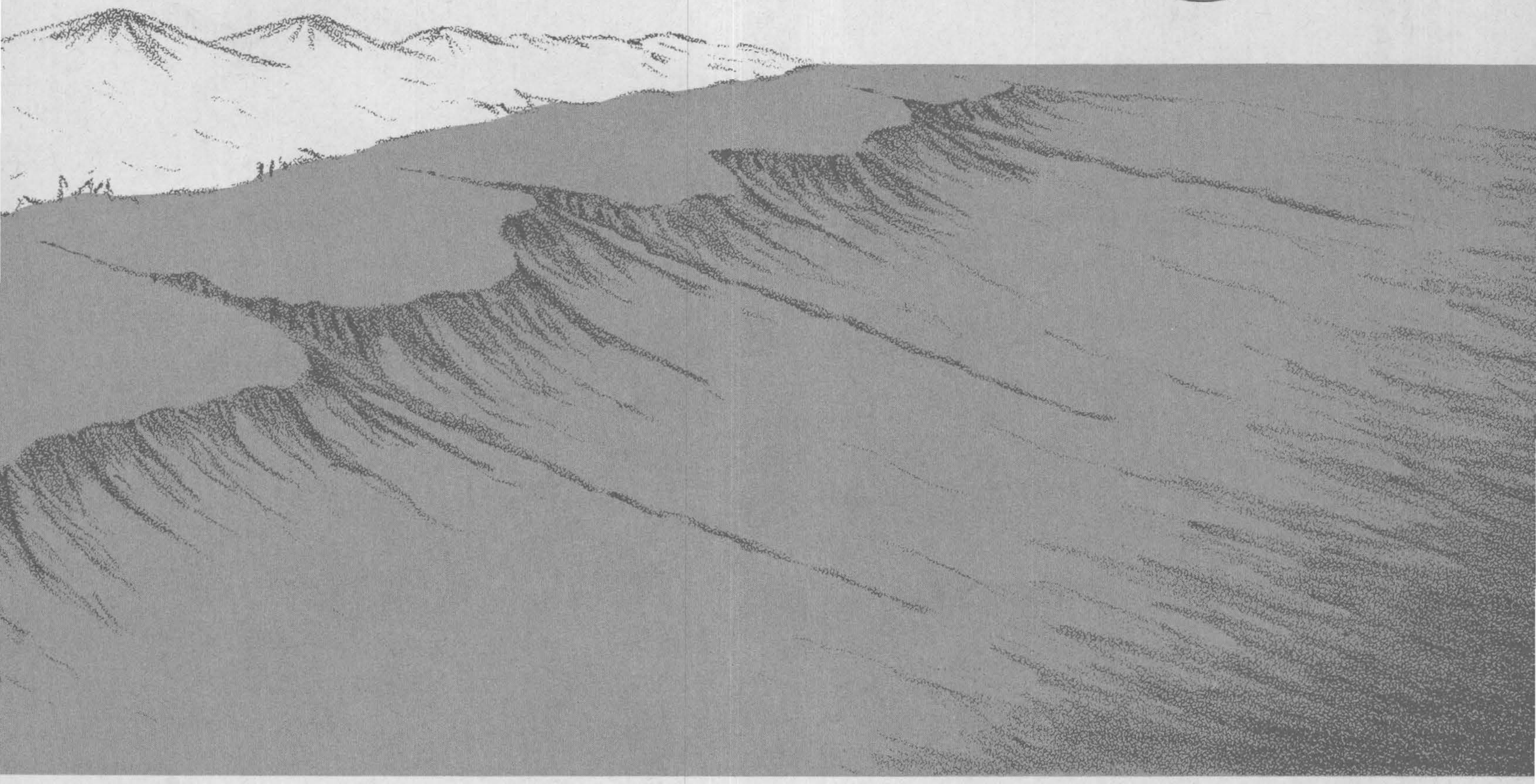
Atlantic Continental Shelf and Slope of the United States



Physiography and Sediments of the Deep-Sea Basin

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-B

Atlantic Continental Shelf and Slope of The United States— Physiography and Sediments Of the Deep-Sea Basin

By RICHARD M. PRATT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-B

A summary of the environment of terrigenous and carbonate sedimentation in the deep-sea basin off the east coast of the United States

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1968

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1 (paper cover)

CONTENTS

	Page
Abstract	B1
Introduction	1
Purpose and scope	1
Previous work	2
Acknowledgments	2
Geologic setting	3
Topography	4
Continental slope	5
Sohm Plain	7
Hatteras Plain	9
Nares Plain	14
Blake Basin	16
Blake Plateau and Bahama Banks	19
Bermuda Rise	22
Sediments	B23
Terrigenous sediments	25
Carbonate sediments	26
Glacial sediments	28
Authigenic sediments	30
Eolian sediments	37
Rates of sedimentation	37
Structure	40
Conclusions	40
Sources of data used in compiling the topographic charts	41
References	42

ILLUSTRATIONS

		Page
PLATE 1.	Map showing deep-sea topography off the Atlantic coast of the United States	In pocket
FIGURE 1.	Map showing density of sounding tracks used in compiling the topographic chart (pl. 1)	B4
2.	Profile down the continental slope south of Nantucket	5
3.	Echo-sounding profile of subdued section of the continental slope south of Block Island	6
4.	Graph showing relation of sediment size and calcium carbonate content to topography near Hydrographer Canyon	7
5.	Profile of Mid-Ocean Canyon in Newfoundland Basin	8
6.	Profile showing the abrupt interruption of Sohm Plain by one of the seamounts of the New England Seamount Chain	9
7.	Projected profile of the New England Seamount Chain	10
8.	Map showing the contact of the Sohm Plain with surrounding steeper topography	11
9.	Cross sections constructed from the topographic chart (pl. 1)	12
10.	Profile showing the flat-floored sediment valleys at the southernmost extremity of the Sohm Plain	13
11.	Profile illustrating subbottom penetration on a flat plain	13
12.	Oblique profile of Hudson Canyon across the continental rise	14
13–15.	Profile showing:	
	13. Wilmington Canyon near its end on the continental rise	15
	14. The depositional front of the present-day Hudson Fan leading to the Hatteras Plain	15
	15. A sequence of channels and associated levees at the north end of the Hatteras Plain	16
16.	Profile illustrating the continuous subbottom reflecting horizon on the Hudson Fan	16
17–19.	Profile showing:	
	17. A depression near Muir Seamount	17
	18. A sedimentary contact between the Hudson Fan and the Bermuda Rise	18
	19. Channellike depression at the base of the Bahama Escarpment near Eleuthera	18
20.	Perpendicular profile across the Blake Ridge	19
21.	High-resolution echogram illustrating subbottom reflectors on the Blake Ridge	20
22.	Map showing the detailed topography of an area of small depressions on the Blake Plateau	20
23.	Bottom photograph illustrating factors that denote strong currents on the Blake Plateau	21
24.	Profile showing the irregular rolling topography on the Bermuda Rise south of Bermuda Island	23
25.	Map of diagrammatic summary of factors influencing sedimentation off the east coast of the United States	24
26.	Map showing locations of described sediment samples collected off the east coast	26
27.	Photograph of cores containing graded beds of sand and silt from the Sohm Plain	27

		Page
FIGURE 28.	Graph showing the relation of sand content to distance from the shelf break in cores collected off New England	B28
29.	Bottom photograph of terrigenous sediment on the continental rise south of New England	29
30.	Map of distribution patterns of calcium carbonate in the North American Basin	30
31.	Photograph of *Globigerina* ooze on the flank of Rehoboth Seamount	31
32.	Bottom photograph of calcareous sand on the flat top of Muir Seamount	32
33.	Bottom photograph of well-sorted globigerinid-pteropod sand on the Blake Plateau	33
34.	Photograph of recent and indurated pteropod ooze from neighboring samples on the Blake Plateau	34
35.	Bottom photograph of coral debris on the Blake Plateau	35
36.	Bottom photograph of glacially derived sand and cobbles on the side of Mytilus Seamount	36
37.	Photograph of manganese oxide encrustation on Rehoboth Seamount	38
38.	Photograph of samples of coral from Muir Seamount showing progressive encrustation by manganese oxide	39

ATLANTIC CONTINENTAL SHELF AND SLOPE OF THE UNITED STATES—PHYSIOGRAPHY AND SEDIMENTS OF THE DEEP-SEA BASIN[1]

By Richard M. Pratt, Woods Hole Oceanographic Institution

ABSTRACT

The major topographic features, or provinces, beyond the continental slope off the Atlantic coast of the United States are (1) Sohm Plain, (2) Hatteras Plain, (3) Nares Plain, (4) Blake Basin, (5) Blake Plateau–Bahama Banks, and (6) Bermuda Rise. The whole of the described area is commonly referred to as the North American Basin. This basin is bounded on the north by Newfoundland Ridge and on the south by Puerto Rico Trench. Topographic features of note within the basin are the divide and the area of depressions between Sohm and Hatteras Plains, the sharply crested Blake Ridge, and the Puerto Rico Ridge.

Recently accumulated data on deep-sea cores has given good evidence that the silt and sand covering the abyssal plains are displaced continental sediments in a virtually quartz-free oceanic environment. These sediments were deposited on a primary volcanic bottom. The primary or volcanic bottom is characterized by abyssal hills and seamounts, and the sediment bottom is characterized by abyssal plains, which extend seaward from the continental margins. The picture that has evolved from the study of topography and sediments off the east coast of the United States is one of eastward transport and deposition of terrigenous sediments on and around primary abyssal hill and seamount topography of the sea floor.

Because the ocean basin is a vast basin of sedimentation, most minor topographic features and even many of the gross features should be considered as constructional landforms in marked contrast to the surface of the continents where erosional factors are most important in molding the landscape. Types of sediments entering the marine environment, therefore, and various processes of sedimentation are important in the formation of the topography of the ocean floor.

Three main types of sedimentary environment are found along the continental margin of the east coast: glacial in the north, terrigenous in the Middle Atlantic area, and carbonate in the south. These sediment distribution patterns can also be traced into the deep-sea basins even to their most seaward extension.

The glacial sedimentary distribution pattern was caused by Pleistocene glaciation in the northern part of the region. Eustatically lowered sea levels resulted in accelerated erosion and in the distribution of sediment directly into the ocean basins. Sediment was also distributed into the ocean by glacial outwash and ice rafting.

Terrigenous sediments have filled the marginal ocean basins off the middle part of the east coast and have spread out across the abyssal plains; they have been transported largely through the mechanism of turbidity currents. They form a graded system extending from the continental slope seaward to the limits of the abyssal plains. Submarine canyons are part of the system and serve the important function of channeling the sedimentary material from the continental platform into the ocean basins. The fill of terrigenous sediment extends all the way to the southern arm of the Sohm Plain between Bermuda and the Mid-Atlantic Ridge, where the Sohm Plain is very flat and consists of terrigenous clay and silt. The Nares Plain receives terrigenous sediment through Vema Gap from the Hatteras Plain.

The Blake Plateau and Bahama Banks to the south are a carbonate province characterized by very thick accumulations of limestone and Recent calcareous sediment. Accretion of the carbonate deposits into steep-sided banks and limited sediment distribution into the adjacent deep-sea basins have resulted in escarpments that form sharp boundaries with the adjacent marginal deeps.

Sediment distribution has also been influenced by various ocean currents.

The terrigenous and carbonate sediments are part of the sedimentary fill of what is referred to by some workers as the east-coast geosyncline.

INTRODUCTION

PURPOSE AND SCOPE

The present study is a sumary of the widely scattered information on the sedimentary environments of the North American Basin off the east coast of the United States. It is an extension of a joint study of the continental shelf and slope by the Woods Hole Oceanographic Institution and the U.S. Geological Survey (Emery, 1966).

Knowledge of sedimentation in ocean basins has progressed to the point where classic geologic concepts can be applied to submarine processes, and analogies can be drawn between submarine features and these more easily studied features on land. Every submarine hill and valley should be explainable in the light of processes at work on the ocean floor, just as every hill and valley on land should be explainable by the processes of erosion and deposition superimposed on the structural framework. Furthermore, interpretations of the history and structure of the continental shelf and slope can be made from a study of the topography and sediment ac-

[1] Contribution 1820 of the Woods Hole Oceanographic Institution, based on work done under a program conducted jointly by the U.S. Geological Survey and the Woods Hole Oceanographic Institution and financed by the U.S. Geological Survey.

cumulated in the adjacent basins. The topographic chart (pl. 1) indicates that comprehensive analysis of land-derived sediments along the east coast must be carried to depositional limits on the abyssal plains.

In discussing the topography off the east coast an effort has been made to avoid new names or terms. The names used in this paper to designate sea-floor features are those approved by the Board on Geographic Names and its Advisory Committee on Submarine Features. A recent general discussion of the topography of the deep-sea floor by Heezen and Menard (1963, p. 236) summarized previous thoughts on submarine terminology.

The general compilation of topography has been carried out in meters although the source data are all in fathoms. It is not practical to change the scale lines on the original echo-sounding profiles, some of which are illustrated in text; in practice oceanographers have learned to tolerate and think in the dual system.

PREVIOUS WORK

Previous work on the sediments off the Atlantic coast can be grouped into early (1850–1940) and recent (1940–65) periods. Early work, initiated by the U.S. Coast and Geodetic Survey in the mid-19th century, was oriented toward charting the coastal region but included sampling and biological analysis as described by Agassiz (1888). Results of early studies of sediments on the continental shelf were recently summarized by Uchupi (1963). To Murray and Renard (1891) and their report on the bottom-sediment samples taken by the H.M.S. *Challenger*, we owe our basic knowledge and classification of deep-sea sediments. Later, Murray and Chumley (1924) added to this knowledge by publishing a description of 1,400 samples from the Atlantic Ocean. Murray's best topographic descriptions appeared in "The Depths of the Ocean" (Murray and Hjort, 1912). Except for routine depth surveys and some bottom sampling along submarine cable routes (Bramlette and Bradley, 1941), few geological investigations were undertaken between the exploratory investigations of Agassiz (1888) and Murray and Renard (1891) and those begun during World War II to meet military needs.

In the late 1940's, Maurice Ewing, from Columbia University, working with the Woods Hole Oceanographic Institution, initiated modern deep-sea work in submarine geology and geophysics off the east coast, introducing piston coring, precision echo sounding, and seismic refraction techniques. In 1948, Lamont Geological Observatory was established in New York with Ewing as director. Since then, Lamont and Woods Hole have had parallel interests in ocean investigations and instrumentation. For example, Lamont developed the precision depth recorder (PDR) by using a recording stylus on electrostatic paper, and Woods Hole developed a precision graphic recorder (PGR) by using wet chemical paper and a helical-wire recorder. Both instruments are now widely used for obtaining a continuous record of depth. Similarly, deep-sea coring and seismic work by the two institutions produced vast quantities of new data. Much of the geophysical data is summarized in an excellent paper by Drake, Ewing, and Sutton (1959). In the present report the topographic terminology generally follows that used by Heezen, Tharp, and Ewing (1959), and the distribution and classification of sediments are primarily based on the core descriptions by Ericson, Ewing, Wollin, and Heezen (1961).

At Woods Hole many basic high-precision sounding data have been accumulated since about 1956 under the auspices of the geophysical group headed by J. B. Hersey. We owe much to Knott and Hersey (1956) for developing instrumentation and interpretation techniques that make the soundings used in the topographic compilation available and reliable. In the most recent research, the extensive use of continuous seismic profiling devices (Hersey, 1963; Ewing, Ewing, and Worzel, 1963) has enabled us to follow structures within the bottom sediments.

ACKNOWLEDGMENTS

The writer is indebted to the entire scientific staff of the cruises cited on pages B41–B42 for observing and recording data and to the ship's officers for maintaining the ship's navigation plot.

Much of the sounding data was made available through the generosity of personnel at Woods Hole Oceanographic Institution, including Frederick C. Fuglister, Elizabeth T. Bunce, John Reitzel, Joseph R. Barrett, and others. William Dunkle, curator of the echo-sounding records at Woods Hole helped a great deal in locating many of the old navigation and sounding records; his personal recollections of many of the cruises eliminated much duplicate effort. Bruce C. Heezen at Lamont Geological Observatory made available the Lamont soundings in the vicinity of the Blake Plateau.

The writer's associates at Woods Hole were particularly helpful. Part of the work was done under the supervision of J. B. Hersey, who first introduced the writer to the art of echo sounding and impressed him with some of the limitations and pitfalls of the data, as well as the great usefulness of precise soundings. K. O. Emery, technical director of the continental shelf and slope program at Woods Hole, supervised the preparation of the paper, and his many suggestions and stimulating criticisms are appreciated. Elazar Uchupi, Davis Fahlquist, Elizabeth T. Bunce, William Dunkle, Andrew Nalwalk, and many others have helped to formulate some of the ideas expressed here, through numerous discussions both on board ship and in the laboratory. John Reitzel furnished most of the cores examined by the writer.

Financial support for the present analysis is from the Office of Naval Research under contract Nonr 2196(00) and from the U.S. Geological Survey under contract 14–0001–8358 with the Woods Hole Oceanographic Institution.

GEOLOGIC SETTING

The North American Basin lies on the east side of the continental slope, the boundary between the continents and the oceans. Studies of the sedimentary environments within this large area of the ocean floor must consider ultimately the relations between the continents and the oceans at this boundary: difference in elevation, postulated contrasts in structure, and concept of permanency (Ewing and Press, 1955; Gilluly, 1955).

The difference in elevation is responsible for the movement of sediment from the land to the basins under the influence of gravity in an essentially irreversible process. The potential sediment supply from orogenic belts, such as the Appalachian Mountains, is great, however, and it is difficult to understand how the relief between the basins and continents is maintained. Gilluly (1955) estimated that erosion would reduce the continents to sea level in less than 10 million years and at its present rate would rework the entire sialic crust every 200 to 300 million years.

The calculated rates at which sediment was supplied to the ocean basins (Hamilton, 1961; Kuenen, 1950) are too high if stable ocean basins throughout the earth's history are assumed. The rates are calculated by various methods and are based on fairly precise dating of the sediments in some columns. Most of these rates would result in a much thicker accumulation of sediment than is actually measured if the rates were applied to the whole span of geologic time. The concept of the permanency of ocean basins, therefore, must be brought into conformity with the measured sediment column and with the geologic data that indicate when its deposition began. Instead of permanent ocean basins, the rates of deposition seem to indicate a subsiding east coast geosyncline bordered by marginal basins of deposition. The accumulated terrigenous and carbonate sediments that fill this geosyncline (as defined by Drake, Ewing, and Sutton (1959) and Murray (1963)) indicate more or less continuous subsidence and deposition since the Cretaceous Period. No strata older than middle Mesozoic have been sampled from any of the major ocean basins.

A useful working hypothesis that helps explain how the relief between the ocean basin and the continent is maintained in spite of continuing sedimentation is the recent concept of spreading ocean basins (Hess, 1962, p. 617; Dietz, 1961; and Wilson, 1963) by which original ocean-floor topography, formed by volcanism along the Mid-Atlantic Ridge, spreads laterally toward the continents. This concept provides an explanation for the Mid-Atlantic Ridge and the marginal basins of sediment accumulation. The fact that there are progressively older sediments away from the midocean ridges seems to substantiate the concept (Hess, 1962; Wilson, 1963).

Because the ocean basin is a vast basin of sedimentation, most minor topographic features and even many of the gross features should be considered as constructional landforms in marked contrast to the surface of the continents where erosional factors are most important in molding the landscape and even perhaps in maintaining difference in elevation between basin and shelf. Many of the structural concepts of the past are not supported by present analysis of topography off the east coast.

The types of sediments deposited are important to an understanding of the topography of the continental margin and the ocean basins. Three natural sedimentary provinces occur along the east coast: (1) glacial to the north, (2) terrigenous off the Middle Atlantic States, and (3) carbonate off the South Atlantic States and the Bahama Islands. These sedimentary provinces transcend the morphologic boundaries of the shelf and slope and can be traced from mappable source areas on land into the sediment-distribution pattern of the deep-sea basins.

Oceanic sediments are usually divided into terrigenous, or land derived, sediments and pelagic sediments, those formed in the sea itself (Murray and Renard, 1891). In the present study, pelagic sedimentation has been given little emphasis because the area is dominated by terrigenous sedimentation derived from the east coasts of the United States and Canada, especially in the western North Atlantic where basins are small, inflowing rivers are large, and pelagic production is low compared with that of equatorial regions (Arrhenius, 1961, p. 131). Three natural sedimentary provinces occur along the east coast: (1) glacial to the north, (2) terrigenous off the Middle Atlantic States, and (3) carbonate off the South Atlantic States and the Bahama Islands. These sedimentary provinces transcend the morphologic boundaries of the shelf and slope and can be traced from mappable source areas on land into the sediment distribution pattern of the deep-sea basins.

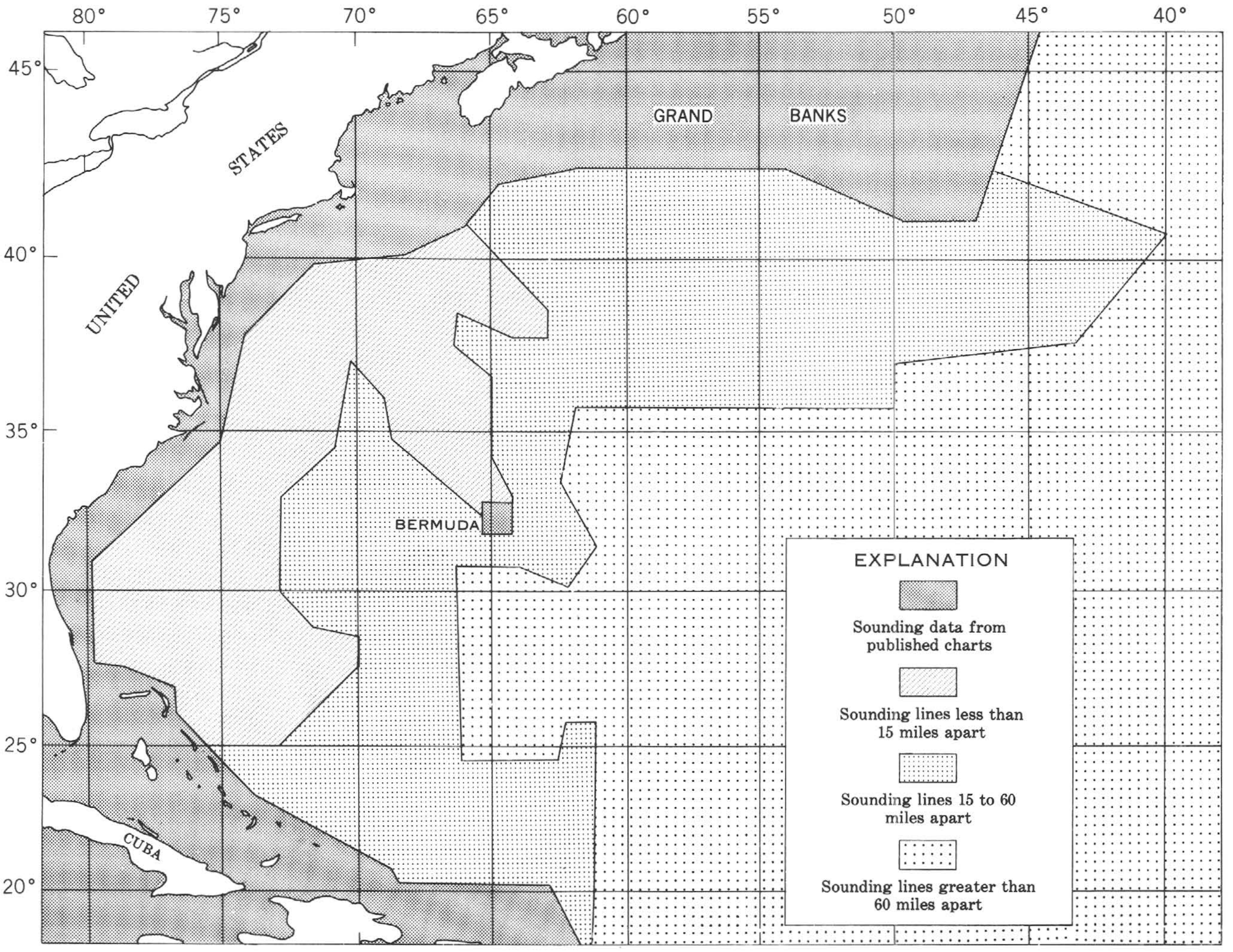


FIGURE 1.—Density of sounding tracks used in compiling the topographic chart (pl. 1).

TOPOGRAPHY

The topographic chart (pl. 1) is designed primarily to portray the sedimentary environment off the east coast of the United States; in this report this includes the general region between the continental slope and the Mid-Atlantic Ridge. Contours of the deep sea are based on original sounding data obtained by Woods Hole Oceanographic Institution, with additional data on the Blake Plateau from Lamont Geological Observatory. Data for the continental shelf and slope are from published charts of the U.S. Coast and Geodetic Survey and the U.S. Hydrographic Office. The sources of data used in compiling the map are tabulated in the section on "Sources of data used in compiling the topographic charts"; the density of sounding tracks is shown in figure 1.

The soundings were compiled in fathoms on standard plotting sheets (1 : 750,000), and contours in meters were drawn directly on the sheets by using a conversion table incorporating the change from fathoms to meters and the correction for sound velocity (Matthews, 1939). In many places where the relief is low, it was possible to locate the position of a contour from an echo-sounding record without reading and tabulating the entire record.

A cardinal axiom in all bathymetric work is that a map of soundings can be no more accurate than the navigation that determines the locations of the soundings. The steeper the topography the more critical accurate navigation becomes. For most of the abyssal plains and the continental rise, where the topography is simple, the accuracy is within the limits of the readability of the sounding records (± 5 meters). In areas of steep topography, such as the margins of the Bahama Banks and Blake Plateau, the accuracy of the chart is controlled more by navigational limitations (in the order of ± 5 nautical miles) than by the precision of the soundings.[2] East of the sediment plains, particularly

[2] In all marine surveying, nautical miles are used rather than statute miles. A nautical mile is defined as a minute of arc on the equator and is equivalent to 6,080.2 feet.

south and east of Bermuda, the topography is a complex of closed depressions and hills, and the density of the sounding lines is insufficient to delineate the features involved adequately. In this area, contours were included on the map to complete the topographic picture and should be thought of as form lines rather than as specific indications of depth.

The bottom topography off the east coast can be described in terms of seven natural physiographic provinces: (1) the continental slope, (2) Sohm Plain, (3) Hatteras Plain, (4) Nares Plain, (5) Blake Basin, (6) Blake Plateau–Bahama Banks, and (7) the Bermuda Rise, as shown on plate 1. The northern limit of the study area is the natural boundary made by the Grand Banks and the Newfoundland Ridge, which extends eastward to the foothills of the Mid-Atlantic Ridge. The Puerto Rico Trench on the south has been excluded from this discussion because it is isolated by the Puerto Rico Ridge from the influence of sediment derived from the east coast. The Puerto Rico Trench and the associated channels north of Haiti and Cuba, lying along a major structural break, delineate the southern limit of the carbonate facies of the gulf and Atlantic coast sediment prism (Murray, 1963). The whole of the described area is commonly referred to as the North American Basin.

CONTINENTAL SLOPE

The continental slope is the topographic boundary between the continent and the ocean basin. It is a complex feature. The recovery of Tertiary and Cretaceous rocks (Stetson, 1936; Northrop and Heezen, 1951) from the slope indicates that most of this escarpment is primarily an area of slow sedimentation, with some erosional activity, as indicated by the canyons. Most sounding profiles across the slope (figs. 2, 3) generally show two separate types of bottom: a steep irregular upper slope and a smooth lower slope. These may reflect a change from an erosional slope to a slumped and debris-covered slope. Scalloped topographic features and discontinuous beds shown on seismic reflection profiles are indications that segments of the slope off Cape

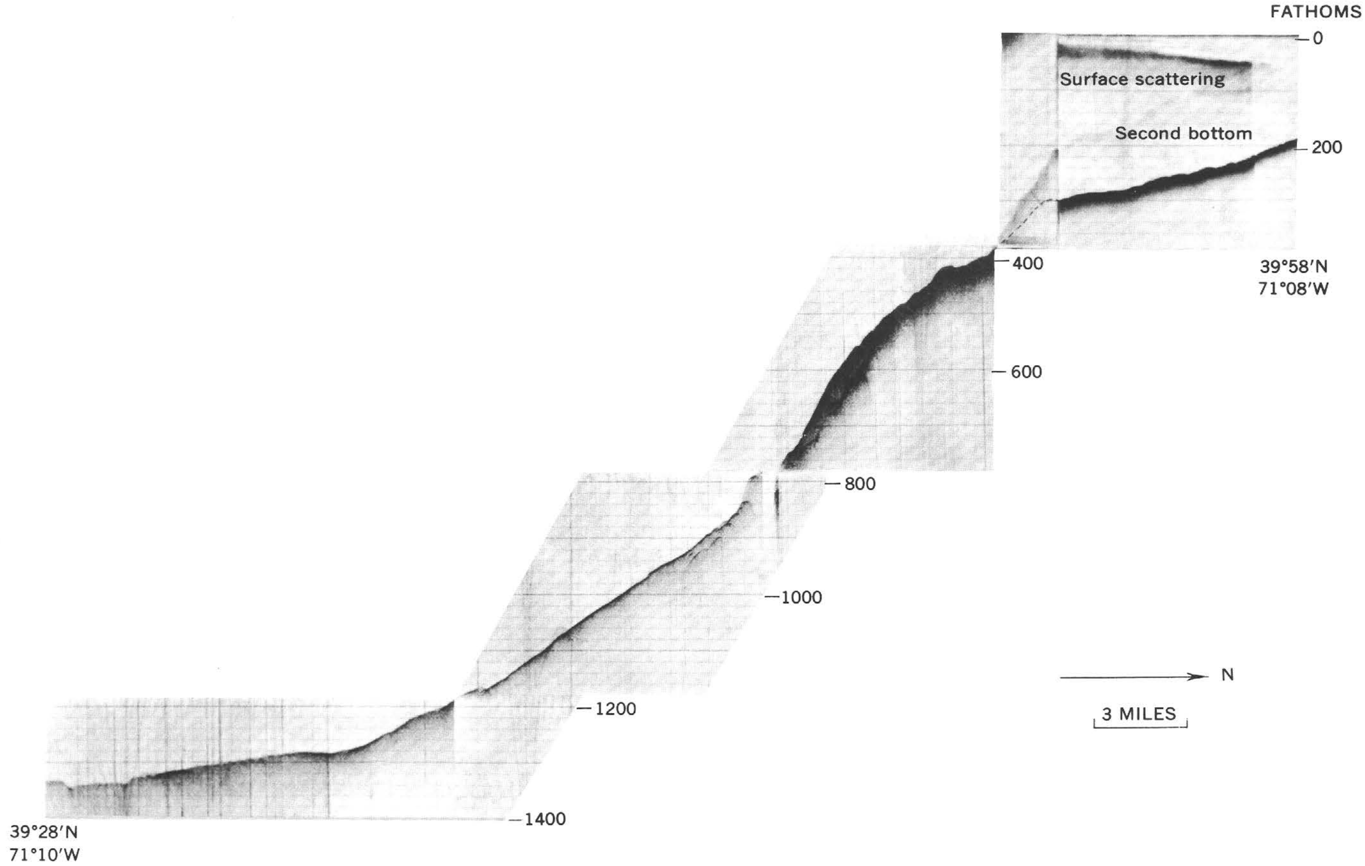


FIGURE 2.—Profile down the continental slope south of Nantucket. Note the steep irregular slope from 300 to 900 fathoms and the even slope, possibly mostly slumped debris, from 900 to 1,280 fathoms. The lower abrupt change in gradient is characteristic of profiles in the area and seems to indicate the change from slumping and gullying on the slope to the smoothly graded profile of the continental rise. Echo-sounding depths are measured in fathoms using an assumed sound velocity in water of 800 fathoms per second: 1 fathom = 1.82 meters = 6 feet.

283-159 O—68——2

Hatteras (Ewing, Ewing, and Worzel, 1963) and the Laurentian Channel (site of the Grand Banks earthquake, Heezen and Ewing, 1952) may be characterized largely by slump and slump depression-type topography.

The continental slope may also be considered in terms of the three main types of sedimentary environment included upon it: (1) glacial in the north, (2) terrigenous in the Middle Atlantic area, and (3) carbonate in the south. East-northeast of Georges Bank the slope characteristics were strongly influenced by Pleistocene ice. The southern New England-Middle Atlantic slope is typical of an unglaciated, noncarbonate environment. The continental slope off the Blake Plateau and the Bahama Banks divides into two separate geomorphic features, the Florida-Hatteras Slope and the Blake Escarpment. The carbonate slopes of this southern area are discussed in the section on "Blake Plateau and Bahama Banks."

A sharp break in profile at approximately 2,000 meters marks the change from the continental slope to the continental rise. The break also corresponds to a change from the rugged canyon-broken topography of the slope to the smooth gradient that is characteristic of the rise. In most sections (figs. 2, 3) the base of the slope is better defined, although more variable in depth, than the slope-shelf break at the top of the slope. It obviously marks the major topographic boundary, as well as sediment boundary (fig. 4), between the ocean basin and the continental platform. Seismic profiles (Knott, Hoskins, and Weller, 1963) give strong supporting evidence that the slope, at least in the New York-New England area, is a depositional rather than a simple tectonic feature. Records showing forest-type bedding indicate that the continental shelf is prograding outward at the top of the slope and that the rise is onlapping upward at the base of the slope. In this respect, the continental slope may maintain itself; it is the boundary between these different processes of sedimentation, one on the shelf and the other in the deep sea, as well as the major topographic boundary between the continental platform and the ocean basin.

Submarine canyons on the slope have graded profiles that merge basinward with profiles of the continental rise; coarse sand and flat-bottomed channels in some of them indicate that at some time in their history they acted as channelways for much of the sediment that now floors the abyssal plains. The most important canyons off New England that feed sediment into the Sohm Plain are the Georges Bank canyons—Oceanographer, Veatch, Lydonia, and others (Veatch and Smith, 1939)—and The Gully east of Sable Island. No canyons are associated with the Northeast Channel (between Georges and Brown Banks) and the Cabot Channel, the two major breaks in the northern part of the Atlantic Continental Shelf. These two channels were probably shaped in large part by the advance of Pleistocene ice.

Study of seismic profiles and recovery of semiconsolidated to consolidated rocks in dredge samples indicate that the canyons are cut into the bedrock of the continental slope. The channels extending from the canyons across the continental rise, however, may be constructional, bounded partly by submarine levees.

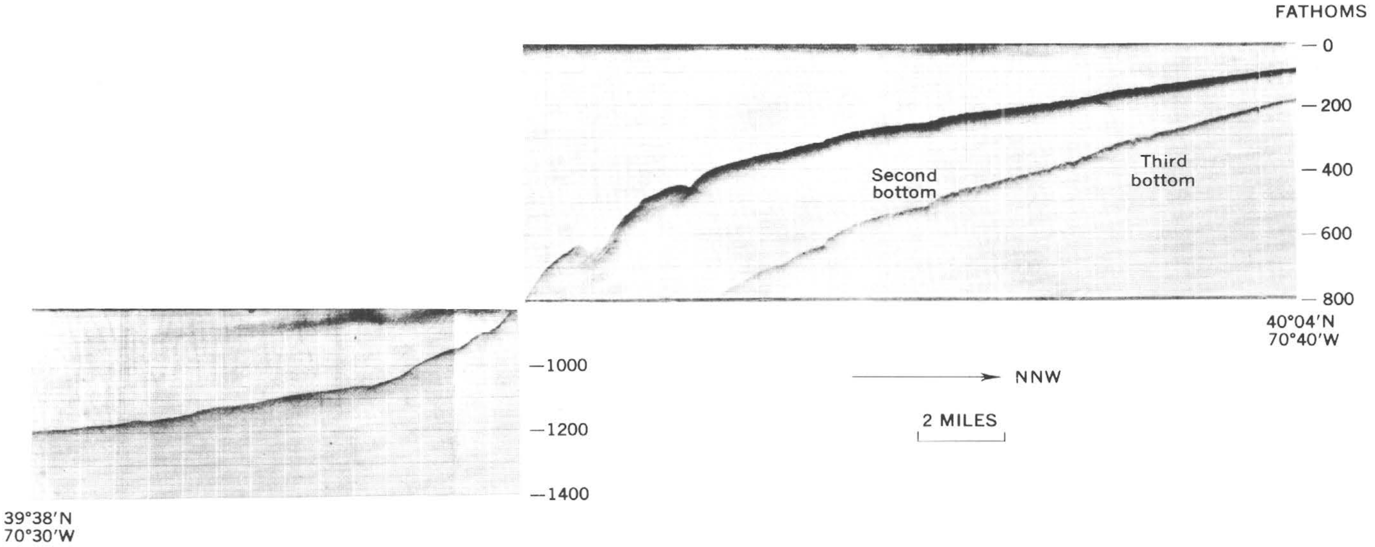


FIGURE 3.—Echo-sounding profile of subdued section of the continental slope south of Block Island. The ship's track of this profile is at right angles to the slope. Here the continental rise has developed upward to a rise-slope break at 1,050 fathoms, and the smooth topography of this shelf extends down to 400 fathoms.

Hudson, Baltimore, Wilmington, and Norfolk are the principal canyons of the Middle Atlantic slope (Veatch and Smith, 1939). In contrast to the New England canyons, each has a deep channel extending seaward and cutting into the continental rise, probably because the canyons lie off the mouths of major Pleistocene rivers and are south of the direct influence of Pleistocene glaciers. Confusion exists about Hatteras Canyon (Heezen, Tharp, and Ewing, 1959). It has been defined on the continental rise but has not been traced across the continental slope and shelf. Several deep gullylike features that were found in the area may be interpreted best as slump scours. This interpretation is supported by the prominent scalloped pattern of displaced strata shown on continuous seismic profiles across the slope (Ewing, Ewing, and Worzel, 1963). In fact, between lat 33° N. and 37° N. the entire continental slope is extremely steep and scalloped and has small steep indentations and closed depressions that indicate a slump-(rather than a canyon) dominated topography.

SOHM PLAIN

The Sohm Plain (Suhm Deep of Murray and Hjort, 1912; Heezen, Tharp, and Ewing, 1959, p. 57) is the largest of the deep-sea or abyssal plains in the North American Basin; its area is approximately that of the United States east of the Mississippi River. It is bordered on the north by the continental slope and rise off the New England coast and the Grand Banks, on the northeast by the Newfoundland Ridge, and on the south by the Bermuda Rise. A large arm of the plain extends southward between Bermuda and the Mid-Atlantic Ridge (Heezen, Ewing, and Ericson, 1955).

The western limit of the Sohm Plain is a divide, defined by the 4,950-meter contour at about lat 37°30′ N., long 65°30′ W.; this divide separates it from the Hatteras Plain (pl. 1). Eastward from the divide the plain has a gentle slope of about 1:3,000. South of Georges Bank, the continental rise forms a transition zone between the Sohm Plain and the continental slope. The approximate boundary between the plain and the continental rise is defined by change in slope from less than 1:1,000 on the plain to more than 1:1,000 on the rise (Heezen, Tharp, and Ewing, 1959). South of the Newfoundland Ridge the plain has a sharp boundary and gradients parallel to the rise; this topography seems to indicate that most sediment on the plain has come from the east and west rather than from the rise (pl. 1).

The easternmost end of the Sohm Plain merges with the Mid-Ocean Canyon of Heezen, Tharp, and Ewing (1959, p. 66), which drains south from the Newfoundland and Labrador Basins (pl. 1) as shown in figure 5. At about lat 38° N., long 43° W., the canyon spreads into the Sohm Plain with a gentle westward gradient. Because sedimentary deposits occur on both the north and the south edges of the plain in this area, the canyon may be a major source of sediment here. At long 51° W. the

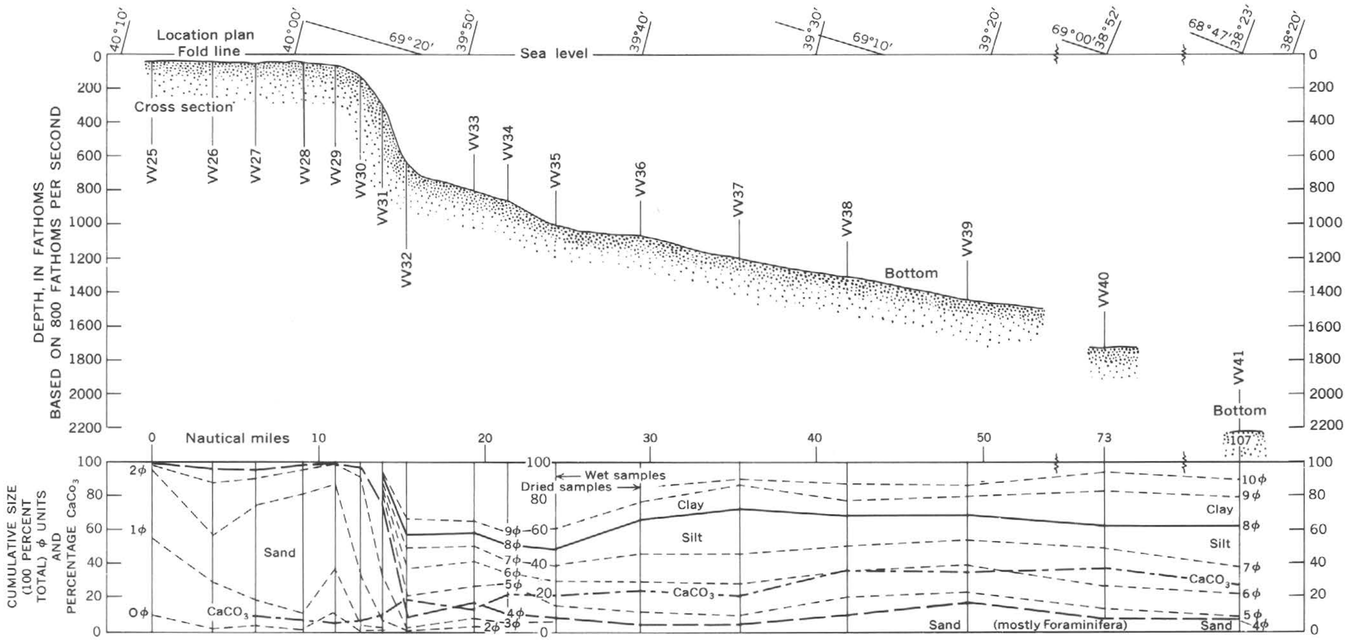


FIGURE 4.—Relation of sediment size and calcium carbonate content to topography in a sample section at right angles to the continental slope near Hydrographer Canyon. The sharp topographic break at the base of the slope is also a sharp textural break. Calcium carbonate on the shelf is in the form of a shell debris and that on the continental rise is probably mostly Foraminifera.

eastward gradient of the main Sohm Plain and the westward gradient from the canyon meet in a low spot delineated by the 5,420-meter contour. An enclosed depression 10 or 20 meters deep has developed adjacent to the rise south of Newfoundland Ridge.

A series of steep seamounts and abyssal hills with sharp topographic breaks (pl. 1 and fig. 6) extend along the southern part of the Sohm Plain. Here the problem is not to identify the plain on the basis of bottom character and slope but rather to map the intricate wiggles and bends of the plain boundary as it twists around the seamounts. The boundary is a depositional contact, formed by sediment that has been transported across the plain and deposited around the seamounts.

A line of seamounts called the New England Seamount Chain (Northrup, Frosh, and Frassetto, 1962) extends in a southeasterly direction across the Sohm Plain (pl. 1 and fig. 7). The abrupt contacts of the seamounts with the abyssal plain, as well as the subsurface structure shown in recent seismic profiling (Hersey, 1963), indicate that the sediment has been deposited around the seamounts, partially burying them. At about long 60° W. the seamounts partially obstruct the easterly sediment movement; this results in channeling between the seamounts. The chart (pl. 1) shows almost flat gradients near lat 38° N., long 62° W. which extend eastward to a channel between the seamounts (lat 38° 40′ N., long 61° W.). This channel has been called Mid-Ocean Canyon No. 2, by Heezen, Tharp, and Ewing (1959). Similar channels and presumed scour depressions are at the base of other seamounts. Where the abyssal plain bends southward at long 58° W., the relation between the seamounts and channels is difficult to determine because soundings are sparse. Projected gradients give evidence of at least one channel connection between the western and southern arms of the Sohm Plain (figs. 8, 9), although most of the flat areas

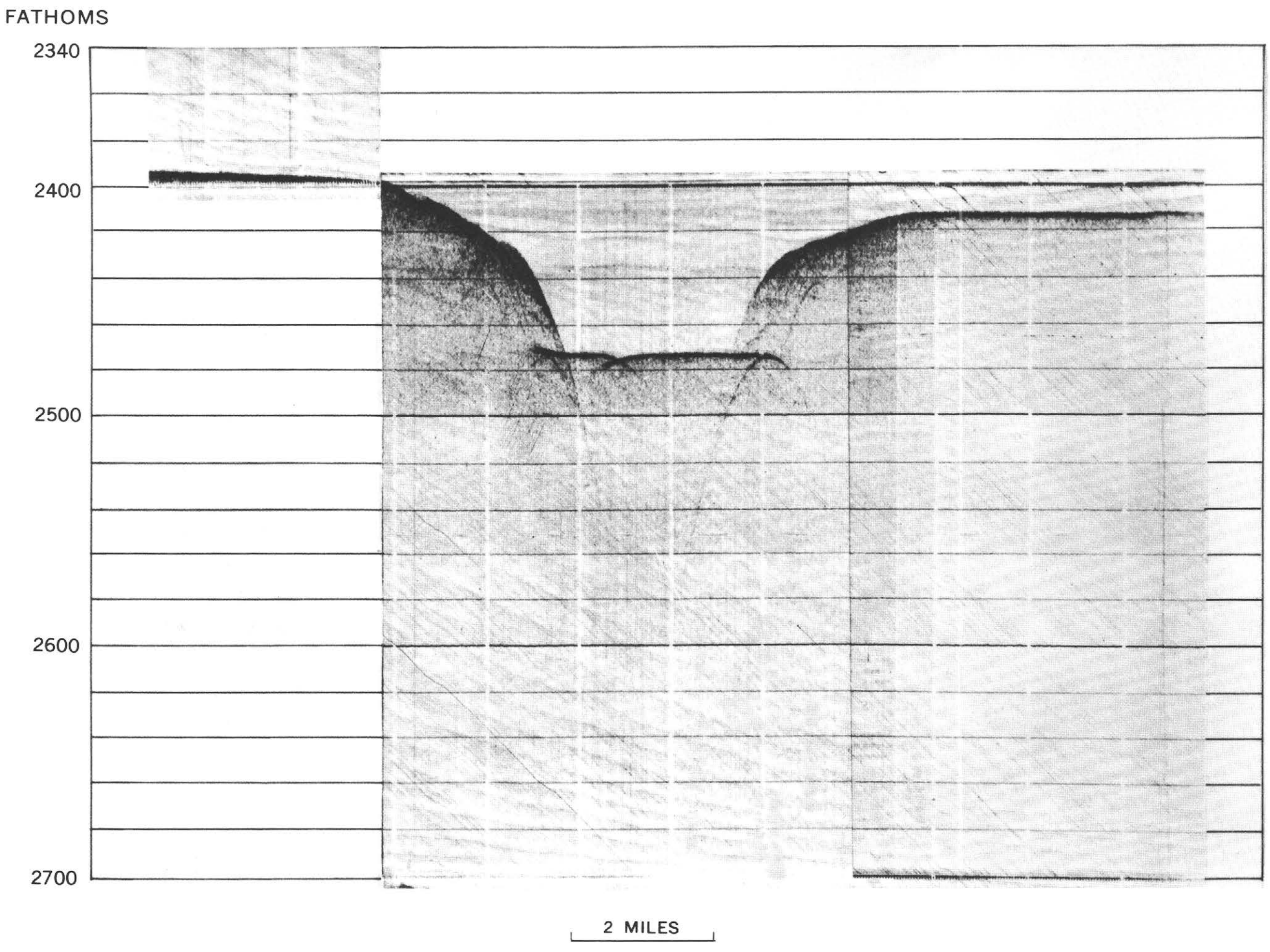


FIGURE 5.—Profile of the channel in Newfoundland Basin that is called Mid-Ocean Canyon by Heezen, Tharp, and Ewing (1959). This canyon leads into the eastern arm of the Sohm Plain. The flat bottom suggests graded conditions of transport. In cross section this canyon is similar to those cutting through the slope although its genetic history may be different.

between seamounts are merely embayments off the main plain.

The southern arm of the Sohm Plain, extending between the Bermuda rise and the foothills of the Mid-Atlantic Ridge, deepens gently southward to 5,600 meters at about lat 30° N. (fig. 9, *A–A′*). Here it breaks into several channels or flat-floored valleys between abyssal hills and can no longer be recognized as a continuous plain. The exact southern limit cannot be determined because of lack of sufficient sounding coverage. In some places, adjacent valleys are connected in such roundabout ways that their floors may be at different levels (fig. 10). Seismic profiles and echo-sounding records reveal that these valleys are filled with sediment. The sediment must be exceptionally porous because it is readily penetrated to depths of 80 or 100 meters with an ordinary 12-kc echo sounder (fig. 11).

HATTERAS PLAIN

The Hatteras Plain lies between the base of the continental slope and rise off the east coast and the Bermuda Rise, from about lat 35° N., south to the Bahama Banks. It was named Hatteras Abyssal Plain by Heezen, Tharp, and Ewing (1959, p. 58) because of the prominent relation of the deep plain to Cape Hatteras, although Murray and Hjort (1912) mentioned the Keltie and Mill Deeps in the same region.

Like the Sohm Plain to the northeast, the landward boundary of the Hatteras Plain merges into the continental rise, at least as far south as the Blake Ridge (lat 33° N.), where the overall character of the basin boundary changes. The eastern edge of the Hatteras Plain, which abuts the Bermuda Rise, is poorly defined because of the scarcity of east-west sounding tracks in this region of relatively low relief. Except where the plain is constricted at about lat 29° N., a broad channel lies along the eastern edge of Hatteras Plain. The abrupt change from an extremely flat abyssal plain to the rolling topography of the Bermuda Rise is clearly shown by differences of the bottom character, as well as the relief. Hersey, Caufield, and Hoskins (1963) have found

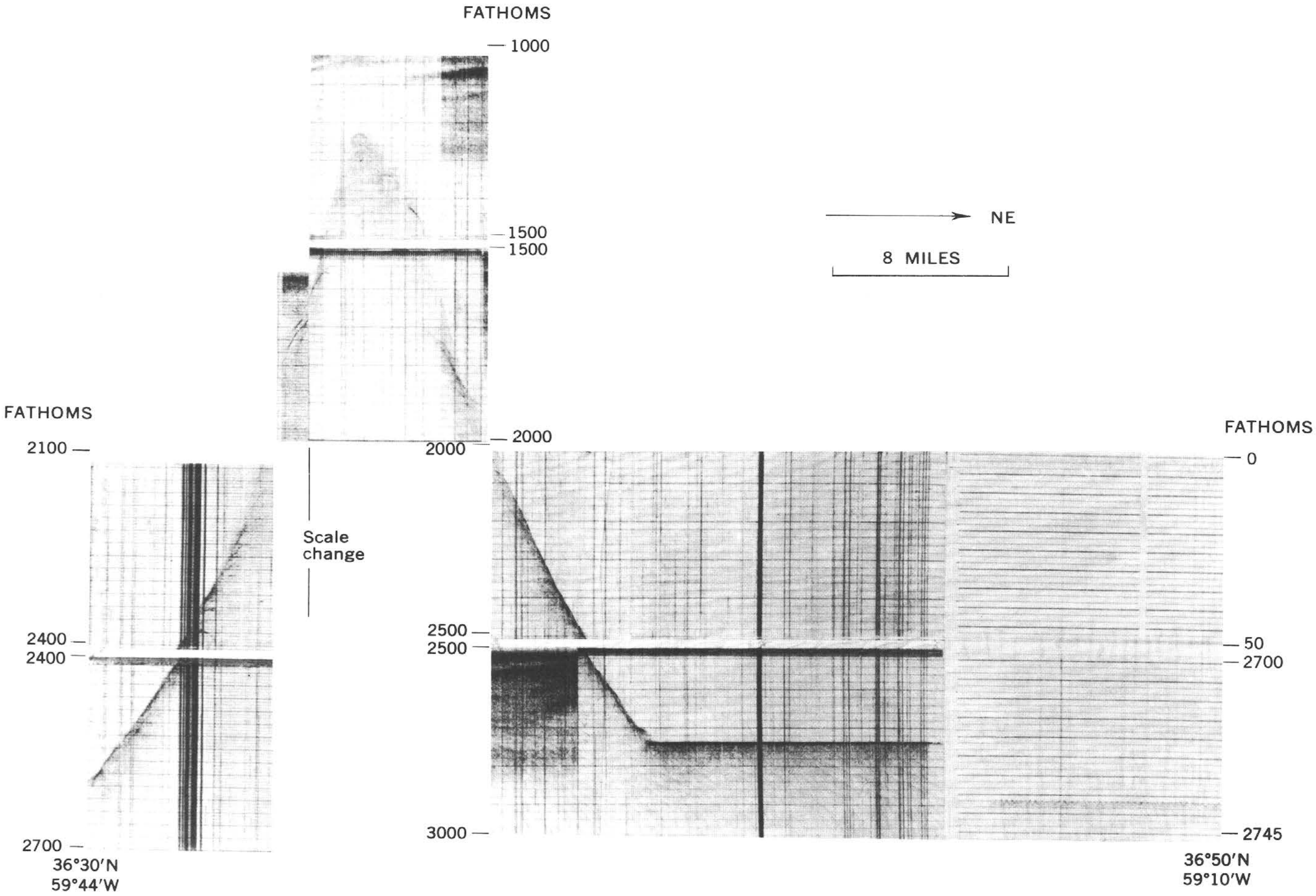


FIGURE 6.—The abrupt interruption of the flat expense of the Sohm Plain by one of the seamounts of the New England Seamount Chain. The uniform flatness of the plain indicates active deposition against the seamount and a lack of much debris from the side of the seamount. The high-resolution section on the right shows an indication of subbottom layering that is characteristic of plains of terrigenous turbidites.

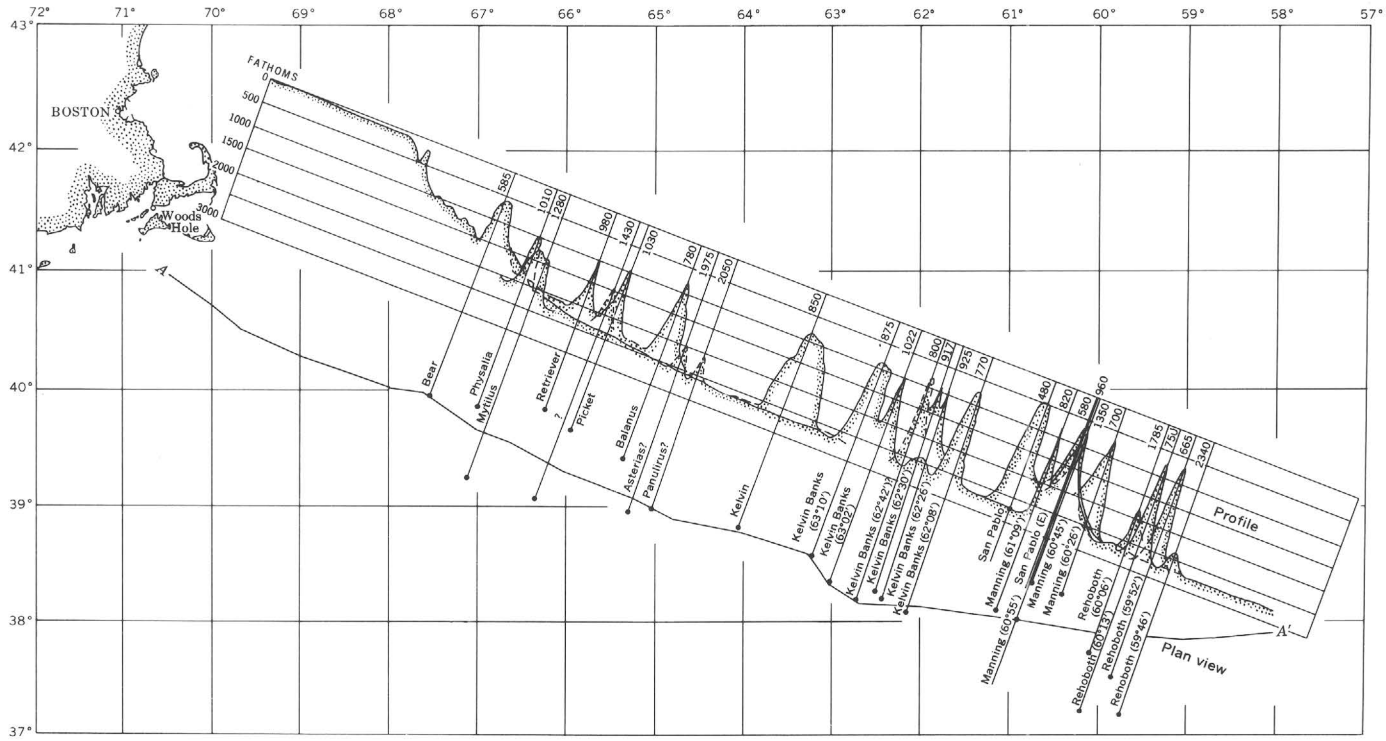


FIGURE 7.—Projected profile of the New England Seamount Chain. These seamounts are localized along what is probably a deep-seated structural trend. Attempts to relate some of their tops to sea-surface action and their bases to crustal warping were inconclusive. Sediments of the Sohm Plain have filled in around the seamounts and form a graded slope profile extending seaward from the continental slope.

similar changes in subbottom seismic reflection, from one complex reflector near Bermuda to several nearly horizontal smooth reflectors on the plain.

The south end of the Hatteras Plain lies at an intermediate level in the sediment transport system that extends from the Blake Basin to the Hatteras Plain and then through Vema Gap to the Nares Plain (pl. 1). In this region an arm of the Hatteras Plain extends southeastward between the Puerto Rico Ridge and the Bahama Banks, where a depression about 27,000 km² in area is encompassed by the 5,500-meter contour (pl. 1 and fig. 9, *J–J′*). It is noteworthy that the maximum depth in this closure lies in a troughlike low adjacent to the Bahama Banks. The position of this low point is similar to the position of lowest point in the Blake Basin. The presence of the plain also establishes the fact that the Outer Ridge of Heezen, Tharp, and Ewing (1959, p. 33) is not a continuous structure but separates into Blake Ridge and Puerto Rico Ridge.

Most sediments on the floor of the Hatteras Plain seem to be supplied through and by the Hudson and other canyons, which extend seaward from the mid-Atlantic coast of the United States (figs. 12, 13). The northern derivation of the sediment is shown by the southerly slope of the plain, as well as by the terrigenous nature of the deposits. Complex hills with intervening channellike features at lat 36° N. and from long 67° to 69° W. are probably the main depositional front of the Hudson Fan; along this front sediment is delivered directly into the north end of the plain (figs. 14, 15). Even if sediment were transported eastward toward Caryn Seamount (lat 36°40′ N. long 67°30′ W.), it should still reach the Hatteras Plain through a series of southward-grading channels (fig. 9, *E–E′*).

The relations of the Hudson Canyon to the Sohm and Hatteras Plains presents an intriguing problem. Hudson Canyon is by far the largest canyon along the east coast and was the major outlet of the Hudson River during Pleistocene time for some glacial stages of the Great Lakes. This is suggested by the magnitude of the Hudson River channel on the continental shelf, as well as by the relief and size of the canyon and the Hudson Fan. The prominent ridge extending from lat 36° N., long 66° W., southeast toward Muir Seamount, (lat 34° N., long 62°40′ W.) has the same gently rolling topography and bottom characteristics that characterize the ridge and hills farther west at the end of the present Hudson Fan (fig. 16). Thus, topographic evidence suggests that at the time of greatest turbidity flow, clastic sediment was carried nearly as far east as Muir Seamount. A similar ridge to the north (lat 37° N., long 62°–65° W.) may have been built into the Sohm Plain,

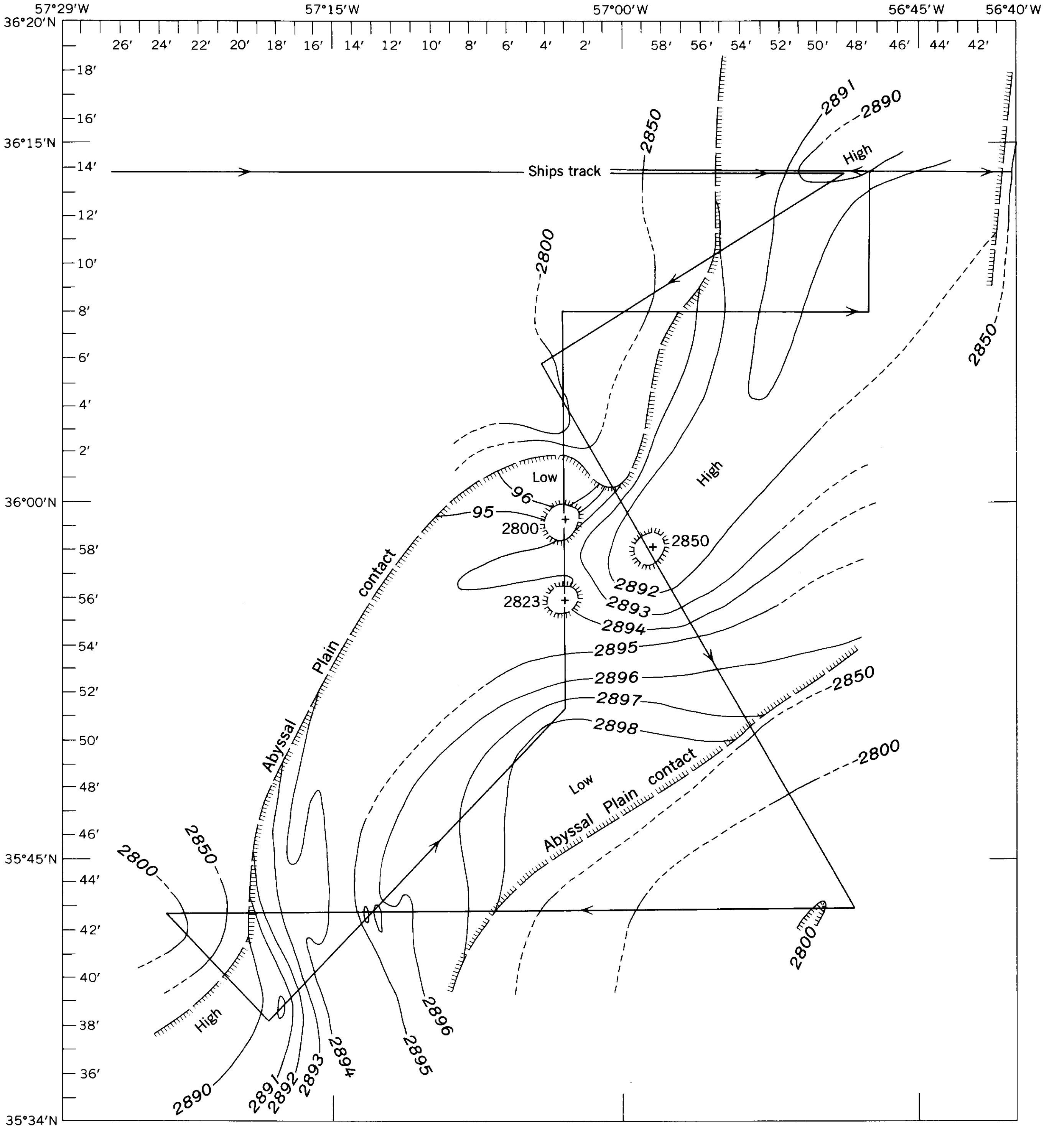


FIGURE 8.—A small part of the contact of the Sohm Plain with surrounding steeper topography. As indicated in plate 1, this is probably part of a through-flowing channel from the northern part of the Sohm Plain to the southern arm. Note the resemblance in this interpretation of the high and low spots to stream channel features. Relative depths to the nearest fathom are valid; the absolute depth is dependent on the velocity of sound in the water column at the time the soundings were taken and the accuracy of the timing by the recorder. Depth, in fathoms, based on 4,800 feet per second uncorrected.

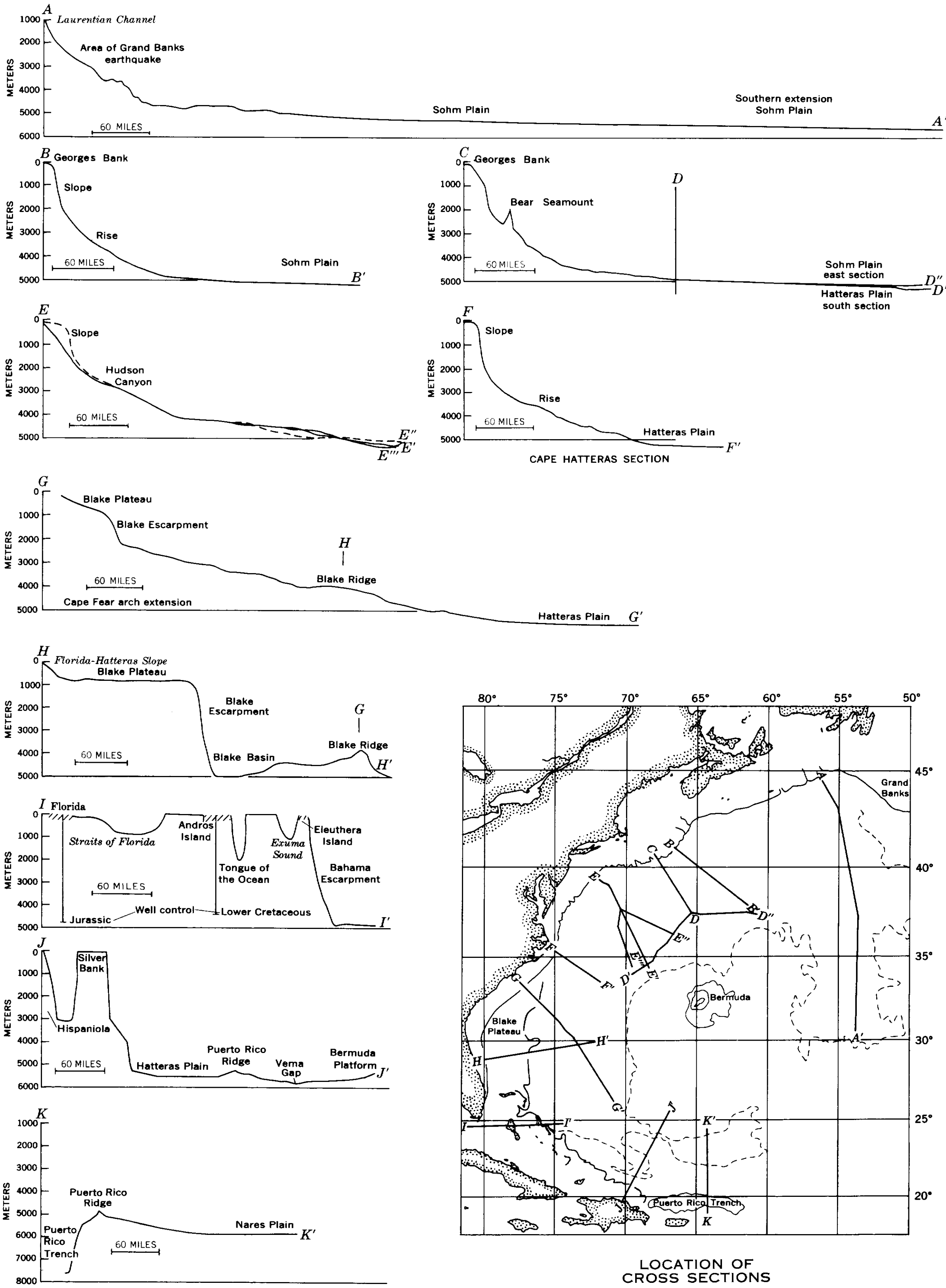


Figure 9.—Cross sections constructed from the topographic chart (pl. 1) illustrate various features described in the text. Their general order is from north to south.

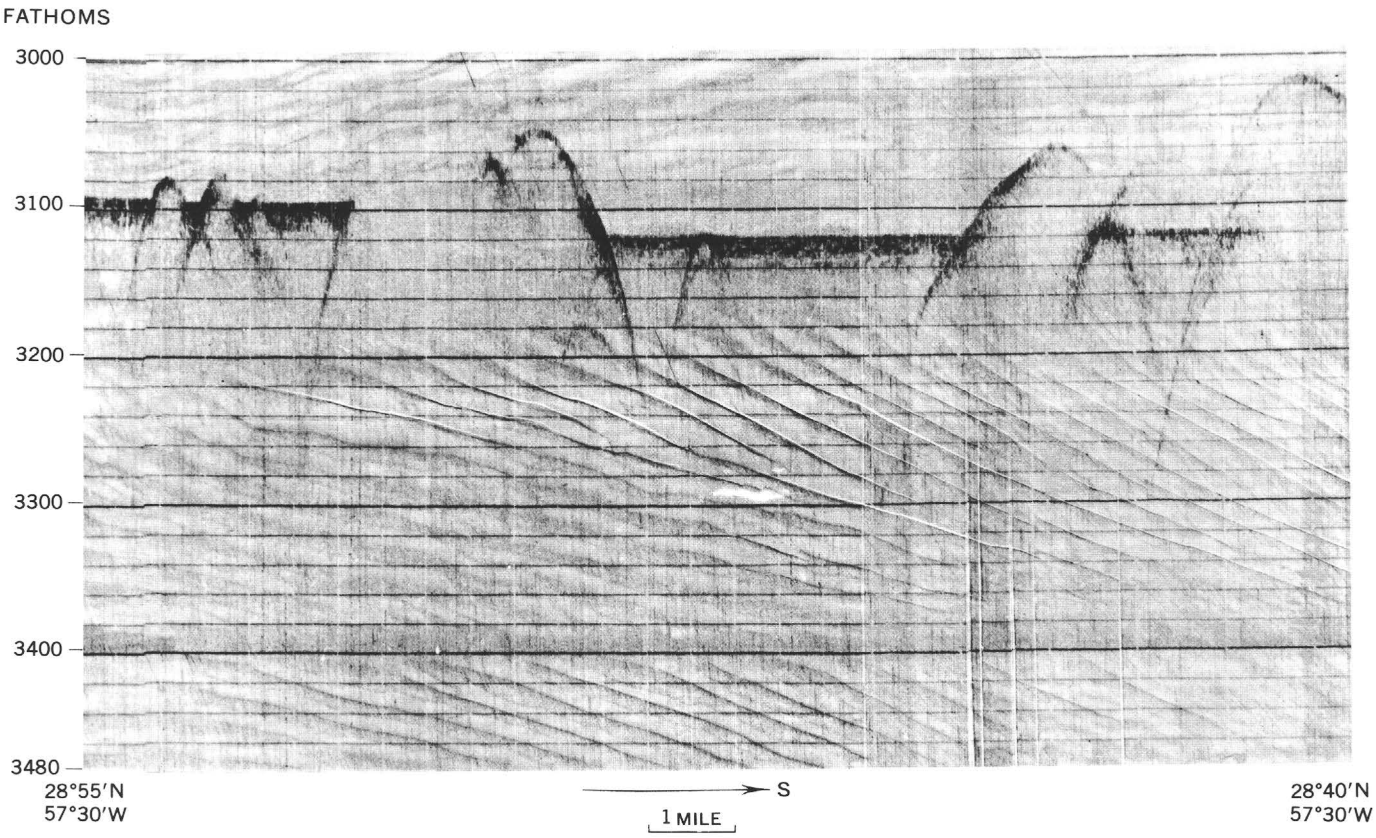


FIGURE 10.—Flat-floored sediment valleys of slightly different depths at the southernmost extremity of the Sohm Plain. The different depths suggest a restricted passageway between the intervening seamounts or even a sill between the two basins. Parts of the hills are too steep to reflect energy back to the ship. Recent seismic profiles indicate the flat areas are sediment fillings between the hills.

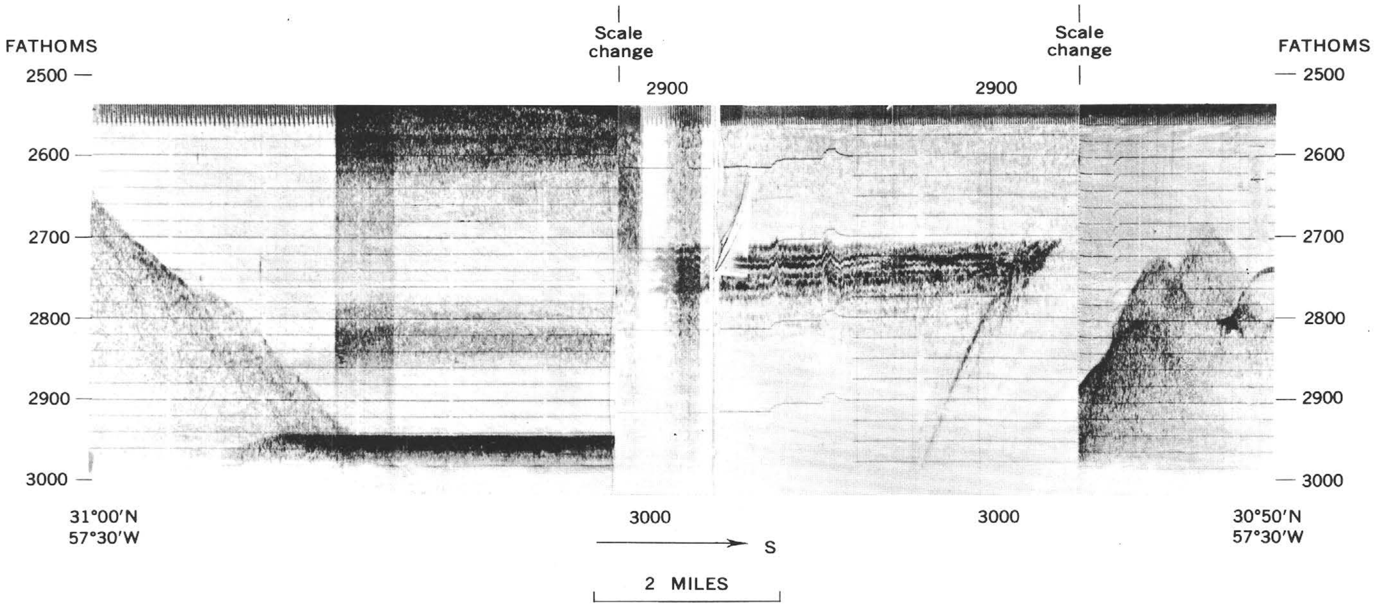


FIGURE 11.—Profile illustrating subbottom penetration on a flat plain by a switch to the 100-fathom scale on a flat-floored sediment valley south of the Sohm Plain. The hazy dark bottom is actually several separate reflections from subbottom horizons that are enlarged and shown in more detail in the high-resolution section. The slight vertical wiggles are caused by the movement of the ship and recorder over the waves. Note how the traces of the plain bottom extend into the side echoes of the hill slope.

283-159 O - 68 - 3

closing the large depressions between the ridges and Muir Seamount (figs. 17, 18). The topography suggests that Hudson Canyon turbidity currents once flowed directly into the Sohm Plain (inferred by Heezen, Tharp, and Ewing, 1959, p. 122, pl. 20). Excess sedimentation to the north and channel cutting toward the south have since diverted turbidity currents into the Hatteras Plain (fig. 9, *D–D′*).

NARES PLAIN

The Nares Plain takes its name from a depression called the Nares Deep, which was charted many years ago (Murray and Hjort, 1912, p. 129, fig. 3); its areal extent originally included the Puerto Rico Trench. This nearly flat plain extends from Vema Gap (lat 24° N., long 67° W.) eastward to long 61° W. (Heezen, Tharp, and Ewing, 1959). Its eastern limit is poorly known; it probably has a very irregular depositional boundary merging into the abyssal hills to the east. Other boundaries have been better defined on the basis of several good north-south sounding lines. The northeastern end of the plain disappears in several channels that drain northeastward into basins of varying depth, some of which are enclosed by the 6,000-meter contours (lat 28° N., long 61° W.). These lower basins are partly filled with flat-lying sediments easily penetrated by sound. Farther east in the area of the rugged but poorly surveyed abyssal hills, individual basins or depressions are more than 6,400 meters deep. Thus, the Nares Plain (5,800–5,900 meters) is perched above the deeper holes northeast of it.

The southern margin of the plain rises gradually onto the Puerto Rico Ridge (Bunce and Hersey, 1963). Near lat 22° N., long 64° W., the only discernible topographic distinction is a gradual change in gradient (fig. 9, *K–K′*). The Puerto Rico Ridge is a relatively high area of rolling topography between the Nares Plain and the Puerto Rico Trench. The ridge is distinctly asymmetrical; its crest reaches 4,800 meters near the steep north wall of the Puerto Rico Trench (fig. 9, *K–K′*). The morphology suggests that the southern edge of the Nares Plain has been tilted up along the ridge and that the axis of sedimentation has shifted northward. In the course of time, higher sediment levels

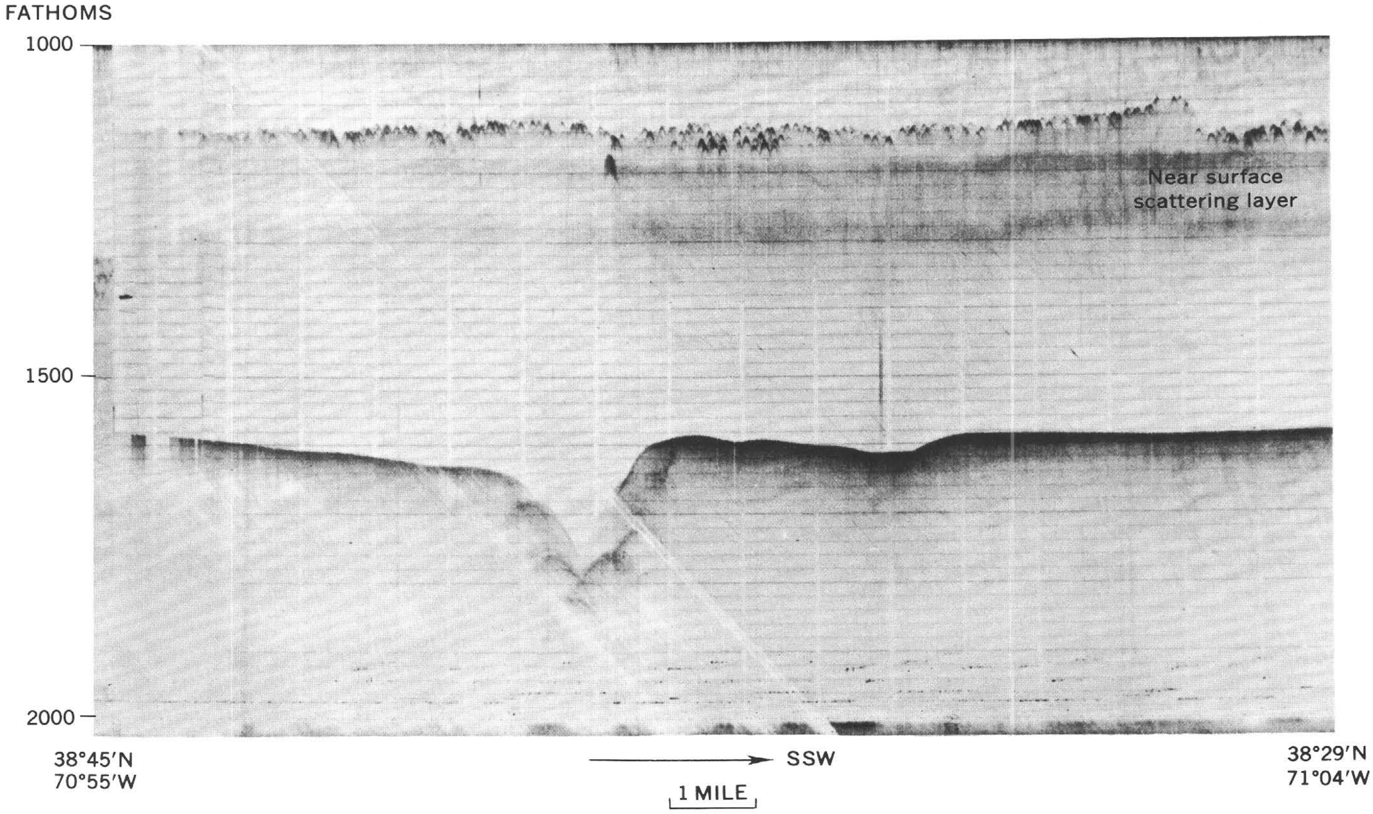


FIGURE 12.—Oblique profile of Hudson Canyon across the continental rise. The canyon is about 200 fathoms deep, sharp sided, and less than 2 miles wide; these features make accurate contouring of a small-scale chart difficult. The generally flat highly reflective bottom of the continental rise stretches out to either side. In an echo-sounding trace like this one, great care must be used to interpret the true bottom depth. True bottom is probably at 1,820 fathoms, and the real side slopes are masked by side echoes.

in the basin and progressive northward tilting may allow turbidity currents to flow into the depressions along the northeastern edge of the Nares Plain. Recent geophysical studies of the oceanic crust and mantle by Bunce and Fahlquist (1962), Worzel and Shurbet (1955), and others have shown complex structural anomalies in this region.

Vema Gap, which extends from about lat 25° N., long 70° W., to lat 24° N., long 67° W. (Heezen, Tharp and Ewing, 1959) is the channel through which sediments from the Hatteras Plain are transported to the Nares Plain. Echo-sounding profiles indicate that the gap at its most restricted point is a steep-walled canyon only 5 miles wide. At the Hatteras Plain end of the Vema Gap (Heezen and Menard, 1963, p. 247), small channels funnel into the gap, but the Nares end debouches onto an extremely smooth eastward-sloping plain. Echo-sounding coverage is not dense enough to show whether or not scour depressions have actually deepened and shaped Vema Gap, but the constricted profile and relatively steep gradient suggest large current velocities.

If the hypothesis of sediment dispersion on the Hatteras Plain is valid, then the concept of sediment dis-

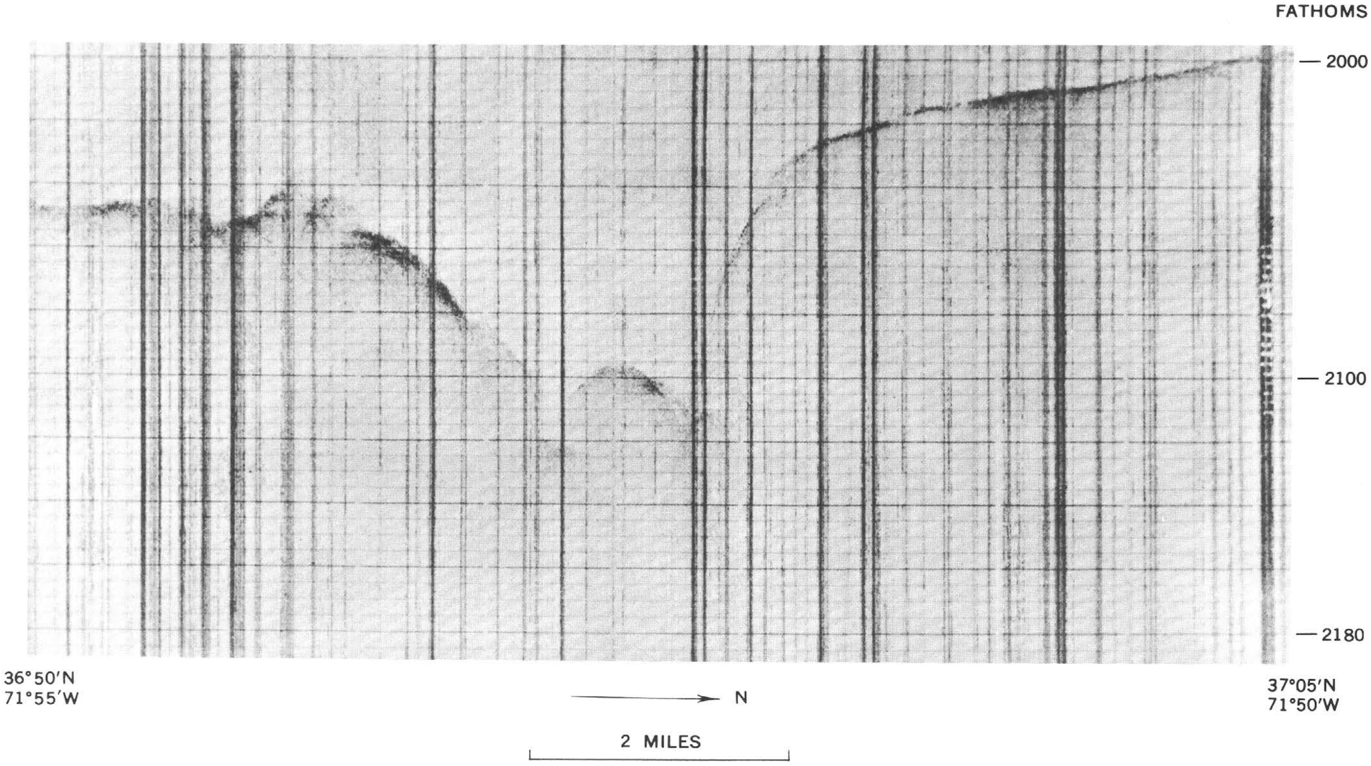


FIGURE 13.—Wilmington Canyon near its end on the continental rise. The difference in height of the two sides is partly due to the obliqueness of the profile, but it may also indicate that more sediment was contributed from the north side. The vertical streaking on the record is caused by the pitching of the ship.

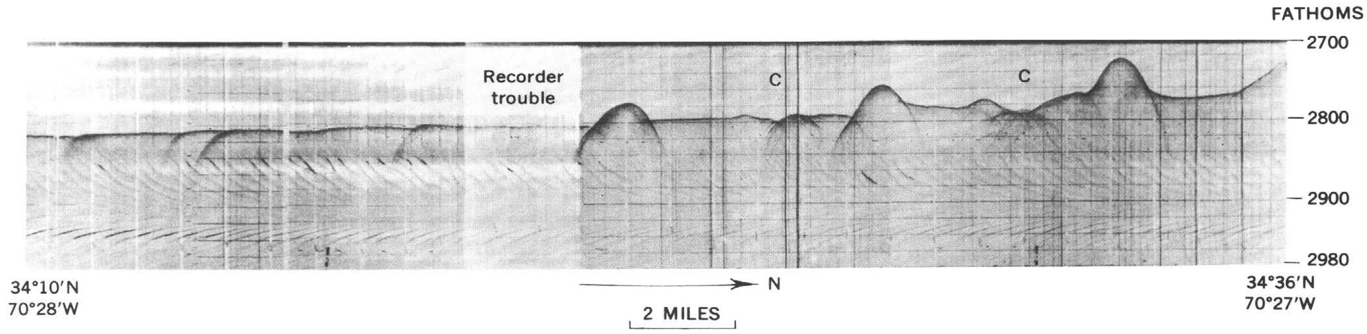


FIGURE 14.—The depositional front of the present-day Hudson Fan leading to the Hatteras Plain. The hills are interpreted as depositional features associated with small channels (c) that merge into the small depositional fronts, such as those shown on the left. This is a straight profile that probably cuts across meandering features.

persion by turbidity currents may be extended to explain the transportation of sediments to the Nares Plain; thus the ultimate source of the sediments in the Nares Plain would also be from the Middle Atlantic States through the Hudson and associated canyons (pl. 1). Cores taken in the Nares Plain contain quartzose silt (Ericson, Ewing, Wollin, and Heezen, 1961), a further indication that the sediments are derived from noncarbonate continental areas. The Puerto Rico Trench to the south and depressions on the north eliminate the possibility of terrigenous sedimentation from other directions.

BLAKE BASIN

The Blake Basin lies south of the Hatteras Plain and east of the Blake Plateau. It was called the Blake-Baha-

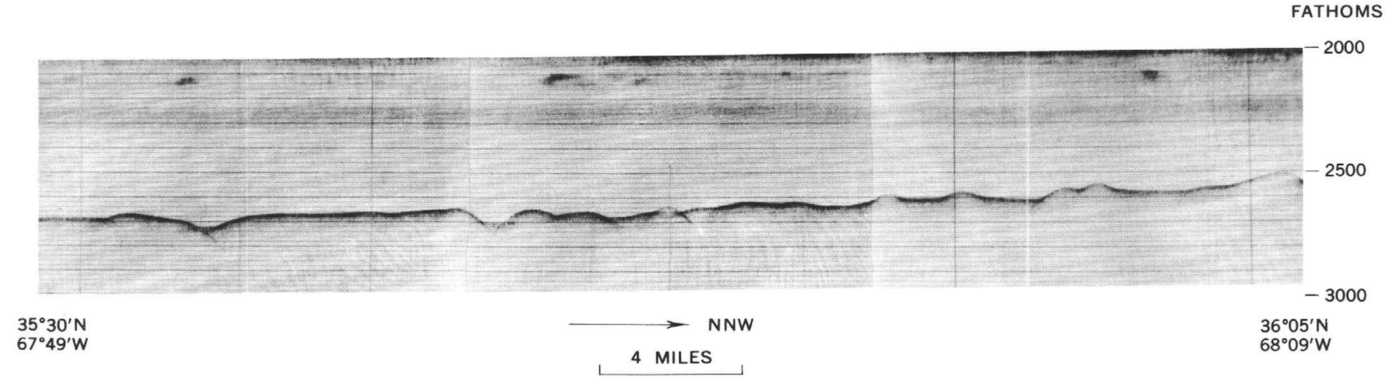


FIGURE 15.—A sequence of channels and associated levees at the north end of the Hatteras Plain. The channel on the left is the deepest in the profile. The higher channellike depressions may be used only intermittently or may be the result of a single episode of deposition.

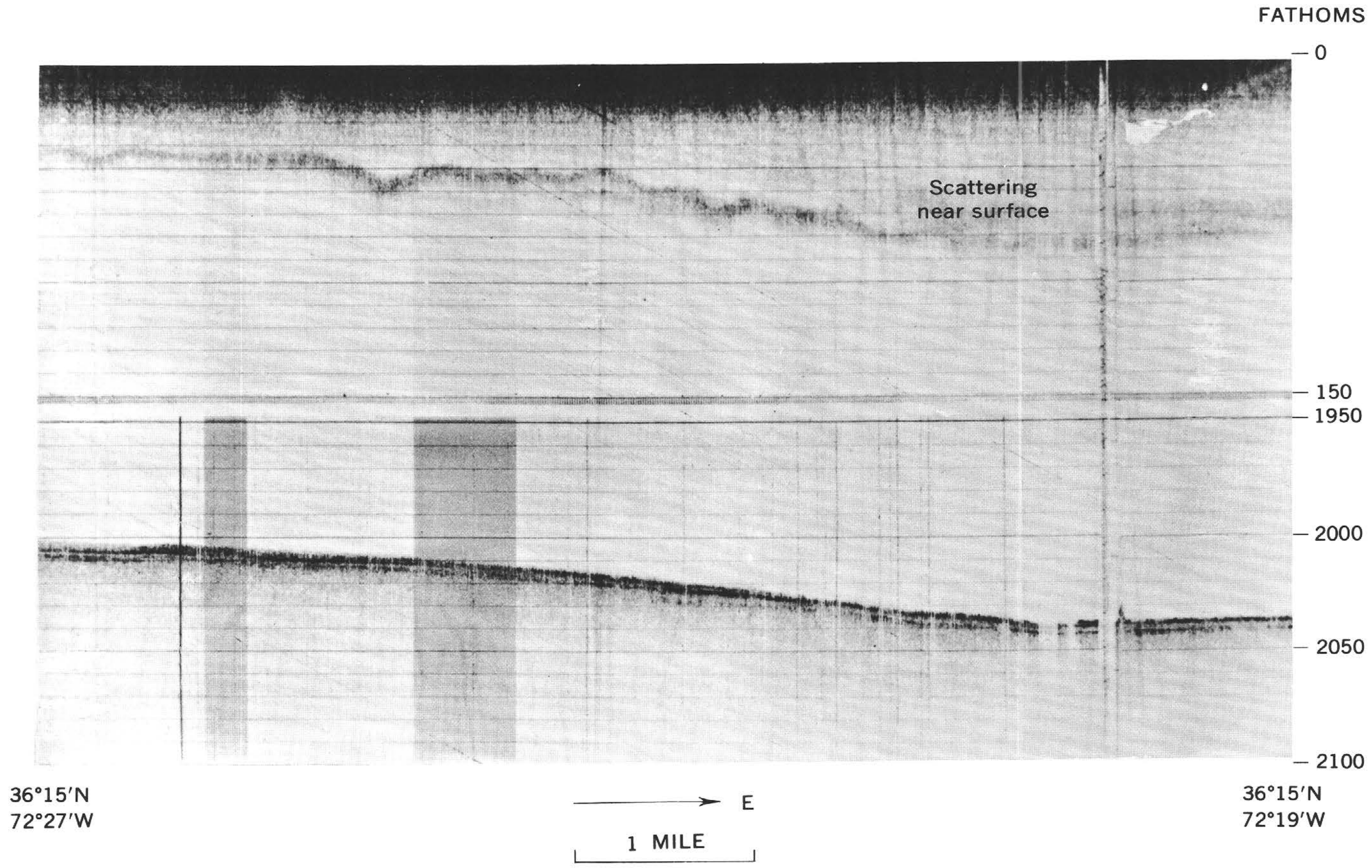


FIGURE 16.—Continuous subbottom reflecting horizon on the Hudson Fan. This type of bottom record is probably indicative of episodal floods of terrigenous sediment. Cores taken in the area contain a high percentage of quartz sand.

ma Abyssal Plain by Heezen, Tharp, and Ewing (1959). The flat-lying sediment of this enclosed basin forms a flat surface called the Blake Plain. The axis of maximum depth lies adjacent to the Blake Escarpment on the west; a gentle slope leads up onto the Blake Ridge to the east. A maximum depth of 5,024 meters was recently recorded by the writer although older records show questionable deeper places. The boundary of the Blake Basin is not easily defined except along the Blake Escarpment, where echo traces indicate a steep marginal slope at the base of the escarpment. Samples taken from the flat plain are entirely calcareous mud and foraminiferal ooze. Ericson, Ewing, Wollin, and Heezen (1961, p. 206) have described calcareous turbidites in the basin that have graded bedding and contain shallow-water faunas. Cores containing Tertiary and Cretaceous sediment have been obtained from the escarpment (Ericson, Ewing, and Heezen, 1952). Perhaps the Blake Basin is maintained as a closed depression because of the damming effect of turbidites debouching from the Northwest Providence Channel (lat 26° N., long 77° W.) and the Tongue of the Ocean (lat 24° N., long 77° W.) (pl. 1). The basin has a sill, defined by the 4,750-meter contour, northeast of Eleuthera (lat 25°30′ N., long 76° W.). A broad channel trends southeastward from the sill onto the Hatteras Plain. This channel has a steep gradient in the southeastern part of its course and a gentle gradient in the northwestern part. In cross section the axis of maximum depth lies against the Bahama Banks, as shown in figure 19.

The Blake Ridge extends from the Blake Escarpment in the vicinity of Cape Fear (lat 32°30′ N., long 76°30′ W.) southeastward to lat 27° N., long 71° W. It is characterized by a steep northeast side which gradually levels out with increasing depth and grades into the Hatteras Plain (figs. 20, 9, *G–G′*). Near the crest, irregularities indicate slumping and sliding of sediment from the upper slope, a process which tends to accentuate the sharpness of the crest. The southwest flank of the ridge has a gradual slope and is characterized locally by gently rolling hills (lat 30° N., long 75° W.), which have smooth boundaries and seem to be depositional rather than tectonic or volcanic. South of the hills are several elongate rolling ridges and depressions. Frequent subbottom layering shown by some bottom echoes (figs. 20, 21) also indicates that the ridge is depositional. Thus, most minor features on the ridge

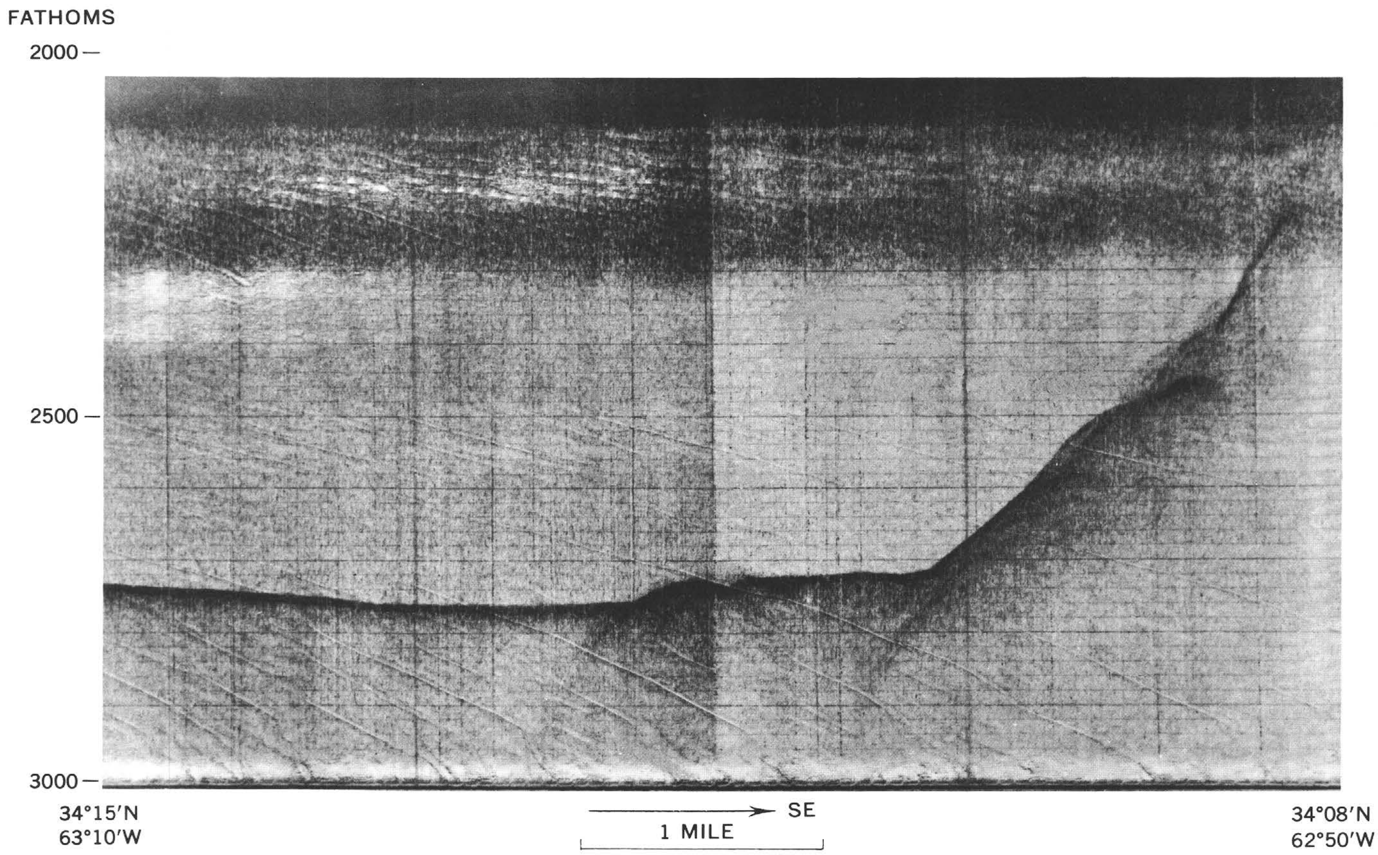


FIGURE 17.—A depression near Muir Seamount. It may be the result of isostatic sinking in an area of relatively reduced sedimentation because Muir Seamount does not seem to be an area presently receiving turbidity deposition.

are best explained as sedimentary deposits laid down by active currents. Recent seismic work by Hersey, Bunce, Wyrick, and Dietz (1959) and Ewing, Ewing, and Worzel (1963) has shown the ridge to be basically a sedimentary structure although underlying basement strata may be rather complicated (Hersey, Bunce, Wyrick, and Dietz, 1959, p. 460). Seismic velocities within the topographic limits of the ridge are those expected in unconsolidated and partly consolidated sediment.

In striking contrast to the profile of the continental slope and rise farther north, the profile of the Blake Basin lacks a depositional slope leading seaward from the Bahama Banks and Blake Plateau (pl. 1; fig. 9, *H–H′*, *I–I′*). The channels that cut through the banks appear to be graded (Hurley, 1963), or at least to have an uninterrupted downhill slope, and are spectacularly steep; however, it is evident from the topography—a lack of large debris slopes and cones—that the volume of the sediment contribution from the plateau is minor. In fact, the topography suggests that the sediments in the Blake Basin are derived from the direction of the Blake Ridge and are deposited against the Blake and Bahama Escarpments. Where the Hatteras Plain is adjacent to the Bahama Escarpment, terrigenous sedi-

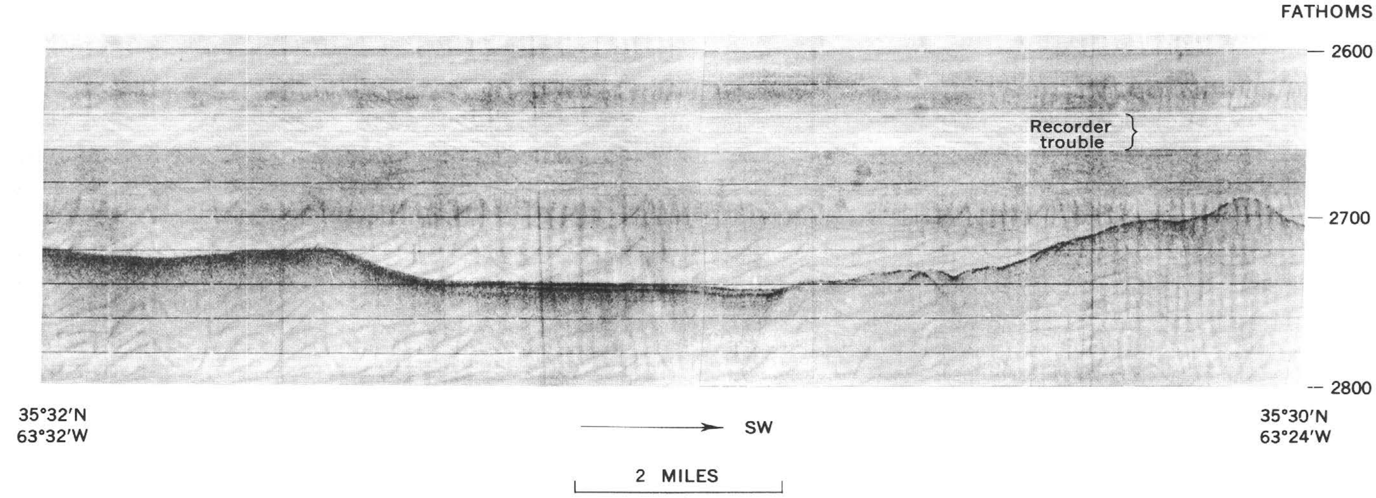


FIGURE 18.—A sedimentary contact between the Hudson Fan and the Bermuda Rise in the depression area north of Bermuda. The sharply defined bottom on the right is probably covered with *Globigerina* ooze. The hazy, soft bottom on the left probably is fine terrigenous material. The middle section could be a small channel but is more likely the prograding end of a terrigenous fan being deposited against the hills on the right.

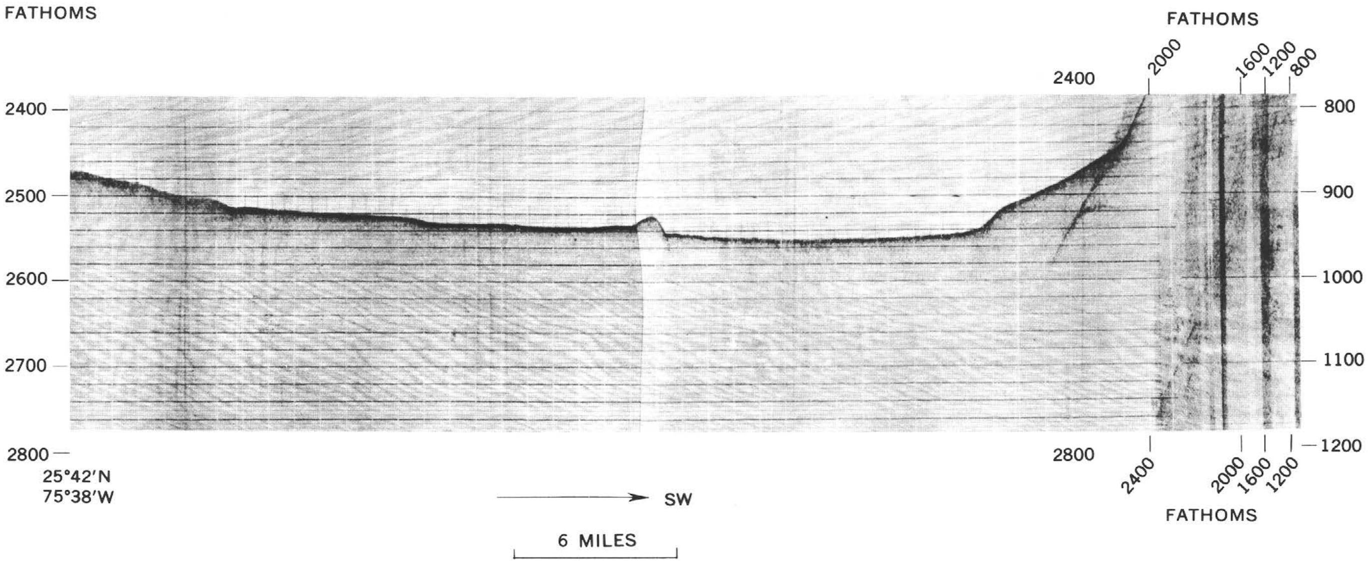


FIGURE 19.—Channellike depression at the base of the Bahama Escarpment near Eleuthera. This continuous steeply sloping feature, apparently drains eastward from the Blake Basin into the Hatteras Plain. Note the small bump in the middle, which is probably a natural levee. The Bahama Escarpment on the right is lost in side echoes and reverberations.

ment from as far away as the Hudson Canyon might be deposited close to the Bahama Banks. Because of the depths involved, however, it is difficult to say whether the very low carbonate values in the area are due to solution, or to masking by terrigenous sediment, or both. Another factor related to the lack of deposition from the adjacent banks is that carbonate sediments tend to consolidate into banks and reefs rather than to move out as turbidity flows.

BLAKE PLATEAU AND BAHAMA BANKS

The Blake Plateau and Bahama Banks are part of the continental margin rather than the ocean basin. However, they have large areas at depths greater than those of the continental shelf, and their sediments are usually considered to be indicative of the oceanic environment. The Blake Plateau and Bahama Banks, as well as Florida, form a southerly extending carbonate province of the Atlantic-Gulf coast Tertiary geosyncline (Murray, 1963). The province consists of a thick sequence of Tertiary and Mesozoic calcium carbonate deposits; this thick sequence is indicated by data from deep wells in southern Florida and on Andros Island (fig. 9, *I–I′*) and by geophysical data. Recent carbonate sediments of many types in the region are described in numerous publications (Cloud, 1962; Newell, 1955, 1959; Rusnak and Nesteroff, 1963).

The most striking topographic feature of the area is the extremely steep outer escarpment that extends from Blake Spur (lat 30° N., long 76°30′ W.) to the end of Navidad Bank (lat 20° N., long 69° W.) Steep-walled, steep-graded submarine canyons drain off the Bahama Banks and debouch onto the Hatteras Plain and into the Blake Basin.

The entire area is characterized by the uniformity of bank and channel topography—including the northernmost subbank platform, the Blake Plateau. The deep channel draining the Blake Plateau just north of Little Bahama Bank (lat 27° N., long 77° W.) is not greatly different from the Northwest Providence Channel to the south. Similarly, the bank on which San Salvador is perched (lat 24° N., long 74°30′ W.) is surrounded on three sides by depths of 4,000 meters and does not differ greatly from the Blake Spur, which is surrounded on three sides by deep water. North of lat 31° N. the outer escarpment merges with the continental slope and the distinctive Blake Plateau–Bahama Bank morphology disappears.

The Gulf Stream, or Florida Current as it is also called in this region, and other currents greatly influence

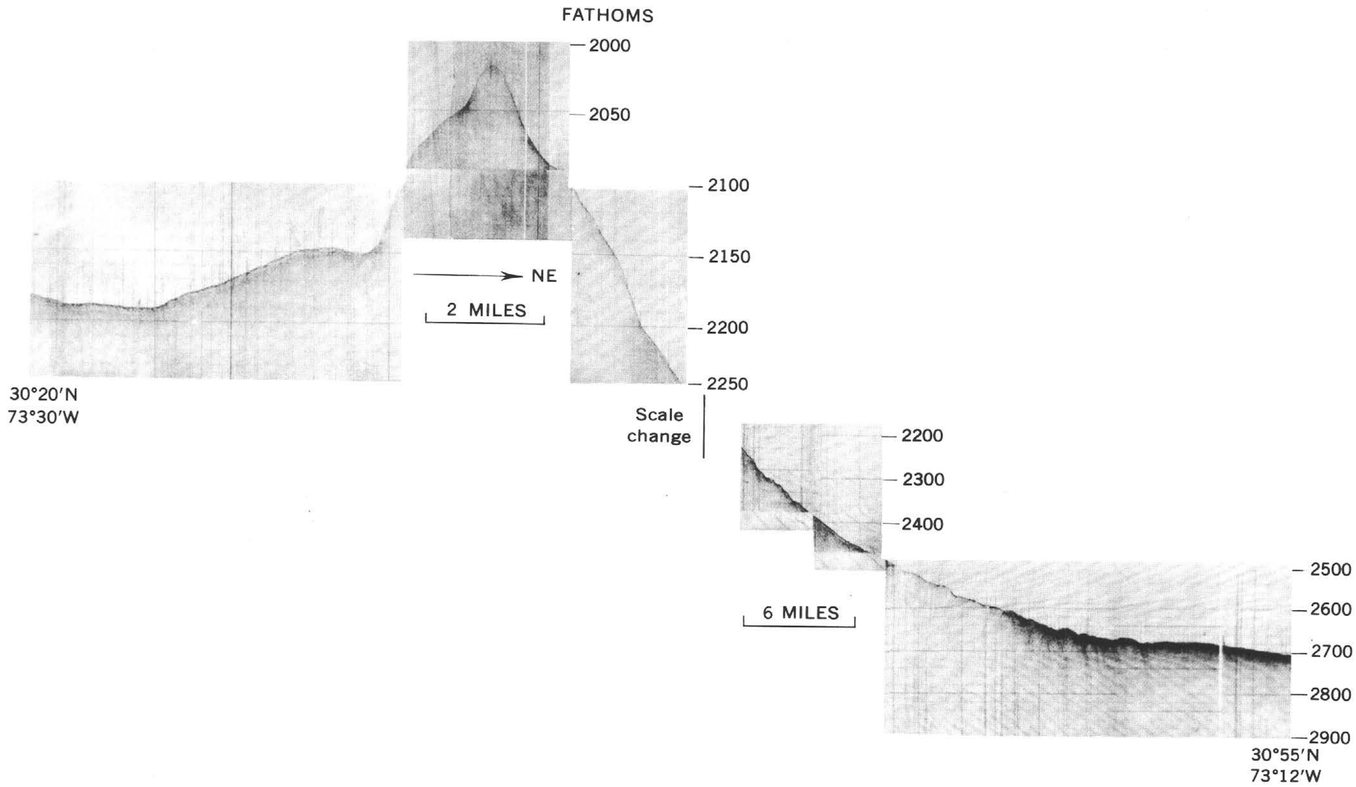


FIGURE 20.—Perpendicular profile across the Blake Ridge. Note the sharp crest and the steep northern slope. Numerous crossings indicate that the ridge is continuous and not a seamount. Note the subbottom penetration on the left, and the sharp irregular bottom reflection on the right side of the ridge.

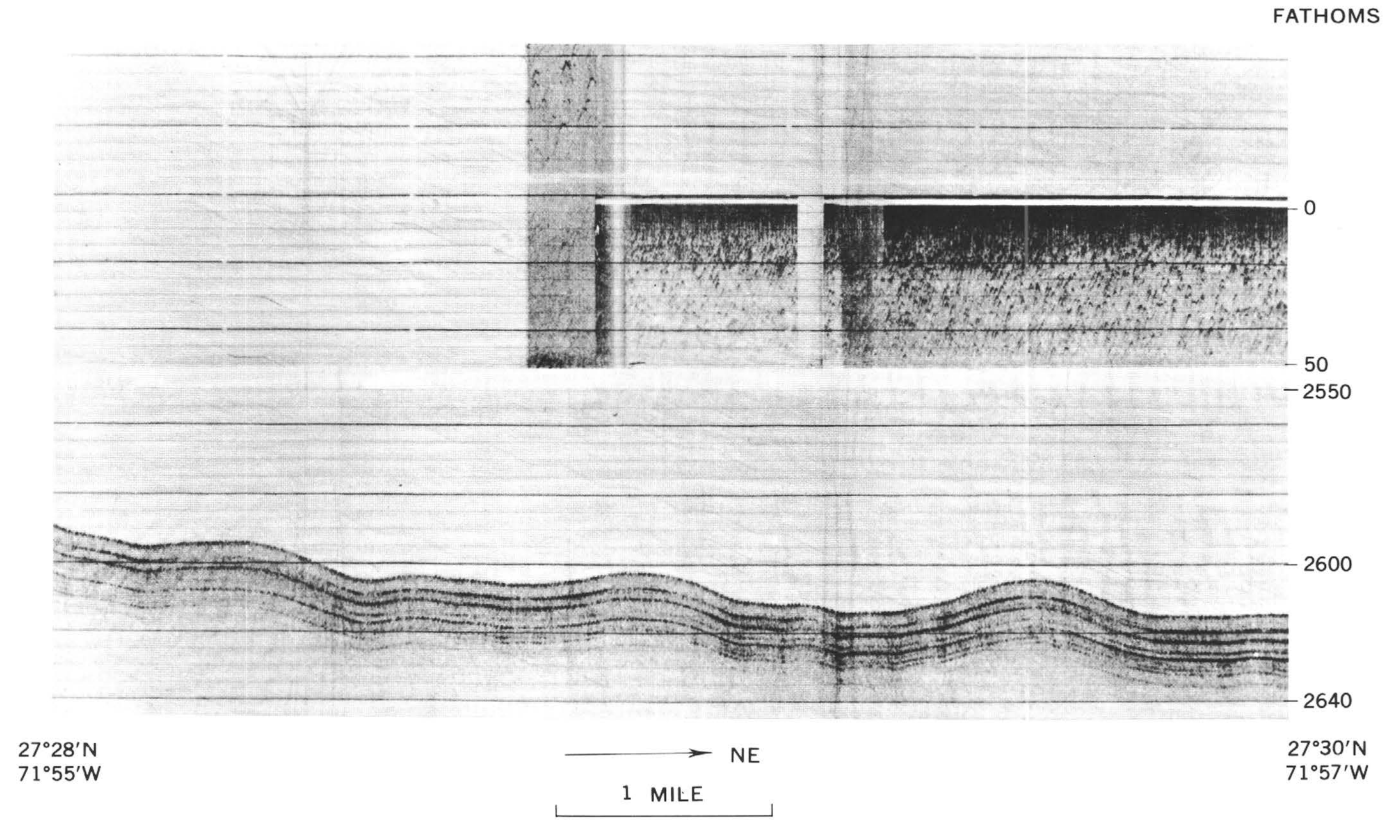


FIGURE 21.—High-resolution echogram illustrating subbottom reflectors on the Blake Ridge. Surveying in the area reveals that the subbottom reflectors are two-dimensional features. They probably represent successive episodes of flooding by sediment-laden currents. Note the high resolution of the near-surface scatterers in the upper channel.

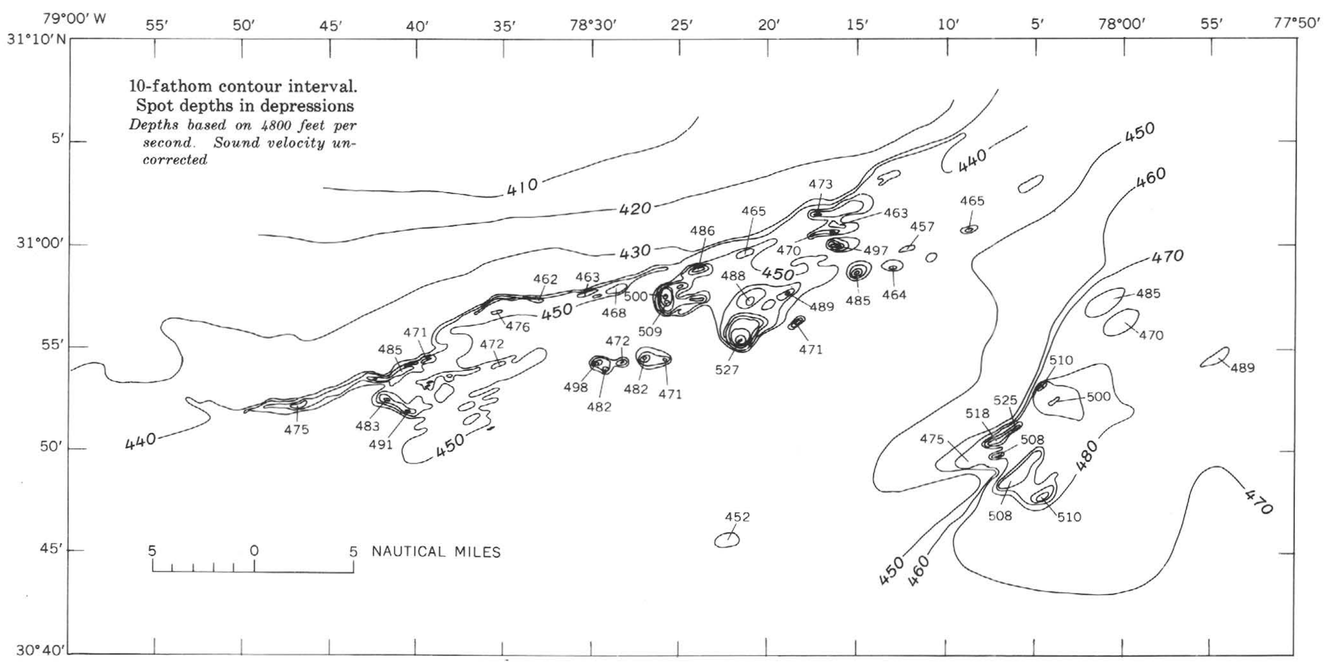


FIGURE 22.—Detailed topography of an area of small depressions on the Blake Plateau. The depressions are believed to be a result of scour, although solution holes and structural control may have influenced their initial development. Strong northeast-flowing bottom currents have been measured in the area.

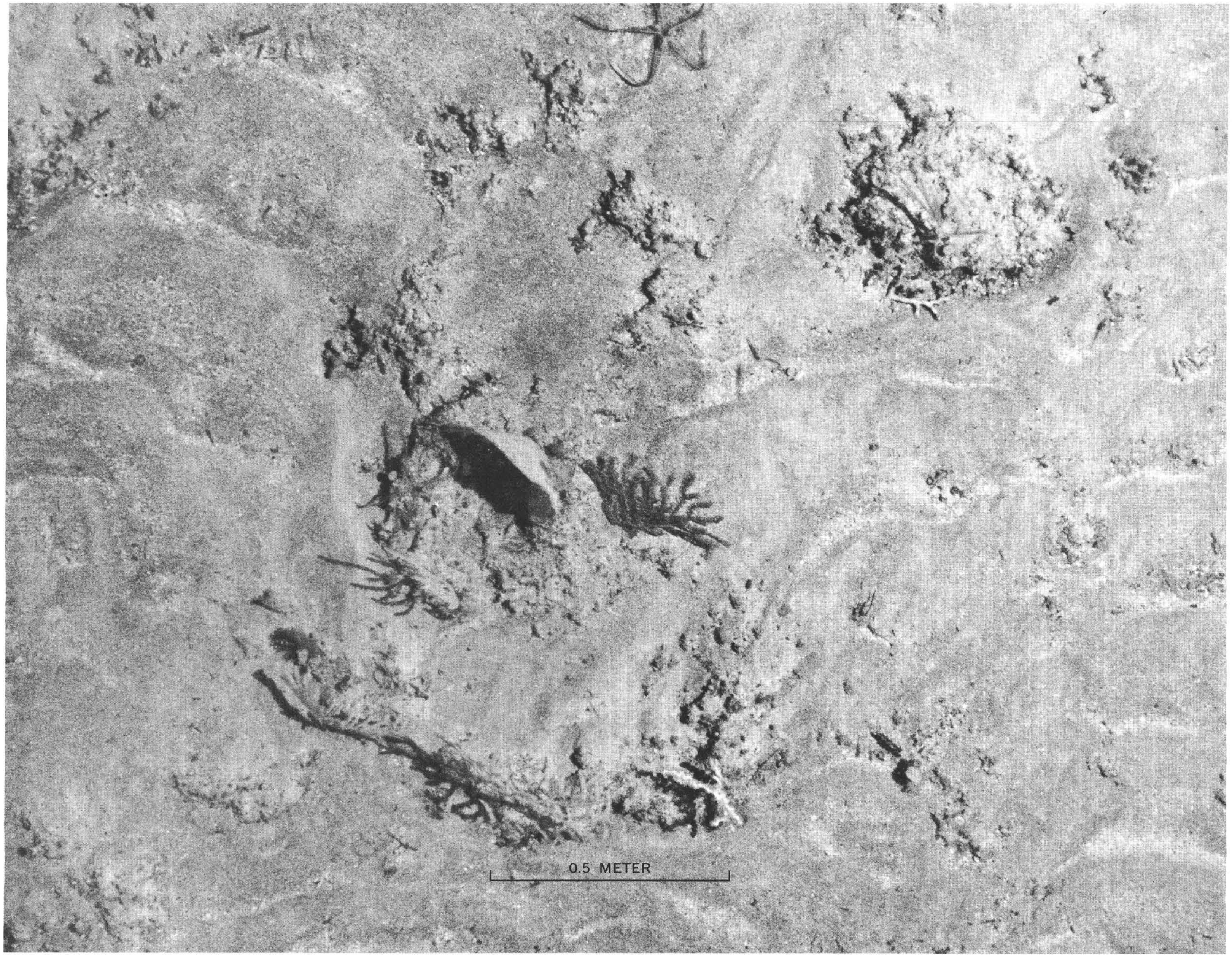


FIGURE 23.—Bottom photograph illustrating factors that denote strong currents on the Blake Plateau. The large cupped sponge in the center grows with the cup facing upcurrent to catch maximum water; the sea fans also orient themselves normal to the current. More mobile organisms, like the crinoid at the top middle, stream out with the current. Current ripples and lee accumulations are evident in almost every photograph from this area.

the topography in the Blake-Bahama area. Not only does the Gulf Stream transport sediment northward and act as a barrier to the offshore transport of terrigenous sediment, but there is mounting evidence that it may actually shape and maintain its channel through the Straits of Florida and across the Blake Plateau (Pratt, 1963). The depth beneath the axis of the Gulf Stream changes less than 100 meters from Cay Sal Bank (lat 24° N., long 80° W.) to the northern end of the Blake Plateau (lat 33° N.), a distance of 1,000 kilometers. Locally along the axis, however, are steep-sided depressions with as much as 250 meters of relief; they are probably best explained as scour depressions, eroded and maintained by the current (fig. 22). Currents averaging 50 cm per sec have been measured on the bottom (Pratt, 1963) (fig. 23). Bottom photographs and dredge hauls in the axis of the stream show that locally sediment has been removed and the bottom is paved with crusts and nodules of manganese.

Another major current system that perhaps affects the topography in the area is the trade-wind-driven North Equatorial Current. The northern boundary of the Trade Wind Belt coincides with the northernmost island of the Bahama Islands; furthermore, the prow-shaped appearance of the windward islands, such as Eleuthera (lat 25° N., long 76°10′ W.), may be the result of dominant waves and currents from the east. The distribution of currents would also tend to limit the eastward transport of sediment from the banks into the adjacent ocean basin.

Several reasonable hypotheses have been proposed for the structure of the Blake Plateau and Bahama Banks. The best seems to be the barrier-reef hypothesis of Newell (1955, 1959), which considers the banks to be built-up deposits of calcium carbonate. One mode of accumulation of present-day shallow-water carbonate deposits is in the form of steep-faced banks and reefs, many of which are stabilized around a coral framework. This characteristic of carbonate reefs has been noted many times in connection with the development of atolls and barrier reefs. Discontinuities revealed by the geophysical work on the Blake Plateau (Hersey, Bunce, Wyrick, and Dietz, 1959) can be interpreted partly as facies changes and carbonate reefs rather than as faulting and folding. Significantly, large-scale faulting in the area has not been demonstrated by actual stratigraphic displacement. Moreover, similar escarpments dominate the carbonate facies on the west side of the Florida Platform and the Yucatan Peninsula.

The sampling of indurated calcereous ooze containing Miocene Foraminifera indicates that the Blake Plateau is essentially a Miocene surface (Ruth Todd, written commun., 1962; Ericson, Ewing, and Heezen, 1952) probably preserved from the time when carbonate accretion no longer effectively kept up with subsidence (Newel, 1959). The marked similarity of the Miocene sediments to modern pelagic ooze dredged from the Blake Plateau indicates that the Gulf Stream has probably been a relatively constant environmental factor since the Miocene. Recent drilling of three holes on the Blake Plateau substantiates this (Joint Oceanog. Inst. Deep Earth Sampling Program, 1965). Causes for the termination of carbonate accretion on the Blake Plateau in the Miocene are unknown but may be a combination of (1) shift in the prevailing wind pattern from the Northeast Trades to the Westerlies, (2) general cooling below the temperature of optimum coral-reef growth, (3) influx of turbid terrigenous sediments and (4) erosion by the Gulf Stream.

BERMUDA RISE

The Bermuda Rise (Heezen, Tharp, and Ewing, 1959, p. 74) extends outward from Bermuda Island in the middle of the North American Basin. The rise is nearly surrounded by abyssal plains covered with terrigenous sediment derived from the continent; so, it exists as a separate carbonate sediment province. Heezen, Tharp, and Ewing (1959) gave rather complicated terminology to the features of the Bermuda Rise, but because the area is topographically so complex and relatively unexplored, only a general presentation is given here. Sounding data on the Bermuda Rise are difficult to correlate and contour because the bottom has numerous closed depressions and small hills with dimensions smaller than the spacing of the sounding lines (fig. 24). Many of these small features have been omitted from the generalized picture on the contoured chart (pl. 1). More detailed sounding control near Bermuda Island, however, presents a picture of the topography which can be extrapolated into areas of poor control.

In general, the Bermuda Rise slopes up to a pedestal on which Bermuda Island is situated. North and east of the island, however, the rise forms a generally elevated platform having numerous seamounts, scarps (Heezen, Tharp, and Ewing, 1959, p. 76), sediment-filled channels (fig. 9, *L–L′*) and closed basins. The available topographic data in this area are limited and inconclusive. Closed basins exist both northwest of Bermuda near the Sohm Plain and between Bermuda and the Nares Plain. Thus the simple impression that the Bermuda Rise is surrounded by abyssal-plain sediments lapping onto it is not completely accurate. As explained in the discussion of the Hudson Fan, the depression at the northwest edge of the Bermuda Rise may be due partly to changes in the sedimentary regime in the area. Depressions southeast of Bermuda, however, are apparently due to the failure of terrigenous sediment to reach them. Along the west margin of the rise, there is a reasonably clear picture of the submarine topography. Here the sediments of the Hatteras Plain encroach on the hills and swells of the Bermuda Rise. In general, the deeper the Hatteras Plain becomes toward the south and the Nares Plain toward the east, the farther the boundary of the Bermuda Rise is from Bermuda.

Bermuda is unique among oceanic islands because it has apparently been relatively stable and at sea level since the Cretaceous Period (Ericson and Wollin, 1963). Murray and Renard (1891) and later Ericson, Ewing, and Heezen (1952, p. 498) have noted that shallow-water biologic elements in the present-day sediment on the Bermuda Rise, such as calcareous algae, increase in abundance as Bermuda is approached. Thus, Bermuda has been a probable source of shallow-water sediments throughout the Tertiary Period. Seismic refraction work (Officer, 1955) and gravity measurements (Woollard, 1954) give further evidence of thick accumulations of sedimentary material around Bermuda. Much of the rolling hill-and-valley-type topography and the evidence of closed depressions upslope from low hills suggest that large-scale slumping and sliding, even on gentle slopes, may be an important sedimentary process on the Bermuda Rise. The gently rolling hills are in sharp contrast to the rugged igneous seamounts, some of which seem to project through the sediments (pl. 1 and fig. 24).

SEDIMENTS

The ocean basin is a vast basin of sedimentation. As such, most minor topographic features and even many of the gross features should be considered as constructional landforms in marked contrast to the surface of the continents where erosional factors are most important in molding the landscape. The Atlantic coast of the United States is structurally a stable coast but one of very active sedimentation. Therefore, the types of sediments entering the marine environment and the various processes of sedimentation are important in the formation of the topography of the ocean floor.

Fundamentally there are two types of ocean bottom: (1) a primary or volcanic bottom characterized by abyssal hills and seamounts, similar to that along the Mid-Atlantic Ridge, and (2) a secondary or a sediment-covered bottom characterized by abyssal plains that extend seaward from the continental margins. The sediment bottom along the east coast can be divided into three natural sedimentary provinces: (1) glacial to the north, (2) terrigenous off the Middle Atlantic States, and (3) carbonate off the South Atlantic States and the Bahama Islands. These sedimentary provinces transcend the morphologic boundaries of the shelf and slope and can be traced from mappable source areas on land into the sediment distribution pattern of the deep-sea basins (fig. 25).

From classic studies of the bottom samples taken on the H.M.S. *Challenger* Expedition, Murray and Renard (1891) classified marine sediments under two major categories: (1) pelagic (originating in the ocean) and

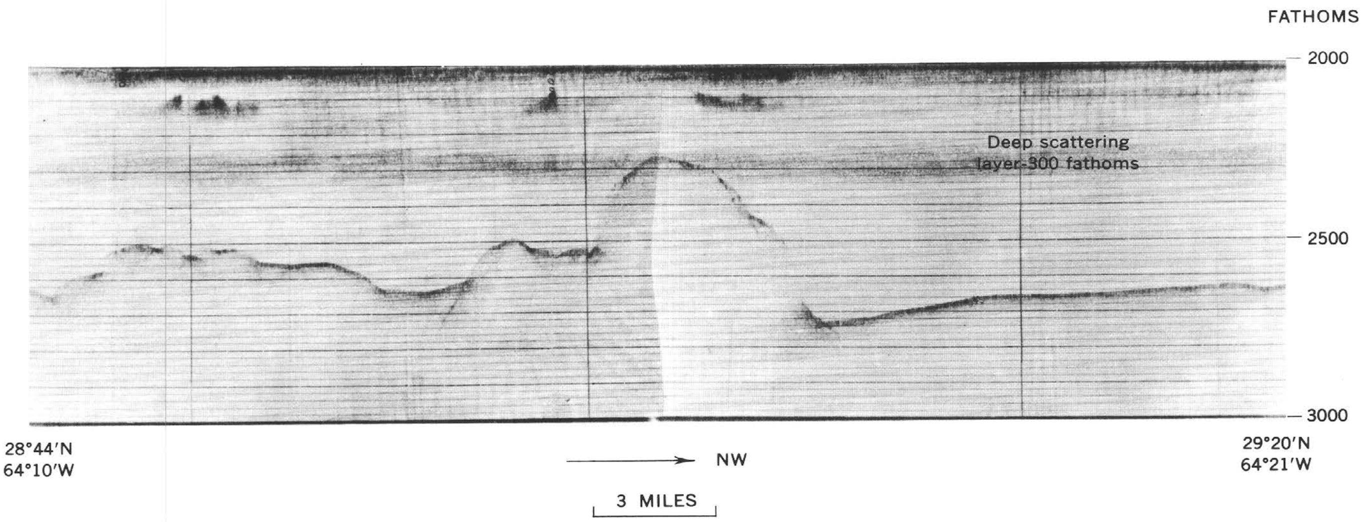


FIGURE 24.—Irregular rolling topography on the Bermuda Rise south of Bermuda Island. The topography is broken by a small seamount or abyssal hill of about 450-fathom relief. The depression to the right of the hill is a feature that occurs at the bases of numerous hills on the Bermuda Rise. The depressions are probably closed and make it nearly impossible to accurately portray the topography by contouring.

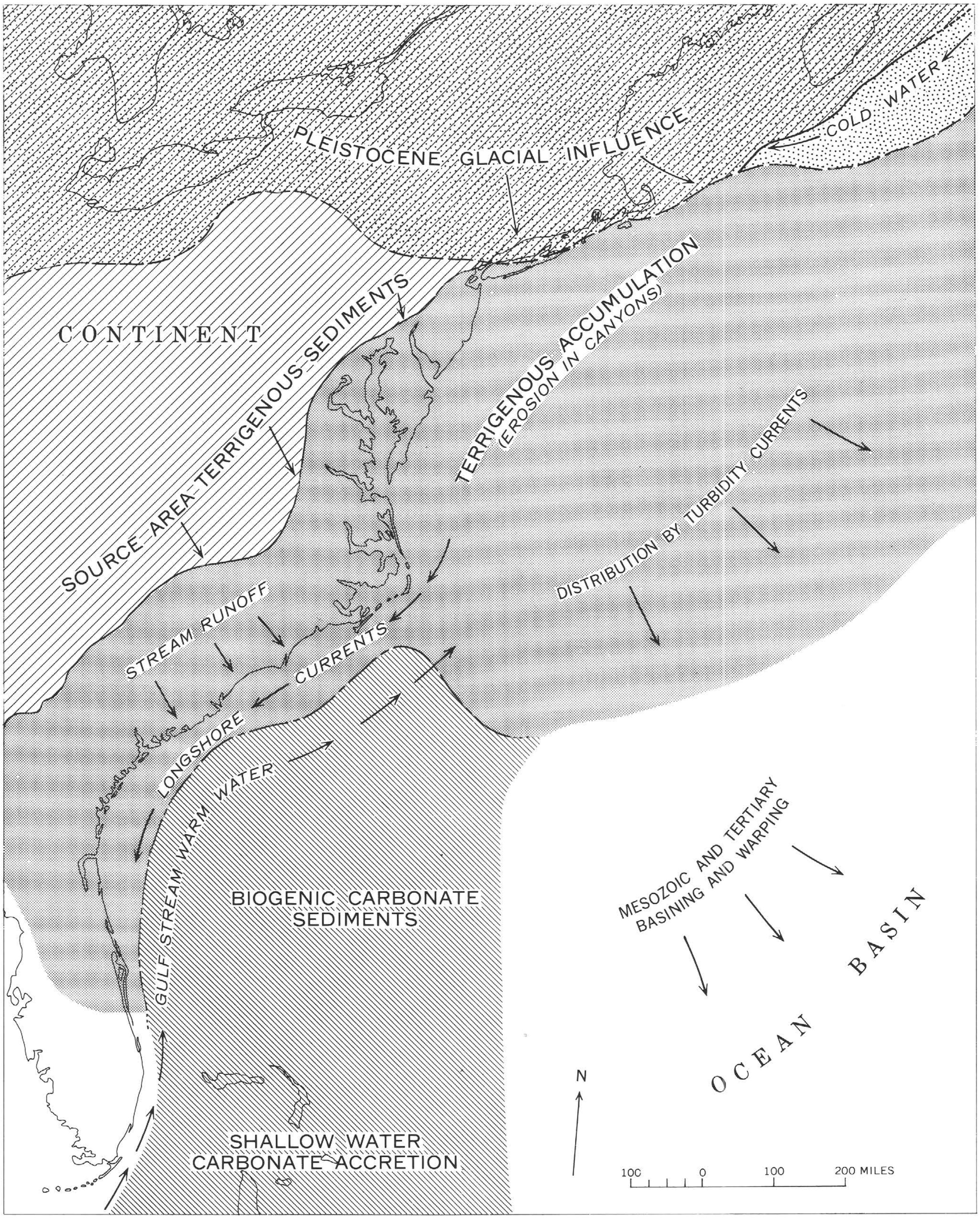


FIGURE 25.—Diagrammatic summary of factors influencing sedimentation off the east coast of the United States.

(2) terrigenous (derived from land). Later workers (Kuenen, 1950; Revelle, 1944) have generally followed this classification. Pelagic sediments usually are further classified on the basis of the presence or absence of carbonate constituents, whereas terrigenous deposits usually are thought of as noncarbonate quartzose sediments. Recently there have been attempts to describe sediments on the basis of color and physical properties to avoid any genetic connotation (Ericson, Ewing, Wollin, and Heezen, 1961, p. 203; Olausson, 1960), but the older terminology is still generally used.

Pelagic sediments are widely distributed throughout the North American Basin. The amounts and nature of these sediments have been described by Ericson, Ewing, Wollin, and Heezen (1961) and others. In the present study, pelagic sedimentation has been given little emphasis because the area is dominated by terrigenous sedimentation derived from the east coasts of the United States and Canada (Ericson, Ewing, Wollin, and Heezen, 1961; Ewing, Ewing, and Talwani, 1963), especially in the western North Atlantic where basins are small, inflowing rivers are large, and pelagic production is low compared with that of equatorial regions (Arrhenius, 1961, p. 131).

The terrigenous sediments and the processes that deposited them may be separated in the general order of their abundance and importance in relation to the morphology of the ocean floor of the North American Basin, namely, (1) terrigenous, meaning quartzose continentally derived sediments, (2) carbonate, or calcium carbonate sediments formed mainly as the result of organic production in shallow water, (3) glacial, a special condition of terrigenous sedimentation, (4) eolian, apparently formed equally well in both terrigenous and carbonate environments, and (5) authigenic, not important in the development of morphological features but definitely important as environmental indicators.

TERRIGENOUS SEDIMENTS

Terrigenous sediments constitute the bulk of the deposits along the east coast continental margin. The main source areas for these sediments are the folded and metamorphosed rocks of the Appalachian Mountains and the crystalline rocks of the Piedmont province. At the start of the depositional cycle, the Appalachian Mountains were younger and higher and therefore constituted an even better source of sediment than they do today. A flat-lying prism of Cretaceous and Tertiary sediments, the Coastal Plain sequence, rests unconformably upon the crystalline rock of the Piedmont and supplies a much smaller amount of sediment for marine deposition. It is possible, although not yet proved, that rocks as old as Triassic may be present locally at the base of the prism (Gilluly, 1964, p. 484).

Most knowledge of the composition and thickness of the sediments in the structural basin beneath the continental shelf, slope, and rise comes from offshore seismic work and extrapolation of data from wells on shore. From the thin edge exposed in outcrops along the Piedmont, the sediment prism thickens eastward and seaward (Maher, 1965). Data from wells indicate sediment thicknesses of nearly 10,000 feet at Cape Hatteras, 6,000 feet at Cape May, and more than 15,000 feet in southern Florida. The thicknesses of the sediments in the marginal basins offshore are commonly 15,000 to 20,000 feet, and a maximum thickness of 30,000 feet was found south of the Grand Banks in the outer of two parallel marginal troughs (Drake, Ewing, and Sutton, 1959). The sediments and their structural environment have been discussed in terms of a geosyncline by various writers (Drake, Ewing, and Sutton, 1959; Murray, 1963).

Evidence from cores (Ericson, Ewing, Wollin, and Heezen, 1961) and from bottom samples (fig. 26) suggests that the terrigenous fill extends to the limits of the abyssal plains. Especially signficant are turbidity-current deposits consisting of graded beds of quartz sand and silt (fig. 27) that are found on the abyssal plains where one would expect an essentially quartz-free environment.

Ericson, Ewing, and Heezen (1952) were the first to core graded deep-sea sand off the east coast although Daly (1942) earlier recognized the possible role of turbidity currents in canyon cutting. Heezen and Ewing (1952) and Elmendorf and Heezen (1957) have attributed submarine cable breaks on the Grand Banks during 1929 to turbidity currents that were triggered by an earthquake; these currents flowed down the banks and into the Sohm Plain.

Quartz sand is a distinctive constituent of most sediments deposited by turbidity currents. The sand may be part of a well-sorted graded sequence, but more commonly it is silty. The wide distribution of sand on the abyssal plains provides evidence of active currents with sufficient competence to transport sand-sized material relatively long distances. Figure 28 shows the percentage of sand in the total core length plotted against increased distance from the continental shelf off New England, based on core data provided by Ericson, Ewing, Wollin, and Heezen (1961). It is apparent that the coarse sand has accumulated primarily on the submarine fans off the ends of the canyons and that the finer material has moved to the seaward limits of the abyssal plains.

At the ends of the abyssal plains where the ocean floor is nearly flat, echo soundings are characterized by

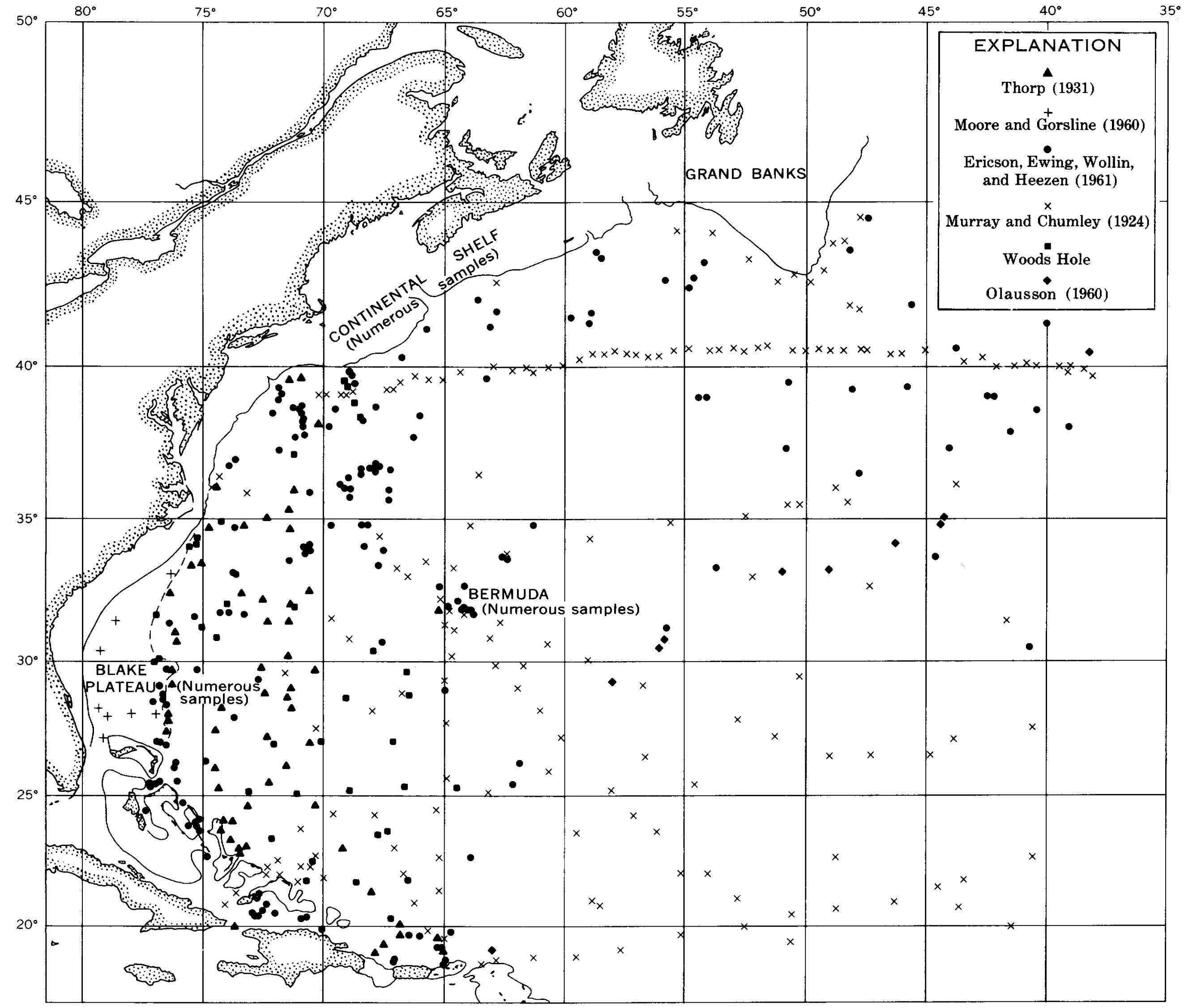


FIGURE 26.—The locations of described sediment samples collected off the east coast.

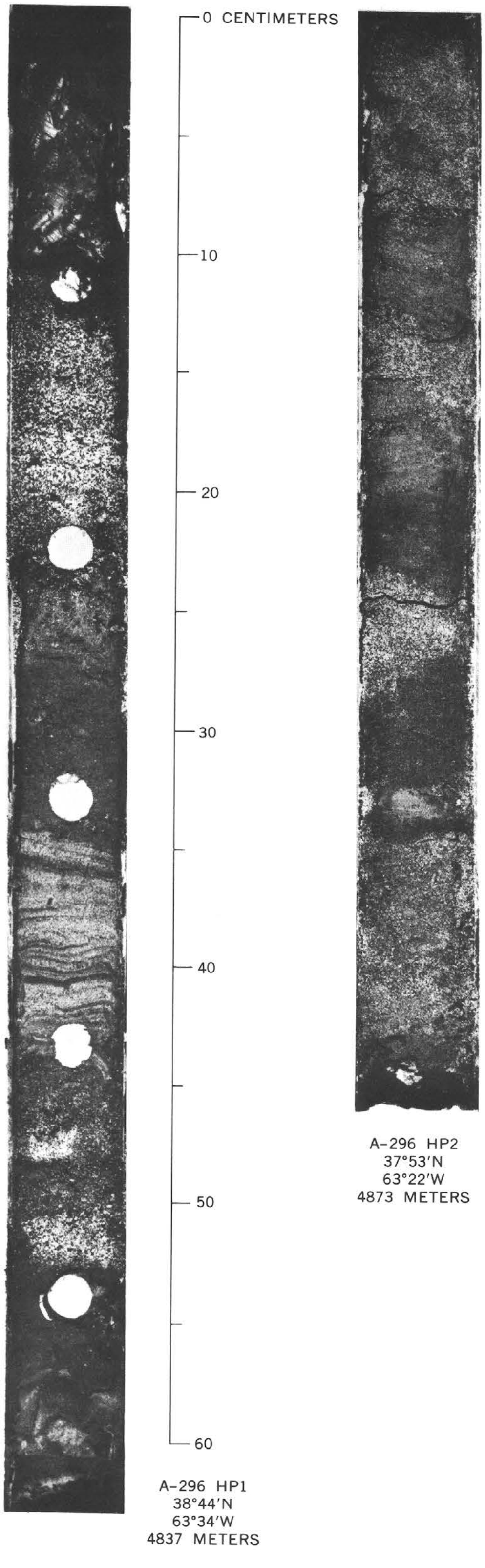
subbottom reflections (figs. 10, 11). The high acoustic penetration by means of echo-sounding devices can be attributed primarily to high sediment porosity. (Hamilton and others, 1956). Those sediments which are highly porous are clays and silty clays.

Murray and Chumley (1924) described numerous samples of red clay from the Hatteras Plain and elsewhere. This red clay has been described classically as a pelagic deposit—mainly a carbonate ooze from which the organic carbonate remains have been removed by solution. Actually, a close mineralogical similarity exists between deep-sea "red clay" and lateritic sediments contributed by the rivers. Therefore, some workers consider most Atlantic red clay to have a terrigenous origin (Biscaye, 1965). Most sediment samples from the continental slope and the continental rise are best described as brown mud and appear similar to many nearshore mud deposits (fig. 29).

The thixotropic properties of the clays (Kerr, 1962) undoubtedly influences the distribution of sediments on the sea floor. Mobile clay may flow on very gentle slopes, in contrast to carbonate sediments, which tend to consolidate into various reef formations. This contract has been noted in deep-sea deposits (Hamilton, 1961, p. 64).

CARBONATE SEDIMENTS

Off the southern part of the east coast, carbonate deposits cover large areas in both shallow and deep water. Most calcium carbonate on the continental shelf is biogenic and of local origin. In deep water, however, it may have been transported and deposited in a manner similar to terrigenous deposits; thus, carbonate sands,



carbonate turbidites, and carbonate eolianites are possible. This parallelism of carbonate and terrigenous deposits in their various modes of occurrence can be a source of confusion in classification.

Within the North American Basin, carbonate sediments are concentrated in three general areas: (1) the abyssal hills leading up to the Mid-Atlantic Ridge, (2) the Blake Plateau and Bahama Banks, and (3) the region around Bermuda (fig. 30). The three areas have essentially three different processes of carbonate formation; pelagic sedimentation, reworking of pelagic deposits, and active reef building.

The abyssal hills near the Mid-Atlantic Ridge are subject to typical particle-by-particle accumulation of planktonic foraminiferal tests—true pelagic sedimentation. This kind of sedimentation occurs on all elevated areas that are above the solution depth for carbonate and beyond the influence of turbidity currents, including seamounts. Thus, the seamounts of the New England Seamount Chain are underwater "islands" blanketed by high-carbonate ooze (fig. 31) and surrounded by terrigenous abyssal-plain deposits.

The second major geographic occurrence of carbonate deposit is on the Bahama Banks and Blake Plateau at the margin of the ocean basin. Here most deposits, especially in the channels (figs. 32, 33, 34), are formed by the reworking and mixing of pelagic sediments with shallow-water oolitic and fine-grained carbonate deposits. In addition, some inorganic carbonate accretions may occur on the Bahama Banks (Cloud, 1962, p. 103). In some local basins, as the Tongue of the Ocean, turbidity currents composed of carbonate sediments are important means of sediment distribution (Rusnak and Nesteroff, 1963). At present, the contribution of true reef corals on the Bahama Banks is not significant, but this may be a temporary result of Pleistocene cooling (Newell, 1955, p. 314). On the Blake Plateau, deep-water coral is abundant locally and has accumulated into mounds or banks of sedimentary significance (fig. 35) (Stetson, Squires, and Pratt, 1962).

In the third area, that surrounding Bermuda, the carbonate is mostly biogenic sand produced on actively growing reefs. The sands have been transported downward and outward by wind, currents, slumping, and other processes.

FIGURE 27.—Cores containing graded beds of sand and silt from the Sohm Plain. Some of the sand is very well sorted, but most is silty. Reworking by bottom currents, as well as by turbidity currents, may be important in the sorting. The left-hand core has a layer of Recent mud at the surface, whereas the right-hand one indicates sand at the surface. (The white spots are holes where samples were taken.)

Ocean currents are probably more important than turbidity currents or wind action in distributing carbonate sediments on the deep ocean floor. If the Gulf Stream transports sediments, as suggested by the writer (Pratt, 1963, p. 248), carbonate deposits similar to those of the Blake Plateau should be found in the deep ocean basin east of the northern end of the Blake Plateau. The distribution patterns of calcium carbonate on the Blake Ridge (fig. 30) and of *Globigerina* sand in some cores are probably best explained by current distribution, although the basinward sweeping of the carbonate sediments by the Gulf Stream may be modified by a southerly component in the deep currents beneath the Gulf Stream (Swallow and Worthington, 1961). The position of the Gulf Stream affects the boundary between the calcareous ooze and quartzose detrital sediments along the west side of the Blake Plateau.

GLACIAL SEDIMENTS

The offshore sedimentary history of the North Atlantic Ocean north of the latitude of New York City is complicated by the influence of glaciation. The influence is twofold: (1) the direct distribution of glacial material in the sea by ice rafting and wind, and (2) the climatic conditions and sea-level changes associated with glaciation that make the adjacent land vulnerable to erosion and to changes in the sediment regime.

Glaciers and icebergs directly contribute an abundance of glacial erratics to the bottom in northern seas (fig. 36). Glacial erratics have been dredged on the continental slope as far south as the latitude of New Jersey, on many seamounts of the New England Seamount Chain, and on the Mid-Atlantic Ridge as far south as lat 30° N. The distribution of blue clay associated with cold nonoxidizing conditions follows a similar pattern, extending across the Atlantic north of Bermuda (Murray and Chumley, 1924).

The pattern of glacial-sediment distribution has been complicated by the action of turbidity currents that have spread glacial sand and by the lack of distinctive criteria to distinguish some glacial sediments from Recent deposits. Obviously, much of the western North Atlantic as far south as the Grand Banks is receiving ice-rafted debris at present, and the prominence of the trough called the Mid-Ocean Canyon by Heezen, Tharp, and Ewing (1959, p. 69) may indicate recently active bottom currents from glacial sources. Sand derived from this trough is characterized by unweathered feldspar;

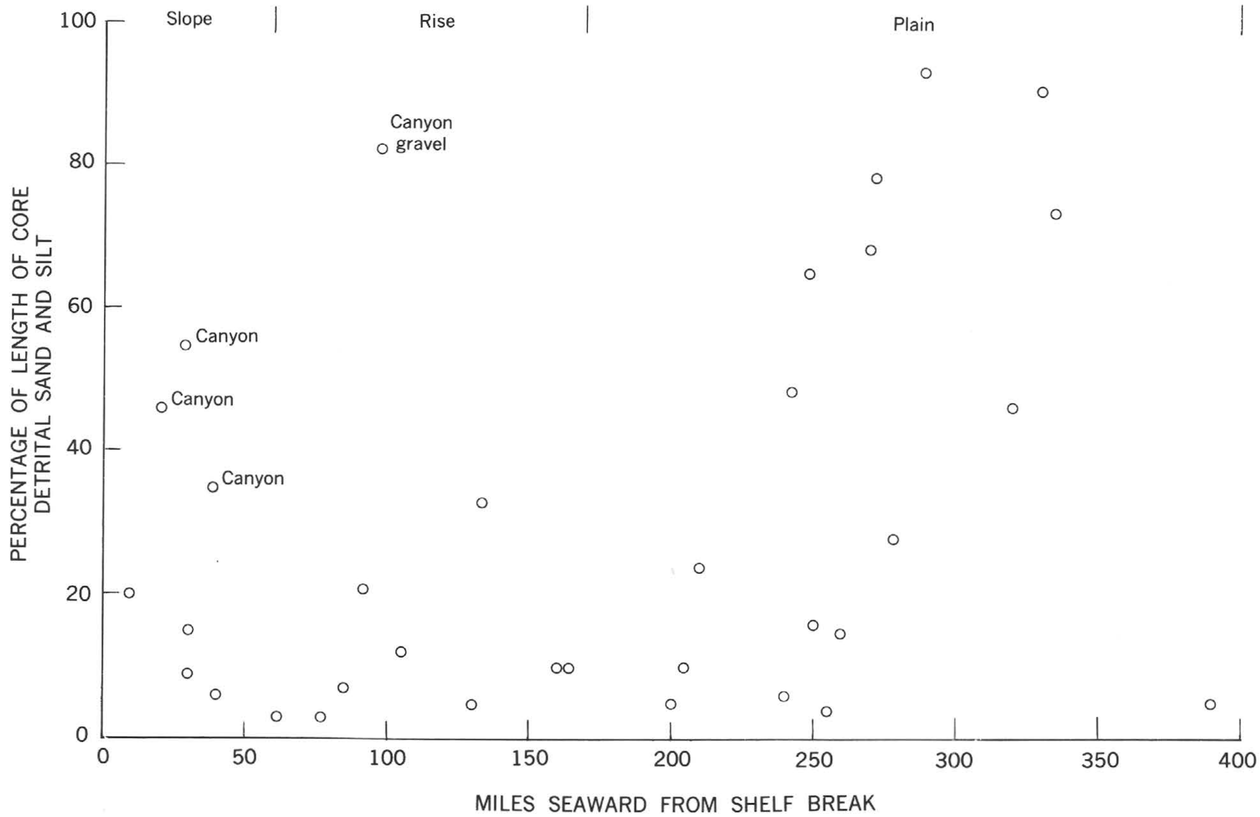


FIGURE 28.—Relation of sand content to distance from the shelf break in cores collected off New England. Sand distribution in this area is probably greatly influenced by submarine fan deposits off canyons (data from Ericson, Ewing, Wollin, and Heezen, 1961, p. 218–222).

FIGURE 29.—Bottom photograph of terrigenous sediment on the continental rise south of New England (lat 39°48′ N., long 68°56′ W., 2,129 m). The sediment is grayish-brown silt and clay. Note the abundant animal tracks and burrows although most of the biomass is buried.

in contrast, material derived from the East Coast Continental Shelf is characterized by quartz-rich glauconite-bearing sand (Hubert, 1962).

During the Pleistocene Epoch, a large part of the continental shelf was exposed to erosion as a result of a lowering of sea level, possibly as much as 159 meters (Donn, Farrand, and Ewing, 1962). The extent of this lowering is shown conservatively by the 100-meter cross hatching on plate 1. Factors leading to increased sedimentation in the deep sea during the ice advances are (1) increased availability of sediments, including the entire exposed continental shelf, (2) the absence of shelf basins, resulting in the direct discharge of sediment into the major ocean basin, (3) generally accelerated erosion of the land owing to lowered base level, less vegetative cover, and changing climatic conditions, (4) exposure of the shelf to wind denudation, especially along glacial fronts where winds are ordinarily severe; and (5) availability of glacial outwash material, including rock flour and erratics.

AUTHIGENIC SEDIMENTS

A few special types of authigenic sediments constitute a minor amount of the deep-sea deposits off the east coast, but they do not significantly influence the deep-sea topography. The most common type is manganese nodules and encrustations, which are widely dis-

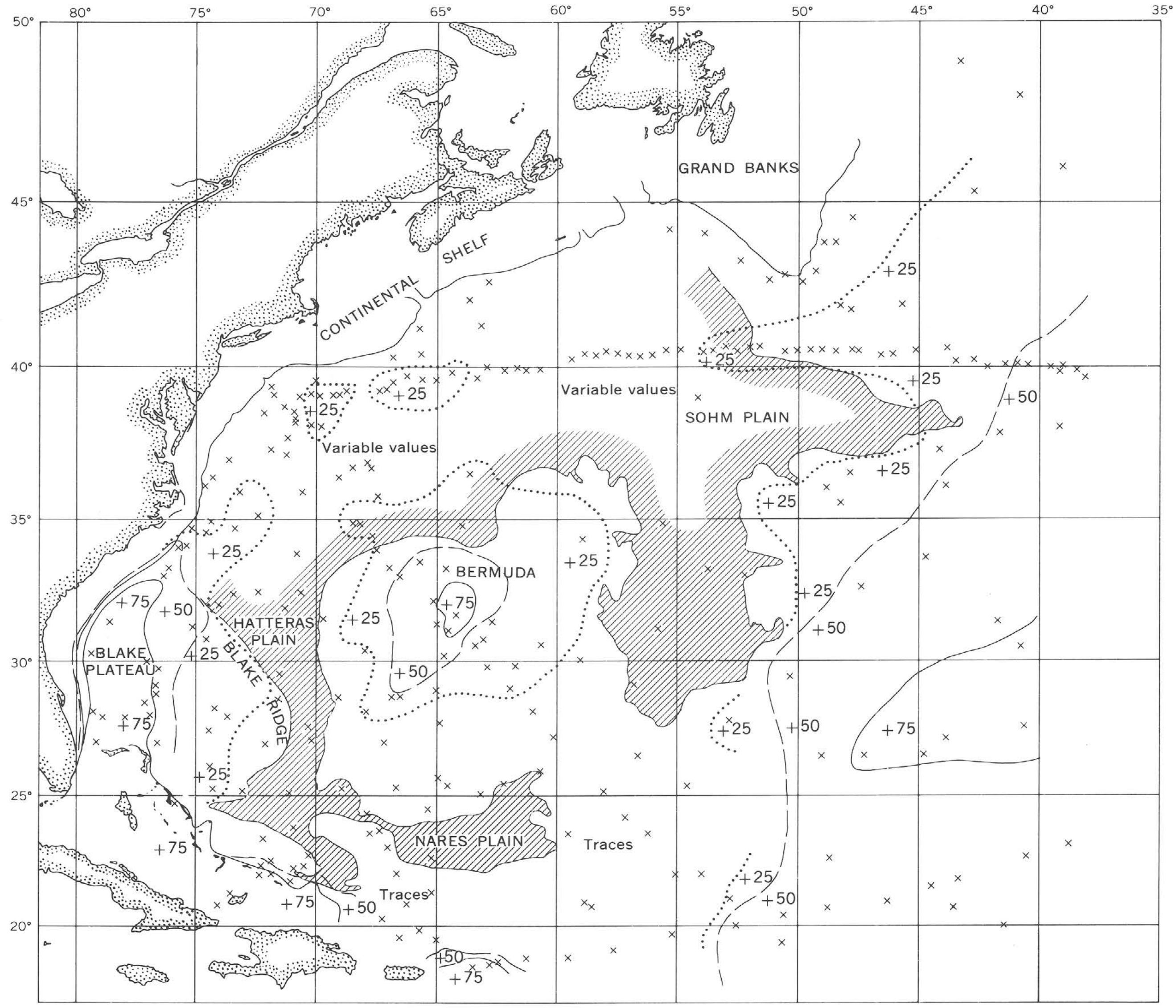


FIGURE 30.—Distribution patterns of calcium carbonate in the North American Basin. Only surface values at the control stations (+) were used in the plot, although some cores in marginal areas (X) have little carbonate at depth even though the surfaces may be nearly pure carbonate ooze. Numbers represent the percentage of carbonate in the sediment.

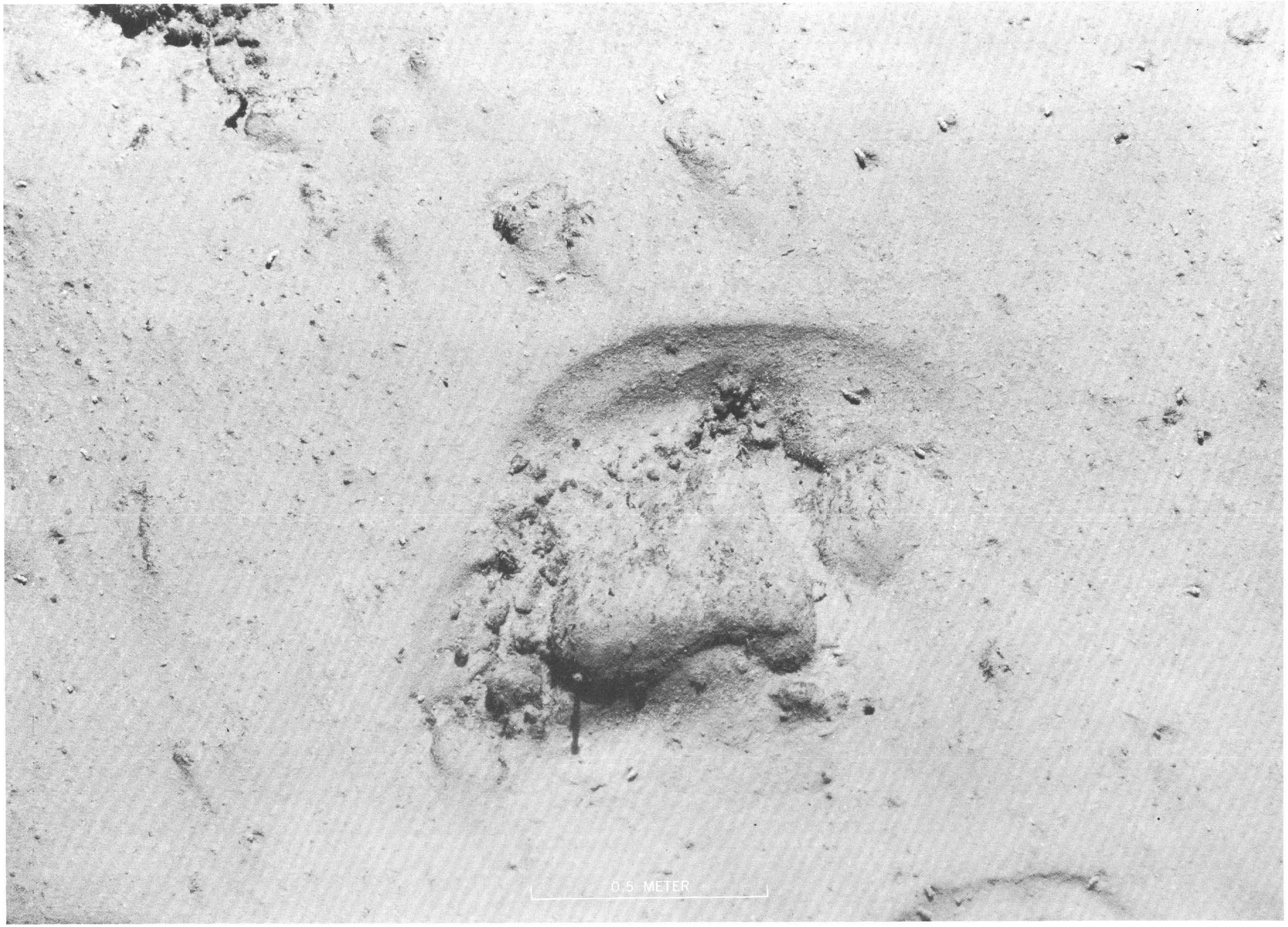


FIGURE 31.—*Globigerina* ooze on the flank of Rehoboth Seamount (lat 37°40′ N., long 59°59′ W., 4,861 m) in the New England Seamount Chain. The sediment is fine-grained light-gray ooze with abundant foraminiferal tests. It is the typical sediment on high areas out of reach of turbidity currents. In this photograph, scour depressions and lee accumulations indicate considerable redistribution by bottom currents.

FIGURE 32.—Bottom photograph of calcareous sand on the flat top of Muir Seamount (lat 33°33′ N., long 62°24′ W., 1,554 m). Sorting and rippling by bottom currents is apparent in the picture. The fine material consists mostly of foraminiferal tests, and the larger particles are pteropods, coral fragments, and other organic debris. This is another illustration of carbonate accumulation out of reach of turbidity currents. Trails are evidence of animal life on bottom.

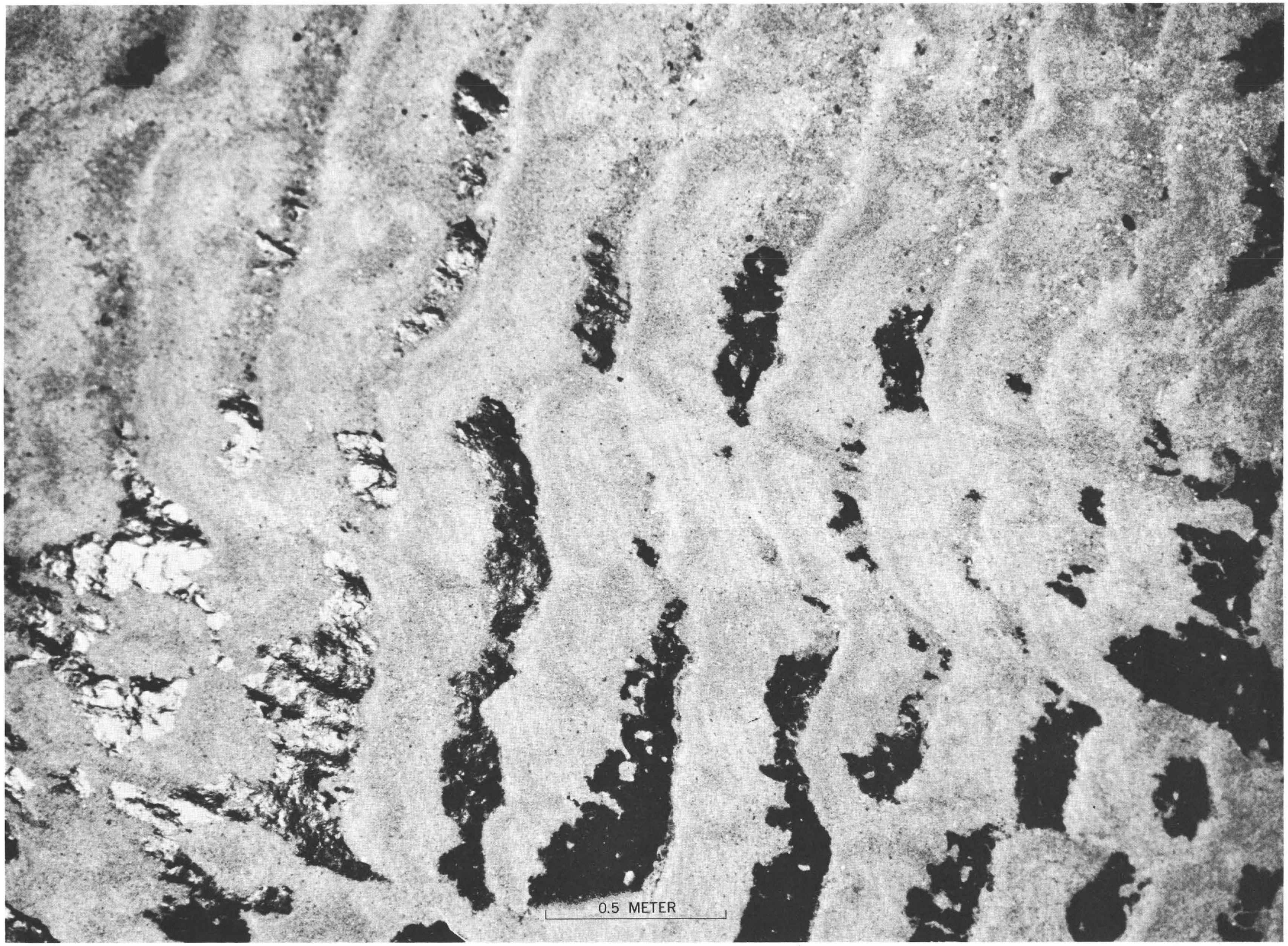


FIGURE 33.—Bottom photograph of well-sorted globigerinid-pteropod sand on the Blake Plateau (lat 30°49′ N., long 78°50′ W., 1,390 m). This sand is being moved over a manganese oxide-encrusted bottom (dark areas in photograph). Measurements show that bottom currents in the area have velocities up to 50 cm per sec in the same general direction as surface currents of the Gulf Stream. The hard manganese pavement limits downward erosion.

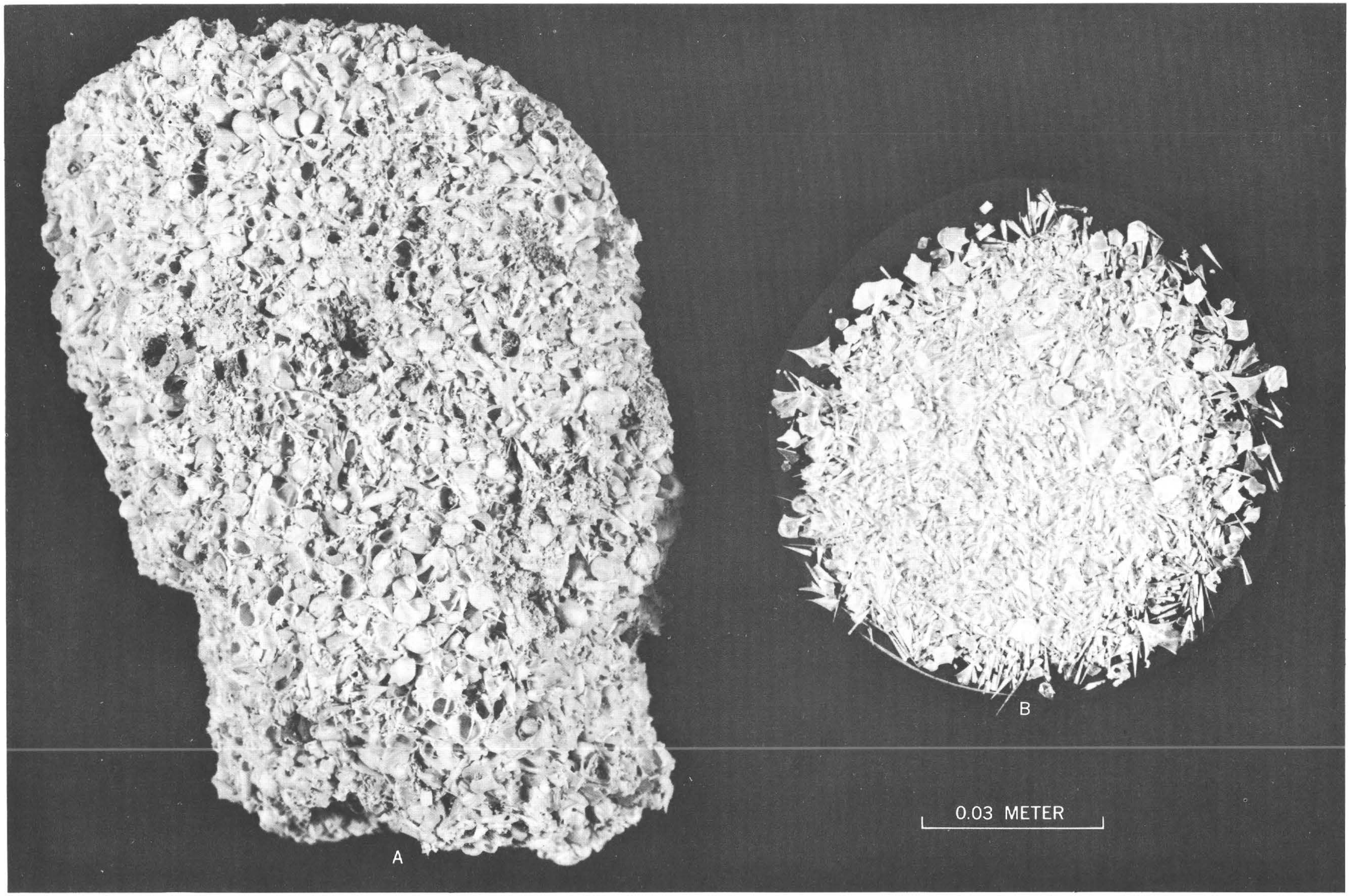


FIGURE 34.—Comparison of recent and indurated pteropod ooze from neighboring samples on the Blake Plateau. *A*. Indurated ooze (30°54′ N., 78°39′ W., 819 m). *B*. Recent ooze (30°53′ N., 78°51′ W., 795 m). Preliminary analysis of the Foraminifera indicates that the indurated rock is Miocene in age; the close similarity of the two samples shows that there has been little environmental change since Miocene time.

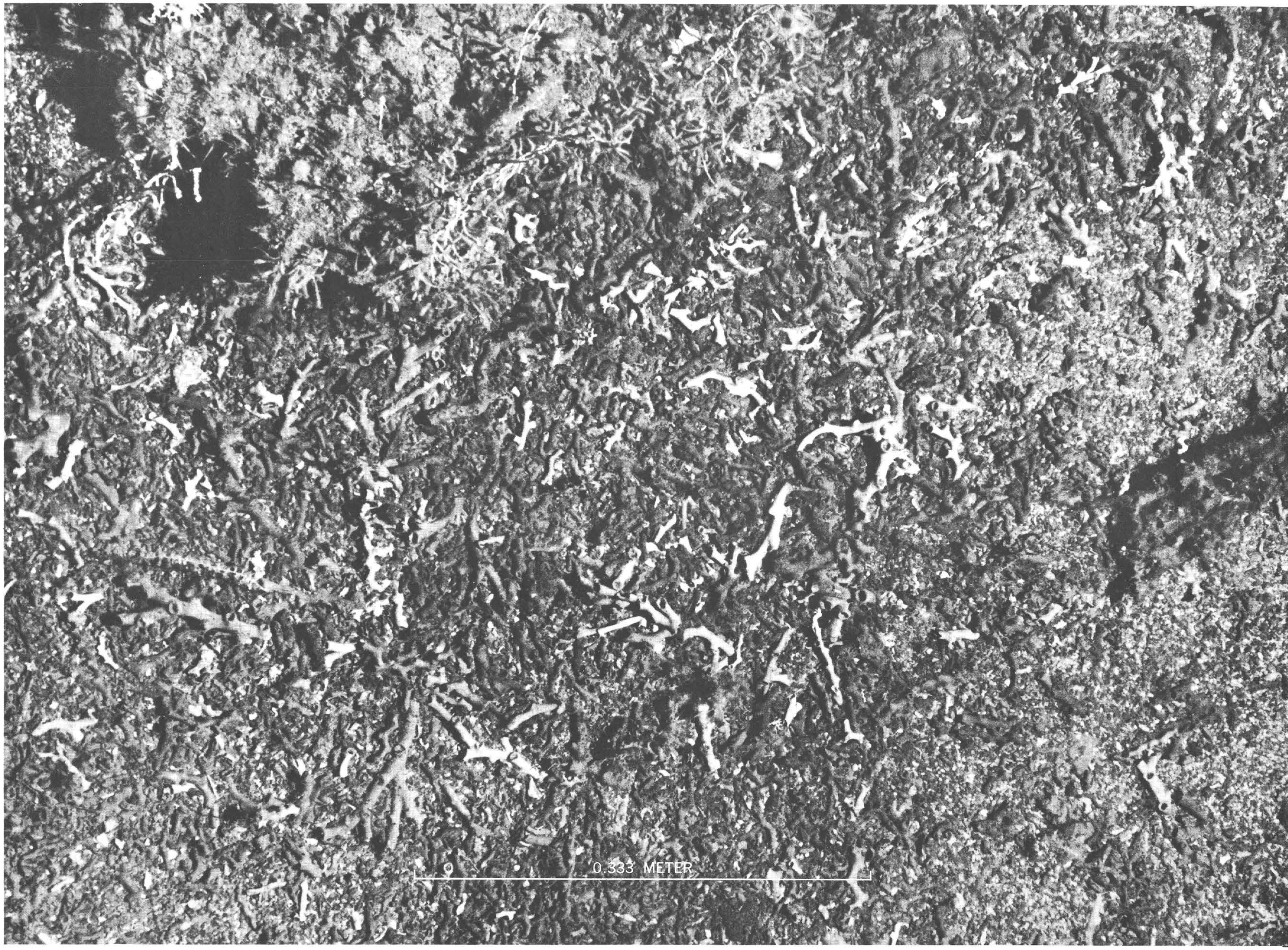


FIGURE 35.—Bottom photograph of coral debris on the Blake Plateau (lat 31°52′ N., long 77°20′ W., 1,350 m). Most of the coral is the ahermatypic species *Lophelia prolifera* and *Dendrophyllia profunda*. The abundant coral growth in this area is probably the result of favorable currents and absence of rapid sedimentary deposition. Coral accumulates locally into mounds or bumps reaching 140 meters in height.

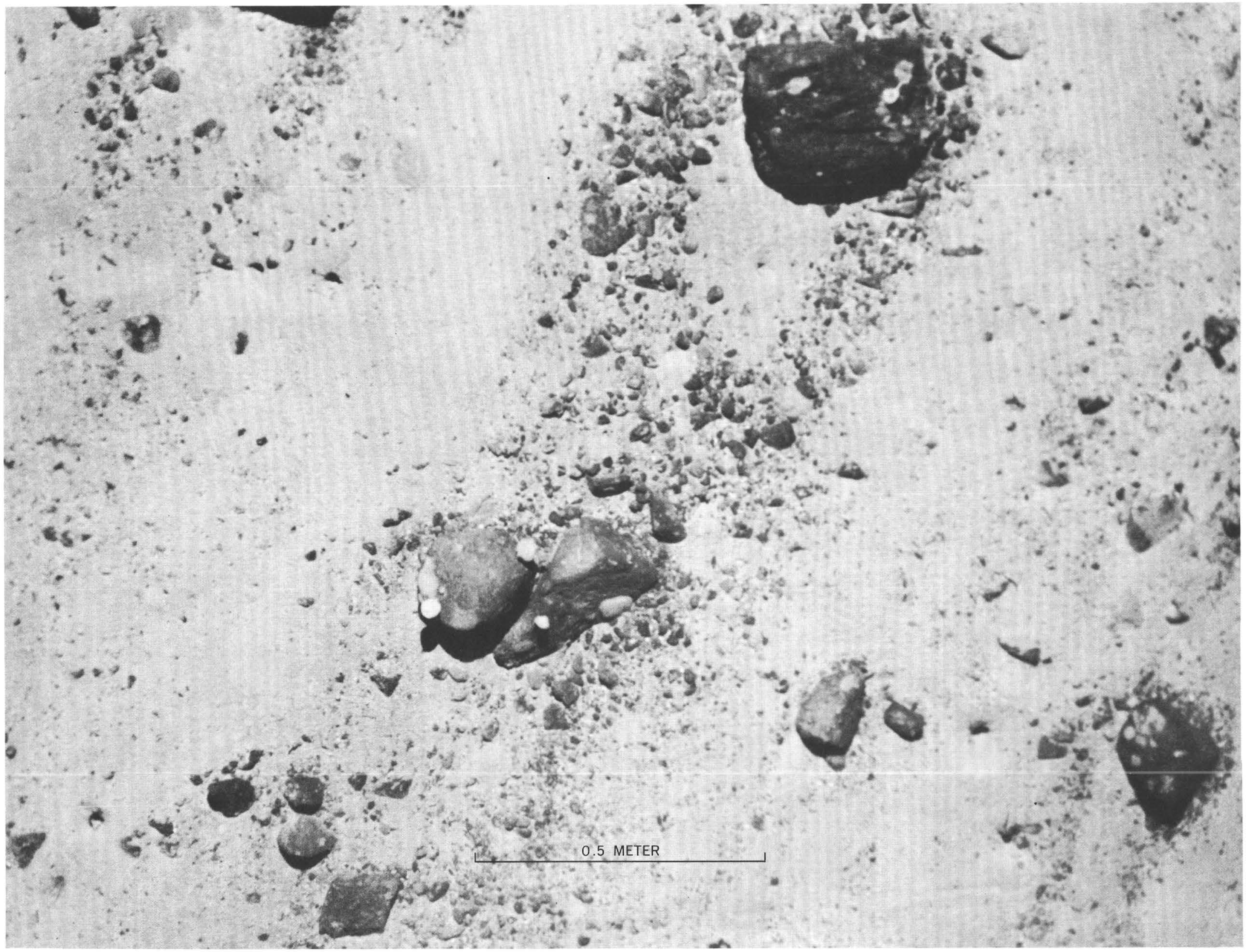


FIGURE 36.—Bottom photograph of glacially derived sand and cobbles on the side of Mytilus Seamount (lat 39°21′ N., long 67°04′ W., 2,506 m). To reach this elevated position the glacial material must have been ice rafted. The linear pebble trains are probably caused by downslope movement rather than by bottom currents.

tributed on seamounts, in the deep ocean basin, and on the Blake Plateau. Under favorable conditions of non-clastic deposition, such as beneath the Gulf Stream on the Blake Plateau, nodules apparently form an extensive pavement and partly control the depth of current scouring (fig. 33). Photographs and dredged samples from the outer part of the New England Seamount Chain and Caryn Peak also indicate extensive encrustations of manganese oxide (fig. 37) which acts as a binding agent in areas of ooze or other organic debris and thus helps to stabilize the bottom (fig. 38).

Phosphate-rich nodules are found locally near shore but do not affect the geomorphology of the sea floor. A few have been dredged from the Blake Plateau and are believed to be comparable to the Miocene phosphate deposits in sediments of the Carolinas and Florida.

Glauconite-rich sediments also occur in the continental shelf and slope environment, but there is some question as to how much of the glauconite in the sediments is reworked from the Costal Plain sequence. Glauconite used as a trace mineral shows that the source of some deep-sea turbidites is the East Coast Continental Shelf (Hubert, 1962). The only area in which glauconite is known to be forming at present is along the inner margin of the Blake Plateau.

EOLIAN SEDIMENTS

Probably far more important than generally realized are the windblown or eolian sediments in the deep sea. The wide distribution of windblown dust has been mentioned by numerous investigators; sand- and silt-sized materials, although overlooked in many places, also have a wide range (Arrhenius, 1961). Murray and Chumley (1924) described the presence of a few grains or rounded iron-stained quartz in numerous deep-sea samples taken off the east coast, and Young (1939) explained the presence of certain minerals around Bermuda as blown in from continental sources. Calcareous eolianite that makes up the present islands of Bermuda and the Bahamas must represent only a small fraction of the total material derived from local reefs and blown about during stages of lowered sea level. Large quantities of material also must have been blown off and deposited in deep water around the islands.

RATES OF SEDIMENTATION

Studies of sedimentation in the deep sea usually include attempts to determine the total thickness of the sediment column and the rate of deposition. The thickness of sediment can be determined from seismic reflection, seismic refraction, drill holes on adjacent land and at sea, and by extrapolating into the ocean environment known stratigraphic structures deduced from land mapping. The outstanding summaries of the available seismic refraction data by Drake, Ewing, and Sutton (1959) and Hersey, Bunce, Wyrick, and Dietz (1959). have added greatly to the interpretation of an east coast geosyncline. Similarly, direct rates of sedimentation through radioisotopic and foraminiferal dating (Ericson, Ewing, Wollin, and Heezen, 1961, p. 275, 279) and direct measurement of sediment falling to the bottom (Kuenen, 1950, p. 384) supersede the indirect speculative methods of the past. The average of 210 radiocarbon and paleontological determinations of sediment accumulation rates in the Atlantic made by Ericson, Ewing, Wollin, and Heezen (1961) is 6.8 cm per 1,000 years. This rate is probably too high for deposition in general because extreme rates up to 274 cm per 1,000 years are included; moreover, sediments recovered by coring probably include deposits formed during the abnormal events of the Pleistocene. The basic fact revealed by the data is, however, that rates of sedimentation off the east coast are more variable and far greater than general oceanic rates postulated in the past. Submarine fans of graded sand off the ends of the canyons, and the canyon cutting, dated by the Recent and Tertiary sediments in the canyon walls (Stetson, 1936), may be largely the results of Pleistocene events. Estimated relative rates of clay and carbonate deposition also substantiate the increased (about twice) Pleistocene rates (Turekian, 1964).

Rates of sedimentation are directly measurable in the wells penetrating the Coastal Plain sequence. In the deep well on Cape Hatteras that penetrates 3,050 meters of sediment ranging in age from Recent to Lower Cretaceous, deposition was at an average rate of 2.2 cm. per 1,000 years. The greater relative thickness of Cretaceous sediments (2,100) however, indicates rates of 3.4 cm per 1,000 years during Cretaceous time. Similarly, a well on Andros Island penetrated about 4,440 meters of carbonate sediments to the top of the Lower Cretaceous, and these sediments must have accumulated at a rate of about 5.0 cm per 1,000 years. The relatively thick Cretaceous section indicates greater rates of subsidence and sedimentation during the early phases of deposition in this region. If sedimentation in the deeper parts of the offshore geosyncline (Drake, Ewing, and Sutton, 1959) is assumed to have started during Cretaceous time, then depositional rates must have been about 4.5 cm per 1,000 years to allow for the 6 kilometers of average accumulation. The remarkable fact is that rates of sediment accumulation from various determinations are of the same order of magnitude, especially if compaction in older rocks is considered. Furthermore, the time necessary for the accumulation of the sediments fits well into a scheme

FIGURE 37.—Manganese oxide encrustation on Rehoboth Seamount (lat 37°39′ N., long 59°59′ W., 4,861 m). This type of rough crust seems to be characteristic of areas where clastic sediments are absent. The thickness or sediment volume contributed by this type of deposit is unknown, but the general tendency for manganese oxide to accrete in nodules is well shown.

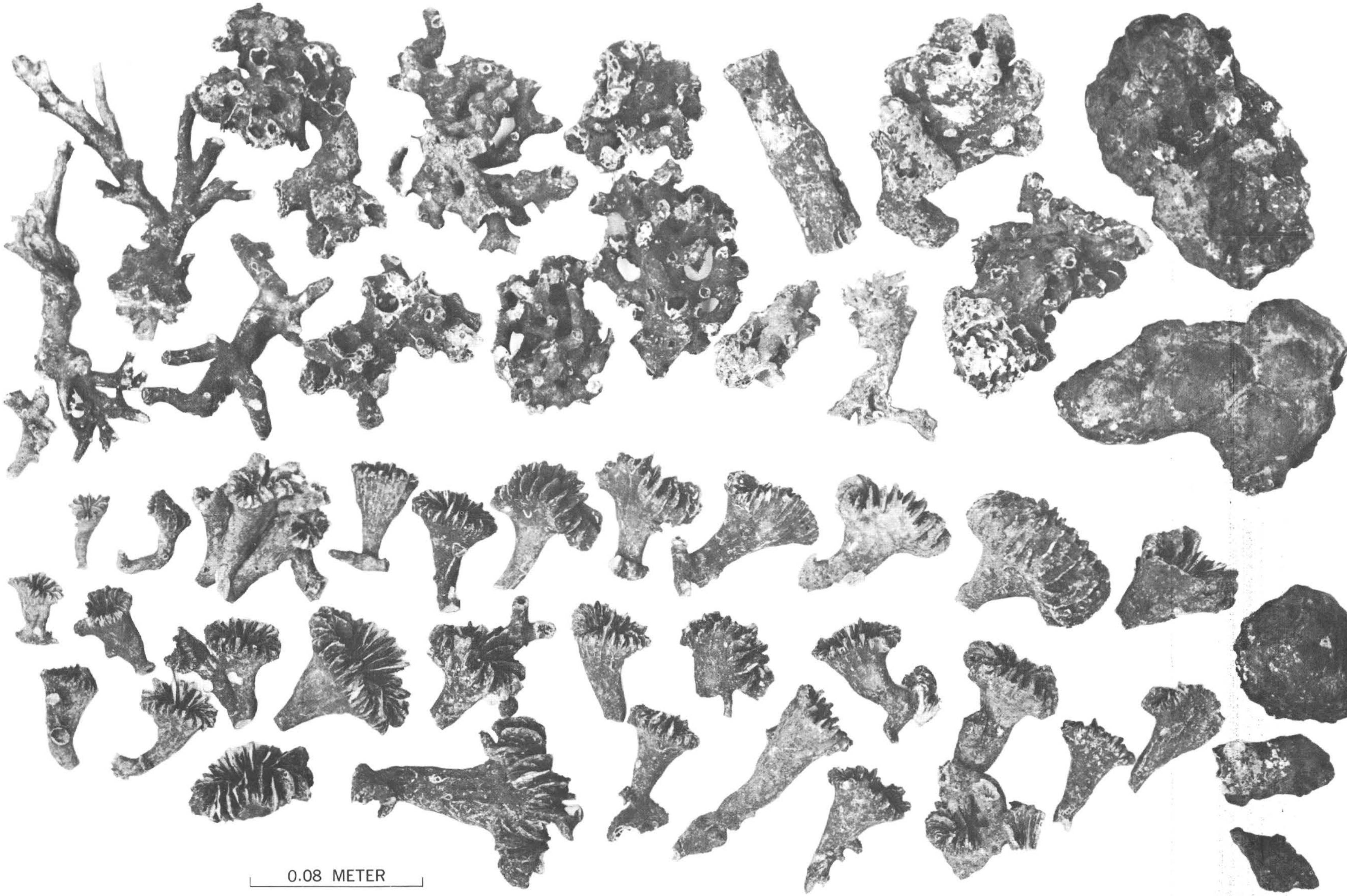


FIGURE 38.—Samples of coral from Muir Seamount (lat 33°36′ N., long 62°25′ W., 1,383 m) showing progressive encrustation by manganese oxide. Both deep-water coral and encrusting manganese oxide commonly occur on the tops of seamounts. The samples are arranged so that manganese encrustation increases from left to right.

of late Mesozoic and Tertiary sedimentary basins formed on the flanks of an eroding Appalachian mountain system.

STRUCTURE

Many of the structural concepts of the past are not supported by the present analysis of the topography off the east coast. The Blake Escarpment and the Bahama Escarpment could be interpreted as fault scarps on the basis of topographic relief, yet no actual stratigraphic displacements have ever been demonstrated along them. Furthermore, seismic evidence (Heezen, Tharp, and Ewing, 1959, p. 122, pl. 26) indicates that deep crustal layers rise and thin seaward of the scarps rather than deepen, as would be required by normal faulting.

The Puerto Rico Trench, on the other hand, is best explained as a fault feature (Bunce and Fahlquist, 1962, p. 3964). It is part of a major structural trend which continues westward between Hispaniola and Cuba, as indicated by the complex topography south of the Bahamas (pl. 1) and by earthquake epicenters (Elmendorf and Heezen, 1957, p. 1087).

Interpretation of the geomorphology of the sea floor from the Puerto Rico Trench northward to the Grand Banks does not require faulting or folding. A probable exception to this is the pronounced bend in the coastline south of Long Island where both gravity and magnetic data indicate possible transcurrent fault displacement that continues into the New England Seamount Chain, but even this may be late Paleozoic in age (Drake, 1963). The Cape Fear arch of North Carolina and the Ocala arch of Florida are similar broad features, approximately at right angles to the trend of the coastline; they probably reflect basement trends. Possible structural interpretations of the Cape Fear arch extension into the deep sea are discussed by Hersey, Bunce, Wyrick, and Dietz (1959, p. 460).

Small faults of various types may exist almost anywhere, but it is always questionable whether they are directly responsible for the morphology. In fact, faulting might be expected as the result of isostatic adjustments along such topographic features as the Blake and Bahama Escarpments. Faults may also control the location of canyons and erosional scarps such as the north edge of Georges Bank (Drake, Ewing, and Sutton, 1959). The problem here is one of differentiating between fault scarps and fault line scarps, a familiar problem in geologic interpretation.

Earthquake epicenters are notable for their scarcity and lack of alinement along the East Coast Continental Slope (Elemendorf and Heezen, 1957, p. 1087). In fact, the whole Tertiary and Cretaceous history of the Atlantic Coastal Plain, as revealed by conventional land geologic mapping and stratigraphic interpretation is one of slow epeirogenic subsidence without volcanism and without major faulting. There is no reason to expect the submerged part of the east coast sedimentary environment to be very different.

CONCLUSIONS

The picture that has evolved from a study of the topography and sediments off the east coast of the United States is one of eastward transport and deposition of terrigenous sediments on and around the primary abyssal hill and seamount topography of the sea floor as summarized in figure 39. A useful working hypothesis that gives a fundamental structural basis to the study of basin sedimentation is Hess's idea (1962, p. 617) of a laterally spreading ocean basin centered along the Mid-Atlantic Ridge. Along this volcanically and seismically active ridge, the primary volcanic topography develops, and upon the volcanic sea floor are superposed the sedimentary deep-sea deposits and the various geomorphic features associated with sedimentation.

The source of the greatest volume of sediments in the ocean basins off the east coast is the North American Continent itself. Terrigenous sediments, largely through the mechanism of turbidity currents, have filled the marginal ocean basins off the east coast and have spread out across the abyssal plains. They form a graded system extending from the continental slope seaward to the limits of the abyssal plains. Submarine canyons are part of the system and serve the important function of channeling the sedimentary material from the continental platform into the ocean basins. The special conditions of Pleistocene glaciation, including eolian transport and ice rafting during low stands of sea level, probably accelerated sedimentation on the floor of the sea, especially in the northern area.

The continental rise-abyssal plain sediment system includes smaller topographic features such as channels and hills explainable by processes of submarine sedimentation and erosion. Submarine channels range from the "Mid-Ocean Canyon," 150 meters deep, and the seaward extension of Hudson Canyon, 375 meters deep, to small discontinuous rills barely discernible on a sounding record. Similarly, many of the hill-like features can be resolved into natural levees or submarine-fan deposits.

The Bahama Banks and the Blake Plateau form a carbonate province which extends seaward into the adjacent Blake Basin. Carbonate sediments in the deep sea may be displaced shallow-water sediments from reefs and banks or may be the remains of pelagic organisms in the ocean. An interesting factor brought out by the study is the comparative immobility of shallow-water carbonate sediments. This probably accounts for the steep outer escarpment on the Bahama Banks and the Blake Plateau, as well as the lack of extensive turbidite fills marginal to the carbonate region. The same factor may maintain the Blake Ridge.

Pelagic sediments are found everywhere, but they are highly diluted and masked by nearshore terrigenous sediments. Surprisingly, some of the best examples of pelagic ooze exist on the Blake Plateau and on similar banks where a combination of currents to winnow off fine sediment, and a favorable growth environment has resulted in rich well-sorted deposits of pteropod and Foraminifera tests. Recent seismic reflection data over the mid-ocean abyssal hills has shown that the accumulation of pelagic sediments is much less than was previously thought (Ewing, Ewing, and Talwani, 1963). Furthermore, the classic red clay formed from volcanic ash and continental and meteoric dust is less abundant in the northwest Atlantic Ocean than it seems to be in other oceans.

The terrigenous and carbonate sediments described here are part of the sedimentary fill of the east coast geosyncline as defined by Drake, Ewing, and Sutton (1959) and Murray (1963). The accumulated sediments indicate more or less continuous subsidence and deposition since the Cretaceous Period. The lack of volcanos and earthquakes supports the concept that in the past the offshore deep-sea sediments were deposited in a structural environment similar to the present one, and in a broad sense, the record of the accumulated sediment reveals the history of the adjacent deep-sea basins.

SOURCES OF DATA USED IN COMPILING THE TOPOGRAPHIC CHARTS

The following Woods Hole Oceanographic Institution Reference Numbers were used entirely or in part. Reference numbers are considered as unpublished manuscripts although they are available for limited circulation.

Cruise Navigation Report
Atlantis Cruise 247, January to June, 1959
For the International Geophysical Year
By Arthur R. Miller
WHOI 60–16

Oceanographic Data from *Crawford*
Cruise 16, 1 Oct to 11 Dec, 1957
For the International Geophysical Year
By W. G. Metcalf
WHOI 58–31

Report on *Atlantis* Cruise 260
11 Oct to 7 Nov, 1960
By R. M. Pratt
WHOI 62–19

Cruise Navigation Report
Yamacraw Cruise 10
Atlantic Ocean–Mediterranean Sea
Compiled by D. A. Fahlquist
Editor: W. M. Dunkle
WHOI 62–18

Cruise Navigation Report
Atlantis Cruise 242
Atlantic Ocean–Mediterranean Sea–Red Sea–Indian Ocean
Compiled by: D. A. Fahlquist and C. A. Neumann
Editor: W. M. Dunkel
WHOI 62–28

Cruise Navigation Report
Chain Cruise 28
North Atlantic Ocean
Compiled by: R. M. Pratt
Editor: W. M. Dunkle
WHOI 63–14

Cruise Navigation Report
Atlantis Cruise 280 and 281
North Atlantic Ocean
Compiled by: S. L. Thompson
Editor: W. M. Dunkle
WHOI 62–42

Cruise Navigation Report
Chain Cruise 7
North Atlantic Ocean–Mediterranean Sea
Compiled by: R. M. Pratt and W. M. Dunkle
WHOI 63–23

A Guide for Echo Sounder Observers
WHOI Tech. Memo 3–56
By Sydney T. Knott and W. M. Dunkle

Cruise Navigation Report
Chain Cruise 11
Atlantic Ocean–Caribbean Sea
Compiled by: R. M. Pratt, A. J. Nalwalk and W. M. Dunkle
Editor: W. M. Dunkle
WHOI 62–7

Cruise Navigation Report
Chain Cruise 13
Atlantic Ocean–North Sea–Baltic Sea
Compiled by: R. M. Pratt and A. J. Nalwalk
Editor: W. M. Dunkle
WHOI 62–8

Cruise Navigation Report
Chain Cruise 17
Atlantic Ocean–Romanche Tranch
Compiled by: T. T. Bunce, M. C. Stalcup, and C. E. Parker
Editor: W. M. Dunkle
WHOI Ref. No. 62–9

Cruise Navigation Report
Chain Cruise 19
Atlantic Ocean–Puerto Rico Trench
Compiled by: E. T. Bunce, A. J. Nalwalk, and S. S. Jacobs
Editor: W. M. Dunkle
WHOI 62–10

Cruise Navigation Report
Chain Cruise 21
Atlantic Ocean–Mediterranean Sea
Compiled by: R. M. Pratt and F. Workum, Jr.
Editor: W. M. Dunkle
WHOI 62–11

Report on *Atlantis* Cruise 266
June to July, 1961
By Thomas R. Stetson
WHOI 61–35

Bathymetric and Sediment Survey of the Tongue of the Ocean, Bahamas. Part I. Bathymetry and Sediments
By William D. Athearn
WHOI 62–25

The following Woods Hole Oceanographic Institution cruise tracks and echo-sounding records were entirely or partly used in the bathymetric compilation. Cruises of each ship are numbered consecutively, starting with 1.

A.	224	*Chn.*	12	*A.*	287
Chn.	5	*Cr.*	40	*A.*	260
Chn.	9	*A.*	255	*A.*	266
Chn.	1	*A.*	213	*A.*	247
Yam.	6	*A.*	192	*Cr.*	16
A.	251	*A.*	206	*A.*	280
Chn.	2	*Be.*	82	*A.*	281
Yam.	3	*Be.*	96	*Chn.*	11
Yam.	9	*A.*	223	*Chn.*	13
Chn.	3	*A.*	219	*Chn.*	17
A.	229	*A.*	221	*Chn.*	19
A.	282	*Chn.*	20	*Chn.*	21
Chn.	34	*A.*	231	*Yam.*	10
AII.	1	*Cr.*	7	*Chn.*	28
Yam.	8			*Chn.*	7

A.	R/V *Atlantis*	*Chn.*	R/V *Chain*
AII.	R/V *Atlantis II*	*Cr.*	R/V *Crawford*
Yam.	USCGC *Yamacraw*	*Be.*	R/V *Bear*

The following cruise tracks with soundings in the Blake Plateau area were obtained through the courtesy of Bruce C. Heezen, Lamont Geological Observatory: Vema 6, Vema 12, Vema 10, Vema 15, Atlantis 167, Atlantis 148.

The following published charts were used in compiling the Bathymetric Chart and various index charts. They were used mainly in reference to coastal and shallow-water features.

U.S. Coast and Geodetic Survey Charts

1000 Cape Sable to Cape Hatteras
1001 Cape Hatteras to Straits of Florida
1002 Straits of Florida and approaches
1106 Bay of Fundy to Cape Cod
1107 Georges Bank and Nantucket Shoals
1108 Approaches to New York, Nantucket Shoals
1109 Cape May to Cape Hatteras
1110 Cape Hatteras to Charleston
1111 Charleston Light to Cape Canaveral [Cape Kennedy]
1112 Cape Canaveral [Cape Kennedy] to Key West

U.S. Hydrographic Office Charts

HO 948 Hispaniola with Windward and Mona Passages
HO 5617 Grand Banks of Newfoundland
HO 6610 Cape Race to Cape Henry
HO 6611 Cape Race to Sable Island
HO 5723 Approaches to Bermuda Island

General published references showing small-scale, precision, echo-sounding profiles across the North American Basin, or detailed soundings over limited areas, are:

Fuglister, F. C., 1960, Atlantic Ocean atlas of temperature and salinity profiles and data from the International Geophysical year of 1957–1958: Woods Hole Oceanog. Inst. Atlas ser., v. 1, 209 p.

——— 1963, Gulf Stream 60, *in* Sears, Mary, ed., Progress in oceanography, Volume I: London, Pergamon Press, p. 265–357.

Heezen, B. C., and Tharp, Marie, 1957, Physiographic diagram Atlantic Ocean (Sheet 1): [Palisades, N.Y.], Lamont Geol. Observatory, Columbia Univ., map [reprinted as separate map to accompany Geol. Soc. America Spec. Paper 65, 1959, cited below].

Heezen, B. C., Tharp, Marie, and Ewing, Maurice, 1959, The floors of the oceans; I, The North Atlantic: Geol. Soc. America Spec. Paper 65, 122 p.

Hurley, R. J., Siegler, V. B., and Fink, L. K., Jr., 1962, Bathymetry of the Straits of Florida and the Bahama Islands. Part I. Northern Straits of Florida: Bull. Marine Sci. Gulf and Caribbean, v. 12, no. 3, p. 313–321.

REFERENCES

Agassiz, Alexander, 1888. Three cruises of the *Blake:* Harvard Coll., Mus. Comp. Zoology, v. 14, 314 p.

Arrhenius, Gustaf, 1961, Geological record on the ocean floor, *in* Sears, Mary, ed., Oceanography: Am. Assoc. Adv. Sci. Pub. 67, p. 129–148.

Biscaye, P. E., 1965, Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans: Geol. Soc. American Bull. 76, no. 7, p. 803–832.

Bramlette, M. N., and Bradley, W. H., 1941, Geology and biology of North Atlantic deep-sea cores between Newfoundland and Ireland; Lithology and geologic interpretations: U.S. Geol. Survey Prof. Paper 196–A, p. 1–34.

Bunce, E. T., and Fahlquist, D. A., 1962, Geophysical investigation of the Puerto Rico trench and outer ridge: Jour. Geophys. Research, v. 67, no. 10, p. 3955–3972.

Bunce, E. T., and Hersey, J. B., 1963, Continuous seismic profiles of the outer ridge north of Puerto Rico [abs.]: Am. Geophys. Union Trans., v. 44, no. 1, p. 62.

Cloud, P. E., Jr., 1962, Environment of calcium carbonate deposition west of Andros Island, Bahamas: U.S. Geol. Survey Prof. Paper 350, 138 p.

Daly, R. A., 1942, The floor of the ocean, new light on old mysteries; The Page-Barbour Lectures at the University of Virginia, 1941: Chapel Hill, Univ. North Carolina Press, 177 p.

Dietz, R. S., 1961, Continent and ocean basin evolution by spreading of the sea floor: Nature, v. 190, no. 4779, p. 854–857.

Donn, W. L., Farrand, W. R., and Ewing, Maurice, 1962, Pleistocene ice volumes and sea-level lowering: Jour. Geology, v. 70, no. 2, p. 206–214.

Drake, C. L., 1963, The Atlantic margin of North America [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 47, no. 2, p. 355–356.

Drake, C. L., Ewing, Maurice, and Sutton, G. H., 1959, Continental margins and geosynclines; The east coast of North America north of Cape Hatteras, *in* Ahrens, L. H. and others, eds., Physics and chemistry of the earth, [v.] 3: London, Pergamon Press, p. 110–198.

Elmendorf, C. H., and Heezen, B. C., 1957, Oceanographic information for engineering submarine cable systems: Bell System Tech. Jour. v. 36, no. 5, p. 1047–1093.

Emery, K. O., 1966, Atlantic continental shelf and slope of the United States—Geologic background: U.S. Geol. Survey Prof. Paper 529–A, 23 p.

Ericson, D. B., Ewing, Maurice, and Heezen, B. C., 1952, Turbidity currents and sediments in North Atlantic: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 3, p. 489–511.

Ericson, D. B., Ewing, Maurice, Wollin, Goesta, and Heezen, B. C., 1961, Atlantic deep-sea sediment cores: Geol. Soc. America Bull., v. 72, no. 2, p. 193–285.

Ericson, D. B., and Wollin, Goesta, 1963, Times traces in sediment; Ocean bottom is probed for knowledge: Nat. History, v. 72, no. 2, p. 52–61.

Ewing, Maurice, and Press, Frank, 1055, Geophysical contrasts between continents and ocean basins, *in* Poldervaart, Arie, ed., Crust of the earth—a symposium: Geol. Soc. America Spec. Paper 62, p. 1–6.

Ewing, Maurice, Ewing, John, and Talwani, Manik, 1963, Sediment distribution in the oceans; The Mid-Atlantic Ridge [abs.]: Am. Geophys. Union Trans., v. 44, no. 1, p. 63.

Ewing, Maurice, Ewing, John, and Worzel, J. L., 1963, The continental margin between Cape Hatteras and the Bahamas Islands [abs.]: Am. Geophys. Union Trans., v. 44, no. 1, p. 62.

Gilluly, James, 1955, Geologic contrasts between continents and ocean basins, *in* Poldervaart, Arie, ed., Crust of the earth—a symposium: Geol. Soc. America Spec. Paper 62, p. 7–18.

——— 1964, Atlantic sediments, erosion rates, and the evolution of the continental shelf; some speculations: Geol. Soc. America Bull., v. 75, no. 6, p. 483–492.

Hamilton, E. L., 1961, Stratigraphy of the deep-sea floor, *in* Sears, Mary, ed., Oceanography: Am. Assoc. Adv. Sci. Pub. 67, p. 51–84.

Hamilton, E. L., Shumway, George, Menard, H. W., and Shipek, C. J., 1956, Acoustic and other physical properties of shallow-water sediments off San Diego: Acoust. Soc. America Jour., v. 28, no. 1, p. 1–15.

Heezen, B. C., and Ewing, Maurice, 1952, Turbidity currents and submarine slumps and the 1929 Grand Banks earthquake: Am. Jour. Sci., v. 250, no. 12, p. 849–873.

Heezen, B. C., Ewing, Maurice, and Ericson, D. B., 1955, Reconnaissance survey of the abyssal plain south of Newfoundland: Deep-Sea Research, v. 2, no. 2, p. 122–133.

Heezen, B. C., and Menard, H. W., 1963, Topography of the deep-sea floor, *in* Hill, M. N., ed. The sea; v. 3, The earth beneath the sea; history: New York, Interscience Publishers, p. 233–280.

Heezen, B. C., Tharp, Marie, and Ewing, Maurice, 1959, The floors of the oceans; I, The North Atlantic: Geol. Soc. America Spec. Paper 65, 122 p., 30 pls.

Hersey, J. B., 1963, Seismic profiling and geologic exploration in the deep sea [abs.]: Am. Geophys. Union Trans., v. 44, no. 1, p. 61.

Hersey, J. B., Bunce, E. T., Wyrick, R. F., and Dietz, F. T., 1959, Geophysical investigation of the continental margin between Cape Henry, Virginia, and Jacksonville, Florida: Geol. Soc. America Bull., v. 70, no. 4, p. 437–465.

Hersey, J. B., Caufield, David and Hoskins, Hartley, 1963, Seismic reflection profiles across the Bermuda Rise [abs.]: Am. Geophys. Union Trans., v. 44, no. 1, p. 64.

Hess, H. H., 1962, History of ocean basins, *in* Geol. Soc. America, Petrologic studies: a volume in honor of A. F. Buddington: New York, p. 599–620.

Hubert, J. F., 1962, Dispersal patterns of Pleistocene sands on the North Atlantic deep-sea floor: Science, v. 136, no. 3514, p. 383–384.

Hurley, R. J., 1963, Bathymetry of Florida Straits [abs.]: Am. Geophys. Union Trans., v. 94, no. 1, p. 67.

Joint Oceanographic Institutions Deep Earth Sampling Program, 1965, Ocean drilling on the continental margin: Science, v. 150, p. 709–716.

Kerr, P. F., 1962, Possible quick-clay motion in turbidity currents: Science, v. 137, no. 3528, p. 420–421.

Knott, S. T., and Hersey, J. B., 1956, Interpretation of high-resolution echo-sounding techniques and their use in bathymetry, marine geophysics, and biology: Deep-Sea Research, v. 4, no. 1, p. 36–44.

Knott, S. T., Hoskins, Hartley, and Weller, Richard, 1963, Deltaic structure in the shallow-water sediments of the continental shelf and slope south of New England [abs.]: Am. Geophys. Union Trans., v. 44, no. 1, p. 64.

Kuenen, Ph. H., 1950, Marine geology: New York, John Wiley & Sons, 568 p.

Maher, J. C., 1965, Correlation of subsurface Mesozoic and Cenozoic rocks along the Atlantic Coast: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 18 p.

Matthews, D. J., 1939, Tables of the velocity of sound in pure water and sea water for use in echo-sounding and sound-ranging: London, Hydrographic Dept., Admiralty, H.D. 282, 52 p.

Moore, J. E., and Gorsline, D., 1960, Physical and chemical data for bottom sediments, south Atlantic coast of the United States: U.S. Fish and Wildlife Service Spec. Sci. Rept.—Fisheries, no. 366, 84 p.

Murray, G. E., 1963, Geologic history and framework of Gulf-Atlantic geosyncline [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 47, no. 2, p. 364–365.

Murray, John and Hjort, Johan, 1912, The depths of the ocean * * *: London, Macmillan and Company, 821 p.

Murray, John, and Chumley, James, 1924, The deep-sea deposits of the Atlantic Ocean: Royal Soc. Edinburgh Trans., v. 54, pt. 1, 252 p.

Murray, John, and Renard, A. F., 1891, Report on deep-sea deposits, *in* Great Britain, Challenger Office, Report on the scientific results of the voyage of H.M.S. Challenger * * * 1873–1876 * * *: [Edinburgh] printed for H.M. Stationery Off. [by Neil and Co.], 525 p.

Newell, N. D., 1955, Bahamian platforms, *in* Poldervaart, Arie, ed., Crust of the earth—a symposium: Geol. Soc. America Spec. Paper 62, p. 303–316.

——— 1959, The coral reefs—Pt. 1, Questions of the coral reefs; Pt. 2, Biology of the corals: Nat. History, v. 68, no. 3, p. 119–131; no. 4, p. 226–235.

Northrop, John, and Heezen, B. C., 1951, An outcrop of Eocene sediment on the continental slope: Jour. Geology, v. 59, no. 4, p. 396–399.

Northrop, John, Frosh, R. A., and Frassetto, Roberto, 1962, Bermuda-New England seamount arc: Geol. Soc. America Bull., v. 73, no. 5, p. 587–593.

Officer, C. B., Jr., 1955, Geological interpretation of a series of seismic reflection profiles from Bermuda to the continental margin: Deep-Sea Research, v. 2, no. 4, p. 253–260.

Olausson, Eric, 1960, Description of sediment cores from the North Atlantic: Swedish Deep-Sea Exped., 1947–1948, Rept., v. 7, f. 5, p. 229–286.

Pratt, R. M., 1963, Bottom currents on the Blake Plateau: Deep-Sea Research, v. 10, p. 245–249.

Revelle, R. R. D., 1944, Marine bottom samples collected in the Pacific Ocean by the Carnegie on its seventh cruise: Carnegie Inst. Washington Pub. 556, 180 p.

Rusnak, G. A., and Nesteroff, W. D., 1963, Modern turbidites: Terrigenous abyssal plain versus bioclastic basin, *in* Miller, R. L., ed., Papers in marine geology (Shepard commemorative volume): New York, Macmillan and Co., p. 488–507.

Stetson, H. C., 1936, Geology and paleontology of the Georges Bank canyons; Pt. I, Geology: Geol. Soc. America Bull., v. 47, no. 3, p. 339–366.

Stetson, T. R., Squires, D. F., and Pratt, R. M., 1962, Coral banks occurring in deep water on the Blake Plateau: Am. Mus. Novitates, no. 2114, 39 p.

Swallow, J. C., Worthington, L. V., 1961, An observation of deep counter currents in the western North Atlantic: Deep-Sea Research, v. 8, p. 1–20.

Thorp, Eldon, 1931, Descriptions of deep-sea bottom samples from the western North Atlantic and the Caribbean Sea: Scripps Inst. Oceanography Bull., Tech. ser., v. 3, 1, p. 1–31.

Turekian, K. K., 1964, The geochemistry of the Atlantic Ocean basin: New York Acad. Sci. Trans., v. 26, no. 3, p. 312–330.

Uchupi, Elazar, 1963, Sediments on the continental margin off eastern United States: U.S. Geol. Survey Prof. Paper 475–C p. 132–137.

Veatch, A. C., and Smith, P. A., 1939, Atlantic submarine valleys of the United States and the Congo submarine valley: Geol. Soc. America Spec. Paper 7, 101 p.

Warren, B. A., 1963, Topographic influences on the path of the Gulf Stream: Tellus, v. 15, p. 167–183.

Wilson, J. T., 1963, Continental drift: Sci. Am., v. 208, no. 4, p. 86–100.

Woollard, G. P., 1954, Crustal structure beneath oceanic islands *in* Bullard, E. C., and others, A discussion on the floor of the Atlantic Ocean: Royal Soc. London Proc., Ser. A., v. 222, no. 1150, p. 361–387.

Worzel, J. L., and Shurbet, G. L., 1955, Gravity interpretations from standard oceanic and continental crustal sections, *in* Poldervaart, Arie, ed., Crust of the earth—a symposium: Geol. Soc. America Spec. Paper 62, p. 87–100.

Young, J. A., Jr., 1939, Minerals from deep-sea cores and surface deposits of Bermudian calcareous sediments: Am. Jour. Sci., v. 237, no. 11, p. 798–810.

U. S. GOVERNMENT PRINTING OFFICE : 1968 O - 283-159