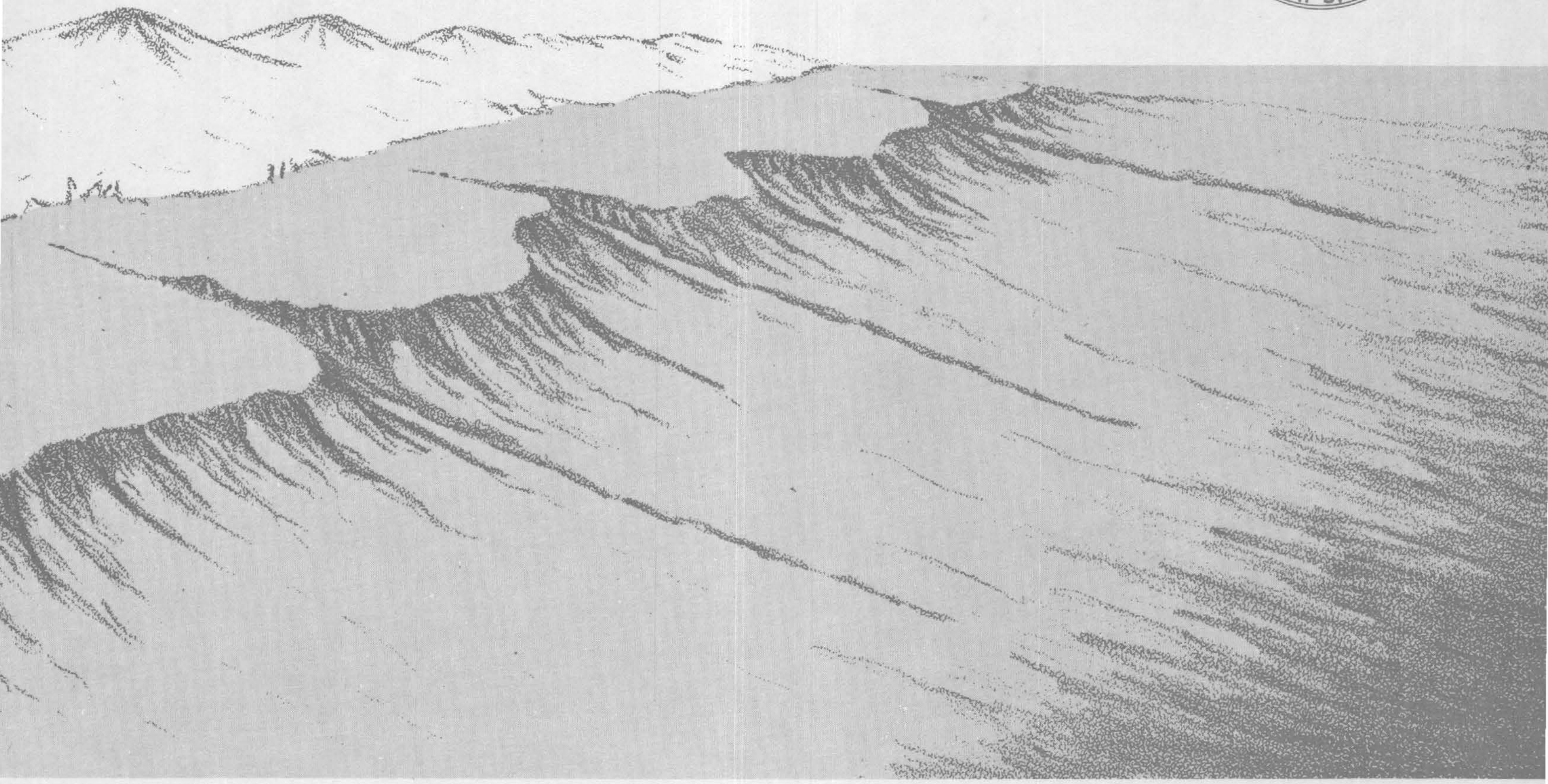
Atlantic Continental Shelf and Slope of the United States



Sand-Size Fraction of Bottom Sediments, New Jersey to Nova Scotia

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-K

Atlantic Continental Shelf and Slope of the United States—Sand-Size Fraction of Bottom Sediments, New Jersey to Nova Scotia

By JAMES V. A. TRUMBULL

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-K

Distribution of the sand-size fraction of bottom sediments on the continental margin from New Jersey to Nova Scotia, their source, and local modification processes

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 72-600176

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 55 cents (paper cover)
Stock Number 2401–2185

CONTENTS

ILLUSTRATIONS

ATLANTIC CONTINENTAL SHELF AND SLOPE OF THE UNITED STATES—SAND-SIZE FRACTION OF BOTTOM SEDIMENTS, NEW JERSEY TO NOVA SCOTIA [1]

By James V. A. Trumbull

ABSTRACT

Examination of the sand-size fraction of surface sediments divides the continental shelf off the Northeastern United States into three distinctive areas. These are the glaciated Gulf of Maine and Nova Scotia shelf, the shallow high-energy Georges Bank–Nantucket Shoals area, and the more normal continental shelf south of New England and Long Island and east of New Jersey.

Surface sediments of the Gulf of Maine are predominantly of relict glacial origin and have been reworked little since deposition. They are poorly sorted, and their sand-size fraction is mostly composed of quartz and feldspar grains, rock fragments, and dark minerals. Fine-grained micaceous sediments are being deposited in local basins off the eastern Massachusetts and New Hampshire coasts and in the protected waters and nearshore basins of the coast of Maine. Larger topographic basins nearer the center of the Gulf of Maine have flat accretionary floors on which clay, some silt, sand-size mica flakes, and foraminiferan tests and other organic debris are now settling. Basins in areas of high currents in the eastern and northeastern Gulf of Maine are mostly covered with relict sand and some gravel, as is Northeast Channel, the only deep-water hydraulic entrance to the gulf. Well-sorted fine quartzose sands inshore of Georges Bank and inshore of the shallow shelf near Nova Scotia were winnowed from those areas during the postglacial transgression and are also now relict.

Sediments of most of the Nova Scotia shelf are generally similar to the poorly sorted glacially derived rock debris of most of the Gulf of Maine, though the Nova Scotia shelf also contains topographic basins floored with fine-grained sediment.

Georges Bank is more than 50 km from land, but large areas of it are less than 60 m deep. Over most of the shallower parts of the bank little but clean quartz sand and minor amounts of detrital glauconite have survived the constant wave turbulence and current transport. The perimeter of the bank is marked by slight concentrations of detrital glauconite eroded from the coastal plain strata underlying the bank. The sands of Nantucket Shoals in general share the characteristics and the environment of Georges Bank.

Sand covers most of the continental shelf south of New England and Long Island and east of northern New Jersey. Most of the sand is well sorted and moderately well rounded. The sand was deposited primarily as glacial and fluvial outwash during glacial-stage lowering of sea level and was slightly reworked during the following transgression. It is therefore relict in origin. Silt on the middle and outer shelf south of Martha's Vineyard apparently postdates the transgression. River-derived gravel blankets a large area on the inner half of the shelf off northern New Jersey. Holocene detrital sand occurs in a narrow zone off the sandy beaches of New Jersey and Long Island. Narragansett Bay, Long Island Sound, and other protected inshore areas are floored primarily with Holocene micaceous silty sediment.

Over all the continental shelf the primary components of the sand-size fraction are quartz and feldspar, with a strong admixture of rock fragments and dark minerals in the glaciated Gulf of Maine and Nova Scotian shelf, and with a variable admixture of foraminiferan tests and shell fragments. Locally, very high concentrations of glauconite are found in the bight between New Jersey and Long Island and south of Long Island.

Except in the vicinity of Georges Bank, glauconite appears to be forming along the entire length of the outer continental shelf and upper slope. Other authigenic minerals include only minor amounts of pyrite and possibly limonite.

Compared with the shelf sediments, the sand-size fraction of upper continental slope sediments is enriched in glauconite, mica, and dark minerals and is impoverished in rock fragments. The slope sediments off Georges Bank, Northeast Channel, and the Nova Scotia shelf contain more quartz, feldspar, and rock fragments and less mica and biogenic material than the slope sediments south of New England. The percentage of foraminiferan tests in the sand fraction increases at the rate of 2.5 percent per 100-meter depth increase on the slope south of New England, but the rate is 1.5 percent off Georges Bank and northeastward.

Most of the sediments on the upper continental rise between Hudson Canyon and Georges Bank contain less than 2 percent sand, and only about 10 percent of the sand is detrital, the remainder being mostly foraminiferan tests. In certain areas of the rise, however, 10–25 percent of the sediment is sand, and 53–82 percent of the sand fraction is detrital in origin. Those areas probably indicate mass transport from the continental slope. Much poorly sorted glacially derived

[1] Contribution 2416 of the Woods Hole Oceanographic Institution, based on work done under a program conducted by the U.S. Geological Survey and the Woods Hole Oceanographic Institution and financed by the U.S. Geological Survey.

sediment characteristic of the floor of the Gulf of Maine is present on the continental slope outside northeast Channel. Normal hemipelagic sedimentation has not yet deeply buried these anomalous sediments of the slope and rise.

INTRODUCTION

The conventional methods of studying unconsolidated marine sediments—size, heavy-mineral, X-ray, chemical, and paleontological analysis—have recently been supplemented by an improved technique of displaying the results of binocular microscope examination of the washed sand-size fraction. Originated by Shepard and Moore (1954) in a study of Gulf of Mexico sediments, the technique is a direct and effective method of characterizing and differentiating sediments and their environments. In the work herein reported, the technique has been applied to the surficial sediments off the Northeastern United States to aid in revealing the geologic and oceanographic history of the area and to determine the present-day processes and the distribution of sediment types.

DESCRIPTION OF AREA

This report covers the continental shelf from northern New Jersey to Nova Scotia and the adjacent continental slope and upper continental rise (fig. 1).

The area of continental shelf under consideration is about 230,000 km², or about two-thirds of the

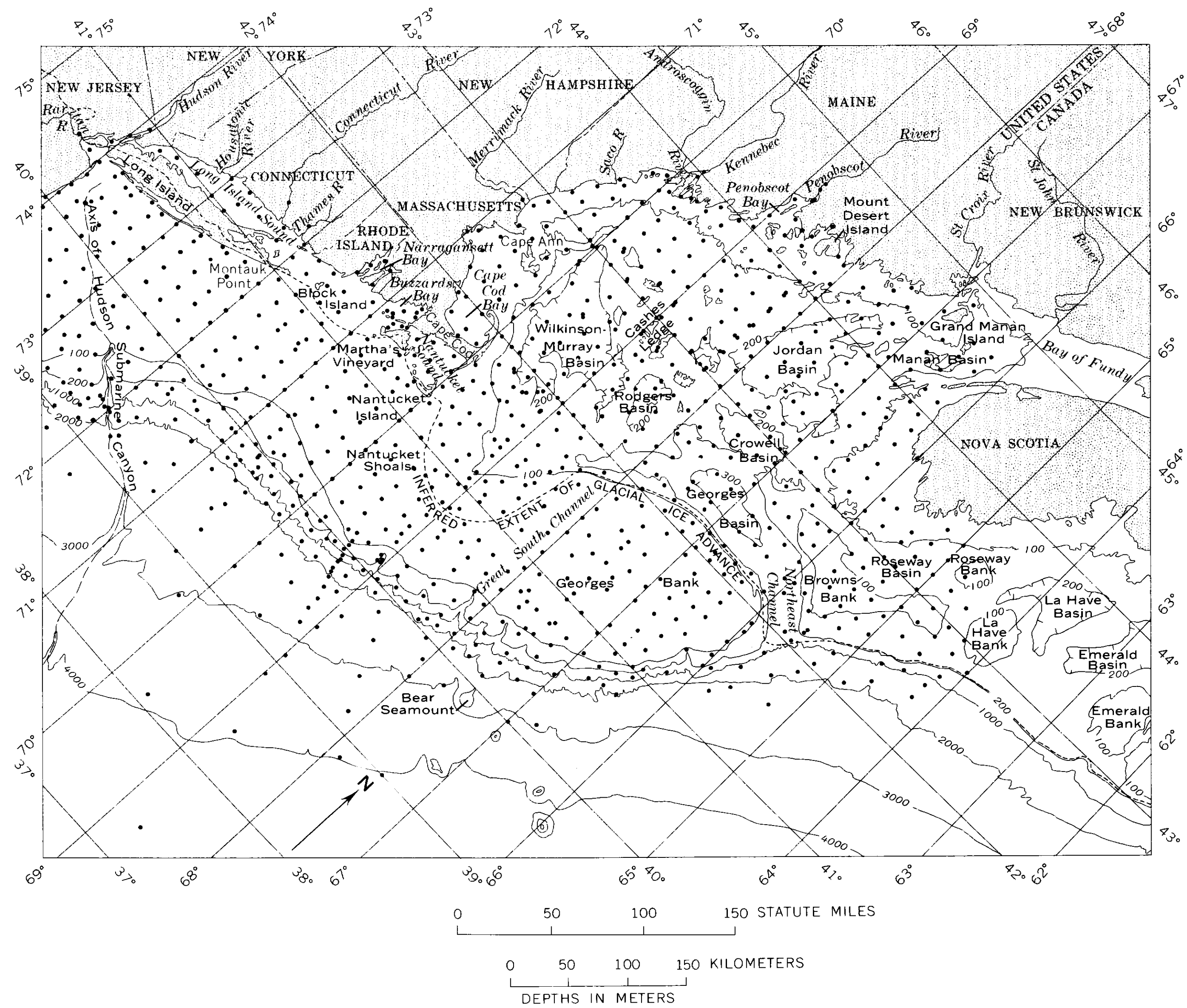


FIGURE 1.—Map of the continental margin off the northeastern coast of the United States, showing sample localities.

area of the entire continental shelf along the east coast of the United States. Maximum width of the continental shelf in the mapped area is about 400 km. The continental slope and continental rise here investigated total, respectively, 33,000 and 84,000 km^2. The total area under consideration, 347,000 km^2, is about twice that of the six New England States.

All available soundings in the mapped area have been compiled by Uchupi (1965a). Because of its detailed contouring, Uchupi's map should be at hand when this report is read.

The mapped area has two distinct shoreline types. The shoreline of Nova Scotia and most of Maine is rocky, highly irregular in outline, and generally lacking in sandy beaches. It is bordered on the seaward side by a zone of irregular rocky bottom 25–50 km wide. The contrasting shoreline type is a straight or gently curved sandy beach, bordered by an offshore zone of generally smooth sandy bottom. The latter shoreline type is represented by the outer end of Cape Cod, the shores of Nantucket, the south shore of Long Island, and the New Jersey coast. The shoreline from southern Maine south to Cape Cod and thence westward through Long Island Sound is a mixture of the two types: Rocky headlands and points alternate with generally smooth sandy beaches. Johnson (1925) presented details of coastal morphology in this area.

The coastal area includes numerous bodies of protected water in restricted communication with the sea. The Maine coastline is so irregular that much of its length is occupied by generally small protected water bodies. The largest are Penobscot Bay, into which the Penobscot River discharges, and Casco Bay. From Casco Bay south to Cape Cod the coast is predominantly open, but from Cape Cod to New Jersey much of the coastline is sheltered. Major protected water bodies there are Cape Cod Bay within the hook of Cape Cod, Nantucket and Vineyard Sounds, Buzzards Bay, Narragansett Bay, Block Island and Long Island Sounds, and Raritan Bay in northern New Jersey. The bottom sediments of those protected areas are strongly affected by restricted communication with the sea.

The outer Nova Scotia continental shelf resembles other glaciated shelves of the world (Holtedahl, 1958) in having basins on its inner part and banks on its outer part. For example, La Have Bank on the outer half of the shelf has a minimum depth of 77 m, but the Roseway Basin on the inner part of the shelf has a maximum depth of 185 m. Similarly, Browns Bank, south of Nova Scotia, has a minimum depth of 33 m, but between it and Nova Scotia is a passage more than 120 m deep.

Although the southern and southwestern parts of the Gulf of Maine are relatively smooth-floored, the northwestern, central and northeastern sides have numerous ridges, pinnacles, and gullies. Within the gulf are no fewer than 21 topographic basins separated by ridges, swells, and banks. Basin depths range from 64 to 377 m (Uchupi, 1965b).

Georges Bank, seaward of the Gulf of Maine, is delineated by the 100-meter depth contour, and about half of it is shallower than 60 m. Between Georges Bank and Browns Bank is Northeast Channel, the only deep-water entrance to the Gulf of Maine. Sill depth is between 220 and 240 m. At the southwestern end of Georges Bank is Great South Channel, a shallow and weakly delineated secondary hydraulic entrance to the Gulf of Maine. Its sill depth is between 60 and 80 m. Between Great South Channel and Nantucket Island is Nantucket Shoals. Its depths are generally less than 40 m, and in general character it is similar to Georges Bank. The shallower parts of both Georges Bank and Nantucket Shoals contain large sand ridges (Jordan, 1962; Stewart and Jordan, 1964).

The continental shelf from Nantucket Shoals southwestward to the limit of the area is of the conventional type in that depths generally increase continuously to seaward, and the 100-meter depth contour is near the outer edge. The inner and central shelf between Long Island and New Jersey is cut by Hudson Channel, and the outer shelf is deeply incised by Hudson Canyon.

Water depths at the outer edge of the continental shelf in the mapped area are in the range 130–160 m.

The gradient of the continental slope is from 1° to 6°. The transition at the base of the slope to the more gently inclined continental rise is at depths close to 2,000 m, except at the northeastern end of the mapped area where it is at almost 1,000 m. Relief on the continental slope thus ranges from about 800 to about 1,800 m. Between Northeast Channel and the New Jersey coast the continental slope is incised by 10 major named submarine canyons that indent the shelf edge and by numerous gullies.

The outer boundary of the area studied was determined by the limit of sampling rather than by a natural boundary. The water depth at the outer edge of the continental rise, where it meets the Sohm Abyssal Plain, is about 5,000 m, whereas the deepest sample used in this study is from a depth of 4,560 m. In general, sample coverage extends to a depth of about 2,000 m in the area north from Bear Seamount and, in a more open pattern, to a depth of about 4,000 m in the area to the southwest of Bear Seamount.

HYDROLOGY

The tidal range at the shoreline is about 1–2 m in most of the area, but it increases to about 4 m at the entrance to the Bay of Fundy. Because of that high range, vertical or horizontal restrictions on water flow cause high-velocity bottom currents that can be effective geologic agents. Nantucket Shoals, Georges Bank, Browns Bank, and the shallow area between Browns Bank and Nova Scotia have high-velocity bottom currents because they constrict the flow of water into and out of the Gulf of Maine; these areas show the effects of sediment winnowing and transport. Surface current velocities exceed 1 knot over most of those areas. On the shallower parts of Georges Bank they average 2 knots at the tidal maximum (U.S. Coast and Geodetic Survey, 1967), though far higher velocities have been recorded. The velocity of bottom currents is largely unknown. One measurement from the bottom of Northeast Channel showed 0.6 knot at the peak of the tidal cycle. The constriction at the eastern end of Long Island Sound causes tidal currents that have largely removed fine-grained sediment and left a bouldery bottom. Surface currents there exceed 5 knots (U.S. Coast and Geodetic Survey, 1947).

The 10 largest rivers discharging in the area have average discharges at the mouth that range from 640 m^3 per second (22,790 cfs) to 46 m^3 per second (1,625 cfs) (C. D. Bue, unpub. compilation). In decreasing order of average discharge, they are the Hudson, Connecticut, Kennebec-Androscoggin, Penobscot, Merrimack, Saco, Housatonic, St. Croix, Thames, and Raritan Rivers. The St. John River, which discharges into the Bay of Fundy 40 km beyond the mapped area, has an average discharge of more than 700 m^3 per second (25,000 cfs), more than any river within the area.

GEOLOGIC SETTING

The land adjacent to the mapped area has a crystalline basement of igneous and metamorphic rocks mostly of Paleozoic age. The basement is exposed at the surface (or is covered by a thin deposit of glacial material) throughout most of New England and Nova Scotia, and it probably underlies nearly the entire adjacent continental shelf. Sedimentary and intercalated basaltic volcanic rocks of Triassic age are downfaulted into the basement on both sides of the Bay of Fundy and beneath its floor and extend southwestward a considerable distance beneath the Gulf of Maine (Tagg and Uchupi, 1966; fig. 8 of present report). Another such downfaulted block of rocks of Triassic age reaches the coast in central Connecticut.

A seaward-thickening prism of predominantly clastic sedimentary rocks of Cretaceous and Tertiary age overlies the crystalline basement. It is subaerially exposed in northern New Jersey and on Martha's Vineyard and is known to underlie Long Island, parts of Cape Cod, the continental shelf south of them, Georges Bank, and parts of the Gulf of Maine (Schlee and Cheetham, 1967) and the continental shelf seaward of Nova Scotia (Marlowe, 1965). This sedimentary prism crops out on the continental slope at least from Georges Bank southwestward.

Continental glaciers crossed much of the area from a generally northward direction during the Pleistocene. The probable limit of glacial advance is marked by terminal moraines on Long Island, Block Island, Martha's Vineyard, and Nantucket, and is thought to be at or near the northwestern flank of Georges Bank (fig. 1). All of the Gulf of Maine and Northeast Channel and probably most, if not all, of the Nova Scotian continental shelf were glaciated (King, 1967). A generally thin deposit of till and other glacial detritus was deposited over the glaciated area, and outwash material was carried beyond the limit of glacial ice. During glacial maxima, eustatic sealevel lowering on the order of 115 m (King, 1967) to 165 m (Ewing and others, 1963) exposed much of the continental shelf.

PREVIOUS WORK

On becoming Superintendent of the U.S. Coast Survey in 1844, A. D. Bache directed that bottom samples brought up by the sounding lead in hydrographic surveying be preserved (Pourtalès, 1872, p. 220). The first systematic collection of such samples was made by his brother, G. M. Bache, in the section of coast between Rhode Island and New Jersey, at least as early as 1844 (U.S. Coast Survey, 1848, p. 25). The samples were examined microscopically and described by Bailey (1851), who expressed surprise at the large number of Foraminifera in the samples and noted the presence of fossils of Paleozoic age in gravels offshore from New Jersey.

Supplementing Bailey's work with his own observations, L. F. Pourtalès of the U.S. Coast Survey published (1870, 1872) a bottom-sediment map of the east coast of the United States. The map was accompanied by a descriptive text. Bailey's was the first published work on marine geology on the east coast, and Pourtalès' was the first bottom-sediment map. Pourtalès recognized the area of fine-grained sediments on the midshelf south of New England and knew that glauconite was forming at the present time but that the high concentration of glauconite just off New York City was derived from older rocks.

Systematic dredging for scientific purposes, as distinguished from the collection of samples adhering to armed sounding leads, was begun by the U.S. Coast Survey shortly after the Civil War. The first such dredging on the east coast north of the latitude of Delaware Bay was done in 1880 on the third cruise of the Coast Survey Steamer *Blake*, under the direction of Alexander Agassiz (Agassiz, 1881). Descriptions of the samples were published by John Murray (1885) and Agassiz (1888). During 1883–87 the steamer *Albatross* of the U.S. Fish Commission also did considerable bottom dredging, especially along the seaward side of Georges Bank (Townsend, 1901).

The presence of fossiliferous rocks of Tertiary age on Georges Bank was established by A. E. Verrill (1878). After study of the U.S. Fish Commission's collection of rocks gathered from Georges Bank and other banks by Gloucester fishermen (Upham, 1894), Verrill (1878, p. 324), correctly concluded that "these fragments have been detached from a very extensive submerged Teritiary formation, at least several hundred miles in length, extending along the outer banks from off Newfoundland nearly to Cape Cod, and perhaps constituting, in large part, the solid foundation of those remarkable submarine elevations." Dall (1925) later restudied the material. Verrill wrote extensively on the topography and geology of the continental shelf and upper slope. His work has recently been reviewed by Schopf (1968).

Johnson and Stolfus (1924) demonstrated that the Georges Bank cuesta is both topographically and geologically analogous to Long Island and onshore New Jersey. Burbank (1929) studied the particle-size distribution and the composition of the light and heavy mineral suites in 170 samples from the Gulf of Maine and the Bay of Fundy. Trowbridge and Shepard (1932) analyzed numerous nearshore bottom samples from the area between Boston and Cape Cod; seaward of an inshore zone of sand they found a zone of rocky bottom, beyond which particle size decreased regularly to silt and clay in nearshore basins. Hough (1932) commented that the rocky bottom was probably a lag concentrate of till, and Stetson and Schalk (1935) considered it a concentrate of a fluvial-glacial deposit. By use of sediment pans, Stetson and Schalk found that sand from the nearshore area was in transport across the zone of rocky bottom in times of heavy storms. Sediment pans were also used by Raymond and Stetson (1931; Stetson, 1938, p. 30) south of Martha's Vineyard, where poorly sorted material of 10μ median diameter was in transport past a well-sorted sand bottom of 560μ median diameter.

In studying the origin of Georges Bank, Shepard, Trefethen, and Cohee (1934) considered that glaciers extended on to the bank top and (in agreement with present views) that the sediment of much of the floor of the Gulf of Maine "was not derived through aqueous sedimentation, but is composed of glacial deposits, possibly somewhat modified by present marine conditions" (p. 297).

Henry C. Stetson of Harvard University and the Woods Hole Oceanographic Institution was a leading investigator of continental margin geology. In his view, the shelf sediments are slowly becoming adjusted to present sea level. The midshelf silt and clay area south of New England, for instance, he took to be an area of present-day sedimentation slowly covering the sand bottom inherited from the Pleistocene (Stetson, 1938, 1939). Highly rounded quartz grains in a zone off the southern New England coast he believed to be the result of wind action on dunes exposed during Pleistocene sea level lowering (Stetson, 1934).

Stetson also did much dredging in east-coast submarine canyons during the years 1934–40. This work established the presence of sedimentary rocks of Late Cretaceous, Eocene, Miocene, and younger Tertiary age beneath the outer continental shelf and upper continental slope (Stetson, 1936, 1949; Stephenson, 1936; Bassler, 1936; Cushman, 1936). Current velocities in Gilbert and Lydonia Canyons and on the nearby shelf were measured in 1936, and Stetson (1937; Colton, 1964, p. 5) concluded that because the shelf and canyon velocities were similar, the currents were not the cause of canyon cutting.

Alexander (1934), after examining heavy minerals in Stetson's shelf samples, thought deposition was now going on over most of the shelf, an idea corrected by Shepard and Cohee (1936). After examining 700 samples collected by the Coast and Geodetic Survey between Delaware Bay and Martha's

472-199 O - 72 - 2

Vineyard, Shepard and Cohee concluded that the shelf sediments are largely relict from previous conditions and are partly a lag concentrate.

Cushman (1939) and Northrop and Heezen (1951) reported sediment of Eocene age on the continental slope south of Rhode Island at depths of 880 and 1,000 m. Northrop (1951) divided the shelf south of Martha's Vineyard into zones on the basis of changes observed in bottom photographs and short cores. McMaster has studied the particle-size distribution and environment of deposition (1960) and the heavy minerals (1962) of Narragansett Bay, and Garrison and McMaster (1966) and McMaster and Garrison (1966) have made similar studies of an extensive area on the continental shelf off Rhode Island. Data on the particle-size distribution, composition, and bulk properties of 359 cores from the continental shelf off New York City are to be found in the library of the U.S. Naval Oceanographic Office (Cornell University, 1953, Final harbor report, New York, v. 4 A–F). Wigley (1961) studied bottom samples from Georges Bank and Great South Channel as part of Bureau of Commercial Fisheries studies of relations between bottom materials and benthic organisms. Atlases that include generalized bottom-sediment charts of the east coast of the United States have been published by the German Navy (Oberkommando der Kriegsmarine, 1943) and the U.S. Navy (U.S. Naval Oceanog. Office, 1965).

The sediments of Buzzards Bay and Cape Cod Bay were described by Hough (1940, 1942) in considerable detail, with primary emphasis on the particle-size distribution. Twenty years later Moore (1963) restudied the bottom sediments of Buzzards Bay, emphasizing minor- and trace-element composition and comparisons between the sediments there and the lithology of sedimentary rocks.

Sanders has studied relations between the fauna and the particle-size distribution of bottom sediments of part of Long Island Sound (1956) and of Buzzards Bay (1958). McCrone (1966a) and McCrone, Ellis and Charmatz (1961) have described the sediments of Long Island Sound. McCrone (1966b) has discussed those of the Hudson River estuary. Foraminifera of the waters between New Jersey and Nova Scotia have been studied by Cushman (1944), Parker (1948, 1952a, b), Phleger (1952), Todd and Low (1961), and others.

Beach sands between New Jersey and Nova Scotia have been studied by McCarthy (1931, New Jersey and Long Island); Colony (1932, New Jersey and Long Island); Schalk (1938, Cape Cod); McMaster (1954, New Jersey); Taney (1961a, b, Long Island); Krinsley and others (1964, Long Island); and Schlee and others (1964, Cape Cod).

Bottom topography and its geologic significance were studied by Veatch and Smith (1939, submarine canyons and the continental slope); Murray (1947, Gulf of Maine); Torphy and Zeigler (1957, Northeast Channel); and Jordan (1962, Georges Bank). Murray (1947) pointed out and illustrated the sonically dual-bottom nature of some basins in the Gulf of Maine. Sand waves and sand ridges on Georges Bank were described by Jordan (1962) and Stewart and Jordan (1964). King (1967) has described the bathymetry and geology of a part of the Nova Scotian shelf just to the northeast of the area considered here. Uchupi has recently (1968) described the topography of the area here studied. He has prepared (1965a) a bathymetric chart of the area at the scale 1:1,000,000 and contour intervals of 20 and 200 m.

METHODS

A total of 913 bottom samples were analyzed, of which 487 were collected as part of the cooperative program of the U.S. Geological Survey and the Woods Hole Oceanographic Institution, 391 were collected and contributed by the Woods Hole Laboratory of the U.S. Bureau of Commercial Fisheries, 33 were collected by the Woods Hole Oceanographic Institution, and 2 were collected by the U.S. Coast and Geodetic Survey. The distribution of these samples is shown in figure 1. Forty-five samples of beach sand were also analyzed. Nominal sample spacing on the continental shelf is 18 km, or 10 nautical miles. Complete field data on all samples have been tabulated by Hathaway (1966, 1967). The number of samples from each major physiographic region and the average area represented by each sample are as follows:

	Number of samples	Area mapped (Km^2)	Km^2 per sample
Continental shelf	756	229,600	304
Continental slope	104	32,900	316
Continental rise	53	84,300	1,590
	913	346,800	Average—737

About half the samples were taken with a Campbell grab (Emery and others, 1965) and the remainder with a variety of tools. The material analyzed is assumed to represent the upper 15–20 cm of sediment, unless a marked change in composition was noted within that depth, in which cases the upper and lower materials were analyzed separately.

The method of sample examination and presentation of results is that originated by Shepard and Moore (1954) and called by them the coarse-fraction method. On the Texas coast where they worked, the sand fraction is indeed the coarse fraction; but it is not in the glaciated area under discussion here, and here the technique will be termed "sand fraction analysis." The percentage of the sediment that is of sand size is shown in figure 2, which is drawn from data supplied by John S. Schlee.

For each sample, a representative subsample was nondestructively disaggregated, dry sieved at 2 mm, wet sieved at 0.062 mm, and dried to obtain the sand fraction (0.062–2 mm). Samples were examined under a binocular microscope, and the percentage of major component groups was estimated by using percentage diagrams (Terry and Chilingar, 1955) and counts of 200–300 grains. Major component groups were rock fragments, quartz plus feldspar,

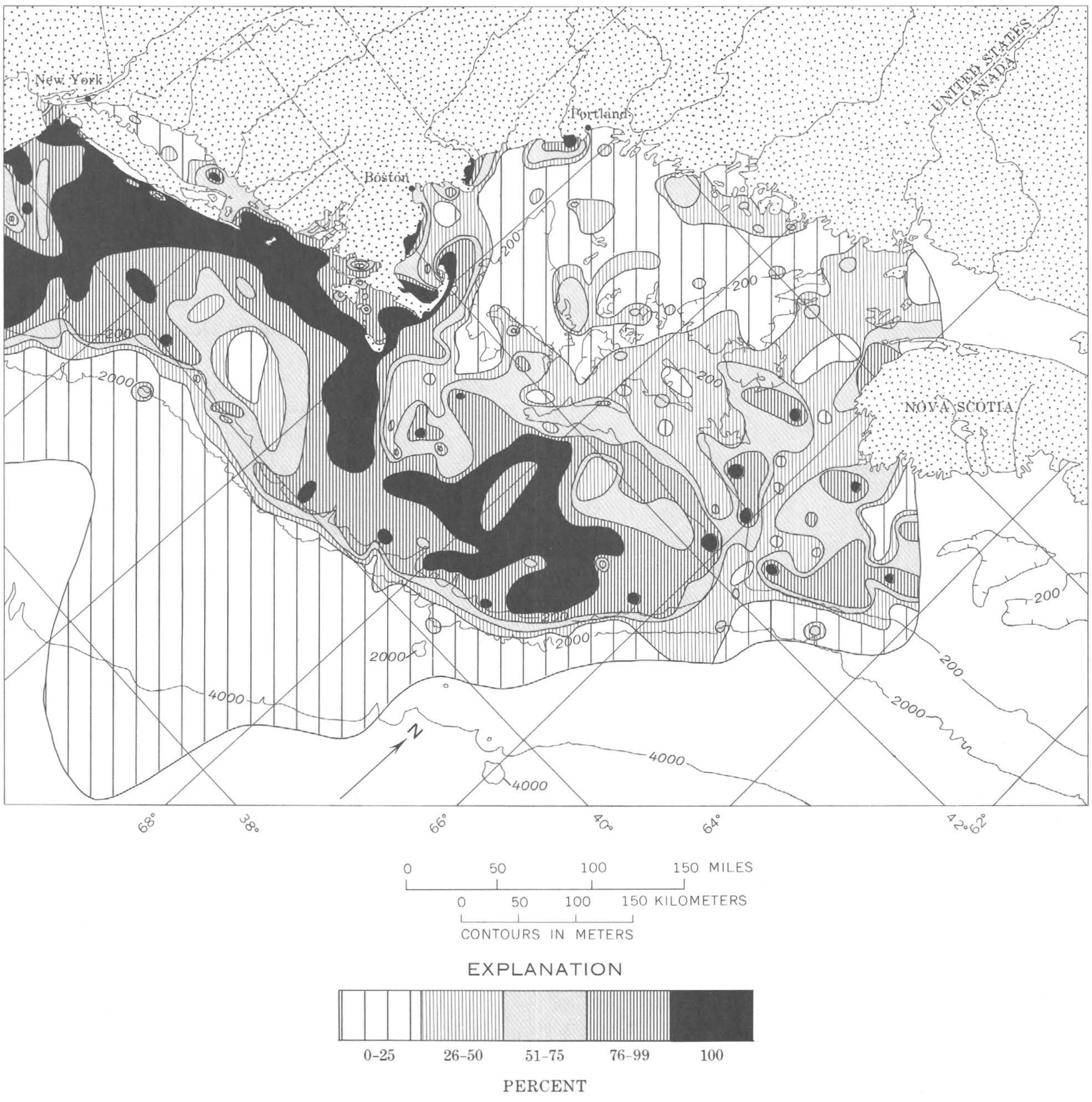


Figure 2.—Percentage of sand-sized material in original sample. Drawn from data supplied by John S. Schlee.

dark minerals, glauconite, mica, Foraminifera, and shell fragments. The presence and relative amount of a number of other usually minor components were also recorded. These included pyrite, limonite, cinders, wood fragments, fibrous plant material, sponge spicules, urchin spines, ostracodes, diatoms, radiolarians, and scolecodonts.

The mapped area was then divided into subareas, each of a distinctive sediment type. That division was based on the results of the preceding examination, on the color and overall appearance of the original samples, and on particle-size distribution data provided by John Schlee. Within each of the subareas, representative samples were sieved into five size grades with the limits 2, 1, 0.5, 0.25, 0.125, and 0.0625 mm. Each size-grade of each sample was examined to determine composition by percentage. By averaging results within each area, the composition by size grades of each area was determined and plotted graphically (fig. 15).

In addition, roundness, sphericity, and degree of frosting and of iron staining were estimated on 100-grain counts of quartz grains in the 0.25- to 0.5-mm size grade, and the mineralogy and morphology of grains of the authigenic minerals glauconite and pyrite were studied.

The work reported here depends on the assumption that a 1-gram split of a half-liter sediment sample can represent the sediment of an area of more than 300 km^2. Assuming that the split is representative of the sample, the validity of that assumption depends on the rate of variation in the sediment with distance. In this area, the assumption is at least workably valid for the continental rise and most of the continental slope, for the samples adequately portray the gradients of compositional and textural change. The same is true of most of the continental shelf. However, in the central and northern Gulf of Maine, in some nearshore areas, and in most protected bodies of water, the rate of change of sediment character with distance is very high. The samples from those areas probably typify the sediments but do not portray local trends of variation. A sample spacing on the order of at least 1 km would be necessary to define individual areas of sediment types in those places.

ACKNOWLEDGMENTS

The cooperation and skill of Captain Harry H. Seibert and the officers and crew of the RV *Gosnold*, and of Captain Arthur D. Colburn of the RV *Asterias*, made possible the marine sampling program. Many persons made up the scientific complement of numerous sample-collecting cruises on RV *Gosnold* and RV *Asterias*, and particular thanks are due William R. Moehl and Arthus E. Wegweiser. Numerous additional samples utilized in the study were contributed by the Woods Hole Laboratory of the U.S. Bureau of Commercial Fisheries, and by Howard L. Sanders and Richard M. Pratt of the Woods Hole Oceanographic Institution. Many of the samples from present-day beaches were collected and made available by John M. Zeigler and William D. Athearn of the Woods Hole Oceanographic Institution.

Kenneth O. Emery and numerous colleagues on the immediate staff of the U.S. Geological Survey-Woods Hole Oceanographic Institution Continental Margin Project were of great help in the preparation of this report and in contributing data on which much of it is based. Numerous members of the scientific community in Woods Hole—on the staffs of the Oceanographic Institution, the Bureau of Commercial Fisheries, and the Marine Biological Laboratory—have supplied specialized information in many fields. Particular thanks are due Roland L. Wigley and Arthus S. Merrill of the U.S. Bureau of Commercial Fisheries and Thomas J. M. Schopf of the Marine Biological Laboratory. Joseph R. Frothingham, Jr., and Arthur C. Laura assisted in the laboratory preparation of samples.

AREAL DISTRIBUTION OF COMPONENTS

Most of the surface sediments of the continental shelf in the area of investigation are detrital in origin, with subordinate amounts of biogenic material, and, in some areas, minor amounts of authigenic material. The sand-size fraction of sediment on the continental slope is also predominantly detrital, but with a biogenic component that increases with depth. Biogenic material, primarily foraminiferan tests, predominates in the sand-size fraction of continental rise sediments.

DETRITAL COMPONENTS

Rock Fragments

The percentage of rock fragments in the sand-size fraction is shown in figure 3. Highest concentrations are found on the glaciated Nova Scotian shelf and in the Gulf of Maine. In an area west of the southern Nova Scotia peninsula, percentages of rock fragments are consistently between 25 and 65; on the outer seaward Nova Scotian shelf, they are 20–40 percent. In the south-central Gulf of Maine and Northeast Channel, percentages are in the 6–30 percent range.

These high percentages result from the glacial origin of the surface sediment. In glacial erosion, mechanical size degradation is more important than chemical weathering, so that intergrain bonds are preserved more often than in chemical weathering. Postdepositional processes that have operated on the glacial material include (1) turbulence, abrasion, and winnowing away of small particles accompanying passage of the shoreline zone during glacial-stage changes of sea level, and (2) the present-day action of currents in selective removal of fine particles and perhaps, in shallower areas, in mechanical abrasion. Selective removal of fine sand by both these processes has resulted in high percentages of rock fragments in the coarse (1–2 mm) lag fraction.

Georges Bank is a shallow high-energy area, and the sand fraction of its shallower parts contains almost no rock fragments. In its shoaler areas, much sand transport occurs during each tidal cycle (Stewart and Jordan, 1964). Low concentrations of rock fragments there are probably due to abrasion, and probably also in some degree to an admixture

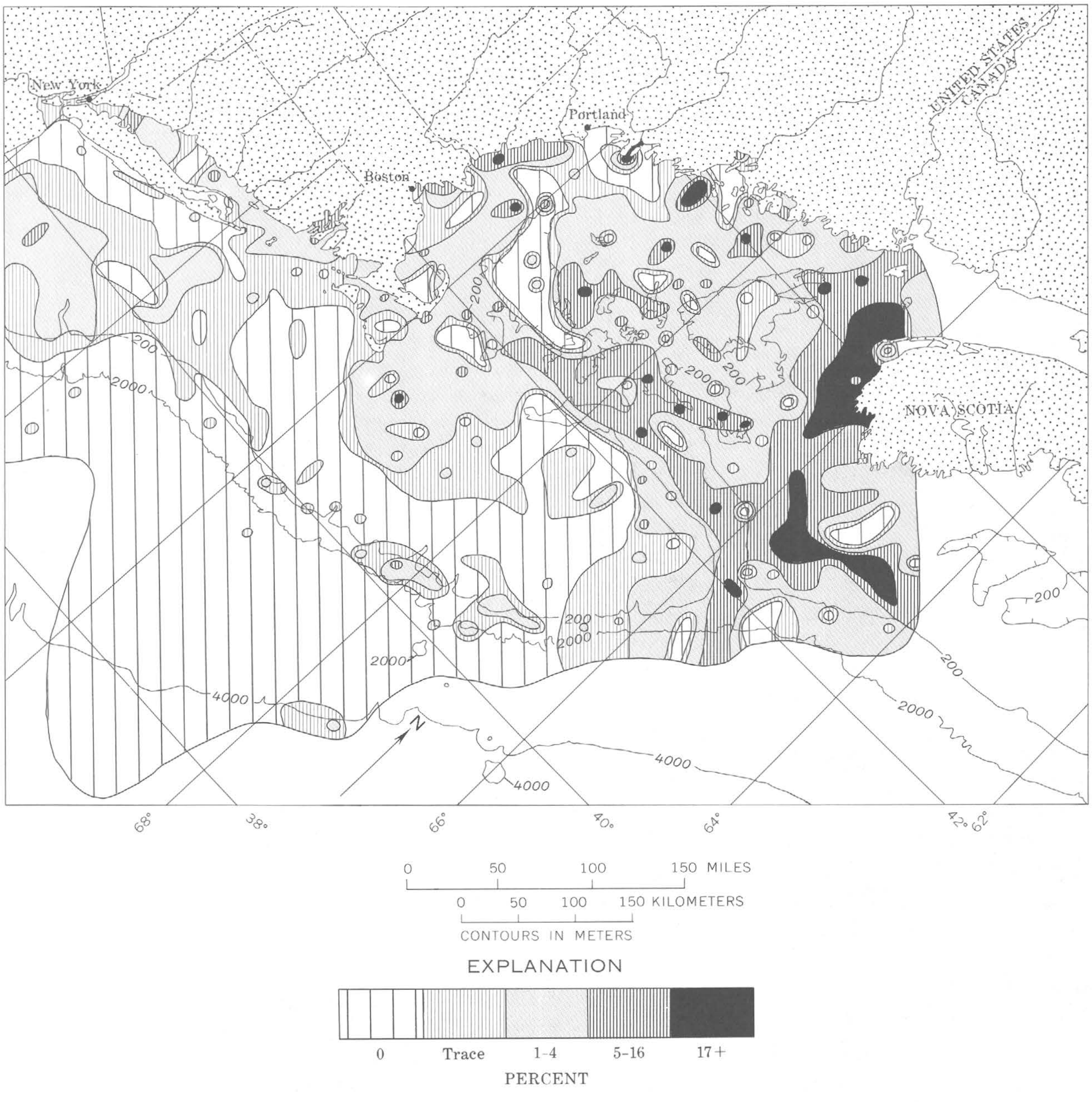


FIGURE 3.—Percentage of rock fragments in sand-size fraction.

of highly quartzose reworked sediments of Cretaceous and Teritiary age. An area of zero rock fragments atop the bank continues over the northwestern boundary slope of the bank and occupies a small part of the floor of the Gulf of Maine at depths as great as 180 m, suggesting sand transport from the top of the bank. The northeastern end and western side of Georges Bank have as much as 5 percent rock fragments in depths as shallow as 60 m. Several places on the continental slope southeast of Georges Bank have as much as 3 percent of rock fragments, which also indicates sand transport from the top of the Bank.

The sands of Nantucket Shoals contain 1 percent or more of rock fragments. The shoals are as shallow and are probably of as high an energy level as the top of Georges Bank, which has less rock fragments. This situation may indicate continuous nourishment of Nantucket Shoals by glacial debris from the Cape Cod-Nantucket area.

Rock fragments are few or lacking on glaciated shelf areas occupied by fine-grained postglacial sediments. Such areas include Roseway and La Have Basins on the Nova Scotian shelf, numerous basins in the Gulf of Maine, protected bays and areas near large river mouths along the coast of Maine, and the eastern half of Cape Cod Bay.

The surface sediments of the continental shelf south of New England and Long Island generally contain less than 1 percent rock fragments. Exceptions are shallow inshore areas such as Long Island and Block Island Sounds, the Narragansett Bay area, Buzzards Bay, and Vineyard and Nantucket Sounds, which have from 1 to 8 percent rock fragments. Those areas are within the limits of glaciation and are floored with sediment transported only short distances (if at all) from the parent glacial deposits. Other exceptions are two areas on the open shelf. Sediments on the midshelf off New Jersey contain 3–5 percent rock fragments. This is an area of gravel that originated as a river deposit during a low stand of the ocean (Schlee, 1964). The same explanation probably applies to an area centered 45 km south of Montauk Point.

The continental slope and upper rise off the northeastern end of Georges Bank and off Nova Scotia commonly have from 1 to 4 percent rock fragments, but on the slope and rise off Northeast Channel, percentages rise sharply to as much as 15 percent. Many of the rock fragments are of igneous or metamorphic origin. It seems clear that glacially derived material from the Georges Bank and from the Nova Scotian shelf has been carried down the slope and upper rise and that material of an even more strongly glacial aspect was transported out of Northeast Channel and down the slope and rise.

Surface deposits of the continental slope and rise southwestward from Bear Seamount are almost entirely lacking in rock fragments. The rock fragments found on the upper slope on each side of the Hudson Canyon are seaward continuations of the areas on the shelf off New Jersey and Long Island that contain high percentages of rock fragments.

Two anomalous samples from the continental rise south of Bear Seamount in depths of 3,820 and 3,975 m each contain 1 percent rock fragments. The fragments are as much as 5 mm across and are predominantly quartzite. The nearest samples in which rock fragments were found are 135 km landward. The presence of these rock fragments so far at sea indicates that a transporting mechanism brought them from at least as far away as the continental slope.

Dark Minerals

What are here termed dark minerals are primarily heavy minerals, which in this area have been studied by Ross (1967, 1970). Dark minerals excluding glauconite will be treated here as a unit component of the sediment. Their concentration ranges from zero in one sample from the outer continental rise to a maximum of 11 percent in the northern Gulf of Maine (fig. 4).

Nearly all the Gulf of Maine has 2 percent or more dark minerals in the sand-size fraction, and 5–10 percent is common in the northeastern Gulf of Maine and the entrance to the Bay of Fundy. The concentration of dark minerals in the Gulf of Maine shows little relation to topography, but Roseway and La Have Basins have less than the surrounding Nova Scotian shelf.

The shallower parts of Georges Bank have only trace amounts of dark minerals. On the northwestern side of Georges Bank, the area of trace amounts extends deeper than 200 m in one area, and a wide 1-percent zone borders the bank. That is an anomalously small amount of dark minerals for the floor of the Gulf of Maine. The cause is probably the transportation of clean quartz sand from the top of Georges Bank. The same phenomenon is apparent on the seaward side of Georges Bank, which is the only place in the mapped area where the continental slope has less than 1 percent dark minerals.

Most of the shelf off Long Island and New Jersey has 2 percent dark minerals. Three to four percent dark minerals is present on the midshelf off New Jersey and south of the eastern tip of Long Island where areas of gravel are present. Eastern Long Island Sound has 3–5 percent dark minerals because strong currents are eroding and transporting glacially derived material. The dark-mineral content of the six samples taken in Narragansett Bay agrees with those reported by McMaster (1962), who found that almost three-fourths of his 15 samples had between 2 and 4 percent heavy minerals.

River sediments also have high dark-mineral percentages, probably because those sediments are derived mostly from glacial deposits. A sample from the Thames River in eastern Connecticut had 6 percent dark minerals, one from the Connecticut River had 4 percent, and several from the Hudson River had 3–5 percent. The Raritan River, with 5 percent in one sample, and Raritan Bay, with 7 percent in one sample, may owe their high dark-mineral content to the erosion of strata of Cretaceous and Teritiary age in which dark minerals had previously been concentrated.

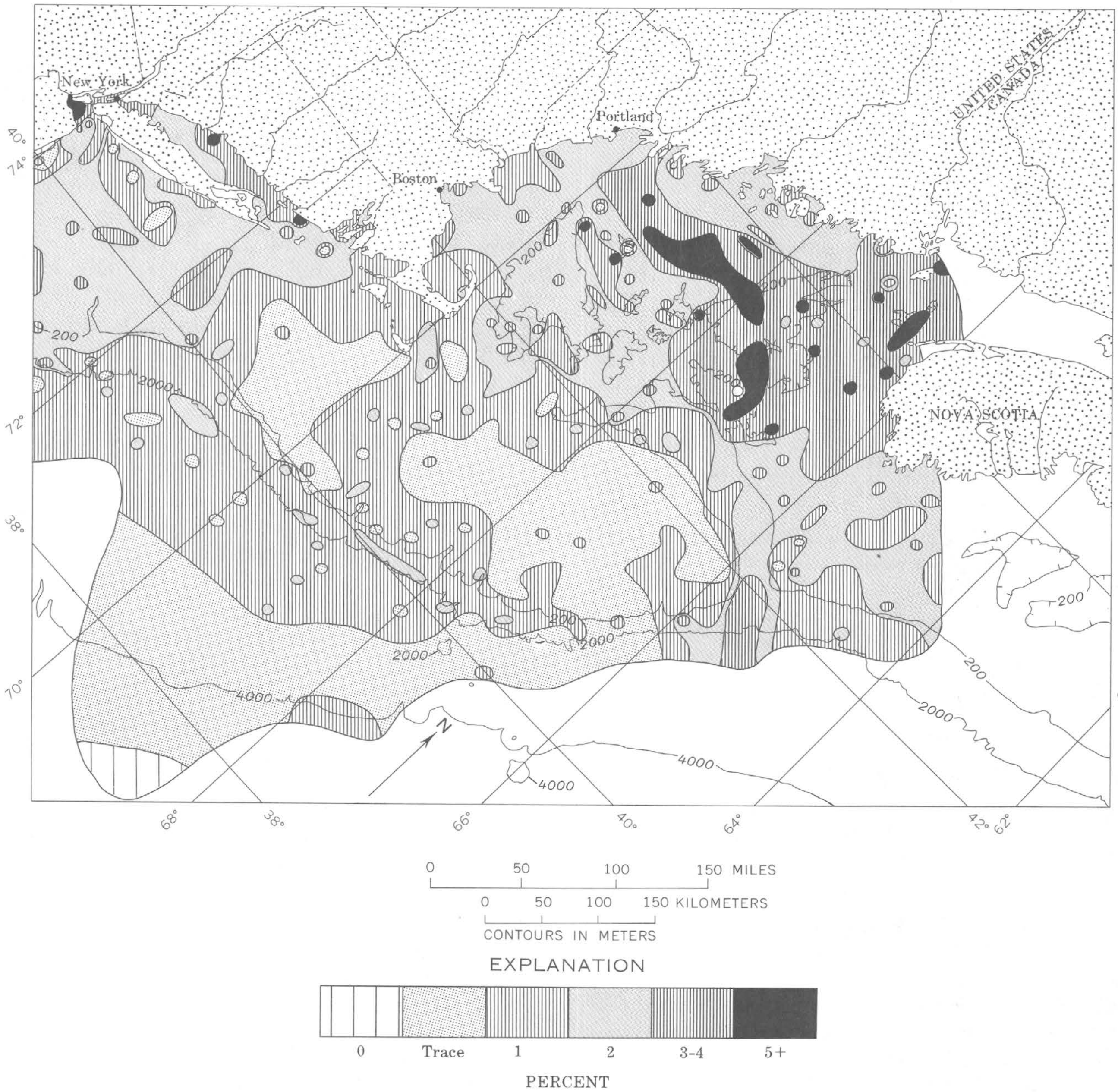


Figure 4.—Percentage of dark minerals in sand-size fraction.

Excepting unusual areas, continental slope sediments contain about 1 percent dark minerals in their sand-size fraction. The slope near the edge of the mapped area southwest of Hudson Canyon has 2–3 percent dark minerals at a depth of about 1,800 m. No reason for these anomalously high values at that depth is evident, but they are probably related to the gravel deposit on the shelf in this area, with its high percentages of dark minerals and rock fragments. Higher than ambient amounts of dark minerals (2 percent) are present in several small areas along the continental slope and upper rise south of New England. They may be related to eroded outcrops of Cretaceous and Tertiary strata higher on the slope. As is true of rock fragments, the continental slope and upper rise seaward of Northeast Channel have anomalously high concentrations of dark minerals (3–4 percent), again showing that the channel has been a conduit for the seaward transport of sediments from the Gulf of Maine.

Continental rise sediments contain as much as 1 percent dark minerals. The line between trace amounts and 1 percent dark minerals is at about 3,200 m depth everywhere southwestward of Bear Seamount, but off the northeastern tip of Georges Bank it is in less than 1,000 m.

It seems a general rule that the more directly a sediment is derived from glacial material, the higher the content of both rock fragments and dark minerals. McMaster (1962) found a similar relationship in the sediments of Narragansett Bay. Goodell (1966) reported that glacial marine deposits of the Antarctic Continental Shelf and Slope in some places contain more than 15 percent heavy minerals.

Mica

The distribution of mica in the sand-size fraction of surface sediments (fig. 5) is an indicator of relative present-day energy levels. Because of their shape, mica particles are readily removed from high-energy areas and transported to, and deposited in, low-energy areas.

The floor of the Gulf of Maine and the Nova Scotian shelf has only trace amounts of mica in the sand-size fraction in areas other than basins. In both areas major basins are fairly well delineated by areas of 1–2 percent mica and more. Nearshore basins off eastern Massachusetts and southern Maine have high mica contents because they are close to the two main mica sources: shoreline erosion of glacial deposits and stream and river mouths. The sediments of protected waters of the southwestern part of the Maine coast commonly have as much as 8 percent mica, whereas those of protected waters in the Penobscot Bay–Mount Desert Island area do not exceed 4 percent. Differences in degree of protection and in tidal range may account for this.

No mica is found in the high-energy environments of Georges Bank, Nantucket Shoals, and Browns Bank, nor on the floors of Great South Channel and Northeast Channel. Presumably this absence of mica is due to the winnowing effect of tidal currents. Stellwagen Bank, a shallow high-energy sand-covered area north of the tip of Cape Cod, lacks mica for the same reason. The effect of high-energy shoreline conditions is seen in the narrow zero-mica band east of the beaches of Cape Cod. Presumably tidal scour is also the cause of the zero-mica areas in Nantucket Sound and southwest of Martha's Vineyard. Inside the hook of Cape Cod is a concentration of as much as 5 percent mica, a result of low-energy conditions in those protected waters.

Most of the continental shelf south of New England and Long Island has only trace amounts of mica. A notable exception is an anomalous mid-shelf and outer-shelf area south of Martha's Vineyard, where fine-grained sediments contain as much as 3 percent mica. This is the only place on the continental shelf other than basins and nearshore protected areas where mica is present in appreciable amounts.

Long Island Sound also illustrates the relation between energy levels and deposition of mica. The highest mica concentrations are where the Sound is broadest and the tital currents correspondingly least swift. The south shore of Long Island and the New Jersey coast, both low sandy barrier-beach areas, have narrow longshore zones lacking in mica, as expected in a high-energy environment. The cause of the zero-mica area at midshelf off the New Jersey coast is not apparent. This is in the area of high gravel, rock fragments, and dark minerals previously noted.

The continental slope has a range of 0 to 12 percent mica, but most samples have from 1 to 4 percent. High-energy conditions near the shelf break are indicated by three zero-mica areas southeast of Nantucket. At the seaward edge of Georges Bank, samples from slightly more than 200 m deep are lacking in mica. The strong concentration of mica on the upper continental slope just southwest of the Hudson submarine canyon may well be related to the deposition of river sediments to form the Hudson apron when most of the shelf was subaerial during Pleistocene glacial periods, as discussed by

Ewing, Le Pichon, and Ewing (1963). Southwest of Georges Bank, the mica concentration in slope sediments increases with depth to a maximum between 1,500 and 2,200 m. In deeper water the concentration decreases, and only trace amounts are present on the outer continental rise. On the continental slope and upper rise northeast of Georges Bank, the maximum mica concentration is at a depth of 1,500 m. Beyond that, there is a decrease with depth that is more rapid than in the area to the southwest of Georges Bank.

Quartz and Feldspar

Except for the continental rise, where tests of planktonic Foraminifera predominate, quartz and feldspar grains dominate the composition of the sand-size fraction of nearly all surface sediments in the mapped area. This is because (1) the surface sediments are predominantly of detrital rather than of authigenic or biogenic origin; (2) the rocks of the mapped area itself and of the source areas of glacial and stream transport are highly quartzitic; and (3) quartz is more resistant to mechanical and

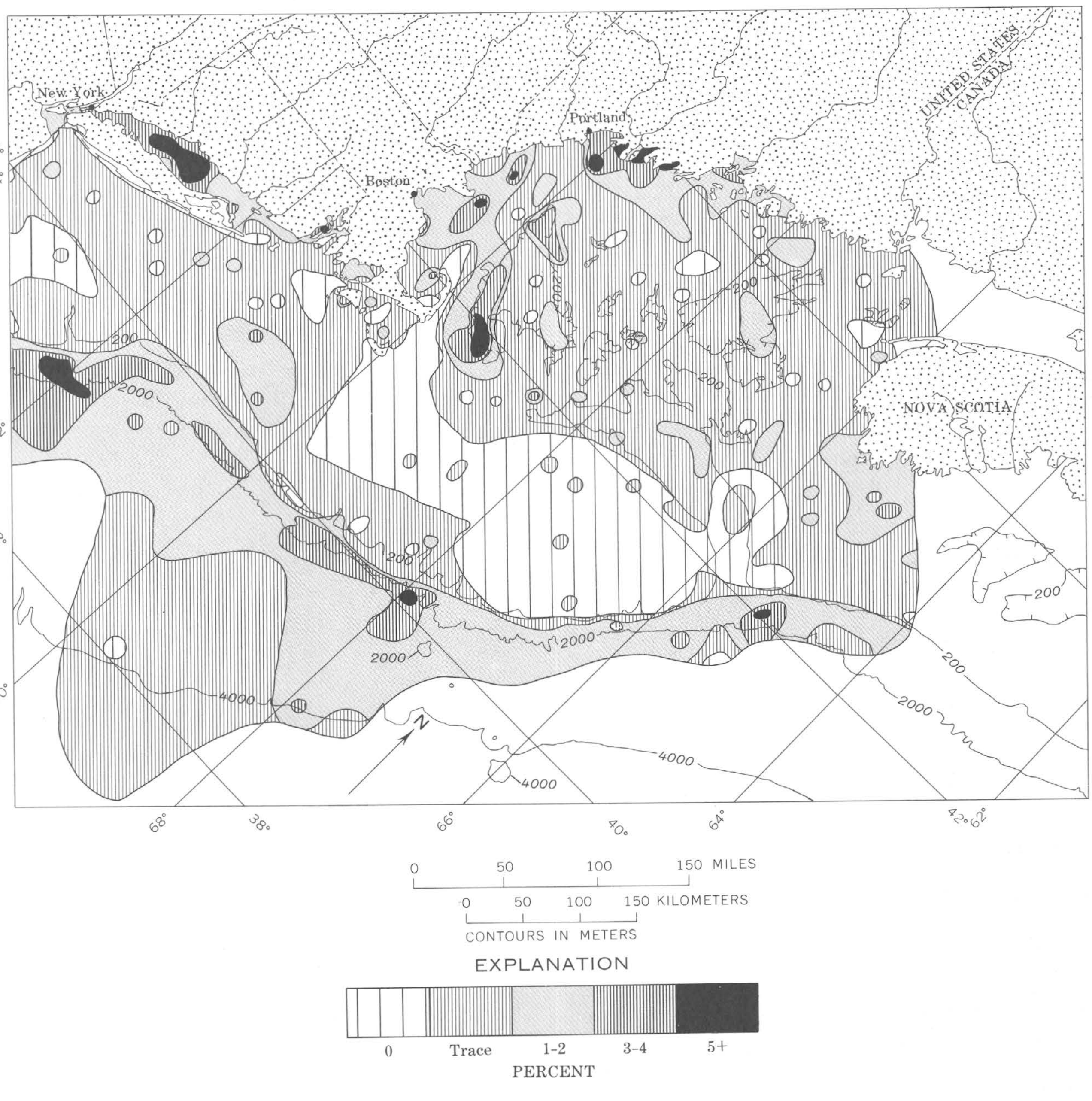


FIGURE 5.—Percentage of mica in sand-size fraction.

chemical degradation than most other constituents of the sand-size fraction. Because quartz dominates most samples, variations in the percentage of quartz and feldspar in the sand-size fraction of surface sediments (fig. 6) are more readily explained by the presence or absence of other constituents than by absolute changes in the concentration of quartz and feldspar.

Quartz and feldspar are considered together as one constituent for purposes of this study. In general it may be said that little feldspar is present in the sand fraction in the nonglaciated parts of the mapped area, and appreciable quantities are present in the glaciated areas. According to John Hathaway (oral commun., 1966), typical ratios between feldspar and quartz in all size classes smaller than 2 mm are 1:2 to 1:4 in the Gulf of Maine, 1:4 to 1:8 in the area of fine-grained sediments on the shelf south of Martha's Vineyard, and less than 1:8 on the shelf south of Long Island.

The mapped area may be divided into three parts with respect to concentration of quartz and feldspar: glaciated shelf areas, nonglaciated shelf areas (including Georges Bank), and the continental rise.

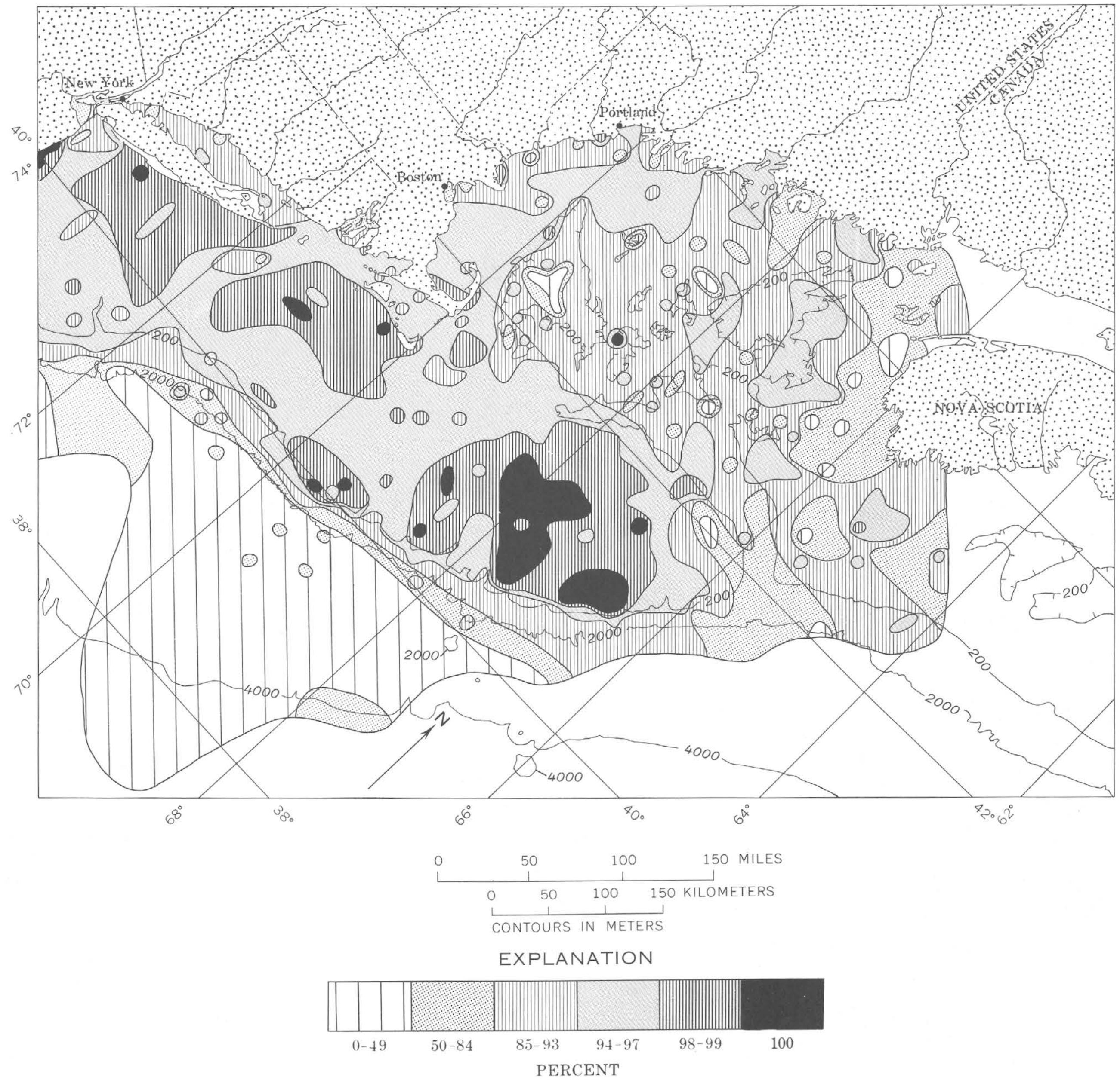


FIGURE 6.—Percentage of quartz and feldspar in sand-size fraction.

The continental slope is an area of transition between shelf characteristics and rise characteristics.

Quartz-feldspar percentages on the glaciated shelf (Gulf of Maine and Nova Scotian shelf) are lower than those on the nonglaciated shelf, because in the glaciated areas dilution is caused by relatively high concentrations of rock fragments, dark minerals, and shell fragments. But within the Gulf of Maine, areas enriched in quartz-feldspar (94–97 percent of sand-size fraction) are found northwest of Georges Bank and southwest of the Nova Scotian shelf. This is probably caused by transport of quartz grains toward the deeper basin center from those shoal, high-energy areas. A zone similarly enriched in quartz-feldspar parallels the coast from Cape Cod to Maine; it probably originated from reworking of glacial sediments. Offshore basins in the west-central and north-central Gulf of Maine have sediment that is almost wholly in the silt and clay sizes. The sand-size fraction there is low in quartz-feldspar because few sand-size grains other than mica flakes and tests of Foraminifera and other biogenic material were deposited.

Most of the continental shelf south of New England and Long Island has 94–99 percent quartz-feldspar. The median particle size of the entire sediment falls in the sand range. In Narragansett Bay and Long Island Sound, which show the effects both of glaciation and of low-energy postglacial deposition, quartz-feldspar content is diluted generally to the 85–93 percent range by appreciable amounts of primarily dark minerals, mica, and shell fragments. In Raritan Bay and the nearby inshore shelf, nonglaciated areas, high percentages of dark minerals and glauconite derived from erosion of the nearby and underlying strata of Cretaceous and Tertiary age have considerably diluted the quartz-feldspar content.

The controlling principle that reworking of sediment in high-energy areas increases the quartz-feldspar content is best illustrated on Georges Bank, where most rock fragments have been degraded to their constituent mineral grains and the smaller grain sizes removed, leaving quartz as the strongly predominant component of the sand-size fraction.

The amount and size of land-derived particles of sand size found on the slope and rise decrease rapidly with increasing depth and distance from the edge of the shelf. With a relatively uniform amount of sand-size foraminiferan tests being added to the slope and rise sediment, the ratio of land-derived quartz and feldspar to foraminiferan tests shows a continuous seaward decrease. The rate of decrease of quartz-feldspar content is 1.5–2.5 percent per 100 m change in depth; the rate of increase in foraminiferan tests is the same.

Seaward of Georges Bank, the continental slope and upper rise have anomalously high concentrations of quartz and feldspar in the sand-size fraction. This enrichment is caused by highly quartzose sands of the bank being carried to and down the slope. In the Northeast Channel area and on the upper continental slope seaward of it, quartz-feldspar percentages are reduced by abnormally great amounts of rock fragments, dark minerals, Foraminifera, and shell fragments.

On the continental rise, most samples from deeper than 2,400 m in the area southwestward from Bear Seamount have less than 10 percent quartz and feldspar in the sand-size fraction. The two major exceptions are a two-sample area 100 m south of Bear Seamount, where quartz-feldspar percentages are 55 and 83, and seven scattered anamalous samples with 53–75 percent quartz-feldspar, in depths ranging from 1,925 to 2,840 m.

Glauconite

Glauconite is widely distributed over the mapped area (fig. 7). Three types are present. The dominant type occurs as dark-green lobate grains with fractured surfaces. It is detrital in origin, having been reworked from beds of Cretaceous and Tertiary age. The other two types are authigenic in origin and are discussed under "Authigenic components."

Detrital glauconite grains are found virtually everywhere that glauconite is shown in figure 7. The largest and least abraded grains are found in several relatively localized source areas, some of which have 35 percent glauconite in the sand-size fraction. Progressively smaller grains showing the effects of abrasion and rounding are found at progressively greater distances from those source areas. The grains average 750μ in diameter in the areas of very high glauconite concentration near land. Average grain diameter decreases to 350μ to 400μ on the inner shelf, to 250μ on the outer shelf and upper continental slope, and to 25μ to 100μ on the lower continental slope and the upper continental rise.

The largest area of high glauconite concentration is on the extreme inner shelf between western Long Island and the northern New Jersey coast. Glauconite makes up from 10–35 percent of the sand-size fraction there. A sample from the present-day beach a few kilometers south of Sandy Hook contains 15 percent glauconite; no other modern beach-sand sample area contains more than 1 percent.

Nearly all the glauconite grains on the shelf between western Long Island and northern New Jersey are of the dark-green lobate type ("free-form" of Burst (1958, fig. 3d); probably "bulbous pellet" form of Ehlmann and others (1963)). They are strongly fractured, and their surfaces are divided into polygonal areas. A number of the fractures are open, and they are commonly oxidized brown at the surface of the grain. On a very small number of the grains, the surfaces themselves show slight oxidation. Dark-green lamellar grains ("accordian" forms of Galliher (1935); "tabular" forms of Light (1952)) are present in trace amounts. A small number of jade-green grains are also present in some samples. The lobate grains have very smooth surfaces, and the darker grains are shiny. Color of grains ranges from dark green (5*GY* 2/2)[2] to medium green (10*GY* 4/6); rare grains are nearly black (7.5*Y* 3/2). Roundness is 0.8–0.9 (rest-position outline, Krumbein, 1941), and Waddell projection sphericity

[2] Munsell system (Goddard and others, 1948).

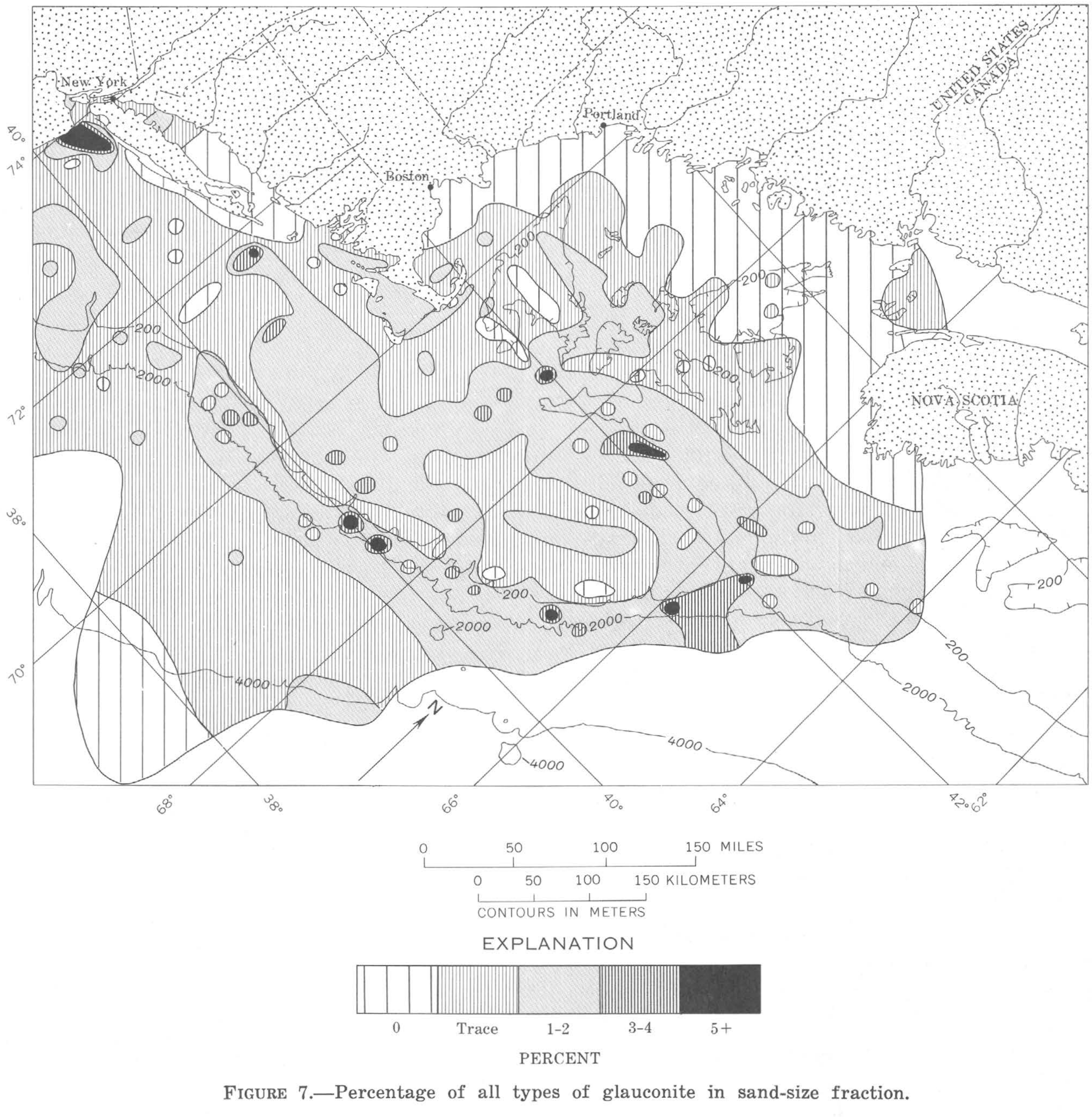


FIGURE 7.—Percentage of all types of glauconite in sand-size fraction.

(Rittenhouse, 1943) is 0.83–0.87, which is to say that the grains are highly rounded but rather imperfectly spherical. Grain size ranges from 250μ to 1.25 mm. Lamellar grains are about 750μ in the direction normal to the plates and half that in the other directions.

The area of high glauconite concentration lies directly along the strike of 11 glauconite-rich formations of Cretaceous and Tertiary age in the New Jersey coastal plain, and the offshore glauconite grains are similar in physical appearance to those found on land (Owens and Minard, 1960). The area is also along the strike of equivalent glauconite-bearing formations known at shallow depth in the subsurface of Long Island, where they are for the most part covered by glacial deposits (Suter and others, 1949). It seems clear that the glauconite in the surficial shelf sediment in this area is derived from coastal plain beds, but whether from those now exposed subaerially in New Jersey or from their equivalents underlying the continental shelf is not clear. The shelf glauconite grains are much and deeply fractured, but nearly all grains are entire; few fragments are present. This suggests that the grains have undergone little transportation and therefore have come from underlying strata.

Large glauconite grains of the detrital type showing little abrasion are also found in high concentration (35 percent) in one sample from 27 km southeast of the eastern tip of Long Island. Most of the surrounding samples contain less than 1 percent glauconite. The glauconite grains of this sample are darker green and are slightly smaller (average 150μ–300μ) than the grains near the northern New Jersey coast. The sample probably represents a residual deposit eroded from a local outcrop of strata of Cretaceous or Teritiary age on the continental shelf.

Concentrations of detrital-type glauconite (as much as 15 percent of the sand-size fraction) are found on nearly all sides of Georges Bank and on the continental slope south of New England. Strata of Cretaceous and Tertiary age underlie Georges Bank and crop out in canyons cutting the slope south of New England; they are the sources of this glauconite.

Detrital glauconite grains are mixed with glacially derived sediments in the central Gulf of Maine and on Browns Bank and the outer Nova Scotian shelf. They indicate the presence of glauconite-bearing Cretaceous or Tertiary strata over those areas at the time of glaciation. Such strata have been detected in only a part of the area in which glauconite grains occur (fig. 8), but it is possible that they are present but are not thick enough to be detected by the seismic method employed. Glauconite is also present in glacial outwash on outer Cape Cod (Zeigler and others, 1964).

Hard medium-green detrital glauconite is also present in trace amounts in a six-sample area at the entrance to the Bay of Fundy. Westward and north-

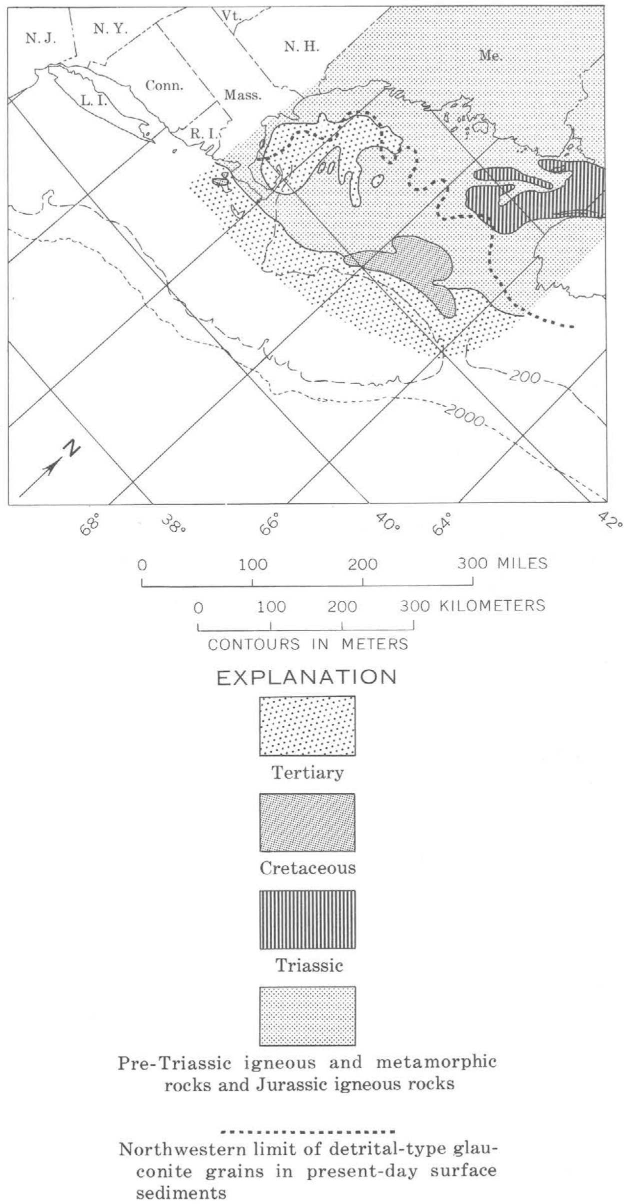


FIGURE 8.—Inshore limit of glauconite in surface sediment, and inferred present-day extent of sedimentary rocks in the Gulf of Maine. Dotted line is from figure 7, this report. Other information is from Uchupi (1966), Schlee and Cheetham (1967), and Chute (1965), and is based largely on interpretation of continuous seismic profiler records.

ward transport by marine currents from the shallow shelf south and southeast of Nova Scotia is the only reasonable explanation of its origin. Glauconite was not detected by Forgeron in his study of Bay of Fundy bottom sediments (written commun., 1966), and glauconite-bearing source rocks are not known beneath the bay or within the drainage area of streams entering the bay (Tagg and Uchupi, 1966; Donald Swift, written commun., 1966).

In some samples from widely scattered areas of the continental shelf, detrital-type glauconite grains have a brown surface stain of ferric oxide. This oxidative process implies, but does not require, a history of subaerial exposure (Pratt, 1962, p. 212). The staining probably originated subaerially during glacial-stage lowering of sea level. Most of the stained samples are from depths of 163 m or less, which is approximately the upper limit of present estimates of the amount of lowering of sea level. The great majority of samples from the continental shelf lack stained glauconite; abrasion in the transgressing surf zone would have tended to remove the soft brown oxide from the grains. Most samples containing the brown grains are from the outer shelf, near where strata of Tertiary age are exposed or are only thinly covered. Probably those samples were not subjected to the abrasion of the surf zone over a long period, as were the samples from most of the shelf. Alternatively, the brown-stained grains may have been oxidized before being eroded from the strata in which they originated.

In samples distant from glauconite source areas, on the continental shelf as well as on the slope and rise, detrital glauconite is mostly in the form of small highly rounded fragments. Glauconite grains in such areas have lost their original surface polish and do not show surface oxidation. Some of them show a color shift from dark green to medium green. This is probably also a result of abrasion, because the inside of unabraded grains is the same shade as that of the small abraded grains. Where this type of glauconite grain is found, quartz grains lack iron staining, and the sand-size fraction is light gray. Samples of this type on the continental shelf above the level of maximum sea level lowering indicate areas where sediment has undergone transportation and abrasion during or since the postglacial transgression.

BIOGENIC COMPONENTS

Foraminifera

The percentage of Foraminifera in the sand-size fraction of surface sediments is shown in figure 9. In the following discussion, the statement that Foraminifera were not observed does not mean that they are totally lacking, but rather that scrutiny of a few grams of material under the microscope did not reveal any. Specialized separation techniques applied to a larger sample would reveal Foraminifera in most cases. In addition, many arenaceous Foraminifera probably were destroyed during drying and mechanical and ultrasonic disaggregation of fine-grained samples (Phleger, 1960, p. 37–38), though many were still observed.

Almost no Foraminifera were found near the eastern Massachusetts and New Hampshire coasts and much of the coast of Maine, including numerous small basin area as much as 50 km offshore. Banks in the Gulf of Maine also tend to lack Foraminifera, particularly in the central and western parts. Bottom currents probably have higher velocities over banks than in deeper water, and they thus tend to prevent accumulation of such small and light particles as foraminiferan tests.

In some of the Gulf of Maine basins of low-energy sedimentation, the percentages of Foraminifera in the sand-size fraction are very high. In the Wilkinson-Murray Basin, for example, three samples contained more than 70 percent Forminifera in the sand fraction. Northeast of that basin, nine other samples from in or near other basins contained from 20–90 percent Foraminifera. Most of the sediment in these basins (with the exception of mica flakes) is finer than sand size, and thus biogenic material, largely foraminiferan tests, predominates in the sand-size fraction. The three samples from the Wilkinson-Murray Basin contain an average of only 0.1 weight percent of sediment larger than 62μ.

Sediments in a large area off the southwestern coast of Nova Scotia and in a belt from there to the northern Maine coast contain from 1–4 percent Foraminifera, and one sample from Roseway Bank seaward from Nova Scotia contains 15 percent. These concentrations are higher than are to be expected from generally high-energy areas. High organic productivity is probably the cause of these high concentrations.

Another area of anomalously high Foraminifera content comprises the floor and flanks of Northeast Channel and the adjacent eastern tip of Georges Basin with as much as 8 percent Foraminifera; the northeastern tip of Georges Bank, with 8–15 percent; and the southern tip of Browns Bank, with 25–30 percent. The Foraminifera population in this general area is made up largely of heavy current-resistant benthonic forms. Ecologic factors probably also cause this localized area of high foraminiferan productivity.

On Georges Bank and the open continental shelf between it and New Jersey, where the bottom sediment is mainly well-sorted quartz sand, Foraminifera are very sparse in depths less than about 70 m, and only trace amounts are present in depths between about 70 and 100 m.

On the continental slope and rise, the percentage of Foraminifera increases rapidly with increasing depth. The sand-size fraction of most samples from deeper than 2,800 m between New Jersey and Bear Seamount contains more than 90 percent Foraminifera. Several exceptions occur in a large area on the upper continental rise seaward of Hudson Canyon and in an area south of Bear Seamount. In the latter area two samples from 2,722 and 2,682 m contained only 30 and 40 percent Foraminifera, respectively.

Seaward of Georges and Browns Banks, sediments of the lower continental slope and upper continental rise have less Foraminifera than are present at comparable depths south of New England. Assuming

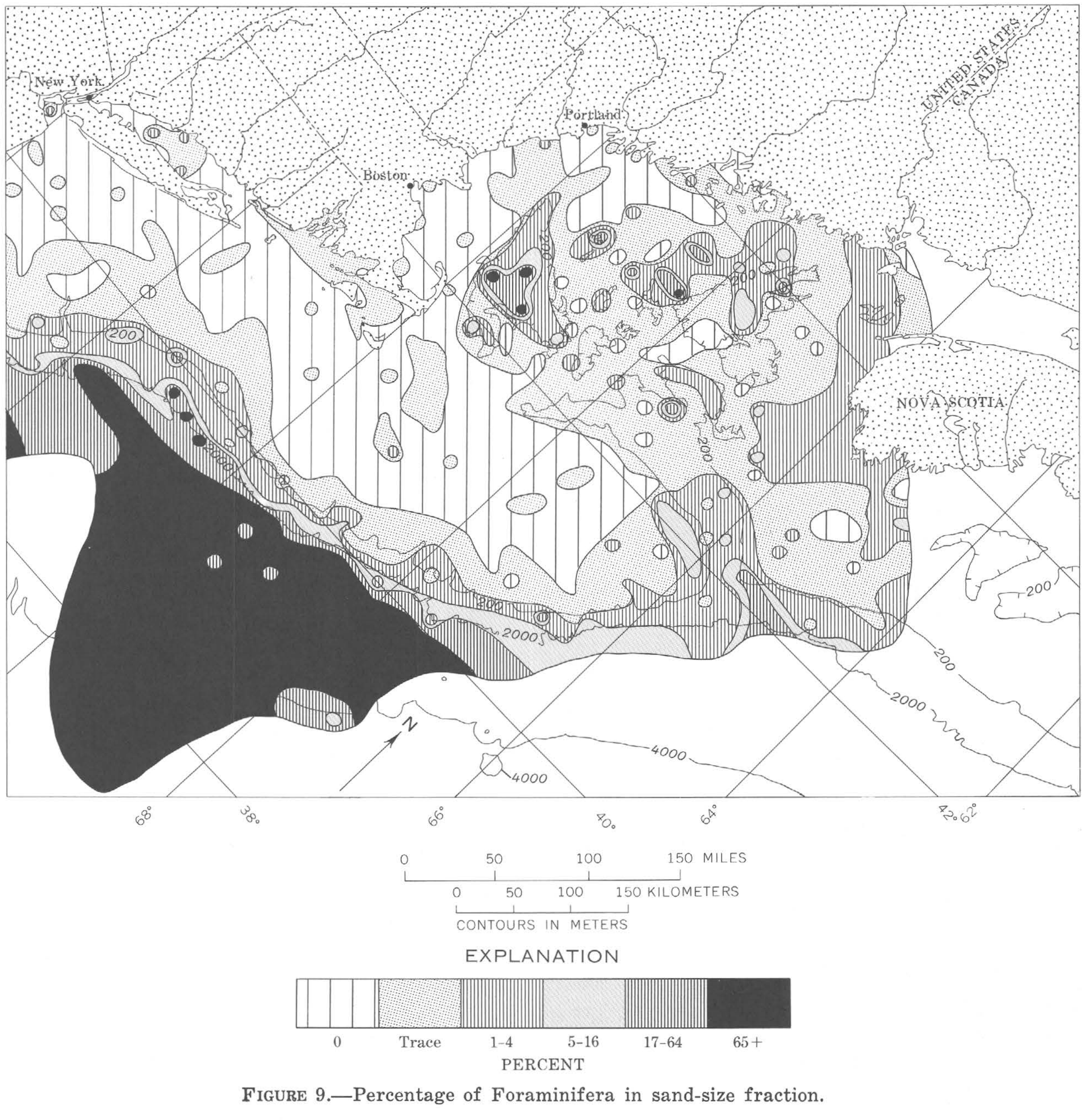


FIGURE 9.—Percentage of Foraminifera in sand-size fraction.

uniform productivity, this indicates that more terrigenous detritus is being transported seaward from the banks than from the shelf to the southwest. Directly off Northeast Channel this effect of detrital dilution is especially marked: a sample from 2,474 m contained only 2 percent Foraminifera.

In two areas foraminiferan tests show effects of chemical solution: basins floored with low-energy sediments in the west-central and north-central parts of the Gulf of Maine, and the outer continental shelf and upper continental slope in depths less than 460 m directly south of Martha's Vineyard. Most of the samples in which pyrite was observed are from those same two areas. Presumably, solution of calcium carbonate tests is caused by low pH within the upper part of the sediment. Formation of pyrite is caused by negative Eh at localized small centers within the sediment. Both effects are probably caused by the reduction of organic matter in the sediment. The two areas in which both phenomena were observed have fine-grained sediments, which are able to accumulate high amounts of organic carbon and which limit the circulation of interstitial water, thus permitting the formation of reducing microenvironments.

Shell Fragments

Shell fragments are predominantly those of mollusks, with pelecypods strongly predominating, and usually a minor amount of gastropods. At the northeastern end of Georges Bank, unusually great numbers of immature pelecypods, 2–3 mm in diameter, were observed. The shell fragments from one sample in that area consist almost entirely of single and clustered serpulid worm tubes. Numerous samples from the Nova Scotian shelf and one from the coast of Maine contain considerable amounts of barnacle fragments. In sandy areas, particularly off New Jersey, Long Island, and southern New England, fragments of sand dollars predominate.

The concentration of shell fragments is shown in figure 10. Most of the Gulf of Maine, Georges Bank, and the continental shelf south of New England and Long Island and east of New Jersey have no more than trace amounts of shell fragments, although some scattered single samples have 5–12 percent. High concentrations of shell fragments are found on Nantucket Shoals, on the northeastern tip of Georges Bank, and in an area extending from the northeastern coast of Maine through the nearshore shelf southwest of Nova Scotia to Browns Bank. Most of the shell fragments in those areas appear to be from massive shells, indicative of the high-energy conditions of the areas in which they are found. This distribution substantiates the observation (based on the distribution of Foraminifera) that the Nova Scotian shelf is an area of high organic productivity.

The protected waters of Vineyard Sound, Narragansett Bay, Long Island Sound, Raritan Bay, and some areas along the coast of Maine also have high concentrations of shell fragments. Most samples have from 1 to 4 percent, but some contain as much as 30 percent, indicating wide variability over short distances. The inshore molluscan shells are mainly thin shelled, indicative of an infauna suited to living in a low-energy environment. In some of these inshore areas, the scarcity of detrital particles of sand size acts to increase the percentage contribution of shell fragments.

With few exceptions, shell fragments were not observed in samples from depths greater than about 200 m.

Other Biogenic Components

Shell fragments and Foraminifera dominate the biogenic components of the sand-size fraction, but a number of other forms are present. Those that occur in significant amounts include sponge spicules, echinoid spines, diatoms, radiolarians, ostracodes, scolecodonts, polychaete acicula, and wood fragments.

Sponge spicules are found nearly everywhere in the Gulf of Maine and on the continental slope and rise (fig. 11*A*). They are almost entirely absent on the sandy shelf east of New Jersey and south of Long Island and New England, and in the Nantucket Shoals–Georges Bank–Browns Bank area. They are, however, present throughout a large area of the middle and outer shelf south of Cape Cod and eastern Rhode Island where the bottom sediments have a high content of silt- and clay-sized particles. Most of the spicules are broken, the fragments commonly being 2–3 mm long. Some fragments are branched but most are not.

Two distinct types of echinoid spines are present in the surficial sediment over large areas; the distribution of each is shown in figure 11*B*. Those spines here designated type A have the appearance of bundles of clear glass fibers and are similar in appearance to spines of the sand dollar *Echinarachnius parma*. They occur in fine-grained sediments in the Gulf of Maine and on the inner shelf south of Long Island and Rhode Island. They are present in nearly all samples from the continental slope and rise, except for a deep-water area in the southeast corner of the mapped area.

Echinoid spines of the type here designated type B are opaque and strongly ridged and tapered. They are similar in appearance to the spines of the purple sea urchin *Arbacia punctulata*. They were found only off the northeastern coast of Maine, on the Nova Scotian shelf, in Northeast Channel, on the northeastern end of Georges Bank, and in isolated areas on the flanks of Georges Bank and southeast of Cape Cod. Nearly all the samples in which they were found are coarse to very coarse gravelly sands or gravels with abundant coarse shell fragments. The maximum depth at which they were found is 318 m.

Diatoms and Radiolaria are rare in the bottom sediments of the continental shelf and the Gulf of Maine. As shown in figure 11*C*, nearly all samples from deeper than 1,000 m contain both. In those deep samples, diatoms are usually present in trace amounts, but Radiolaria make up as much as 5 percent of the sand-size fraction. The single notable exception is three samples from the continental slope and rise just outside Northeast Channel which are

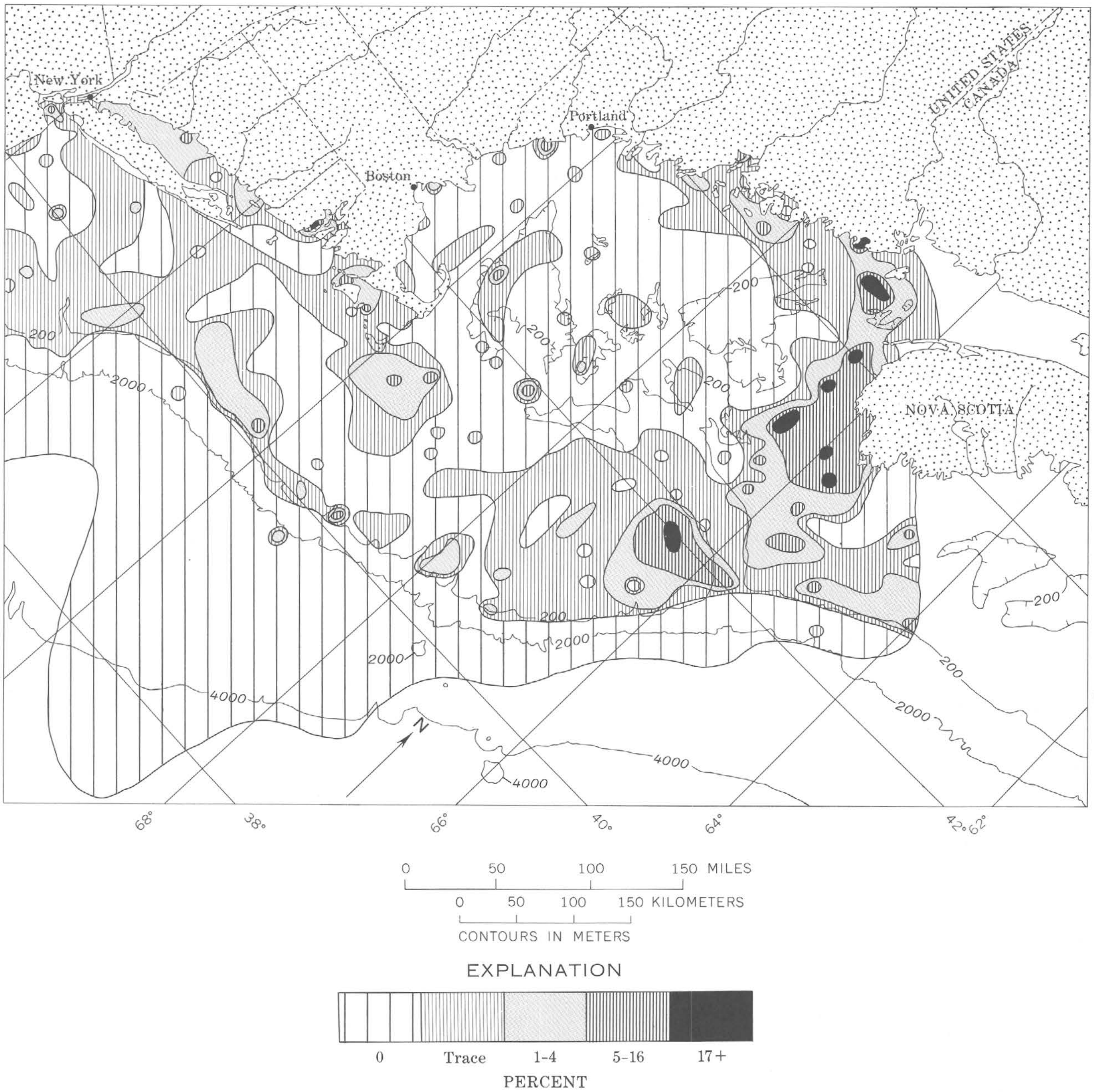


FIGURE 10.—Percentage of shell fragments in sand-size fraction.

lacking in both diatoms and Radiolaria. The samples are also anomalously low in Foraminifera and high in content of rock fragments. They indicate that shallow-water sediment is being carried through the Northeast Channel and being deposited on the continental slope and rise outside it.

Ostracodes were found in the sand-size fraction of only 14 samples widely distributed through the mapped area. Doubtless they were present in far more samples, but they were not observed because no effort was made to separate the biogenic fraction of the sediment, and no special search for ostracodes was made. Intensive work on the ostracode population of the mapped area has been conducted by Hazel (1967).

Scolecodonts, which are annelid worm jaws, are present in amounts of less than 1 percent of the sand fraction in many samples from the Gulf of

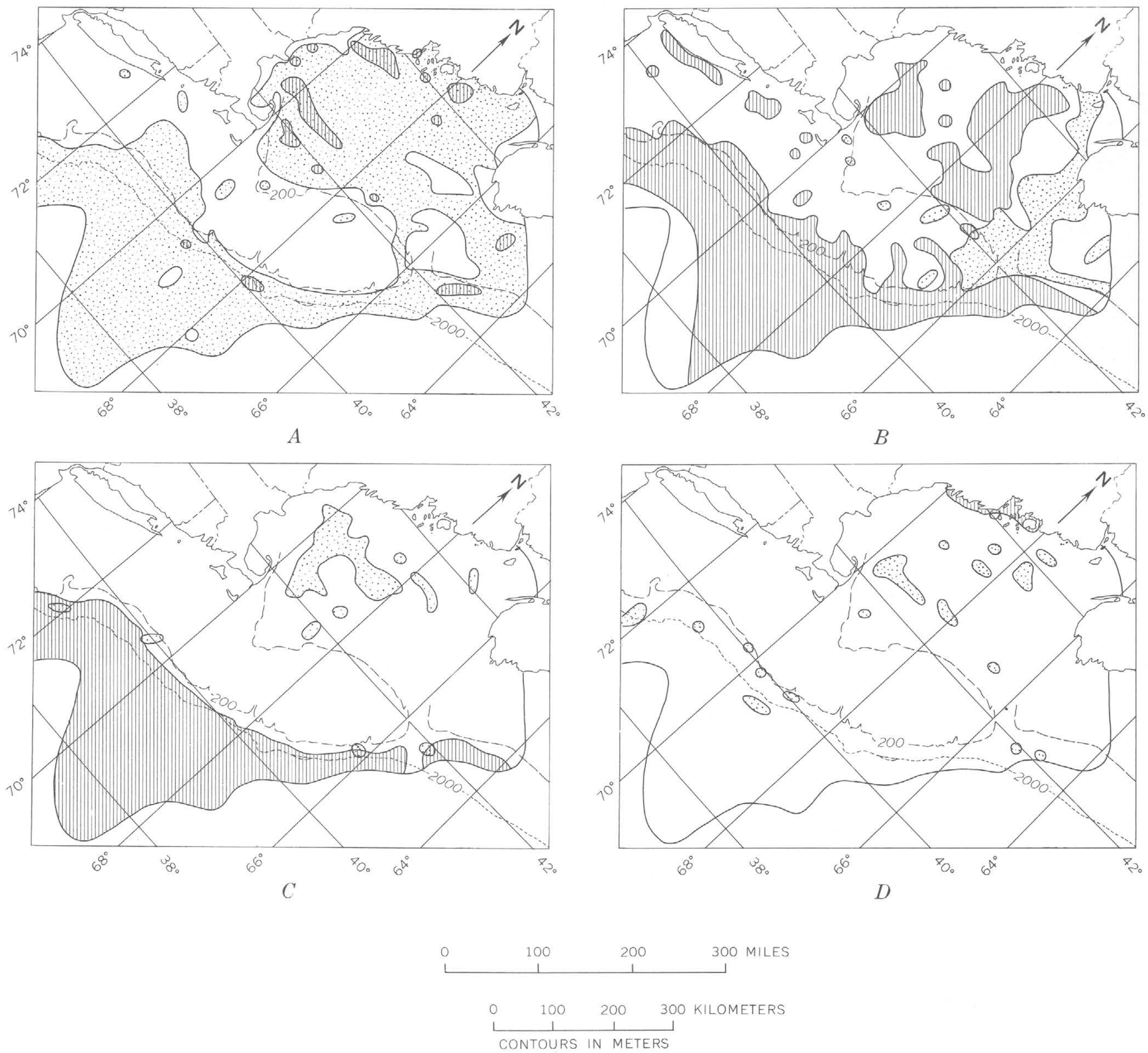


FIGURE 11.—Distribution of minor biogenic components and pyrite in the sand-size fraction. *A*, Distribution of sponge spicules. Stippling indicates concentration of less than 1 percent of sand fraction; line pattern indicates 1 percent or more. *B*, Distribution of type A (stippled) and type B (line pattern) echinoid spines. *C*, Distribution of scolecodonts (stippled) and of samples containing appreciable numbers of both radiolarians and diatoms (line pattern). *D*, Distribution of pyrite (stippled) and of samples containing large amounts of wood fragments (line pattern).

Maine and in a small number of samples from the continental slope (fig. 11*C*). They were found only in fine-grained sediments.

In most samples the scolecodonts are accompanied by dark-brown to black chitinous spicules, straight to slightly curved, pointed at one end, increasing uniformly in diameter to the other end, and measuring from 0.5 to 2 mm long and roughly 50μ wide at the wide end. They are thought to be annelid acicula (Shrock and Twenhofel, 1953, p. 511).

Noncalcareous pearl-white circular objects 100μ to 200μ in diameter, in shape resembling cap mushrooms, were found in profusion (but less than 2 percent) in a sample from near the head of Somes Sound, Mount Desert Island, Maine. They were also found in three samples from 10 miles off the coasts of northern Massachusetts and southern Maine.

Wood fibers and fragments are present in most of the samples from the inshore and protected waters of the central Maine coast (fig. 11*D*). The sand-size fraction of samples from Boothbay Harbor, upper Penobscot Bay, the lower Penobscot River, and Union River Bay contains as much as 98 percent wood fragments. The valleys of the rivers entering these areas have been important lumber-producing areas for many years, and the material is simply sawdust. A small amount of black material showing woody structure is found at various places along the Maine coast and is thought to be the result of forest fires. Wood fibers and fragments are also present in trace amounts in the surficial sediment of the lower reaches of the Hudson and Raritan Rivers and in the Wilkinson-Murray Basin northeast of Cape Cod. Algal fibers and fragments are present in varying amounts in many nearshore samples throughout the area. In a sample from 1.6 km south of Martha's Vineyard, small black and very dark brown fragments showing woody structure are either mineralized or devolatilized wood. These are probably being eroded from nearby exposures of carbonaceous sedimentary rocks of Cretaceous and Teritiary age.

Cinders from burned coal dumped by ships and barges are present in samples from off New York City and Boston and to a lesser extent along the entire coast. The greatest concentration of cinders is in upper Penobscot Bay, the lower Penobscot River, and in Union River Bay, Maine. A sample from off the town of Belfast in upper Penobscot Bay contains 5 percent cinders in the sand-size fraction. Most other samples do not contain more than 1 percent cinders, though a sample from 72 km east of the south end of Cape Cod surprisingly contains 3 percent.

AUTHIGENIC COMPONENTS

Glauconite

Glauconitic internal molds of Foraminifera are found in the surface sediment of the extreme outer shelf and the upper slope throughout almost the entire length of the mapped area. Their distribution is shown in figure 12. The Foraminifera are of both planktonic and benthonic types, and the test material around the molds is in some cases entire, in some, fragmental, and in some, lacking. The glauconite material ranges in color from light yellow brown (7.5*Y* 7/3) through light and dark brownish greens (2.5*GY* 5/4 to 7.5*GY* 4/2) to a nearly black dark green (10*GY* 3/1). A wide range of colors is present within several of the individual samples. It appears visually, on the basis of color and hardness of the material inside the tests, that all gradations from ambient buff-color clay to fairly highly organized glauconite are present within the tests. The glauconite molds are highly detailed and have smooth surfaces.

Thomas G. Gibson of the U.S. Geological Survey examined the samples containing the molds and stated (written commun., 1966) that

> About 19 of the samples contain large enough numbers of glauconitized specimens to pick out a fairly good population or faunal sample. The 19 samples contain faunal assemblages similar to those now found in their respective

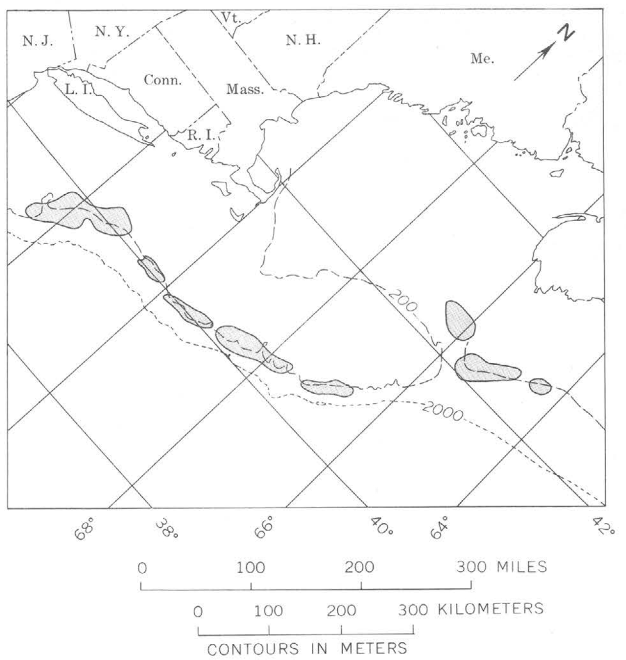


FIGURE 12.—Distribution of glauconitic internal molds of Foraminifera.

depths on the shelf or upper slope. Therefore, my opinion is that the glauconitization of these specimens is occurring in place. Species commonly found as internal molds include *Bulimina marginata*, *Angulogerina angulosa*, *Cassidulina crassa*, and various species of *Globerigerina*.

One interesting aspect is the rather selective glauconitization of the specimens according to species. The planktonic species, mainly species of *Globigerina*, are much more readily preserved in this manner than the benthonic species. This could be due to aperture size as is commonly stated, and the *Globigerina* species do have generally large apertures in comparison to the other associated species, or it could be due to the comparatively large perforations in the test of *Globigerina*. As the filling takes place all the way to the tip or first chamber of the test, wall perforations are something deserving consideration. As the glauconitization is selective, care must be taken in environmental interpretations on the samples.

Of the 57 samples in which glauconitic internal molds of Foraminifera were observed, 49 are from depths of 87–292 m. The remaining eight are from depths between 346 and 802 m, and the molds in several of them show signs of transportation and abrasion.

The fragility of the molds themselves and the fragility of the cracked tests and test fragments adhering to some of the molds argue against their exposure to high-energy conditions of the surf zone. The last time that the amount of sea-level lowering exceeded 80 m was on the order of 15,000 years ago (Shepard, 1963, fig. 3). At least some of this glauconite must have formed since that time.

Another type of glauconite is present near the shelf break from the outer Nova Scotia shelf to the area southwest of Hudson Canyon. Its color ranges from moderately light slightly yellowish green (7.5*GY* 7/6) to moderate yellowish brown (5*Y* 7/4). The grains are mostly irregular in shape. Many of them are angular, and many are crudely pellet shaped. Surface fractures are more numerous and more closely spaced than those in dark-green detrital-type grains. Most grains are small (diameter 100μ–200μ), but some are fairly large (400μ).

This material is thought to be of first-cycle authigenic origin rather than of detrital origin because (1) the depths and areas in which it is found correspond closely to the depths and areas in which authigenic glauconite is found but do not correspond to the distribution pattern of detrital-type glauconite; (2) much of it is soft, deeply fractured, and fragile, yet it shows little effect of transportation; and (3) the dominant color is moderately light yellowish green, characteristic of immature glauconite. Most probably this type of glauconite originated in place in microenvironments of larger physical size than the interior of foraminiferan tests, perhaps in the internal cavities of larger organisms. The pellet-like shape of some grains suggest an origin from fecal pellets.

Pyrite

Pyrite is present in the sand-size fraction in the Wilkinson–Murray Basin and at a number of other scattered localities in the Gulf of Maine, and on the continental slope and upper continental rise south of Long Island and New England (fig. 11*D*). In most samples it is present in trace amounts, but it makes up 3–4 percent of the sand fraction of a few samples.

The pyrite occurs in four forms, of which the most common is rough-surfaced spherules 100μ to 150μ in diameter. The next most common form is irregular angular masses and fragments that consist of clusters of gloubles. Some of these appear to have the shape of intergranular spaces. The third form, cylinders 50μ in diameter and generally 200μ to 300μ long, some circularly ridged, probably originated as internal molds of organisms or tubes. The fourth and rarest type is internal molds of Foraminifera. All four types appear both in the Gulf of Maine and on the continental slope. The spherulitic form is dominant in the clay and silty clay of the Wilkinson–Murray Basin.

The pyrite is of authigenic rather than detrital origin. Ninety percent of the samples containing pyrite in the sand-size fraction have median diameters smaller than 16μ. The average organic carbon content of the pyrite-bearing samples is 1.07 percent (Jobst Hulsemann, oral commun., 1966). X-ray diffractometer analysis shows the material is pyrite rather than marcasite.

The 32 stations at which pyrite was found range in depth from 86–2,187 m. Sixty percent of those stations are between 183 and 284 m, and the median depth within that group is 220–230 m. This is more likely a function of ambient basin-floor depths in the Gulf of Maine than of any depth control of pyrite formation, however.

Limonite

Trace amounts of limonite grains are present on the inner shelf south of New England and on the flanks of the northeastern end of Georges Bank. Alexander (1934) and Shepard and Cohee (1936) thought that at least some of the limonite south of New England was authigenic, but all or nearly all the limonite observed in this study appears to be detrital. This is particularly true of the most common type, which is highly rounded and commonly has a smooth reflective surface. In size and shape those limonite grains are similar to the detrital glauconite of the area, and limonitically altered glauconite grains are common in outcrops and beach sands at the western end of Martha's Vineyard.

CHARACTERISTICS OF QUARTZ GRAINS

ROUNDNESS

Roundness of quartz grains in the size range 0.25–0.5 mm (fig. 13*A*) was estimated by comparing the rest-position outline of 50 or more grains with Krumbein's (1941, pl. 1) roundness chart. (Arithmetic mean roundness is reported here: the ratio of the average radius of curvature of the grain outline to the radius of the maximum inscribed circle.) The roundness numbers of the 129 samples examined range from 0.35 to 0.7. The median is between 0.45 and 0.5.

Roundness is higher on the seaward edges of Georges and Browns Banks and on the continental slope seaward of the banks than it is on the shallowest parts of the banks. Similarly, roundness is higher in a crescent-shaped shelf area south of Nantucket and Martha's Vineyard and on the adjacent continental slope than it is over most of the nearby Nantucket Shoals. Thus quartz grains are rounder seaward of the present-day shoals than they are on those high-energy areas of high grain abrasion to which little or no sediment is being added.

The explanation probably lies in the distribution (fig. 13*D*) of the very highly rounded and frosted quartz grains that are thought to have originated from the action of periglacial winds during glacial-stage emergence of the continental shelf (Stetson, 1934). Those grains are so nearly spherical that any appreciable admixture of them raises the roundness index of the sediment containing them. The present-day distribution of the very highly rounded grains along the outer shelf seems to indicate either that the highly rounded grains were not formed over most of the shallower parts of the shelf, or that the turbulence on the shallow part of the shelf has destroyed their roundness or greatly diluted them since they were formed.

Quartz grains show least rounding in the Gulf of Maine and on the Nova Scotian shelf. This is because the primary sediment source there is till.

SPHERICITY

Waddell projection sphericity of 0.25- to 0.5-mm quartz grains was calculated for 44 samples from the Gulf of Maine, Georges Bank, and the continental shelf and slope southwestward from Georges Bank. Fifty-grain counts were made using Rittenhouse's (1943, fig. 1) visual chart. Values ranged from 82.2 to 85.9. The values showed no geographic coherence or relation to any property of the sediment, although the samples were from a wide range of depths and sediment types. On the south shore of Long Island, Taney (1961b) found that roundness increased westward, in the direction of sediment transport, as is also shown in figure 13*A*; sphericity did not show such a relation.

FROSTING

The distribution of frosted quartz grains was determined by 100-grain counts of 0.25- to 0.5-mm grain in 129 samples and is shown in figure 13*B*. Areas with the greatest number of frosted grains are Georges Bank, the outer shelf south of Nantucket, and nearly the full width of the shelf eastward from New Jersey. The maximum concentration is on the outer shelf south of Nantucket, where 27 percent of the grains are frosted. The concentration in that area and on part of Georges Bank is caused in part by an admixture of the distinctive very rounded frosted grains discussed in a succeeding section. Those distinctive grains have a median diameter of about 0.5 mm, and their distribution therefore does not correspond closely to the distribution of 0.25- to 0.5-mm grains in figure 13*B*.

IRON-STAINED GRAINS

The amount of surface iron staining on quartz grains was determined by 100-grain counts of 0.25- to 0.5-mm grains in 192 samples. The resulting map (fig. 13*C*) shows that the largest area of heavy iron staining is in and near the mouth of the Bay of Fundy, where 45–62 percent of the grains are iron stained. This color is an inheritance from the red sedimentary rocks of Triassic age now exposed in Nova Scotia and New Brunswick and known to be present beneath the Bay of Fundy and a contiguous part of the Gulf of Maine (Tagg and Uchupi, 1966).

Most of the rest of the Gulf of Maine and the continental shelf of Nova Scotia has relatively highly iron stained quartz grains. Iron-stained grains also are found around most of the periphery of Georges Bank. This staining may be due in part to each of the following: (1) Dissemination of grains from rocks of Triassic age from the source in the Bay of Fundy area; (2) inheritance from strata of Tertiary or Cretaceous age, especially at the margins of

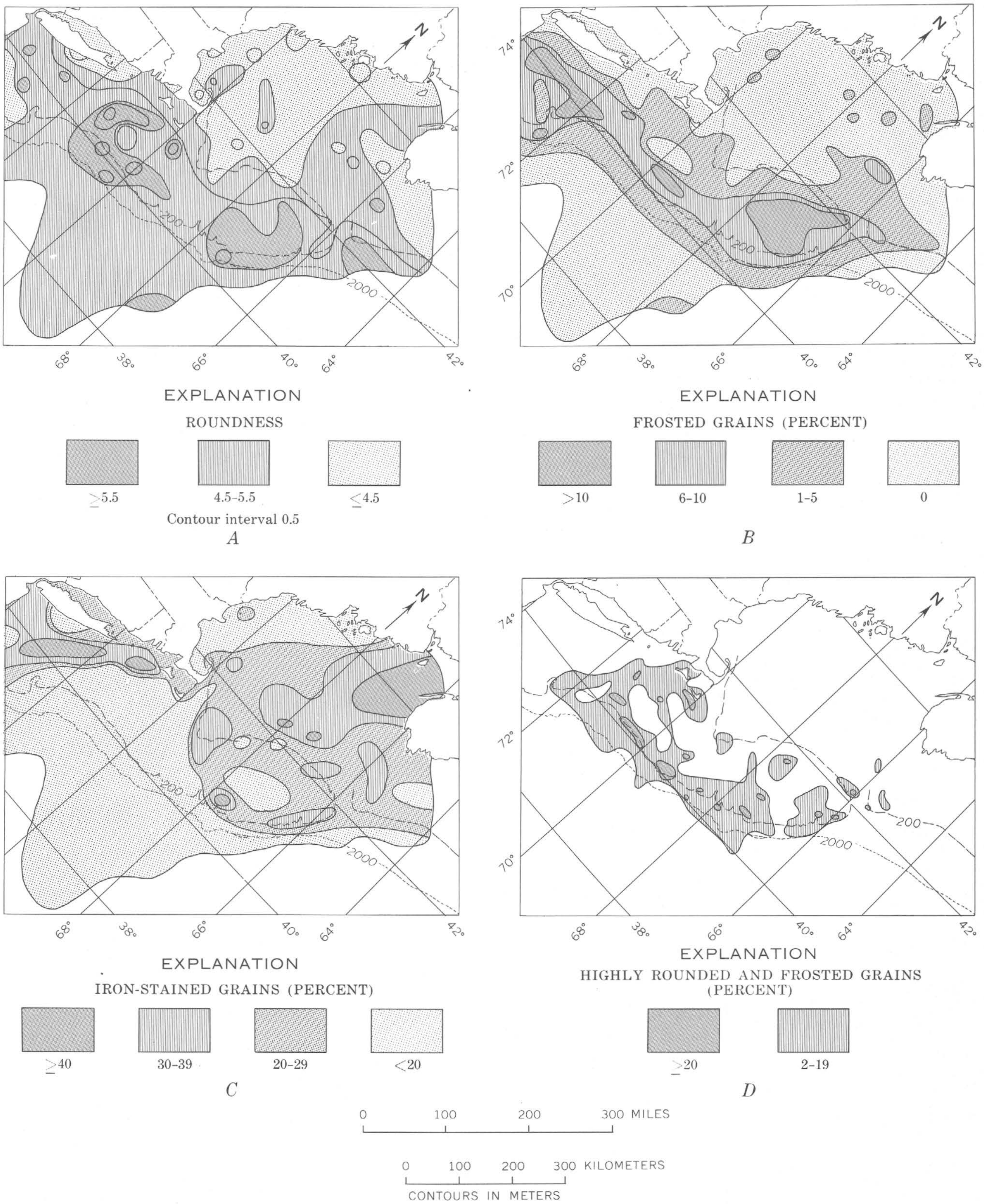


FIGURE 13.—Variation of characteristics of quartz grains. *A*, Roundness of 0.25– 0.5-mm grains. *B*, Frosting on 0.25- to 0.5-mm grains. *C*, Iron staining on 0.25- to 0.5-mm grains. *D*, Highly rounded and frosted grains in the sand-size fraction.

Georges Bank; (3) subaerial weathering on the continental shelf during periods of glacially lowered sea level, and a lack of deposition since then; (4) inheritance from glacially transported grains originally stained subaerially in the soil profile, and little abraded since emplacement. The areas of highly stained grains southeast of Rhode Island and Long Island are probably caused by the second and third reasons listed above. The relative lack of iron-stained grains near shore from Cape Cod to northern Maine is a result of present-day deposition there of grains lacking staining. The relative lack of stained grains in the center of Georges Bank is due to grain abrasion and cleaning caused by strong tidal currents. Many quartz grains on Georges Bank and in other high-energy areas have iron oxide staining only in depressions in the grain surfaces, as if the entire grain had been subaerially stained during the Pleistocene emergence, and the staining since had been abraded from all but the depressions.

Very little iron staining is found in a triangular area southeast, south, and southwest from the vicinity of Nantucket. The demarcation between areas of highly stained and of relatively nonstained grains is sharp southwestward from Martha's Vineyard nearly to the limit of the mapped area. The demarcation was also noted by Stetson (1938, p. 14) due south of Martha's Vineyard. In the area south of Long Island the demarcation is very close to the 60-meter depth contour. In the triangular area of relatively nonstained grains, the entire sediment is dark green and has more organic matter (Jobst Hulsemann, oral commun., 1967) and more silt- and clay-sized particles (fig. 2) than the yellowish iron-stained zone to the northwest. The nonstained area corresponds fairly well in extent with the area of smooth bottom shown on Garrison and McMaster's (1966, fig. 1) 1-fathom-contour map. The topography of the area with iron-stained grains, in contrast, is highly irregular on a small scale. It may be that the absence of iron staining results from deposition of a posttransgression sedimentary unit. Garrison and McMaster (1966) and McMaster and Garrison (1966) suggest the presence of such a unit in the area generally south of Martha's Vineyard. An alternate explanation of the relative lack of iron staining might be the similarity in the extent of the area in which quartz grains are only slightly stained (fig. 13*C*) and the area in which the shelf sediments include some silt and clay (fig. 2). It seems possible that organisms that ingest sediment during feeding may have removed much of the iron staining originally present. In a profile south across the shelf from a point near Martha's Vineyard, Wigley and McIntyre (1964, fig. 1, table 2) showed that the weight per unit area of macrobenthos is high in fine-grained shelf sediments, and that holothurians and other deposit feeders make up much of the macrobenthos.

HIGHLY ROUNDED AND FROSTED GRAINS

Distinctive highly rounded and frosted grains are common in continental shelf and slope sediments south and southeast of southern New England. They are also present in lesser amounts in the area of Browns Bank and in the northeastern part of Georges Bank. Alexander (1934), Stetson (1934), and Shepard and Cohee (1936) also noted them. Median diameter of the rounded grains is approximately 0.5 mm, and most range in size from 0.3 to 1 mm. Roundness (in the sense of Krumbein, 1941) is generally 0.7 to 0.8, and sphericity (in the sense of Rittenhouse, 1943) averages 0.89. Figure 13*D* shows the areas in which the rounded grains exceed 2 percent of the sand-size fraction of the sediment. The pattern shown is affected by the size of the sediment in which the rounded grains are found, because a slight admixture of the highly rounded grains in a sand of the same general size is difficult to identify. Highly rounded and frosted grains were found in nearly all shelf samples from south of New England and Long Island, as was also reported by Shepard and Cohee (1936).

Size, roundness, and sphericity of the distinctive grains are relatively constant throughout the area in which they occur, but the sediments in which they are found range from coarse sands to silts. This indicates that the rounded grains were transported and deposited by a different mechanism than were the sediments in which they occur. The high roundness and well-developed frosting of the distinctive grains has no counterpart in the sediments that were transported and deposited by glacial and water action, again indicating a different mechanism. Frosting of quartz is generally attributed to wind action (Pettijohn, 1957, p. 592; Shepard and Cohee, 1936, p. 448). The frosting on the grains under discussion seems caused by abrasion rather than by solution, for it does not extend into depressions on the grain surfaces. The late glacial deposits on Cape Cod (Mather and others, 1940), Nantucket, Martha's Vineyard, and Long Island are rich in well-developed ventifacts. It seems highly probable that the distinctive highly rounded and frosted quartz grains were given their characteristics and were deposited where they are now found by strong periglacial winds of late Wisconsin time.

SEDIMENT TYPES

No standard classification scheme for mapping marine sediments is established, as it is for mapping rock units on land. Emery's (1952) classification has the virtue of being genetic, with the recognized limitation of including subjective interpretation, and is followed in this report.

The classification is based on the dominant cause of deposition, and sediments of similar origin are mapped as units. Present-day **detrital sediment** is now being deposited in equilibrium with existing conditions. **Relict sediment** was deposited in the past as detrital sediments now are; but since its deposition the circumstances of waves, currents, and sea level have changed, and the sediment does not match present environmental conditions. **Residual sediment** is derived from rock units or prior unconsolidated deposits exposed on the sea floor, with little or no transportation involved. **Organic sediments** result from accumulation of tests, shells, skeletal debris, and the like. **Authigenic sediments** are chemically precipitated or altered minerals that have formed in the marine environment; the commonest are glauconite, phosphorite, maganese oxide, and pyrite. Sediments of other origins include ice-rafted gravels and volcanic deposits. Many sediments are mixtures resulting from several of these origins, but the product of one origin usually predominates.

The topography and the composition of the sand-size fraction on selected traverses are shown in figure 14. Figure 15 shows the average composition and size distribution of the sand fraction in the areas discussed in the following sections, and figure 16 shows the location of the areas and the distribution of Holocene and relict sediments.

MODERN DETRITAL SEDIMENTS

Nonbiogenic sediments now being deposited are originating from rivers, from shoreline erosion, from the shallow-water high-energy wave zone near shore, and from preexisting sediments now being eroded and transported by tidal currents. On the continental slope and rise, sediments are now being deposited by settling of fine particles from the water.

Protected Inshore Areas

The intricate coastline of the area has numerous water bodies protected to some degree from the open sea. Most of the large rivers in the area discharge into such bodies of water, which serve as settling basins for the river-borne sediments. Thus sandy and clayey silt is being deposited in the deeper parts of most protected coastal water bodies. In the shallow parts and in constricted entrances, waves and tidal currents prevent deposition of the fine-grained river-borne detritus. The bottom in such areas is characteristically the bouldery lag deposit of winnowed till.

Considering the coast from southwest to northeast, Raritan Bay is floored with sandy silt and clay higher in dark minerals (7 percent of sand fraction) than protected coastal areas to the northeast. In agreement with the results of McCrone (1966a), most of the central area of Long Island Sound was found to be floored with sandy and clayey silts. They have as much as 6 percent mica and usually 2–3 percent dark minerals in the sand fraction. At the eastern end of Long Island Sound, surface tidal currents have velocities as high as 5.2 knots (U.S. Coast and Geodetic Survey, 1947). This prevents deposition of fine sediment and has left exposed in some places a bouldery bottom that is a lag deposit derived from till, and in other places a poorly sorted silty and clayey sand. The later is a local product of slightly reworked glacial material, indicated by the freshness and angularity of its grains and its content of a few percent each of such labile components as rock fragments and mica.

Sandy and clayey silt is also accumulating in Narragansett Bay. It is derived from glacial material both by coastal and bottom-current erosion and by stream erosion and transport. The sand-size fraction has as much as 8 percent rock fragments, 2–3 percent dark minerals, and as much as 5 percent mica. For further information on the sediments of Narragansett Bay, see McMaster (1960, 1962). Silt and clay derived from glacial material is accumulating in the deeper central parts of Buzzards Bay (Hough, 1940; Moore, 1963) and Cape Cod Bay (Hough, 1942). Sands and rocky lag deposits of glacial drift are common in the shallower areas, and, in Buzzards Bay, near entrances where currents are strong. The sand-size fraction of Cape Cod Bay sediment is more mature than that of most neighboring protected water bodies; rock fragments, dark minerals, and mica rarely exceed 1 percent. This is because no major rivers discharge into the bay, because the bay is more open to the sea than most other protected water bodies, and probably because the source glacial material includes much outwash sand with an earlier history of water transport.

The protected bays and passages of the coast of Maine are accumulating silty clay probably derived from river sediment and from marine erosion of glacial debris. The sand-size fraction, which makes up less than 10 weight percent of the sediment, consists characteristically of few or no rock fragments, 1–4 percent mica, and 2–3 percent dark minerals, in addition to quartz and feldspar, and a variable but small percentage of shell fragments.

Nearshore Beach-Sand Zone

The extreme inner shelf off sandy beaches is floored with relatively clean and mature quartzose sand similar to or identical with that on the adjoining beaches. These sand deposits are of Holocene or immediately pre-Holocene age. Off New Jersey the zone of beachlike sand extends roughly 5 km seaward, to a water depth of about 20 m. Near the northern end of the New Jersey coast, a sample of beach sand contains 15 percent glauconite, and two samples from less than 3 km offshore contain 25 and 35 percent glauconite in their sand-size fraction. A number of highly glauconitic formations strike seaward in that area. South of Long Island the zone of beachlike sand also seems to extend to a water depth of about 20 m. Except for the glauconite area, constituents other than quartz and feldspar rarely exceed 1–2 percent in those areas.

The sandy beaches of New Jersey and Long Island are each about 185 km long. The sandy beaches of the east side of Cape Cod and of the northern Massachusetts, New Hampshire, and extreme southern Maine coasts are each roughly 75 km long. Northeastward from Cape Elizabeth in southern Maine are found only short and pocket beaches as much as a few kilometers long. This progressive shortening is accompanied by an overall decrease in the maturity of the beach sediment, marked by a general increase in angularity of grains and in content of rock fragments, feldspar, shell fragments, and mica. The distance offshore to which beachlike sand is found also decreases progressively northeastward.

Western Gulf of Maine

Holocene sediment probably derived from both rivers and erosion of glacial deposits occupies a coastal belt roughly 50 km wide from Cape Cod to northern Maine. Except in areas adjacent to sandy beaches of southern Maine, New Hampshire, and parts of Massachusetts, the material is predominantly of silt size but includes considerable clay. It floors a chain of small nearshore topographic basins (fig. 1), and over much of its extent, particularly off the Maine coast, it is being deposited in small topographic depressions in a rough terrain of bouldery lag concentrate of glacial material and, at least in the very nearshore area, of bedrock ledges.

The sand-size fraction of this sediment contains on the average 3 percent mica, 2 percent dark minerals, and 1 percent or less of rock fragments.

Basins on the Continental Shelf

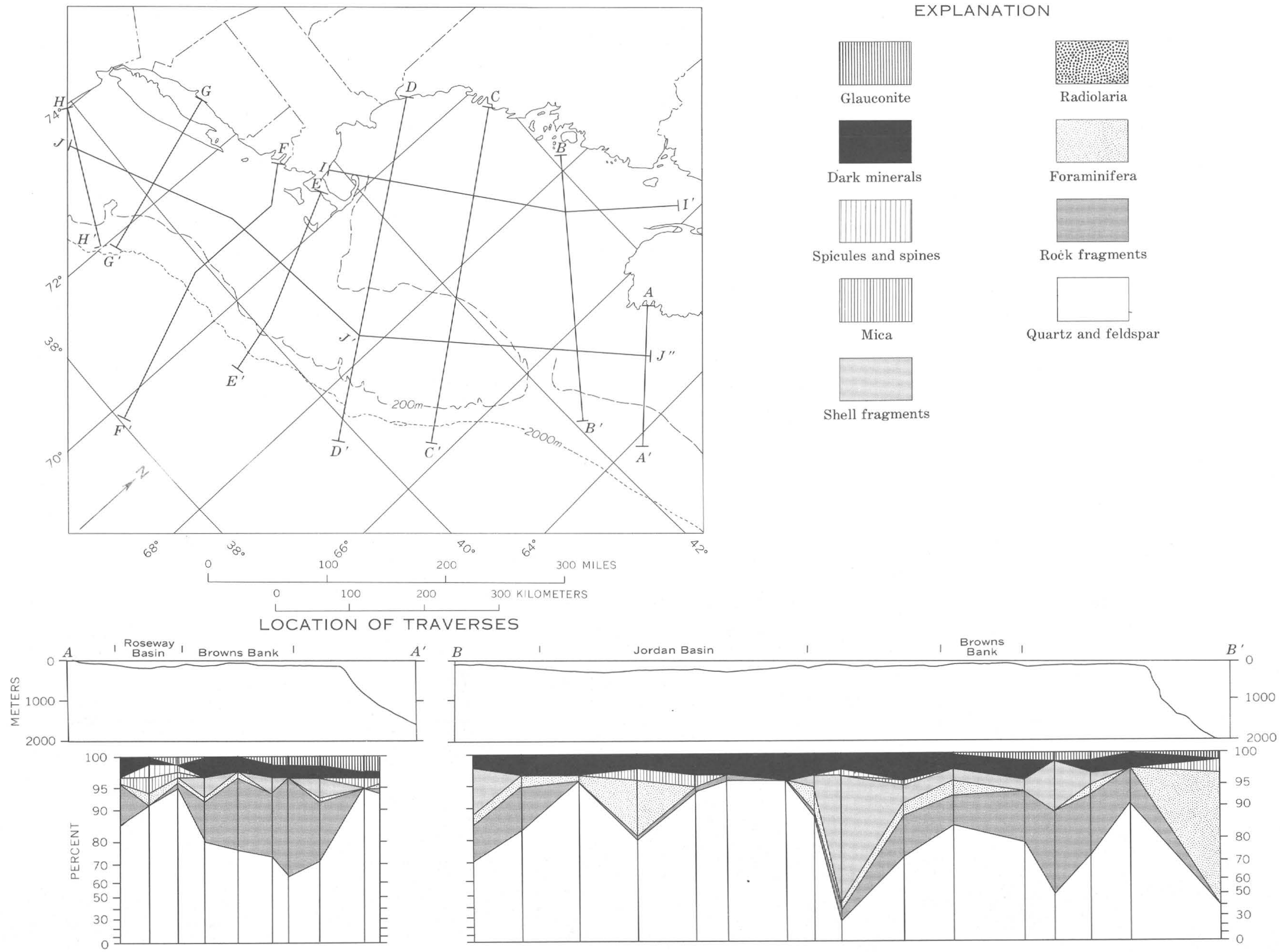
Sediments of the numerous basins in the Gulf of Maine and the Roseway Basin on the Nova Scotian shelf are predominantly silts and clays. Much of the volume of sediment in the basins probably originated from reworking of glacial deposits during and since the last transgression, but probably the surface material is derived at least in part, and perhaps entirely, from rivers and coastal erosion. Both the percentage of sand-size particles and the nature of the sand-size fraction show a broad range.

The Wilkinson-Murray Basin northeast of Cape Cod has the finest sediments (median diameters in the clay-size range) and the smallest percentage of particles of sand size (0–2 percent over large areas) of any basin in the Gulf of Maine. It also has the most distinctive sand-size fraction; foraminiferan tests form as much as 80 percent of it; mica, as much as 15 percent; and sponge spicules, as much as 5 percent. The 2–3 percent of dark minerals is normal for much of the Gulf of Maine, but the quartz-feldspar content is so low (as little as 10–15 percent) that the ratio of dark minerals to quartz-feldspar is unusually high. Percentages of shell fragments range randomly from 0 to 7 percent.

Other basins have higher percentages of sand-size detrital grains, and those grains include more quartz-feldspar and rock fragments and less biogenic components. Basins and parts of basins where the sediment strongly shares the characteristics of the Wilkinson-Murray Basin include the Black, Rogers, and Lindenkohl Basins, the western part of the Jordan Basin, and a small part of the Georges Basin in the Gulf of Maine, and the Roseway Basin on the Nova Scotian shelf. These are the areas shown by the basin pattern in figure 16. Basins in which nearness to shore or velocity of currents has resulted in sediment more akin to till-derived material include the shallow basins near the Massachusetts, New Hampshire, and Maine coasts, the eastern part of the Jordan Basin, and most of the Georges Basin.

Silt Deposit South of Martha's Vineyard

Due south of Martha's Vineyard an area in which the sediment is predominantly of silt size extends


EXPLANATION
Glauconite
Radiolaria
Dark minerals
Foraminifera
Spicules and spines
Rock fragments
Mica
Quartz and feldspar
Shell fragments
200m
2000m
N
0 100 200 300 MILES
0 100 200 300 KILOMETERS
LOCATION OF TRAVERSES
A
A'
Roseway Basin
Browns Bank
B
B'
Jordan Basin
Browns Bank
METERS
PERCENT
0
1000
2000
100
95
90
80
70
60
50
30
0

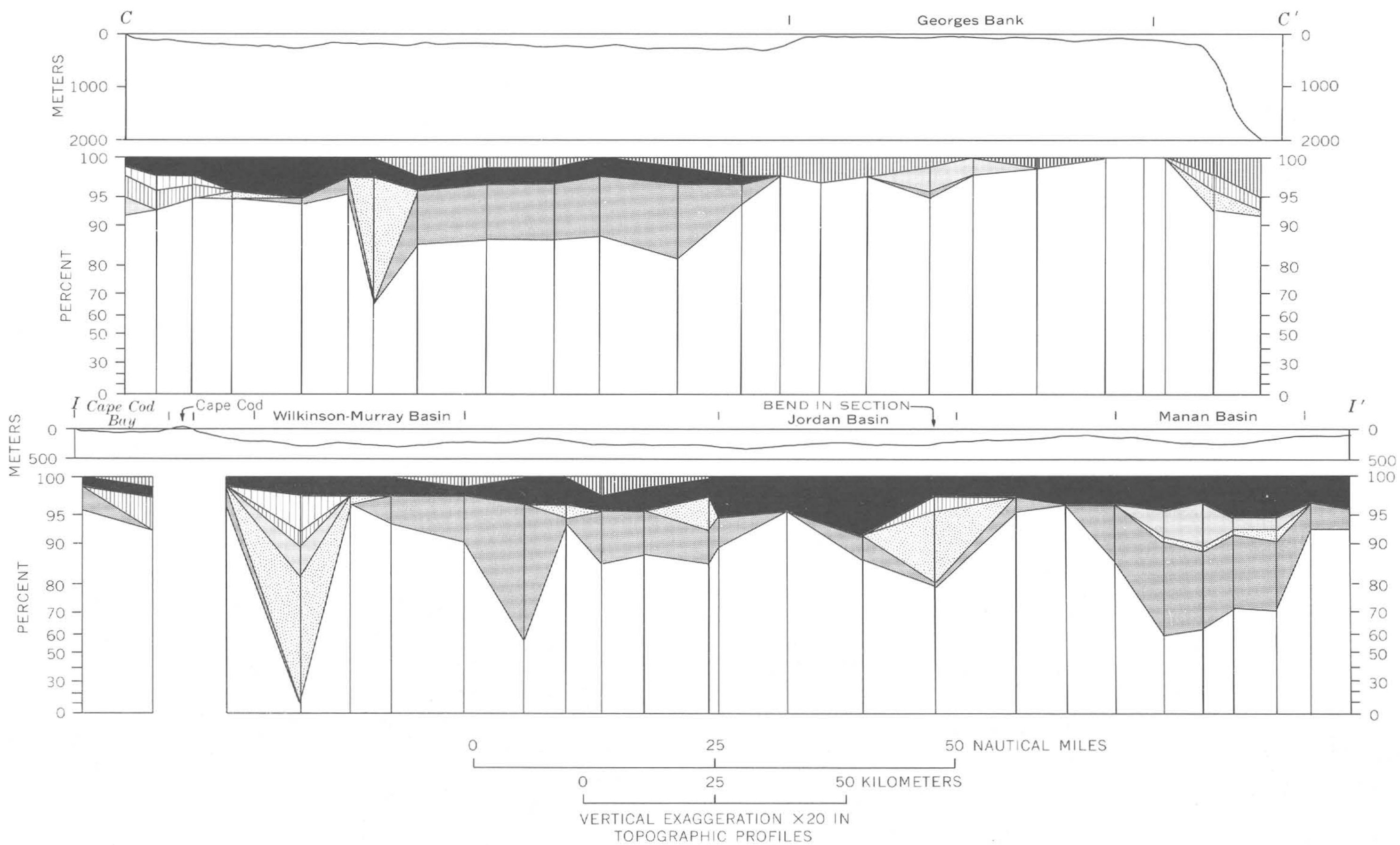
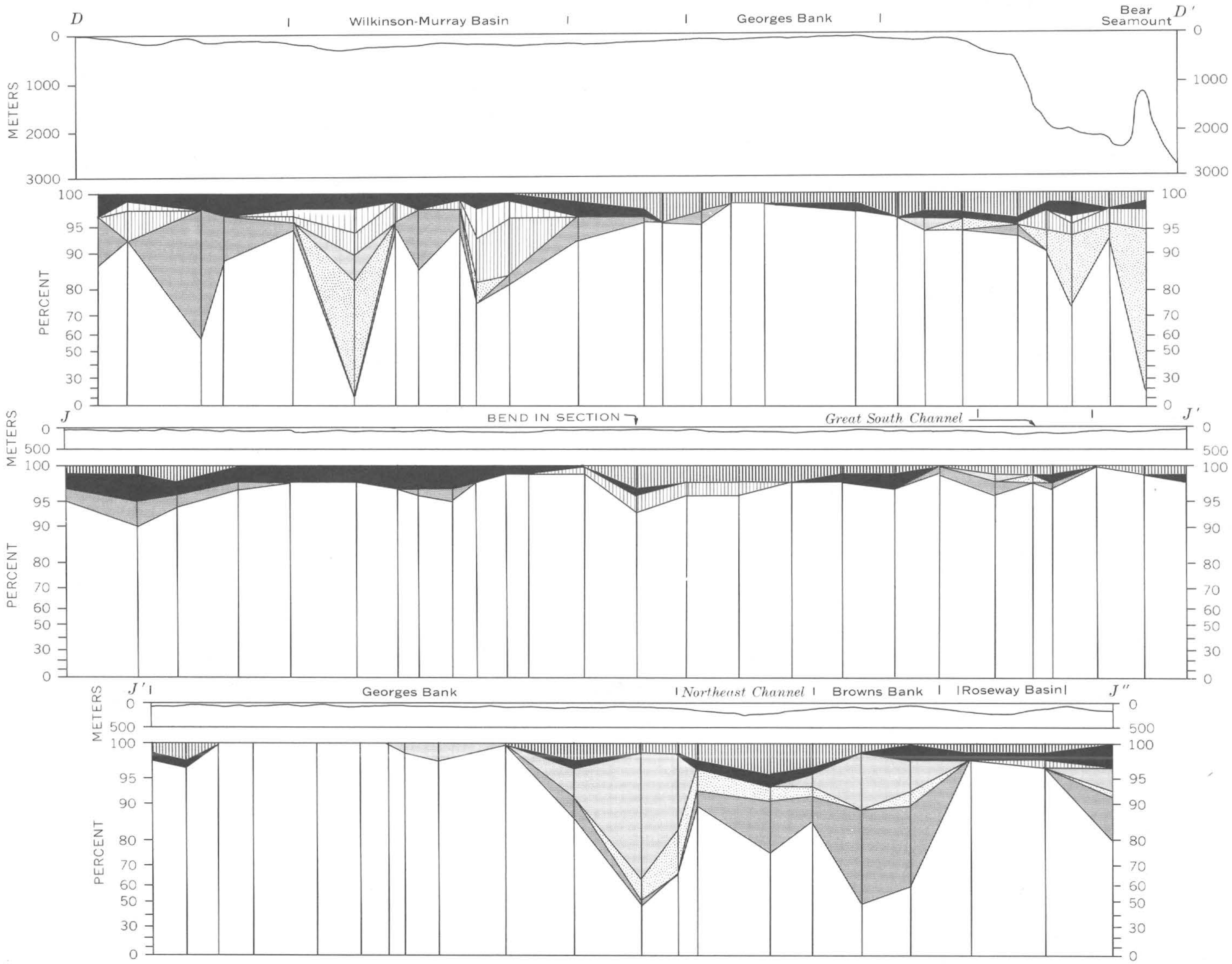


FIGURE 14.—Topography and composition of sand-size fraction on selected traverses. (Figure continued on following pages.)


D
Wilkinson-Murray Basin
Georges Bank
Bear Seamount
D′
METERS
0
1000
2000
3000
PERCENT
100
95
90
80
70
60
50
30
0
J
BEND IN SECTION
Great South Channel
J′
500
J′
Georges Bank
Northeast Channel
Browns Bank
Roseway Basin
J″

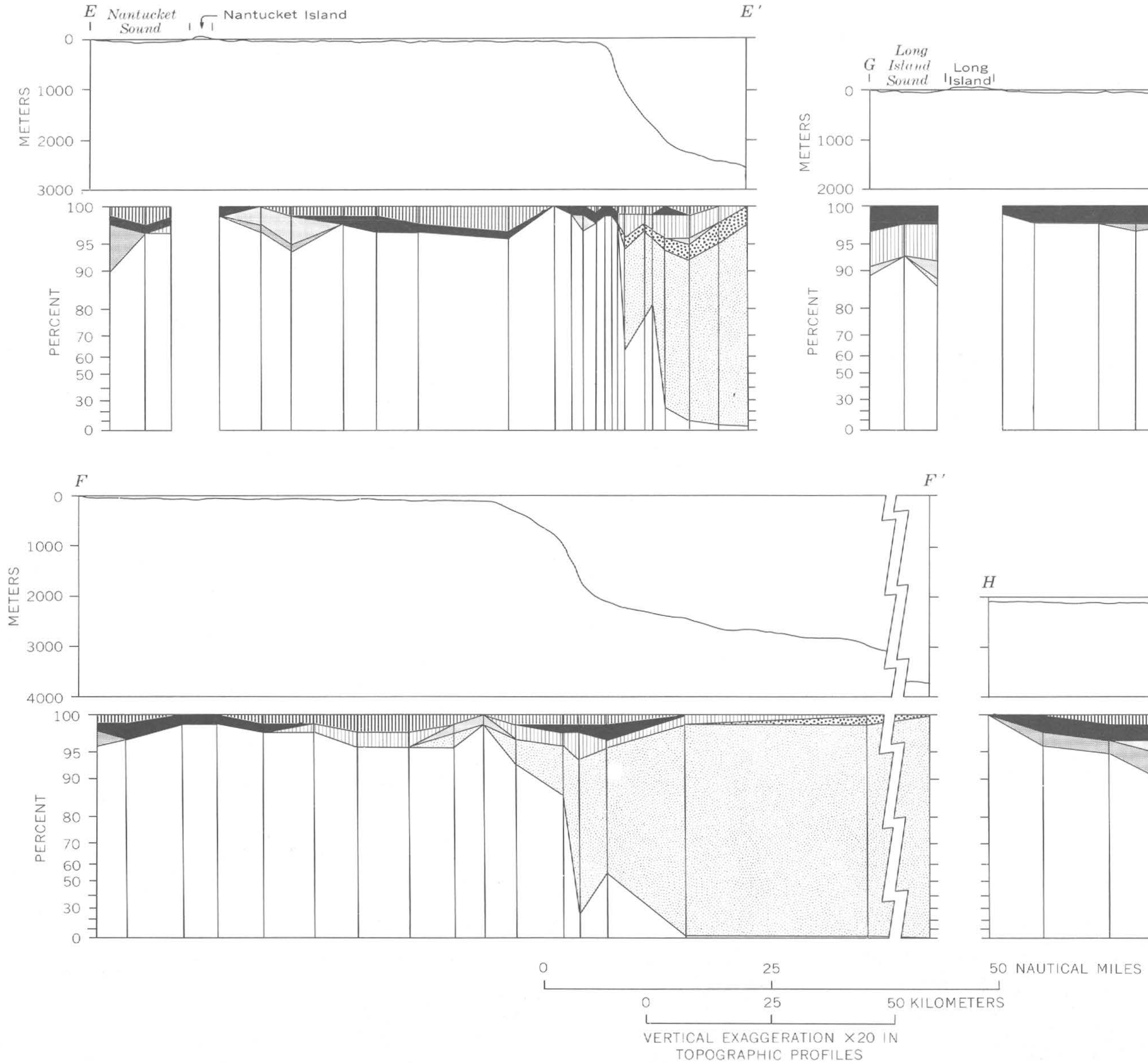


FIGURE 14.—Topography and composition of sand-size fraction on selected traverses—Continued.

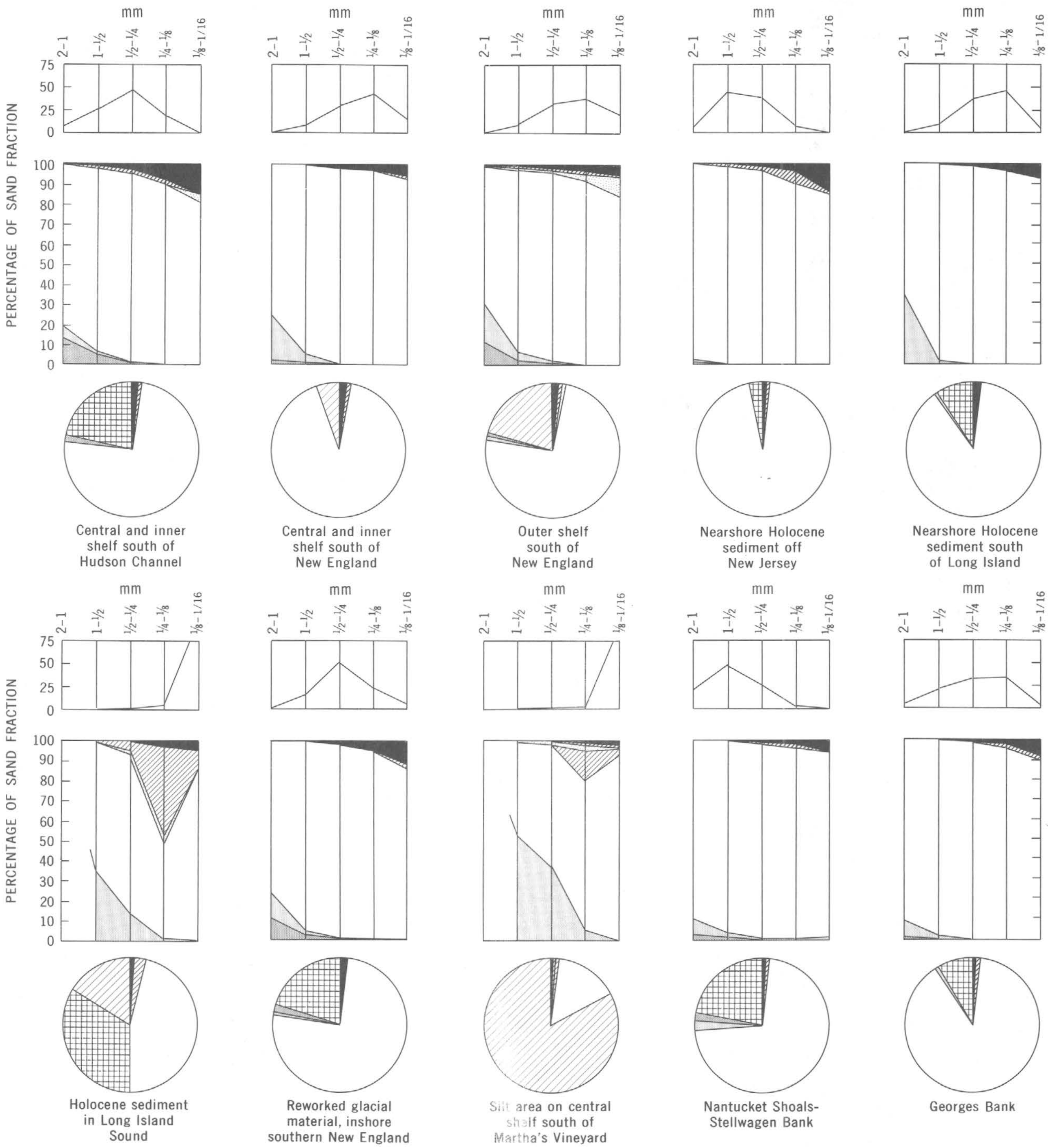
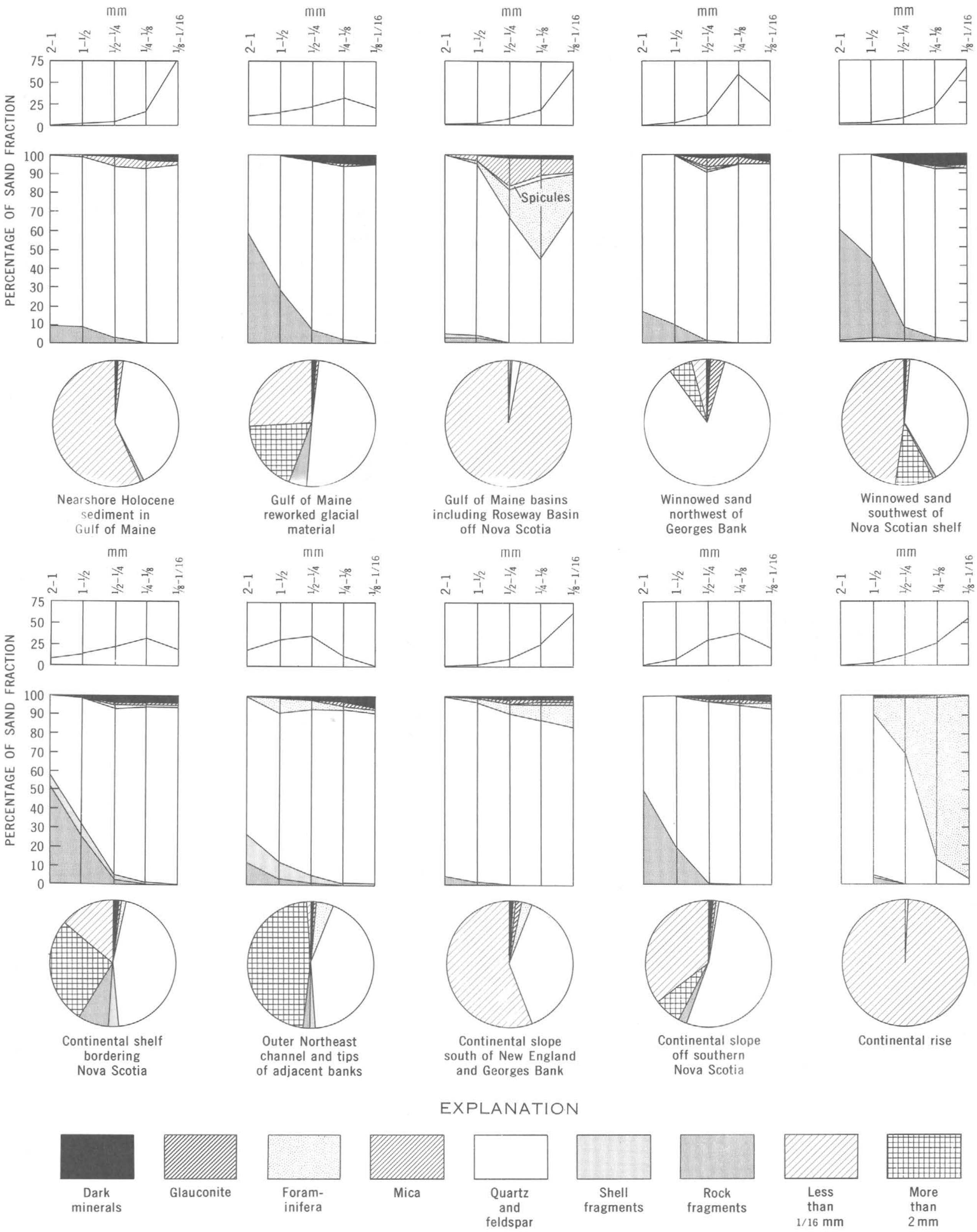
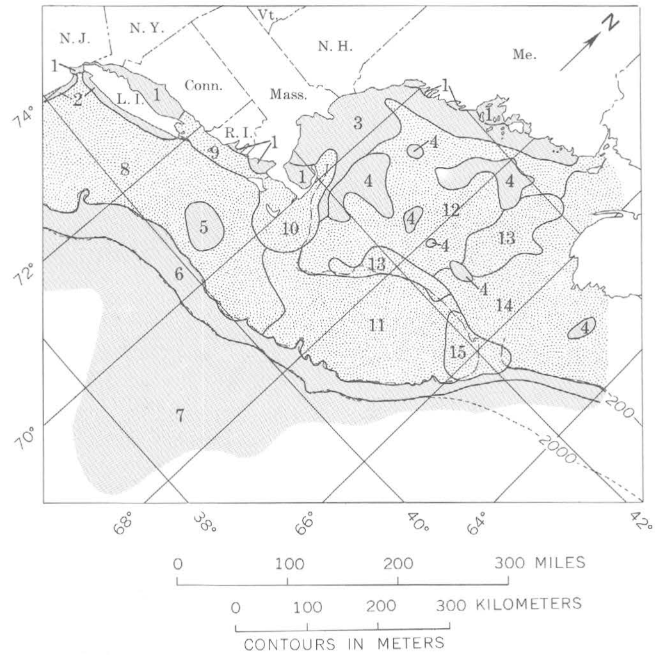


FIGURE 15.—Average composition and size distribution of surface sediment in individual areas. In each diagram the upper rectangle shows the particle-size distribution,



the middle rectangle shows the composition of the sand-size fraction, and the circle shows the composition of the entire sediment. See figure 16 for location of areas.

from the middle of the continental shelf to near its outer edge. The origin of this sediment is unknown. Shepard and Cohee (1936, p. 454) noted that it is "impossible to be sure that this introduction of silt has been going on in recent times." Stetson (1938, p. 38–39) thought that "deposition of silts and clays is occurring on the central portion of the shelf***." McMaster and Garrison (1966, p. 1141) concluded that "the origin *** remains in doubt although it is firmly believed that [the silt deposit] accumulated in a topographic sag or warp in the shelf surface during the Holocene transgression." Garrison and McMaster (1966, p. 286) give evidence that the silt



EXPLANATION

Holocene sediment — Relict sediment

1. Protected inshore areas
2. Nearshore Holocene sand
3. Western Gulf of Maine
4. Basins on the continental shelf
5. Silt area south of Martha's Vineyard
6. Continental slope
7. Continental rise

8. Nonglaciated shelf south of New England
9. Glaciated shelf south of New England
10. Nantucket Shoals—Nantucket Sound—Stellwagen Bank area
11. Georges Bank and Great South Channel
12. Floor of the Central Gulf of Maine
13. Zones of winnowed sand
14. Continental shelf near Nova Scotia
15. Northeast Channel and tips of adjacent banks

FIGURE 16.—Areas of major sediment types and of Holocene and relict sediments. Areas in left column have Holocene sediments; areas in right column have relict.

deposit is relict and that it was deposited rather late in the Holocene transgression.

The composition of the sand-size fraction of the silt deposit differs distinctly from that of the shelf sediments adjacent to the west and less strongly from those adjacent on the east and north. In the silt area, the sand fraction contains less than 1 percent dark minerals and no rock fragments, whereas the sediment on the west contains 1–2 percent dark minerals and from trace amounts to 4 percent rock fragments. The silt area contains 2–3 percent of both detrital glauconite and mica in its sand-size fraction, but most of the adjacent shelf sediments to the west contains less than 1 percent of each. Relatively high percentages of dark minerals and rock fragments typify glacially derived material in this area, and an increase in the content of detrital glauconite indicates an origin involving the sedimentary rocks that underlie the shelf. The relatively low content of dark minerals and rock fragments and the relatively high content of detrital glauconite in the silt area at least suggest that it is more strongly related in origin to the underlying sedimentary rocks than to glacial material. McMaster and Garrison (1966, p. 1140) also suggest that the silt may be derived from an underlying Tertiary bed.

As Garrison and McMaster (1966, p. 286) point out, the area of silt has a smooth surface, and it apparently lacks terraces. The sediment is not typical of that left by a transgressing shoreline, for it is not well sorted (Stetson, 1938, fig. 3) and the content of sand-size grains averages only about 15 percent (John Schlee, oral commun., 1967). It thus was probably deposited after the last marine transgression. The depth at the shoreward side of the silt area is about 60 m. According to Shepard's (1963) curve, sea level was 60 m lower about 13,000 years ago. Presumably that is the upper possible age limit of the silt deposit. Whether the silt is now being deposited remains unknown, but it seems possible that it is being winnowed from glacial sediments of the Nantucket Shoals area. This concept is strengthened by the observation that material of 10μ median diameter is in transport past a well-sorted sand bottom south of Martha's Vineyard (Raymond and Stetson, 1931; Stetson, 1938, p. 30).

Continental Slope

The sand-size fraction of continental slope sediments is enriched in the components of shelf sediments that are scarce in the high-energy zone of relatively clean quartzose sand that occupies the extreme outer shelf. Those components are primarily glauconite, mica, and dark minerals. (See fig. 14, C–F.) Slope sediments are impoverished in rock fragments compared with shelf sediments. This is a function of the decrease in particle size of slope sediments; reduced below the grain size of the constituent minerals, rock fragments become mineral grains.

Seaward of Georges and Browns Banks, the sand-size fraction of slope sediments differs from that south of New England. The percentage of quartz-feldspar grains decreases and the percentage of foraminiferan tests increases at the rate of 2.5 percent per 100-meter depth increase on the continental slope south of New England. On the slope seaward of the banks the rate is only 1.5 percent per 100 m. The slope sediments off the banks are lower in mica and in biogenic components and higher in rock fragments and quartz-feldspar than the "normal" slope sediments south of New England. The effect off the banks is of a seaward flushing of detrital components that tend to remain on the shelf in a "normal" area. This flushing probably has occurred in the banks area because it is near the outer edge of the continental shelf and tidal velocities across the banks are high.

Slope sediments off Northeast Channel are much richer in rock fragments and dark minerals and are lower in quartz-feldspar and Foraminifera than slope sediments off the banks. The sediments off the channel are closely akin to the glacially derived sediments that floor much of the northern Gulf of Maine. They lack evidence of exposure to the high-energy environment of the banks. They must have been winnowed from glacial deposits in the channel itself or have been carried through the channel from the floor of the Gulf of Maine. The junction between continental rise and continental slope is at depths of 1,000–1,200 m seaward of Browns Bank and Northeast Channel, but is at 2,000 m seaward of Georges Bank, indicating that a great volume of sediment has been deposited on the rise off Browns Bank and the Northeast Channel (Uchupi, 1966, p. 3027).

Continental Rise

Continental rise sediments in the mapped area are formed predominantly of detrital silt and clay particles derived from the continent, but the sand-size fraction is mostly biogenic in origin. The median diameter of the entire sediment below depths of 1,000–2,000 m is in the clay-sized range over most of the area. Sand-size material makes up less than 10 percent of most samples, though exceptions are numerous. The calcium carbonate content of the rise sediments does not exceed 40 percent within the mapped area (Hülsemann, 1967, fig. 3).

The sand-size fraction on most of the continental rise deeper than 2,500 m between Hudson Canyon and Georges Bank contains more than 90 percent Foraminifera, with volumetrically minor amounts of radiolarians, spicules, ostracodes, and diatoms, in decreasing order of abundance. Characteristically, the remainder includes 3–5 percent quartz, as much as 2 percent mica, and as much as 1 percent each of dark minerals and glauconite.

Certain rise samples, however, contain only 15–45 percent Foraminifera, but 53–82 percent quartz. (The location of the unusual samples can be seen in figure 6.) From 10 to 25 percent of the unusual samples is of sand size, but most samples from the same depth contain less than 2 percent sand. The material of the unusual samples is characteristic of the continental slope at depths less than 2,000 m, but it is found at depths as great as 4,000 m and at distances of 24–120 km from the slope. Normal rise sediments intervene. Its localized occurrence suggests that the material probably was emplaced by mass transport from the continental slope.

In the vicinity of Hudson Canyon, sediments of the upper rise are also anomalously high in quartz (55–65 percent of sand fraction) and low in Foraminifera (30–40 percent of sand fraction). Too few samples are available to determine whether the area of quartz concentration is genetically related to the canyon, or is another area of the type described in the preceding paragraph.

Seaward transport of sand-size detrital material has been most strongly developed off Northeast Channel. The sand fraction of two samples from depths of 1,934 and 2,474 m directly seaward of the channel averages 80 percent quartz and feldspar and 17 percent rock fragments, dark minerals, and glauconite. Foraminifera and mica total only 3 percent, but southwest from Georges Bank they make up as much as 80–90 percent of the sand fraction at the same depth. Such high percentages of rock fragments and dark minerals are characteristic of the glacially derived sediments within the Gulf of Maine, but not of the high-energy highly quartzose sands of the banks that border Northeast Channel. The available cores from nearby areas indicate that a significant thickness of sediment has been deposited on the continental rise since the last glacial stage (C. D. Hollister, oral commun., 1967). It therefore appears possible that sediment from the Gulf of Maine has been transported through Northeast Channel in postglacial time.

RELICT SEDIMENTS

Nonglaciated Shelf South of New England

Most of the continental shelf south of New England and Long Island and off northern New Jersey is covered by highly quartzose sand of relatively uniform composition. Most of this sand contains less than 1 percent rock fragments and less than 2 percent dark minerals. The general area of the Hudson Channel and an area centered 50 km south of the eastern tip of Long Island are exceptional in that their sands have as much as 5 percent rock fragments and 4 percent dark minerals. Except for two areas of high concentration near Long Island, the glauconite content of the sand ranges from trace amounts to 2 percent. In general, the concentration of detrital glauconite is slightly higher and the concentration of rock fragments and dark minerals is slightly lower in the eastern part of the area than in the western. This indicates that the sediment in the eastern part of the area may include a greater proportion of material derived from the sedimentary rocks that underlie the continental shelf than the western part.

Foraminifera are sparse or lacking on the inner shelf and make up less than 1 percent of the sand over most of the outer shelf. At depths greater than about 120 m, they make up 1–2 percent of the sand, and their concentration increases sharply at greater depths. The maximum percentages of foraminiferan tests in the sand-size range near the outer edge of the shelf in this area are 10 percent at a depth of 139 m and 20 percent at a depth of 235 m. Most of the shelf sands contain less than 1 percent of mica and of shell fragments, although the latter make up as much as 5 percent of the sand-size fraction on the gravelly area south of Hudson Channel.

These shelf sands are considered to be relict because they are coarser than sediment now originating from the nearby land, because submerged terraces marking former shorelines are preserved (Veatch and Smith, 1939; Ewing and others, 1963; Garrison and McMaster, 1966), and because they contain pre-Holocene oyster shells (Merrill and others, 1965). Iron staining on the surface of quartz grains, common in this area, is also a diagnostic property of relict sediments (Emery, 1968). These shelf sediments appear to have been originally deposited as glacial outwash during glacial periods, and to have been only slightly reworked by the transgression of the shoreline after the last glaciation. Gravel on the inner shelf south of Hudson Channel is similarly thought by Schlee (1964) to have been deposited by rivers during regression. Clay on the extreme outer shelf near Hudson Canyon was reported by Ewing, Le Pichon, and Ewing (1963, p. 6314) to have been deposited by the Hudson River when the shelf was subaerial.

Glaciated Nearshore Shelf South of New England

The extreme inner shelf off southern New England is floored by sediment derived primarily from the underlying glacial deposits, probably mostly till. In restricted passages, as at the eastern end of Long Island Sound, tidal currents have eroded the finer material from the till and left a bouldery lag deposit. The less constricted inner shelf between Long Island and Martha's Vineyard is covered mostly by relict clean, well-sorted sand (McMaster, 1960, p. 273). It contains on the average 2 percent each of rock fragments and of dark minerals. It shares the characteristics and probably the origin of the sand on the adjacent seaward shelf, except that gravel remaining from reworking of glacial material is widespread (McMaster, 1960, fig. 13; Northrop, 1951, fig. 1).

According to McMaster (1960, 1962), small areas of Holocene sediment of silt and sand size are now developing on the shelf near Narragansett Bay and Block Island. The situation is similar to that in the western Gulf of Maine, where fine-grained sediment is being deposited on reworked glacial deposits.

Georges Bank, Nantucket Shoals, Great South Channel

The predominantly sandy sediments of central Georges Bank, Nantucket Shoals, Nantucket Sound, and Stellwagen Bank are highly quartzose and occupy areas of high energy. The sediment in those areas probably is primarily of glacial origin and is therefore relict, but reworking during transgression and, in some areas, under present conditions is largely responsible for its present characteristics. Stewart and Jordan (1964) found that ridges of coarse sand on Georges Shoal, one of the shallowest areas on Georges Bank, have moved as much as 300 m westward between two surveys 25–28 years apart, and that when the rotary tidal currents were normal to the ridges, the sand on the entire crest is in violent sheet flow. Jordan (1962, p. 848) found evidence on Georges Bank that sediment is in motion in water depths at least as great as 36 m.

On the basis of available samples, most sandy sediment and the most mature sands on Georges Bank are not found on the shallowest part of the banks, where, presumably, conditions of highest energy exist, but instead are to the southeast. Considerable gravel and sandy gravel is found at the northeastern end of the shallow part of the bank, in depths of 33–56 m (Wigley, 1961, stations 91 and 93–95; John Schlee, oral commun., 1967). This suggests that the high-energy processes of the shallow area of the bank may be acting on and modifying sediment that is not fully mature, and that the net southeastward movement detected by Jordan (1962, p. 846, fig. 7) in the Georges Shoal area may be responsible for moving the rounded, highly quartzose sand that originates on the shallow part of the bank southeastward into deeper water. The limits of the area within which sand is being transported on Georges Bank are not known.

The sands of south-central Georges Bank are the cleanest and most quartzose sands in the mapped area, other than those on some present-day beaches. Over large areas all components of the sand fraction other than quartz and a subsidiary amount of feldspar total less than 1 percent, and quartz grains are rounded, frosted, and very little iron stained (fig. 13). This area of very high energy sands extends southeastward to about the 100-meter depth contour, nearly to the shelf edge.

However, the sediment of the shallowest part of Georges Bank can hardly be considered immature. Mica and Foraminifera are almost totally lacking in the sand-size fraction, and less than 1 percent of rock fragments, dark minerals, and shell fragments is present over most of the area, though some samples contain as much as 2 percent rock fragments. Glauconite makes up 1–2 percent of the sand fraction in many places.

On the deeper margins of Georges Bank, 1–3 percent glauconite, as much as 2 percent shell fragments, and 1 percent dark minerals are the main components of the sand fraction other than quartz and feldspar.

The sand on Nantucket Shoals and Stellwagen Bank and in Nantucket Sound is somewhat less quartzose than that on Georges Bank, but still it is typical of a high-energy environment. It averages 3 percent shell fragments, 2 percent rock fragments, and 1 percent or less of dark minerals and glauconite. Slightly more iron staining is present on quartz grains (fig. 13*C*), and the quartz grains are slightly less well rounded (fig. 13*A*) than those on the shallow part of Georges Bank.

The fact that the sand on Georges Bank is somewhat more mature than that on Nantucket Shoals and nearby areas may result in part from a greater admixture in the Georges Bank sand of second generation quartz grains derived from sedimentary rocks, rather than from any significant difference in postglacial history.

Great South Channel southwest of Georges Bank is also underlain by relict material primarily of glacial origin. The sand fraction of the sediments of Great South Channel is akin to that on the periphery of Georges Bank, but the rock fragment content of 1–2 percent indicates a closer relation to the parent glacial material than is shown by much of the Georges Bank sediment.

Floor of the Gulf of Maine

Most of the central Gulf of Maine outside the basins is covered by a poorly sorted mixture of clay, silt, sand, and gravel. Its wide range of particle sizes, poor sorting, widespread occurrence, and composition indicate that it has originated primarily from till. It was probably exposed to little reworking by the transgressing sea that followed deglaciation, for a marine sedimentary unit now exposed subaerially in coastal Maine intertongues with deposits derived directly from glacial ice (Bloom, 1963). Thus marine conditions followed immediately after glacial withdrawal in areas now above sea level, and that was probably also true at lower elevations farther seaward. The poorly sorted till-derived sediment is obviously relict from earlier conditions because it differs so markedly from the silt and clay now being deposited in depressions floored by the till-derived material (Uchupi, 1966). The area the till-derived material occupies is highly irregular in topography.

The glacial origin of this material is evident also in the composition of its sand-size fraction. Most samples have at least 1–5 percent rock fragments, the average being 10 percent and the maximum 35 percent. Dark minerals make up 2–5 percent of the sand fraction of most samples, and the maximum is 15 percent. Shell fragments are lacking in most samples, and usually less than 1 percent of mica and Foraminifera are present. As much as 1 percent of detrital glauconite occurs in nearly all samples south of an east-west line that lies between lat 43° and 43°30′ N., and glauconite is lacking in nearly all samples north of that line. As previously noted, that line probably represents an approximation of the original landward extent of Teritiary and Cretaceous sedimentary rocks. Quartz grains are subangular and unfrosted and have a variable amount of iron staining. Iron staining increases near the Bay of Fundy, the source area of heavily stained grains from Triassic sedimentary rocks.

Zones of Winnowed Sand

Northwest of Georges Bank and southwest of the shallow shelf southwest of Nova Scotia are two areas of fine and very fine sand that has been winnowed and transported from the adjoining banks by current action. The sand is in depths generally between 150 and 250 m. It is moderately well to well sorted and highly quartzose. The quartz grains are subangular and are heavily iron stained.

Good sorting and small grain size indicate that the sand has been transported by water currents, and the adjoining banks are the obvious sources. Current roses on navigation charts indicate that surface tidal currents exceed 2 knots southwest of Nova Scotia, and stronger currents are found on Georges Bank. However, evidence that this sand is now being transported is lacking, and it is very probably relict.

The winnowed sand northwest of Georges Bank contains several percent of detrital-type glauconite (15 percent in one sample), and 1 percent or less of dark minerals. It is well sorted and is slightly better rounded than that southwest of Nova Scotia. These properties indicate that it was derived either directly or indirectly (through glacial action) from coastal-plain sediments. The winnowed sand southwest of Nova Scotia includes more rock fragments and dark minerals but far less glauconite than the sand northwest of Georges Bank, and it is more angular and not as well sorted. These properties indicate that it was derived largely from glacial material that originated in a crystalline terrane.

Continental Shelf Near Nova Scotia

The bottom sediment near Nova Scotia and seaward over Browns Bank to the shelf edge is basically similar to that on the floor of the central part of the Gulf of Maine. Both are poorly sorted mixtures of clay, silt, sand, and gravel, and both have originated from reworking of till.

In the Nova Scotia–Browns Bank area, however, and particularly between southwestern Nova Scotia and the Maine coast, more gravel and boulders are present than in the central gulf, and the sand fraction contains more rock fragments and dark minerals. Mica makes up less than 1 percent of the sand fraction except in the vicinity of the Roseway Basin and in the immediate vicinity of Cape Sable, the southern tip of Nova Scotia. Glauconite is lacking on the inner shelf (except in the Bay of Fundy, an occurrence discussed in a preceding section), but an average of 1 percent is present on the outer shelf. As in the central Gulf of Maine, an east-west line between lat 43° and 43°30′ N. is the boundary.

Bottom photographs indicate that much of the area near Nova Scotia is armored with gravel and boulders. This fact and the presence of the winnowed sand zone to the southwest indicate that the sediments of the shelf in the Nova Scotia–Browns Bank area have been more extensively reworked than the sediment that floors the central Gulf of Maine. The relict aspect of the zone of winnowed sand indicates that most of the reworking occurred during or soon after the postglacial transgression. It is not known whether modern currents are affecting the bottom sediment in the Nova Scotia area. The available bottom photographs indicate that in general they are not, even though surface current maximum velocities average as high as 2.7 knots (U.S. Coast and Geodetic Survey, 1967, p. 138).

Far more shell fragments and Foraminifera are present in the sand-size fraction in the Nova Scotia–Browns Bank area than in the central Gulf of Maine. In the area southwest of Nova Scotia and northwestward to the Maine coast, the sand fraction contains from 3 to more than 60 percent shell fragments and 1–4 percent Foraminifera. Large areas of Browns Bank and the nearby shelf have only 1–2 percent shell fragments and less than 1 percent Foraminifera, however. The high biological productivity southwest of Nova Scotia is caused by the entrance of cold highly saline nutrient-rich water along the northeastern side of the Gulf of Maine and by vertical mixing of that water caused by tidal currents (Bigelow, 1928, p. 234, 247).

The eastern and southern parts of Georges Basin and the inner part of Northeast Channel in general share the characteristics of the shallower shelf to the north.

Northeast Channel and Tips of Adjacent Banks

The sediments of the outer part of Northeast Channel and of the immediately adjacent parts of Georges and Browns Banks are predominantly gravel, sandy gravel, and gravelly sand (Wigley, 1961, fig. 4). They are similar to those southwest of Nova Scotia in that their sand fractions contain high percentages not only of rock fragments and dark minerals but also of shell fragments and Foraminifera.

The floor of Northeast Channel has as much as 30 percent rock fragments and 2–3 percent dark minerals in its sand fraction. Those components indicate an origin from till. The sediment probably was deposited by glacial ice and has since been reworked, rather than transported into place after being deposited by ice, because much gravel is present, and it is probable that no mechanism since glaciation has been competent to move large and concentrated amounts of gravel. Torphy and Zeigler (1957) also concluded that Northeast Channel had been glaciated.

The sediments of the outer part of Northeast Channel, and those of the tips of the adjoining banks, are characterized by high though locally variable percentages of shell fragments and Foraminifera. Two samples from the northeastern end of Georges Bank contain 35 and 80 percent shell fragments. On both the southern corner of Browns Bank and the floor of Northeast Channel, shell fragments range from less than 1 to 10 percent. Foraminifera, mostly benthonic types, make up 8–15 percent of the sand fraction on the northeastern end of Georges Bank, 3–8 percent on the floor of Northeast Channel, and 25–30 percent in a small area of the shelf on the north side of Northeast Channel in the angle where the trend of the channel intersects the northeastward trend of the shelf edge. These are the highest concentrations of Foraminifera found in the sand-size fraction on the continental shelf in the mapped area, excepting only the basins of the Gulf of Maine and the Nova Scotia shelf in which the sediment is predominantly of slit and clay size. The high organic productivity of outer Northeast Channel and adjacent parts of the bordering banks is probably related to the fact that the channel is the sole deep-water entrance to the entire Gulf of Maine–Bay of Fundy System.

ORGANIC SEDIMENTS

Shell fragments, foraminiferan tests, and other organic material do not form a dominant part of the bottom sediment anywhere in the area, except for a small number of isolated localities along the immediate coast and in the northeastern Gulf of Maine. Those localities are not mapped as organic in origin because the samples are probably from highly local concentrations of organic material.

Foraminiferan tests and remains of other organisms dominate the sand-size fraction in some basins in the Gulf of Maine and over nearly all the continental rise, but in those areas all but a few percent of the bottom sediment is detrital silt and clay.

AUTHIGENIC, RESIDUAL, AND RAFTED COMPONENTS

The mapped area lacks bottom sediments known to be primarily authigenic or residual in origin. Authigenic components include glauconite along the outer shelf and upper slope, pyrite in some basins of the Gulf of Maine and on the slope and upper rise, and possibly limonite on the inner shelf south of New England, but none of those forms as much as 1 percent of the sediment in those areas.

The only major residual component that has been identified is detrital glauconite. In two small areas, one adjacent to the extreme northern coast of New Jersey, and the other 27 km southeast of the eastern tip of Long Island, glauconite makes up as much as 35 percent of the sand-size fraction, which in turn makes up 89 percent or more of the entire sediment. The evidence that this glauconite is probably residual, particularly in the latter area, is its relative lack of abrasion, its high but localized concentration, and the known or predictable proximity of highly glauconitic bedrock.

The ring of glauconite concentrations around Georges Bank also indicates a residual component in the sediment there, derived from underlying coastal-plain sedimentary rocks, but like most nonauthigenic glauconite, it has probably been transported at least a short distance.

Gravel and boulders on the continental shelf and slope beyond the probable limit of glacial moraine and outwash (Schlee and Pratt, 1970) indicate that ice-rafting has been an active agent of transportation in the area, but it is not at present.

GEOLOGIC HISTORY

Glaciation and the resulting regression and transgression of the shoreline are responsible for the present characteristics of most of the surficial shelf sediments in the area, including both glaciated and nonglaciated areas. The probable limit of glacial ice is shown in figure 1.

The preglacial geology and topography of the continental shelf and the adjacent land controlled the type of sediment available to glacial and stream erosion, probably controlled the extent of glacial advance in at least the Georges Bank area, and in large measure determined the present topography.

Before glaciation, the landward edge of the prism of coastal plain sedimentary rocks that underlies the continental shelf was at least as far landward as a line from Raritan Bay along the north shore of Long Island, through Buzzards Bay, across eastern Massachusetts, into the Gulf of Maine at least as far north as lat 42°11′ N. (Chute, 1965), and eastward across the Gulf of Maine between lat 43° and 43°30′ N. The Gulf of Maine existed as an inner lowland and Georges Bank as a cuesta. Northeast Channel probably carried the drainage from the Gulf of Maine (Uchpui, 1965b). The junction between the continental slope and rise off Northeast Channel, Browns Bank, and Nova Scotia was probably deeper and more strongly marked, as it now is south of New England. Whether the submarine canyons antedate glaciation is uncertain.

Glaciation changed the topography by forming the terminal moraines that mark the present shoreline of much of eastern Long Island and southeastern New England. It reshaped the floors of the Gulf of Maine, Northeast Channel, and probably Great South Channel to approximately their present configuration. Stillstands of sea level caused terraces to form on the outer shelf south of New England and Long Island and east of New Jersey (Veatch and Smith, 1939; Ewing and others, 1963; Garrison and McMaster, 1966). The ice deposited a layer of till behind the line of maximum glacial advance in nearshore southern New England, apparently throughout the Gulf of Maine, and over the Nova Scotia shelf. Probably the ice terminated against the northwestern flanks of Georges Bank and outwash covered the bank. Outwash sands and perhaps also terminal or lateral moraines were deposited in the Nantucket Shoals area. Outwash sands and, off New Jersey, fluvial sand with some gravel blanketed the continental shelf seaward of the terminal moraine. The till and outwash material originated primarily from the crystalline bedrock of New England, Nova Scotia, and the glaciated area now covered by water. The till and outwash also includes material from Triassic rocks of the Bay of Fundy area and from the coastal-plain sedimentary strata. During and probably also following glaciation, quantities of sediment were transported out Northeast Channel and over the Nova Scotia shelf and were deposited on the continental slope and upper rise.

No effects directly attributable to glaciations before the Wisconsin have been noted in this study.

During the transgression that followed the last glaciation, the outwash beyond the glacial ice limit and the till in the glaciated areas were reworked and were left in much their present condition. Winnowed sand transported landward from Georges Bank and the shallow shelf near southern Nova Scotia was deposited in two adjacent areas in the Gulf of Maine. Till on the Nova Scotia shelf, in Northeast Channel and the adjacent tip of Georges Bank, and in many areas of the Gulf of Maine was eroded to bouldery and gravelly lag deposits. Most of the fine-grained sediment in the basins of the Gulf of Maine and the Nova Scotia shelf probably originated by transgressive reworking of till.

THE PRESENT REGIME

At present most of the continental shelf appears to be neither receiving nor losing sediment. The relict sediments that floor most of it seem to have been little affected by other than biological action and slight currents since the postglacial transgression of the shoreline. This is true of most of the Gulf of Maine and nearly all of the Nova Scotia shelf and the shelf south of New England and Long Island and east of New Jersey. It is also true of most of Georges Bank, but high-energy conditions on the shallow parts of the bank have probably considerably altered the sediment there. Holocene sand is present and is subject to intermittent transportation along the parts of the coast that have developed as sandy beaches. An anomalous silt area on the middle and outer shelf south of Martha's Vineyard may represent the beginning of the accumulation of fine-grained shelf sediments that can be predicted for the future, barring further glacial stages.

Sediment leaving the rivers is for the most part being deposited in protected nearshore areas, except for the rivers of eastern Massachusetts, New Hampshire, and southern Maine. Most of them discharge directly into the Gulf of Maine rather than into estuaries, bays, or sounds. Much of the small amount of sediment from them seems to be accumulating in a nearshore zone of small topographic basins.

The surface of much of the Nova Scotian shelf, the outer part of Northeast Channel, and the northeastern tip of Georges Bank is in large part armored against further erosion by the gravelly and bouldery lag of glacial deposits. The detrital component of the slope and at least some of the extreme upper rise surficial sediments seaward of Georges and Browns Banks is far greater than that of the slope and rise deposits in the area southwestward from Georges Bank. These slope and rise sediments off the banks are probably relict, but it is notable that they are not deeply buried by normal hemipelagic sediment.

REFERENCES

Agassiz, Alexander, 1881, List of dredging stations occupied during the year 1880 by the U.S. Coast Survey steamer *Blake*, Commander J. R. Bartlett, U.S.N., Commanding: Harvard Univ. Mus. Comp. Zoology Bull., v. 8, p. 95–98.

——— 1888, Three cruises of the United States Coast and Geodedetic Survey steamer *Blake* in the Gulf of Mexico, in the Caribbean Sea, and along the Atlantic Coast of the United States, from 1877 to 1880: Boston, Houghton, Mifflin & Co., 2 v.

Alexander, A. E., 1934, A petrographic and petrologic study of some continental shelf sediments: Jour. Sed. Petrology, v. 4, no. 1, p. 12–22.

Bailey, J. W., 1851, Microscopical examination of soundings made by the U.S. Coast Survey, off the Atlantic Coast of the United States: Smithsonian Contr. Knowledge, v. 2, art. 3, 16 p.

Bassler, R. S., 1936, Geology and paleontology of the Georges Bank canyons; part 3. Cretaceous bryozoan from Georges Bank: Geol. Soc. America Bull., v. 47, no. 3, p. 411–412.

Bigelow, H. B., 1928, Exploration of the waters of the Gulf of Maine: Geog. Rev., v. 18, p. 232–260.

Bloom, A. L., 1963, Late-Pleistocene fluctuations of sea level and postglacial crustal rebound in coastal Maine: Am. Jour. Sci., v. 261, no. 9, p. 862–879.

Burbank, W. S., 1929, The petrology of the sediment of the Gulf of Maine and Bay of Fundy: U.S. Geol. Survey open-file report, 74 p.

Burst, J. F., 1958, "Glauconite" pellets—their mineral nature and applications to stratigraphic interpretations: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 2, p. 310–327.

Chute, N. E., 1965, Geologic map of the Scituate quadrangle, Plymouth County, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–467.

Colony, R. J., 1932, Source of the sands on the south shore of Long Island and the coast of New Jersey: Jour. Sed. Petrology, v. 2, no. 3, p. 150–159.

Colton, J. B., Jr., 1964, History of oceanography in the offshore waters of the Gulf of Maine: U.S. Fish and Wildlife Service, Spec. Sci. Rept., Fisheries no. 496, 18 p.

Cushman, J. A., 1936, Geology and paleontology of Georges Bank canyons; part 4. Cretaceous and Late Tertiary Foraminifera: Geol. Soc. America Bull., v. 47, no. 3, p. 413–440.

——— 1939, Eocene Foraminifera from submarine cores off the eastern coast of North America: Cushman Lab. Foram. Research Contr., v. 15, pt. 3, p. 49–76.

——— 1944, Foraminifera from the shallow water of the northeast coast: Cushman Lab. Foram. Research, Spec. Pub. 12, 37 p.

Dall, W. H., 1925, Tertiary fossils dredged off the northeastern coast of North America: Am. Jour. Sci., 5th ser., v. 10, p. 213–218.

Ehlmann, A. J., Hulings, N. C., and Glover, E. D., 1963, Stages of glauconite formation in modern foraminiferal sediments: Jour. Sed. Petrology, v. 33, no. 1, p. 87–96.

Emery, K. O., 1952, Continental shelf sediments of southern California: Geol. Soc. America Bull., v. 63, no. 11, p. 1105–1107.

——— 1968, Relict sediments of continental shelves of the World: Am. Assoc. Petroleum Geologists Bull., v. 52, no. 3, p. 445–464.

Emery, K. O., Merrill, A. S., and Trumbull, J. V. A., 1965, Geology and biology of the seafloor as deduced from simultaneous photographs and samples: Limnology and Oceanography, v. 10, no. 1, p. 1–21.

Ewing, John, Le Pichon, Xavier, and Ewing, Maurice, 1963, Upper stratification of Hudson apron region: Jour. Geophys. Research, v. 68, no. 23, p. 6303–6316.

Galliher, E. W., 1935, Glauconite genesis: Geol. Soc. America Bull., v. 46, no. 9, p. 1351–1366.

Garrison, L. E., and McMaster, R. L., 1966, Sediments and geomorphology of the continental shelf off southern New England: Marine Geology, v. 4, no. 4, p. 273–289.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, Natl. Research Council, 6 p. (repub. by Geol. Soc. America, 1951).

Goodell, H. G., 1966, Antarctic marine geology: Geotimes, v. 11, no. 4, p. 24–26.

Hathaway, J. C., ed., 1966, Data file, Continental Margin Program, Atlantic coast of the United States, v. 1, Sample collection data: Woods Hole Oceanog. Inst. Reference No. 66–8, 184 p.

——— 1967, Data file, Continental Margin Program, Atlantic coast of the United States, v. 1, Sample collection data, Supplement 1: Woods Hole Oceanog. Inst. Reference No. 67–21, 108 p.

Hazel, J. E., 1967, Classification and distribution of the Recent Hemicytheridae and Trachyleberididae (Ostracoda) off northeastern North America: U.S. Geol. Survey Prof. Paper 564, 49 p.

Holtedahl, Hans, 1958, Some remarks on geomorphology of continental shelves off Norway, Labrador, and southeast Alaska: Jour. Geology, v. 66, no. 4, p. 461–471.

Hough, J. L., 1932, Suggestion regarding the origin of rock-bottom areas in Massachusetts Bay: Jour. Sed. Petrology, v. 2, no. 2, p. 131–132.

——— 1940, Sediments of Buzzards Bay, Massachusetts: Jour. Sed. Petrology, v. 10, no. 1, p. 19–32.

——— 1942, Sediments of Cape Cod Bay, Massachusetts: Jour. Sed. Petrology, v. 12, no. 1, p. 10–30.

Hülsemann, Jobst, 1967, The continental margin off the Atlantic Coast of the United States: Carbonate in sediments, Nova Scotia to Hudson Canyon: Sedimentology, v. 8, p. 121–145.

Johnson, D. W., 1925, The New England-Acadian shoreline: New York, John Wiley & Sons, 608 p.

Johnson, D. W., and Stolfus, M. A., 1924, The submerged coastal plain and old land of New England: Science, new ser., v. 59, no. 1526, p. 291–293.

Jordan, J. F., 1962, Large submarine sand waves: Science, v. 136, no. 3519, p. 839–848.

King, L. H., 1967, On the sediments and stratigraphy of the Scotian shelf *in* Geology of the Atlantic region: Geol. Assoc. Canada Spec. Paper 4, p. 71–92.

Krinsley, David, Takahashi, Taro, Silberman, M. L., and Newman, W. S., 1964, Transportation of sand grains along the Atlantic shore of Long Island, New York: Marine Geology, v. 2, nos. 1–2, p. 100–120.

Krumbein, W. C., 1941, Measurement and geological significance of shape and roundness of sedimentary particles: Jour. Sed. Petrology, v. 11, no. 2, p. 64–72.

Light, M. A., 1952, Evidence of authigenic and detrital glauconite: Science, v. 115, no. 2977, p. 73–75.

McCarthy, G. R., 1931, Coastal sands of the eastern United States: Am. Jour. Sci., 5th ser., v. 22, p. 35–50.

McCrone, A. W., 1966a, Sediments from Long Island Sound (New York)—Physical and chemical properties reviewed: Jour. Sed. Petrology, v. 36, no. 1, p. 234–236.

——— 1966b, The Hudson River estuary—hydrology, sediments, and pollution: Geog. Rev., v. 56, p. 175–189.

McCrone, A. W., Ellis, B. F., and Charmatz, R., 1961, Preliminary observations on Long Island Sound sediments: New York Acad. Sci. Trans., ser. 2, v. 24, no. 2, p. 119–129.

McMaster, R. L., 1954, Petrography and genesis of the New Jersey beach sands: New Jersey Dept. Conserv. and Econ. Devel., Geol. Ser., Bull. 63, 239 p.

——— 1960, Sediments of Narragansett Bay system and

Rhode Island Sound, Rhode Island: Jour. Sed. Petrology, v. 30, no. 2, p. 249–274.

———1962, Petrography and genesis of recent sediments in Narragansett Bay and Rhode Island Sound, Rhode Island: Jour. Sed. Petrology, v. 32, no. 3, p. 484–501.

McMaster, R. L., and Garrison, L. E., 1966, Mineralogy and origin of southern New England shelf sediments: Jour. Sed. Petrology, v. 36, no. 4, p. 1131–1142.

Marlowe, J. I., 1965, Probable Tertiary sediments from a submarine canyon off Nova Scotia: Marine Geology, v. 3, no. 4, p. 263–268.

Mather, K. F., Goldthwaite, R. P., and Thiesmeyer, L. R., 1940, Preliminary report on the geology of western Cape Cod, Massachusetts: Massachusetts Dept. Public Works Bull. 2, 53 p.

Merrill, A. S., Emery, K. O., and Rubin, Meyer, 1965, Ancient oyster shells on the Atlantic continental shelf: Science, v. 147, no. 3656, p. 398–400.

Moore, J. R., III, 1963, Bottom sediment studies, Buzzards Bay, Massachusetts: Jour. Sed Petrology, v. 33, no. 3, p. 511–558.

Murray, H. W., 1947, Topography of the Gulf of Maine, Field season of 1940: Geol. Soc. America Bull., v. 58, no. 2, p. 153–196.

Murray, John, 1885, Report on the specimens of bottom deposits: Harvard Univ. Mus. Comp. Zoology Bull., v. 12, p. 37–61.

Northrop, John, 1951, Ocean-bottom photographs of the neritic and bathyal environment south of Cape Cod, Massachusetts: Geol. Soc. America Bull., v. 62, no. 12, p. 1381–1384.

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.

Oberkommando der Kriegsmarine, 1943, Uboot handbuch der ostküste der Vereinigten Staaten von Nordamerika, Nördlicher Teil (atlas): Berlin, 124 charts.

Owens, J. P., and Minard, J. P., 1960, Some characteristics of glauconite from the coastal plain formations of New Jersey *in* Geological Survey research 1960: U.S. Geol. Survey Prof. Paper 400–B, p. B430–B432.

Parker, F. L., 1948, Foraminifera of the continental shelf from the Gulf of Maine to Maryland: Harvard Univ. Mus. Comp. Zoology Bull., v. 100, no. 2, p. 211–241.

——— 1952a, Foraminifera species off Portsmouth, New Hampshire: Harvard Univ. Mus. Comp. Zoology Bull., v. 106, no. 9, p. 391–423.

——— 1952b, Foraminiferal distribution in the Long Island-Buzzards Bay area: Harvard Univ. Mus. Comp. Zoology Bull., v. 106, no. 10, p. 428–473.

Pettijohn, F. J., 1957, Sedimentary rocks (2d ed.): New York, Harper & Bros., 718 p.

Phleger, F. B., 1952, Foraminifera ecology off Portsmouth, New Hampshire: Harvard Univ. Mus. Comp. Zoology Bull., v. 106, no. 8, p. 315–390.

——— 1960, Ecology and distribution of Recent Foraminifera: Baltimore, Johns Hopkins Press, 297 p.

Pourtalès, L. F., 1870, Der Boden des Golfstromes und der Atlantischen Küste Nord-Americas: Petermann Mitt. aus Justus Perthes' Geographischer Anst., v. 16. p. 393–398.

——— 1872, The Gulf Stream; Characteristics of the Atlantic seabottom off the coast of the United States: Rept. of Superintendent, U.S. Coast Survey, for 1869, app. 11, p. 220–225.

Pratt, W. L., Jr., 1962, The origin and distribution of glauconite from the sea floor off California and Baja California: Univ. Southern California, Ph.D. dissert., 285 p. Available from University Microfilms, Inc., Ann Arbor, Mich.

Raymond, P. E., and Stetson, H. C., 1931, A new factor in the transportation and distribution of marine sediments: Science, new ser., v. 73, no. 1882, p. 105–106.

Rittenhouse, Gordon, 1943, A visual method of estimating two-dimensional sphericity: Jour. Sed. Petrology, v. 13, no. 2, p. 79–81.

Ross, D. A., 1967, Heavy-mineral assemblages in the nearshore surface sediments of the Gulf of Maine *in* Geological Survey research 1967: U.S. Geol. Survey Prof. Paper 575–C, p. C77–C80.

——— 1970, Atlantic continental shelf and slope of the United States—Heavy minerals of the continental margin, southern Nova Scotia to northern New Jersey: U.S. Geol. Survey Prof. Paper 529–G, 40 p.

Sanders, H. L., 1956, The biology of marine bottom communities, *in* Oceanography of Long Island Sound, 1952–1954: Bingham Oceanog. Colln. Bull., v. 15, p. 345–414.

——— 1958, Benthic studies in Buzzards Bay. I. Animal-sediment relationships: Limnology and Oceanography, v. 3, no. 3, p. 245–258.

Schalk, Marshall, 1938, A textural study of the outer beach of Cape Cod, Mass.: Jour. Sed. Petrology, v. 8, no. 2, p. 41–54.

Schlee, John, 1964, New Jersey offshore gravel deposit: Pit and Quarry Mag., v. 57, no. 6, p. 80, 81, 95.

Schlee, John, and Cheetham, A. H., 1967, Rocks of Eocene age on Fipennies Ledge, Gulf of Maine: Geol. Soc. America Bull., v. 78, no. 5, p. 681–684.

Schlee, John, and Pratt, R. M., 1970, Atlantic continental shelf and slope of the United States—Gravels of the northeastern part: U.S. Geol. Survey Prof. Paper 529–H, 39 p.

Schlee, John, Uchupi, Elazar, and Trumbull, J. V. A., 1964, Statistical parameters of Cape Cod beach and eolian sands *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501–D, p. D118–D122.

Schopf, T. J. M., 1968, Atlantic continental shelf and slope of the United States—Nineteenth century exploration: U.S. Geol. Survey Prof. Paper 529–F, 12 p.

Shepard, F. P., 1963, Thirty-five thousand years of sea level, *in* Essays in marine geology in honor of K. O. Emery: Los Angeles, Calif., California Univ. Press, p. 1–10.

Shepard, F. P., and Cohee, G. V., 1936, Continental shelf sediments off the mid-Atlantic states: Geol. Soc. America Bull., v. 47, no. 3, p. 441–457.

Shepard, F. P., and Moore, D. G., 1954, Sedimentary environments differentiated by coarse-fraction studies: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 8, p. 1792–1802.

Shepard, F. P., Trefethen, J. M., and Cohee, J. V., 1934, Origin of Georges Bank: Geol. Soc. America Bull., v. 45, no. 2, p. 281–302.

Shrock, R. R., and Twenhofel, W. H., 1953, Principles of invertebrate paleontology (2d ed.): New York, McGraw-Hill Book Co., 816 p.

Stephenson, L. W., 1936, Geology and paleontology of the Georges Bank canyons; part 2. Upper Cretaceous fossils from Georges Bank (including species from Banquereau, Nova Scotia): Geol. Soc. America Bull., v. 47, no. 3, p. 367–410.

Stetson, H. C., 1934, The origin and limits of a zone of rounded quartz sand off the southern New England coast: Jour. Sed. Petrology, v. 4, no. 3, p. 152–153.

——— 1936, Geology and paleontology of the Georges Bank canyons; part 1. Geology: Geol. Soc. America Bull., v. 47, no. 3, p. 339–366.

——— 1937, Current measurements in the Georges Bank canyons: Am. Geophys. Union Trans., 18th Ann. Mtg., July 1937, p. 216–219.

——— 1938, The sediments of the continental shelf off the eastern coast of the United States: Massachusetts Inst. Technology and Woods Hole Oceanog. Inst., Papers in Physics, Oceanography, and Meteorology, v. 5, no. 4, 48 p.

——— 1939, Summary of sedimentary conditions on the continental shelf off the east coast of United States, *in* Trask, P. D., ed., Recent marine sediments, a symposium: Tulsa, Am. Assoc. Petroleum Geologists, p. 230–244.

——— 1949, The sediments and stratigraphy of the east coast continental margin—Georges Bank to Norfolk Canyon: Massachusetts Inst. Technology and Woods Hole Oceanog. Inst., Papers in Physics, Oceanography, and Meteorology, v. 11, no. 2, p. 1–60.

Stetson, H. C., and Schalk, Marshall, 1935, Marine erosion of glacial deposits in Massachusetts Bay: Jour. Sed. Petrology, v. 5, no. 1, p. 40–51.

Stewart, H. B., Jr., and Jordan, G. F., 1964, Underwater sand ridges on Georges Shoal, *in* Miller, R. L., ed., Papers in marine geology (F. P. Shepard commemorative volume): New York, Macmillan Co., p. 102–114.

Suter, Russell, de Laguna, Wallace, Perlmutter, N. N., and Brashears, M. L., Jr., 1949, Mapping of geologic formations and aquifers of Long Island, New York: New York Water Power and Control Comm. Bull. GW–18, 212 p.

Tagg, A. R., and Uchupi, Elazar, 1966, Distribution and geologic structure of Triassic rocks in the Bay of Fundy and the northeastern part of the Gulf of Maine *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–B, p. B95–B98.

Taney, N. E., 1961a, Geomorphology of the south shore of Long Island, New York: U.S. Army Corps Engineers, Beach Erosion Board Tech. Memo. 128, 50 p.

——— 1961b, Littoral materials of the south shore of Long Island, New York: U.S. Army Corps Engineers, Beach Erosion Board Tech. Memo. 129, 59 p.

Terry, R. D., and Chilingar, G. V., 1955, Summary of "Concerning some additional aids in studying sedimentary formations," by M. S. Shvetsov: Jour. Sed. Petrology, v. 25, no. 3, p. 229–234.

Todd, Ruth, and Low, Doris, 1961, Near-shore Foraminifera of Martha's Vineyard island, Massachusetts: Cushman Found. Foram. Research Contr., v. 12, pt. 1, p. 5–21.

Torphy, S. R., and Zeigler, J. M., 1957, Submarine topography of Eastern Channel, Gulf of Maine: Jour. Geology, v. 65, no. 4, p. 433–441.

Townsend, C. H., 1901, Dredging and other records of the U.S. Fish Commission steamer *Albatross*, with bibliography relative to the work of the vessel, *in* Report of the Commissioner for the year ending June 30, 1900: Washington, U.S. Comm. Fish and Fisheries, p. 387–562.

Trowbridge, A. C., and Shepard, F. P., 1932, Sedimentation in Massachusetts Bay: Jour. Sed. Petrology, v. 2, no. 1, p. 3–37.

Uchupi, Elazar, 1965a, Map showing relation of land and submarine topography, Nova Scotia to Florida: U.S. Geol. Survey Misc. Geol. Inv. Map I–451, 3 sheets, scale 1:1,000,000.

——— 1965b, Basins of the Gulf of Maine *in* Geological Survey research 1965: U.S. Geol. Survey Prof. Paper 525–D, p. D175–D177.

——— 1966, Structural framework of the Gulf of Maine: Jour. Geophys. Research, v. 71, no. 12, p. 3013–3028.

——— 1968, Atlantic continental shelf and slope of the United States—Physiography: U.S. Geol. Survey Prof. Paper 529–C, 30 p.

Upham, Warren, 1894, The fishing banks between Cape Cod and Newfoundland: Am. Jour. Sci., 3d ser., v. 47, p. 123–129.

U.S. Coast and Geodetic Survey, 1947, Tidal current charts, Long Island Sound and Block Island Sound (3d ed.): U.S. Coast and Geodetic Survey.

——— 1967, Tidal current tables, Atlantic Coast of North America, 1968: U.S. Coast and Geodetic Survey, 200 p. (1968).

U.S. Coast Survey, 1848, Report of the Superintendent of the Coast Survey, showing the progress of the work during the year ending October, 1847: Washington, U.S. Govt. Printing Office, 88 p.; *also* Senate Ex. Doc. 6, U.S. 30th Cong., 1st sess., v. 3.

U.S. Naval Oceanographic Office, 1965, Oceanographic atlas of the North Atlantic Ocean, Sec. V, Marine Geology: Washington, U.S. Naval Oceanog. Office, 71 p.

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.

Verrill, A. E., 1878, Occurrence of fossiliferous Tertiary rocks on the Grand Banks and Georges Bank: Am. Jour. Sci., 3d ser., v. 16, p. 323–324.

Wigley, R. L., 1961, Bottom sediments of Georges Bank: Jour. Sed. Petrology, v. 31, no. 2, p. 165–188.

Wigley, R. L., and McIntyre, A. D., 1964, Some quantitative comparisons of offshore meiobenthos and macrobenthos south of Martha's Vineyard: Limnology and Oceanography, v. 9, no. 4, p. 485–493.

Zeigler, J. M., Tuttle, S. D., Tasha, H. J., and Giese, G. S., 1964, Pleistocene geology of outer Cape Cod, Massachusetts: Geol. Soc. America Bull., v. 75, no. 8, p. 705–714.

U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 472-199