor of the trough at 7970 m. (4360 fms.) depth. Both contain a top layer about 15 cm. thick of "red" or brown clay. The average calcium carbonate content of this layer is 0.5 per cent.

Below this normal top there are in both cores three graded layers, one of which is about 200 cm. thick. The uppermost part of this graded layer is composed of clay-size particles, and is distinctly grayer than the normal top, but it is in its carbonate content of more than 36 per cent that it differs from a "typical" deep-water sediment. Downward in this layer there is a very gradual increase in particle size until near the base it becomes well sorted calcareous sand largely composed of the tests of planktonic and benthic foraminifera, small pteropods, and alcyonarian spicules. The carbonate content near the base is 74 per cent. The very shallow-water origin of some of the material is shown by occasional particles of Halimeda.

The shorter one of these two cores ends at 280 cm. still in well-sorted material of shallow-water origin. The longer one at 295 cm. re-enters normal clay of abyssal facies and a carbonate content of 0.3 per cent, thereby disposing of the theory that these layers of shallow-water material are evidence of a recent and sudden subsidence of the floor of the Puerto Rico Trough.

Two cores taken on the northern side of the trough contain only red clay, although the thicknesses penetrated are 185 cm. and 290 cm. Another core from the top of the ridge north of the trough is of "deep-water" facies throughout its length of 260 cm. in spite of the fact that the depth here is 5,011 m. (2740 fms.), that is, 2900 m. (1600 fms.) shallower than the bottom of the trough.

Cores from Northwest Atlantic mid-ocean canyon. Cores taken in and nearby Northwest Atlantic mid-ocean canyon have given more evidence of the important role the turbidity currents play in the topographic evolution of the deep-sea basins (Ewing, Heezen, Ericson, Northrop, Dorman, 1953).

In one of two cores from the canyon bed the upper 123-cm. section is composed of clay and silty clay in part as graded layers. This overlies 2 1/2 meters of well-sorted fine sand. In the other canyon bed core only 2 meters of core were recovered, consisting mostly of graded beds of silt size. There is clear evidence that about 2 meters of sand were lost from the bottom of the core.

A third core from the nearly flat western bank, 90 m. (50 fms.) above the canyon bed, contains numerous graded layers which show that fully three-quarters of the 4.6 meters total thickness was deposited by turbidity currents. Fine sand makes up only 3 per cent of the total thickness. It is inferred that the sediment deposited on the canyon banks was carried in the highest part of the turbidity currents.

Evidence in cores for turbidity currents in the cable break area. In "The American Journal of Science", December 1952, Heezen and Ewing concluded that the breaking of all submarine telegraph cables in sequence from north to south following the Grand Banks earthquake of 1929 could be explained satisfactorily only by supposing that a turbidity current generated in the epicentral area flowed southward, breaking the cables as it reached them.

In the same issue of "The American Journal of Science" Kuenen discussed the magnitude involved. From the volume and density of turbid water necessary to account for the high velocity indicated by the timing of the cable breaks, he calculated a thickness of between 40 and 100 cm. for the graded layer of relatively coarse sediment which Heezen and Ewing assumed would have been deposited over a wide area south of the cable breaks.

Since the appearance of these papers a series of cores have been taken across the southern part of the area affected by the supposed Grand Banks turbidity current in hope of confirming the predicted layer of sand which should overly more "normal" sediments.

Three of these contain a layer of graded silt and muddy sand overlying foraminiferal clay of abyssal facies. Recent deposition of the graded layers is indicated by absence of abyssal sediment overlying them. The thicknesses of the layers are 20,70 and 130 cm. A fourth core which is from the center of the cable break area is composed of 30 cm. of gravel and very coarse-grained sand.

Therefore, it is concluded that the independent evidence afforded by the cable breaks together with the evidence from the cores confirming the presence of the sand layers add up to proof of the reality of turbidity currents as powerful agents of erosion, transportation, and deposition of sediment.

MICROPALEONTOLOGY, STRATIGRAPHY, AND PLEISTOCENE CLIMATES

For the micropaleontological analyses the best species of pelagic foraminifera for a stratigraphical correlation were selected. These were found to be: Globorotalia menardii, G. men. var. tumida, G. men. var. flexuosa, G. puncticulata puncticulata, G. puncticulata hirsuta, G. truncatulinoides, G. scitula; Globigerina inflata, G. bulloides, G. pachyderma, G. eggeri, G. dutertrei; Globigerinoides ruber, G. sacculifer, G. conglobatus; Globigerinella aequilateralis, Orbulina universa, Pulleniatina obliquiloculata, Sphaeroidinella dehiscens.

It has been found that foraminifera other than those listed, and radiolaria, pteropods, and coccoliths are so far not suitable for a quick micropaleontological analysis of the cores.

It is evident that any faunal characteristic which marks a thin layer of sediment in such a way that it can be recognized in a number of adjacent cores may be of use in comparing rates of deposition from place to place. Furthermore, if the layer is not too old, a single radio-carbon date may be used to give absolute rates of deposition in a widely scattered suite of cores. With this object the coiling directions of several species of Globorotalia were studied in detail.[1] It was found that layers only a few centimeters thick are marked by abrupt changes in ratio of right coiling

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1. Bolli, H., The direction of coiling in the evolution of some Globorotaliidae, Cushman Found. Foram. Res., Vol. 1, parts 3-4, pp. 82-89, 1950.

to left coiling individuals of the widely distributed planktonic species, Globorotalia truncatulinoides. The effectiveness of this method of recognizing isochronous layers in groups of cores is shown by figures 2, 4-B and 5-B.

Recent distribution of planktonic foraminifera. With Dr. K. K. Wang, Brooklyn College, work on charts showing present distribution of planktonic foraminifera in the North Atlantic is in progress. It is hoped to have the charts ready for publication in the near future.

Knowledge of the present distribution of these species is essential to correct interpretation of the vertical faunal changes in long cores in terms of water temperature and oceanic circulation.

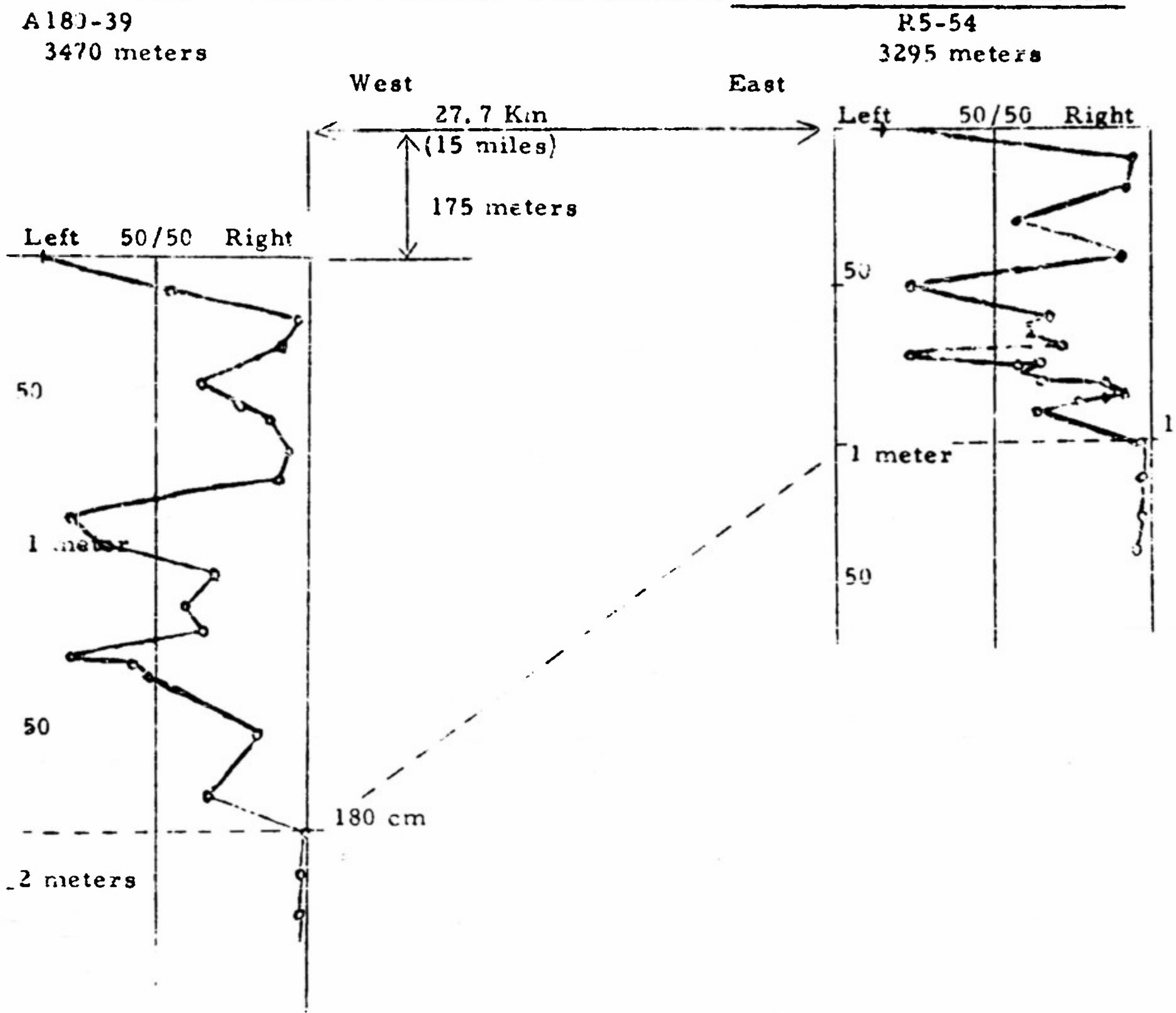
In order to be quite certain that the material described is truly Recent it is necessary to use top samples which have been relatively undisturbed by the coring tube and which have not been permitted to become mixed in transportation to the laboratory. To this end it is customary to take short gravity cores in plastic liners by means of a corer attached to the trigger weight which releases the large piston corer. In description of the Recent fauna the tops of these short cores are used in preference to the tops of the piston cores.

Tentatively, two of the conclusions of the work on present distribution of planktonic foraminifera are:

1. It is generally true that planktonic foraminifera are temperature indicators. But precautions should be taken when a species is widely distributed, and the area involved is of such great extent as the Atlantic Ocean. For instance, Globigerinoides ruber is generally considered as a

Fig. 2

CORRELATION BY COILING DIRECTION of Globorotalia truncatulinoides



Location: 220 km or 120 miles SSW of Hierro, Canary Islands, and
400 km or 215 miles WNW of Oro River, Rio de Oro.

From the correlation it is obvious that the upper 180 cm section of A180-39 is the time equivalent of the upper 100 cm in R5-54. In other words, the rate of deposition at A180-30 has been 1.8 times as fast as that at R5-54.

Both sections are composed of uniform foraminiferal lutite, quite without any silt or sand layers. Thus there is no obvious evidence of turbidity current deposition which might explain the difference in rates of deposition.

Evidently the difference in rate is not a consequence of relative distance from the source of terrigenous sediment because the more rapid deposition has taken place at that station which is more remote from the African coast.

There is no evidence for greater productivity of lime secreting organisms at A180-39. Not only is the $CaCO_3$ content of the two sections very nearly the same, but foram tests actually make up a larger fraction of the sediment in R5-54 where deposition has been slower.

That the more rapid deposition has taken place at the deeper station suggests that turbid water flowing along the ocean floor has been channeled by local topography. Whether the greater density of the water so flowing is due to the turbidity itself, or to higher salinity, lower temperature, or a combination of all three is a question. Whatever the cause, a low velocity is indicated by absence of well sorted layers, and fairly continuous flow, by the lack of distortion in the coiling curve of A180-39 as compared with that of R-54.

The importance of this process of transportation and deposition as a possible explanation for the extraordinarily smooth and nearly level plains of sediment known to fill many depressions in the North Atlantic basin needs no emphasis.

warm water indicator and not to be present in typical cold water samples. Yet it occurs commonly in the same area where Globigerina pachyderma is found abundantly, and Globigerina pachyderma is generally accepted as a cold water indicator.

2. From plotting of the data and drawing of a generalized distribution chart a definite pattern results, showing that the distribution is closely related to the warm and cold currents in the Atlantic Ocean. Recent distribution of Globorotalia menardii in the North Atlantic and the Caribbean as known from 400 widely scattered cores indicates that the clockwise current system of the North Atlantic is a more important factor in the distribution of the species than temperature alone.

To check the correspondence between the foraminiferal tests in the top layer of sediment and the animals actually living in the waters above, 210 plankton tows were made during a recent cruise. Data from the plankton samples will make a valuable supplement to the study of the core tops. In a study submitted as thesis for the degree of Master of Arts to Columbia University, Mr. Julian Kane made a preliminary survey of the distribution of planktonic foraminifera from top core samples.

Climate determinations by planktonic foraminifera. With the probability of establishing a standard section of Pleistocene sediments about 350 climatic curves have been drawn based on the proportion of the number of warm-water to cold-water foraminifera in samples from about 350 cores. Cores with evidence of turbidity currents, erosion, slumping, and re-worked older sediments are not suited for these determinations.

The most important warm-water foraminifera are considered to be Globorotalia menardii, Globorotalia menardii var. flexuosa, Pulleniatina obliquiloculata, and Sphaeroidinella dehiscens. The most important cold-water foraminifera are considered to be Globorotalia scitula, Globigerina inflata, Globigerina bulloides, and Globigerina pachyderma.

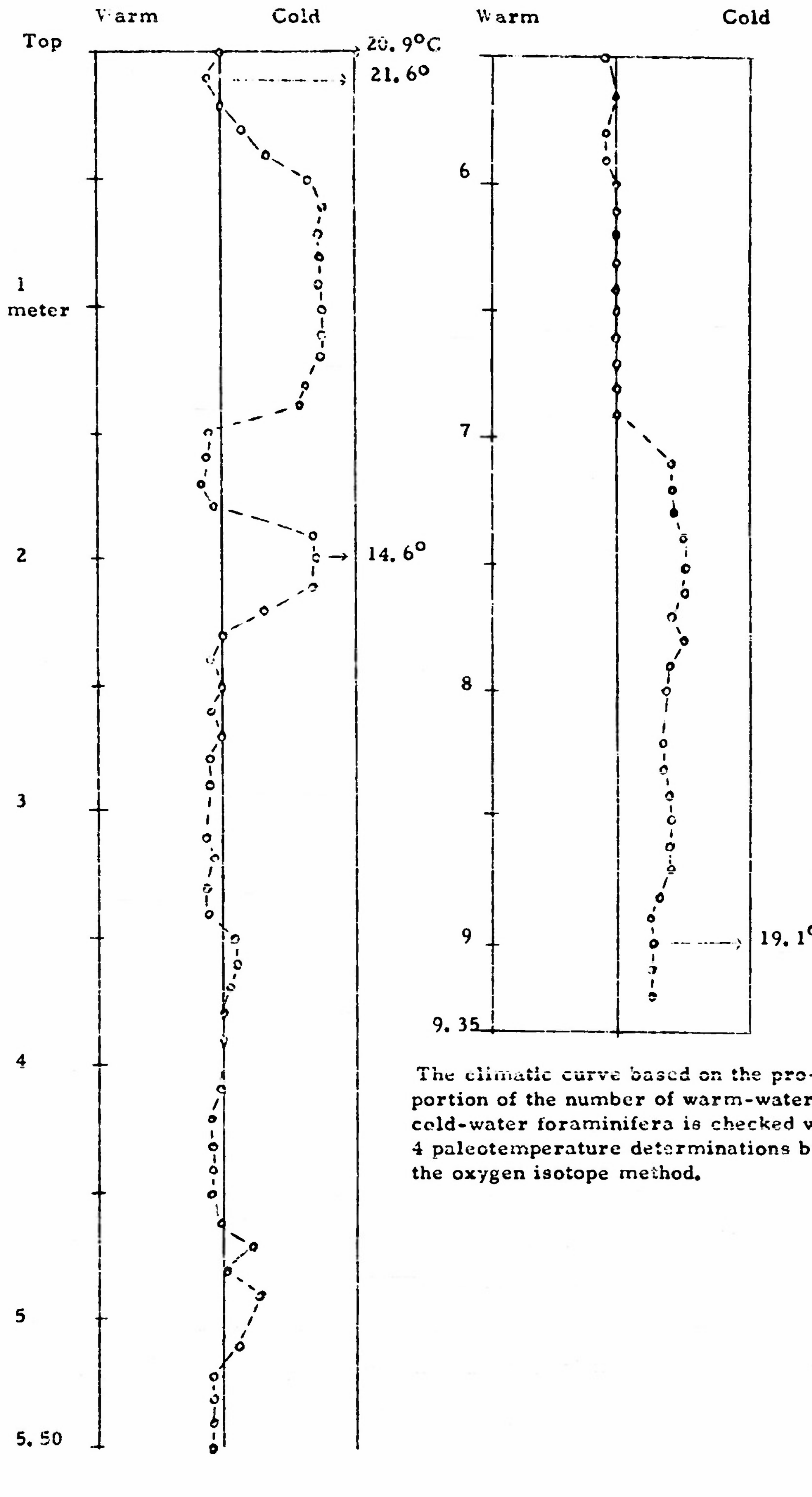
Figure 3 shows an example of a climatic curve. The core, A172-6, is from the crest of an eastern extension of the Beata Ridge in the Caribbean (14°59'N, 68°51'W). The length of the core is 9.35 m. and it is raised from a depth of 4160 m. (2275 fms.). The core is composed of uniform foraminiferal lutite and gives evidence of continuous normal deposition. This core and five others taken along a NW-SE profile from Hispaniola to a point north of Aruba show satisfactory correlation of climatic zones as deduced from the planktonic foraminifera. All pass through a zone of cool-water species corresponding to the Wisconsin glacial stage and into a zone containing a warm-water assemblage characterized by an abundance of Globorotalia menardii flexuosa (Koch). Evidently this corresponds to the Sangamon interglacial stage. Core A172-6 alone is long enough to penetrate the Sangamon and enter a lower zone of cool-water species equivalent to the Illinoian glacial stage.

Figures 4-A and B and 5-A and B show the correlation of the climatic curves as well as the correlation by coiling direction of Globorotalia truncatulinoides.

The four cores, A180-72, A180-73, A180-74, A180-76, are taken near the equator about half way between Africa and South America. The

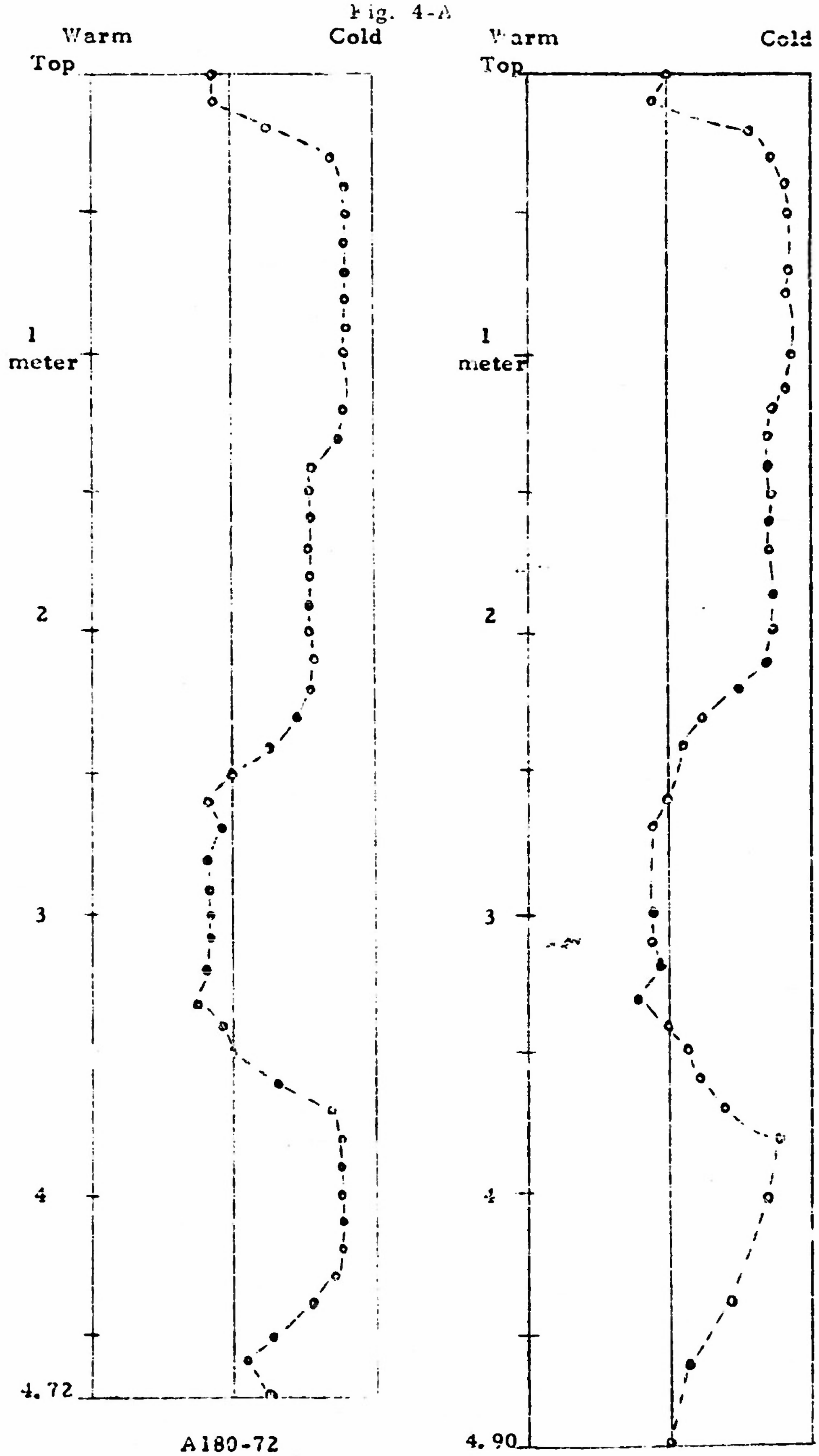
Fig. 3

Core A172-6 (14°59'N, 68°51'W; Depth 4160 m or 2275 fms)



The climatic curve based on the proportion of the number of warm-water to cold-water foraminifera is checked with 4 paleotemperature determinations by the oxygen isotope method.

Fig. 4-A

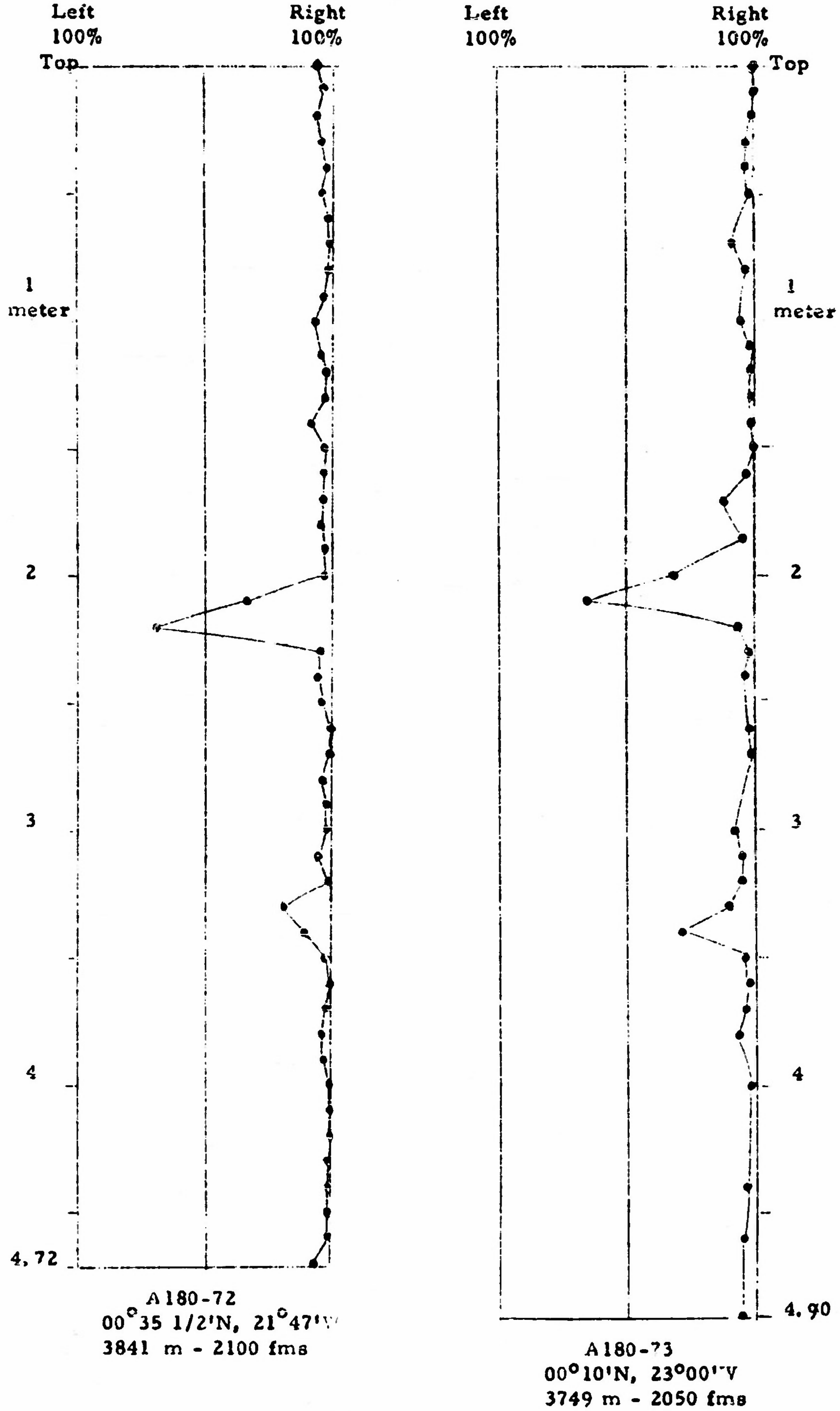


A180-72
00°35 1/2'N, 21°47'W
3841 m - 2100 fms

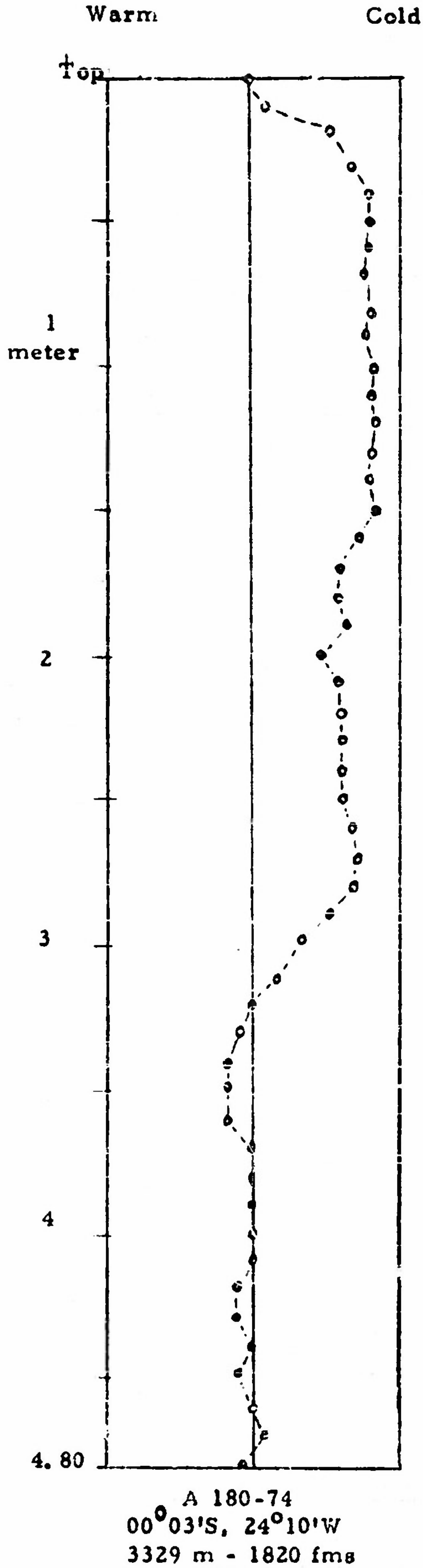
A180-73
00°10'N - 23°00'W
3749 m - 2050 fms

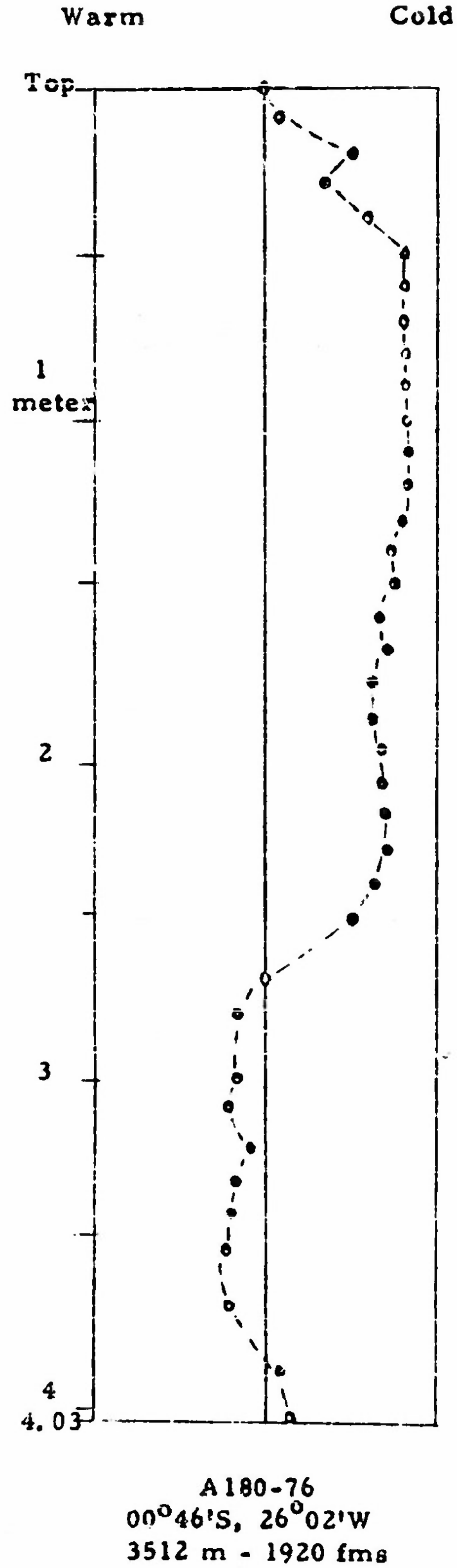
Correlation by
climatic curves

Fig. 4-B



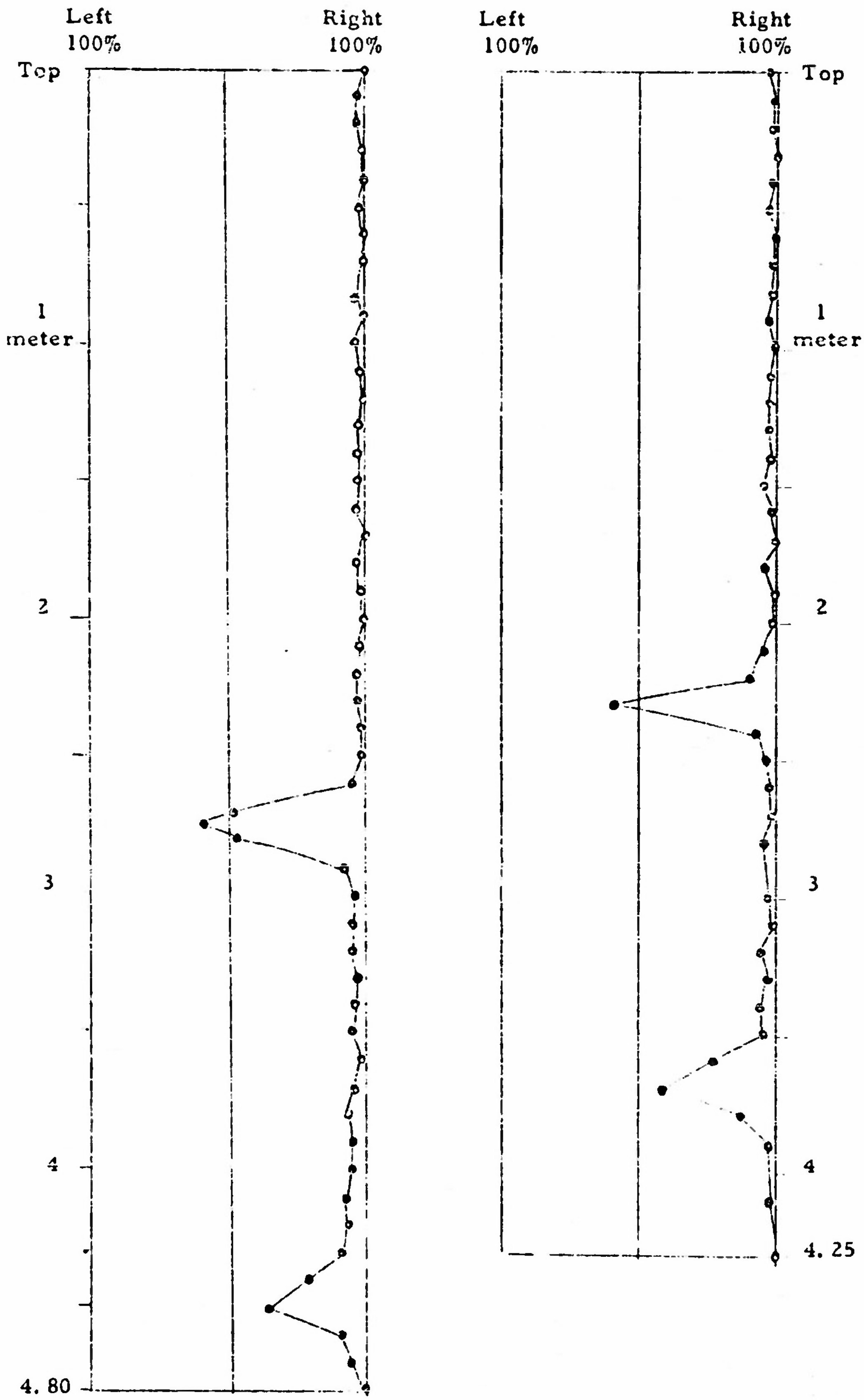
Correlation by coiling direction
of Globorotalia truncatulinoides





Correlation by
climatic curves

Fig. 5-B



A 180-74
$00^{o}03'S$, $24^{o}10'W$
3329 m. - 1820 fms.

A 180-76
$00^{o}46'S$, $26^{o}02'W$
3512 m. - 1920 fms.

Correlation by coiling direction
of <u>Globorotalia truncatulinoides</u>

locations are in order of the cores: 00°35'N, 21°47'W; 00°10'N, 23°00'W; 00°03'S, 24°10'W; 00°46'S, 26°02'W.

A180-72 is 4.72 m. long and is raised from a depth of 3840 m. (2100 fms.); A180-73 is 4.90 m. long, depth 3750 m. (2050 fms.); A180-74 is 4.80 m. long, depth 3330 m. (1820 fms.); A180-76 is 4.25 long, depth 3515 m. (1920 fms.).

All four cores are composed of uniform foraminiferal lutite. The deposition seems to have been continuous and normal. In none of the cores is there any obvious evidence of turbidity currents, erosion, slumping, or re-worked older sediments.

The study of several hundred cores has shown that well-defined faunal zones occur in the Pleistocene section deposited along the path of the present clockwise current system of the North Atlantic.

Throughout the area of Gulf Stream circulation the cores, if sufficiently long, pass through a cold water zone in which Globorotalia menardii menardii is rare or absent, and then through a warm water layer containing G. menardii flexuosa in abundance and into a lower zone containing a meager assemblage of cold water species. Correlation from core to core is confirmed by the remains of other organisms and by changes in the coiling direction of Globorotalia truncatulinoides. There is good evidence that the layers with few or no Globorotalia menardii were deposited during times of Pleistocene glaciation. It is noteworthy that these layers are well defined in cores from the Caribbean and easy to correlate with cores from the equatorial Atlantic some 6000 kilometers (3800 miles) away as well as with cores from the northern Atlantic.

This is regarded as amounting to proof that the zones in question are due to important changes in ecological conditions during the Pleistocene, and not to purely local concentrations of the empty tests by various kinds of bottom scour.

Vertical distribution of G. men. in the cores gives no evidence of a southern shift of the current system during Pleistocene glacial stages. Instead, drastic reduction of volume of flow or even complete cessation of flow is indicated by the simultaneous disappearance of G. men. throughout the North Atlantic.

In order to check the record of climatic changes as inferred from planktonic foraminifera paleotemperature determinations by the oxygen isotope method are being made of several of the Caribbean cores at the Institute for Nuclear Studies, the University of Chicago, under the direction of Dr. Harold C. Urey, and Dr. Cesare Emiliani.

The isotope analyses of core A172-6 (See figure 3) gave the following results:

Sample	Analysis	Temperature
	0/00	°C
Top	-0.99	20.9
10 cm.	+1.16	21.6
200 cm.	+0.41 (+0.42)	14.7 (14.6)
900 cm.	-0.58	19.1

These results confirm the relative temperatures inferred from the foraminiferal assemblages. Oxygen isotope temperature determinations on samples from other cores have also been in reasonably good agreement with the relative temperatures deduced from the foraminifera.

<u>Climatic Optimum</u>. In a core, R10-10, length 4.15 m. (13.5 ft.), depth 4755 m. (2600 fms.), from 185 kilometers (114 miles) east of the Mid-Ocean canyon the post-Wisconsin layer was found to be unusually thick and contained foraminifera indicating a climate markedly warmer than the present. A radiocarbon (C^{14}) age determination was made on a section between 60 and 70 cm. by the geochemistry laboratory at the Lamont Geological Observatory. It was found to be about 5000 years old (See figure 6) This indicates an extraordinarily rapid rate of accumulation for the depth and distance from the continents. It is important to notice that this relatively thick sedimentary sequence shows no disturbance and contains evidence of normal deposition in the form of "worm" burrows and regular alternations of microfaunal changes. It is probable that this core was taken from the bottom of a closed basin in which turbid water collects.

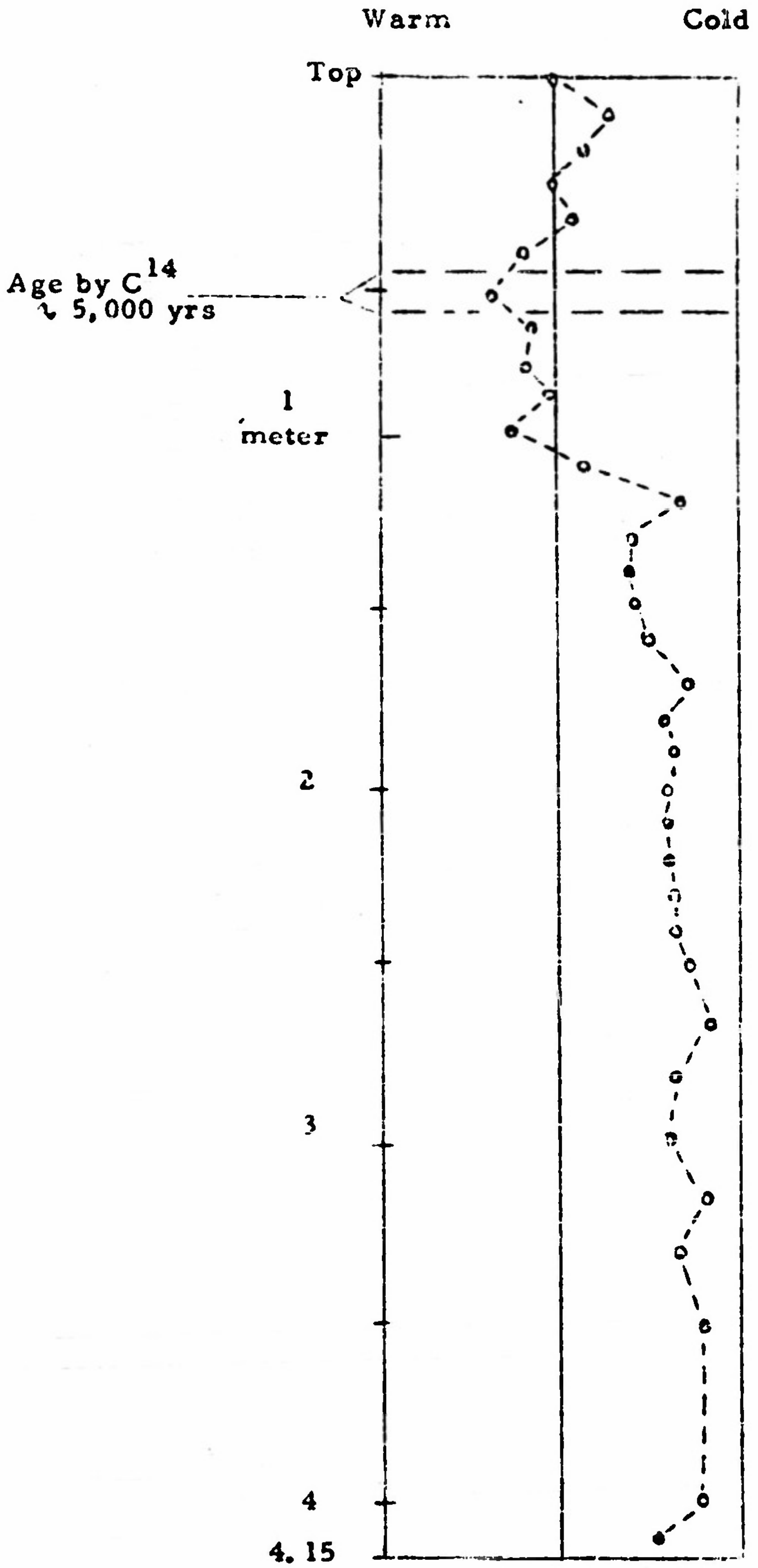
The sample for age determination was purposely taken between 60 and 70 cm. because of the probability that the zone of warmer climate corresponded to the so-called Climatic Optimum of between 4000 and 6000 B. P. Cores such as this when analyzed in detail may be expected to give a fairly complete record of the climatic changes which have taken place since the close of Wisconsin time, that is during the last 10,000 years.

<u>Diatoms</u>. Top samples from about 400 cores have been studied by Mr. Horace G. Barber, Warwickshire, England. Mr. Barber came to the following conclusions in a letter to the laboratory:

Fig. 6

R10-10

41°24'N, 40°06'W
4755m - 2600 fms



Age of the Climatic Optimum within a climatic curve by C^{14} determination.

"Generally speaking the material has a very low content of diatoms and limited to a relatively small number of species. Considering the material is classed as 'Recent Marine' one would expect the frustules to be quite robust and perfect but this is not the case for many are fractured and are only feebly endowed with silica. I can only presume the regions from which the materials were gathered are not productive to diatoms as are the two Arctic seas."

The following species were determined:

Coscinodiscus radiatus
Coscinodiscus robustus
Coscinodiscus lineatus
Coscinodiscus denarious
Coscinodiscus occulus iridis
Coscinodiscus excentricus var. major
Coscinodiscus subtilis
Coscinodiscus gigas
Coscinodiscus excentricus
Coscinodiscus perforatus

Triceratium arctium
Triceratium favus
Hyalodiscus stelliger
Hyalodiscus subtilis
Actinoptychus glabratus
Actinoptychus ralpii
Actinoptychus vulgaris
Melosira sulcata
Navicula lyra
Euodia atlantica
Cocconeis sp.

Radiolarians. Dr. W. R. Riedel, Scripps Institution of Oceanography, is studying the radiolarian assemblages of several samples from cores.

Pollen. To find and investigate pollen Dr. Edward Smith Deevey, Jr., Yale University, has received a series of samples from two cores.

Sediments older than Pleistocene. About 40 cores examined at the laboratory have been found to contain sediments which were deposited before the Pleistocene. One of these taken on the edge of the Blake Plateau contains foraminifera of Lower Cretaceous age.

Although reworked shells of extinct organisms are not uncommon in cores containing graded sand layers of Pleistocene or Recent age, there is good evidence that the sediments in these 40 cores are undisturbed and in the place of original deposition.

For conclusions based on the occurrence of these older sediments see "Turbidity Currents and Sediments in the North Atlantic", Ericson, Ewing, Heezen, 1952, Am. Assoc. Petrol. Geol. Bull., vol. 36, pp. 489-511.

Dr. Alfred R. Loeblich, Jr., Associate Curator, Division of Invertebrate Paleontology and Paleobotany, Smithsonian Institute, U.S. National Museum, is describing for publication the Lower Cretaceous foraminifera in a core, A167-25, from the Blake Plateau.

GEOCHEMICAL INVESTIGATION

Carbonate analyses. The carbonate analyses which give especially the values of $CaCO_3$ content of the sediments define to some extent the lithologic nature of the sediment in question. Over 300 analyses have been made.

For the purpose of this report the following values are selected from a core composed of foraminiferal lutite: at the top of the core the $CaCo_3$ content was 30%, at 60 cm. 34.3%, at 90 cm. 32%, at 110 cm. 22.8%, at 140 cm. 37.8%.

No final conclusions have been made.

Natural radiocarbon (C^{14}) measurements. Under the direction of Dr. J. L. Kulp C^{14} age determinations are made on selected samples from the upper parts of cores at the geochemistry laboratory, Lamont Geological Observatory. (See under Climatic Optimum.) The method permits relatively precise age determination from the present back to about 30,000 years.

Ionium method. This method of age determination is based on the relative amounts of Uranium, Ionium, and Radium in deep sea cores. The experimental data consist of the variation of the radium content as a function of depth in a sediment.

Measurements are being made on a variety of cores at the geochemistry laboratory, Lamont Geological Observatory, in an attempt to determine the type of core on which reliable ages can be obtained (Kulp, Volchok, Holland, Ericson, 1952).

Absolute surface area studies. Since the surface area of deep sea sediments will directly determine the amount of adsorption of ions from ocean water, the relative constancy of surface for a particular sediment type is being investigated at the geochemistry laboratory, Lamont Geological Observatory.

Preliminary results indicate that the surface areas are directly related to adsorbed radium on cores which are useable for Ionium method dating.

Paleotemperature determinations. Samples of planktonic foraminifera from climatic zones, as inferred from the foraminiferal assemblages, in several cores from the Caribbean have been submitted to Drs. H. C. Urey and C. Emiliani at the Institute for Nuclear Studies, the University of Chicago, for temperature determination by the oxygen isotope method. The temperatures found in 5 cores fully confirmed the relative temperatures inferred from the species present in the various assembiages. (For the result of one core see fig. 3 and under Climate determinations by planktonic foraminifera.)

Since this method is not limited by the age of the material and requires no more than a few milligrams of calcium carbonate, it promises to be of much value in the correlation of faunal zones from core to core, and should help to establish standard faunal sequences for the various regions of the Atlantic Ocean.

Organic content. Dr. P. V. Smith, Jr., of the Esso Laboratories, Standard Oil Development Company, has completed the extraction and analysis of four dredge samples off the coast of Africa. The purpose of the study was to gain knowledge of the conditions and processes involved in the formation of petroleum deposits. In a letter to Mr. B. C. Heezen, Dr. Smith came to the following generalizations:

1. The continental shelf sample had more carbonate carbon and less organic carbon than any of the three slope samples.

2. The amount of extractable organic matter increased with increasing water depth.

3. The percentage of hydrocarbons in the extracted organic matter decreased with increasing water depth.

4. As a consequence, the total hydrocarbon content of each of the four samples is just about the same.

5. Paraffin-naphthene and aromatic hydrocarbons were present in all four samples.

Chemical and spectographic analyses. A complete series of chemical and spectographic analyses has been made by Dr. G. E. Hutchinson, Yale University, on samples from three cores taken in the western part of the Atlantic Ocean. Some of the results have been submitted to the Committee on the Chemical Composition of Sediments.

About 40 samples from different cores were sent to Dr. W. W. Moorehouse, University of Toronto. On these samples Mr. Bradshaw has made spectographic determinations of nickel, chromium, cobalt, vanadium and boron.

California Research Corporation is making a spectographic analysis, with special emphasis on titanium, on the top samples from about 350 cores.

Quarters of 56 cores from the Gulf of Mexico are being studied in detail at the Field Research Laboratories, Magnolia Petroleum Company, Dallas, Texas.

PHYSICAL MEASUREMENTS

Mechanical analyses. Numerous mechanical analyses have been made with the aim of obtaining more exact information on the grain size distribution of the sediments. These analyses have given more information on the graded nature of the deep-sea sands deposited by turbidity currents. The plans are to make more mechanical analyses.

Furthermore, 34 samples of silt and sand are being analyzed by Dr. Wilbur Valentine, Brooklyn College.

Density measurements. Density measurements of 65 samples taken from 11 different cores have been made. In spite of the fact that the densities changed at different depths of the cores and from core to core there was no sign of a distinct relationship between location, depths, and lithological composition of these cores.

In order to give an idea of the density of the sediments in question it is mentioned here only the highest value of 2.14 at 130 cm. (dark gray lutite) in a core from 1280 m. (700 fms.) depth, and the lowest value 1.32 at the top of a core (brownish lutite with worm burrows and foraminifera) from 4700 m. (2570 fms.) depth.

It seems possible that if more samples were measured several relationships could be detected.

Sound velocity measurements. In order to find out if the sound velocity through cores could be determined with an ultrasonic pulser 5 tests have recently been made. The velocity determinations were made by the section of seismology at the Lamont Geological Observatory on the basis of the core analyses made at the core laboratory. These are the data from the testing:

The velocity through brown, slightly muddy, fine quartz sand from a depth of 2840 fms. (5190 m.) was 5400 ft/sec. (1650 m/sec.).

One core section from 350 fms. (600 m.) contains green medium sand, slightly muddy, poorly sorted, with shells of foraminifera and other calcareous debris making up about half of the sediment, the remainder and finer fraction being mostly quartz; through this type of sediment the velocity was 5300 ft/sec. (1615 m/sec.).

The velocity through gray,rather muddy, poorly sorted, very fine sand, mostly quartz, was 5250 ft/sec. (1600 m/sec.); the core was from a depth of 735 fms. (1435 m.).

Through light chocolate brown lutite, very uniform, with a median particle diameter of 1 1/2 microns from a depth of 2900 fms. (5310 m.) the velocity of sound was 4920 ft/sec. (1500 m/sec.).

The last core section which was tested contained uniform dark gray lutite. This sediment has a larger calcium carbonate content and greater median particle diameter than the chocolate brown lutite (also called "red clay") mentioned above. The density of this core section was 1.31, and water content: 57% by weight and 74.8% by volume. The core was from a depth of 2610 fms. (4700 m.). The velocity of sound through this last tested core section was 4670 ft/sec. (1425 m/sec.).

The frequency of the ultrasonic pulses was about 65,000-200,000 cps. The accuracy of these preliminary measurements is about 5%.

The data are important for the understanding of the transmission and reflection of sound. Perhaps these sound velocities are also typical of a specific stratigraphical interval.

The plans are that an ultrasonic pulser will be installed on the research vessel which belongs to the Observatory and the velocity of sound should be measured through all the cores that are obtained.

PETROGRAPHY

Clay minerals. The clay mineralogy of three cores is being studied by Dr. Maurice C. Powers, the Johns Hopkins University, Baltimore. Top and bottom samples of two of the cores (location: 37°01 1/2' N. 74°27 3/4'W and 36°08'N, 68°55'W) have been analyzed. In a letter to the laboratory Dr. Powers came to the following conclusions:

"All of the samples contain the same type and amount of clay minerals. There may be just a slight trace of kaolinite present, but the dominant minerals are an illite and a chlorite-like material. The chlorite-like mineral may be forming from a montmorillonoid or a degraded illite or chlorite. I have been able to definitely establish that the chlorite-like mineral becomes stable to higher temperatures as distance from shore is increased. The increase in thermal stability with distance from shore is almost certainly due to a more perfect organization and growth of the chlorite crystal. I may summarize by saying that the sample consists of clay-size quartz particles (less than 10%), illite (about 30%), and a "swelling" chlorite mineral (60%)."

A series of photographs of samples from nine cores has been made at the Electron Microscope Laboratory, Columbia University.

Mr. Abdullah Sayyeb of the Department of Geology, Indiana University, is studying a series of samples from five cores by means of complete mineralogical analyses of the clays and sands.

Series of samples from six cores are being studied by Mr. M. N. Hill, Department of Geodesy and Geophysics, Cambridge University, England. He is investigating the physical properties of deep sea clays.

Volcanic ash zones. A series of samples of volcanic material from deep sea cores is being studied by Professor Erik Norin, Mineralogiska Institutet, Uppsala, Sweden.

Meteoritic dust. About 50 meteoritic spherules have been found in the cores. Several were studied by Dr. J. D. Buddhue, Institute of Meteoritics, University of New Mexico. These have been described in the monograph "Meteoritic Dust", J. D. Buddhue, The University of New Mexico Press, 1950.

Rocks. A collection of several hundredweights of boulders dredged from depths approaching 4575 m. over the Mid-Atlantic Ridge has been analyzed by Dr. S. J. Shand, Columbia University. Some of these boulders are of limestone and the large proportion consists of eruptive rocks referable to the groups holocrystalline gabbroic rocks, basalts (pillow lavas) with and without olivine, and serpentines. The knowledge of composition of the Mid-Atlantic Ridge has been derived hitherto from the islands and island groups which are scattered at long intervals along its course. On these islands the dominant rock is basalt. According to Dr. Shand the collection confirms the predominance of basalt and makes at least two notable additions to the record, namely an abundance of serpentine and a mylonitized gabbro. (For detailed description and analyses see "Rocks of the Mid-Atlantic Ridge" by S. J. Shand, Jour. Geol. vol. 57, pp. 89-92, 1949; and "Age of a Mid-Atlantic Ridge Basalt Boulder", D. R. Carr and J. L. Kulp, Geol. Soc. Am. Bull., vol. 64, pp. 253-254, 1953.)

Dr. H. H. Hess, Princeton University, has analyzed "black sand" leached out of limestone which was obtained in cores from south of Bermuda. In a letter to the laboratory Dr. Hess describes it as "Perovskite, Fi-garnet (melanite), black magnetic opaque material probably titaniferous magnetite and nearly opaque rounded grains of deep red brown color which probably are rutile."

From the 200 fms. (366 m.) seamount east of the Atlantis Seamount ($34^{\circ}08'$ N, $30^{\circ}14'$ W) there was dredged about half a ton of flat calcareous rocks composed primarily of foraminifera, pteropods and bryozoa. The rocks are quite well cemented and appear on underwater photographs to be eroded, rounded fragments of the formation which undoubtedly underlies the truncated top of the mount. At present the temperature at the surface in this area is about 22°C and the temperature near 200 fathoms is about 12° C.

Dr. C. Emiliani, the University of Chicago, has made paleotemperature determinations by the oxygen isotope method on a sample of these rocks. The benthonic foraminifera gave a temperature of 16.8±0.5°C.

A radiocarbon (C^{14}) age determination was made on a sample of the rocks by Dr. J. L. Kulp, Lamont Geological Observatory. It was found to be 12,000±900 years.

The age of the rock, 12,000±900 years according to Kulp, agrees reasonably well with that of the Two Creeks or Allerød phase, which Libby[1] found to have an average age of 11,400±350 years. At that time

1. Willard F. Libby, Radiocarbon Dating, U. of Chicago Press, 1952, p. 88.

of warmer climate sea level ought to have been somewhat higher than it became shortly afterward when the ice sheets re-advanced. Such a lowering of sea level following deposition could very well account for the cementation of the rock and subsequent fragmentation by surf. The temperature, 16.8°, offers no serious objection to this interpretation.

PUBLICATIONS

Ericson, D. B., M. Ewing and B. C. Heezen, Deep-sea sands and;submarine canyons. Bulletin of the Geological Society of America, vol. 62, pp. 961-965, 1951.

Ericson, D. B., M. Ewing and B. C. Heezen, Turbidity currents and sediments in North Atlantic, Bulletin of the American Association of Petroleum Geologists, vol. 36, pp. 489-511, 1952.

Ericson, D. B., North Atlantic deep-sea sediments and submarine canyons, Transactions of the New York Academy of Sciences, pp. 50-53, Dec., 1952.

Kulp, J. L., H. L. Volchok, H. D. Holland and D. B. Ericson, Thick source alpha activity of North Atlantic cores, Journal of Marine Research, XI, pp. 19-27, 1952.

Ewing, M., B. C. Heezen, D. B. Ericson, J. Northrop and J. Dorman, Exploration of the Northwest Atlantic mid-ocean canyon, Bulletin of the Geological Society of America, vol. 64, pp. 865-868, July 1953.

Ericson, D. B., Deep-sea cores and currents in the Pleistocene North Atlantic; will be delivered at the meeting of the Geological Society of America, November 10, 1953.

Ericson, D. B., B. C. Heezen and M. Ewing, Further evidence for turbidity currents from the 1929 Grand Banks earthquake; will be presented by Ericson at the meeting of American Association for the Advancement of Science in Boston, December 30, 1953.

Ericson, D. B., Correlation by coiling direction of Globorotalia truncatulinoides; submitted for publication.

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