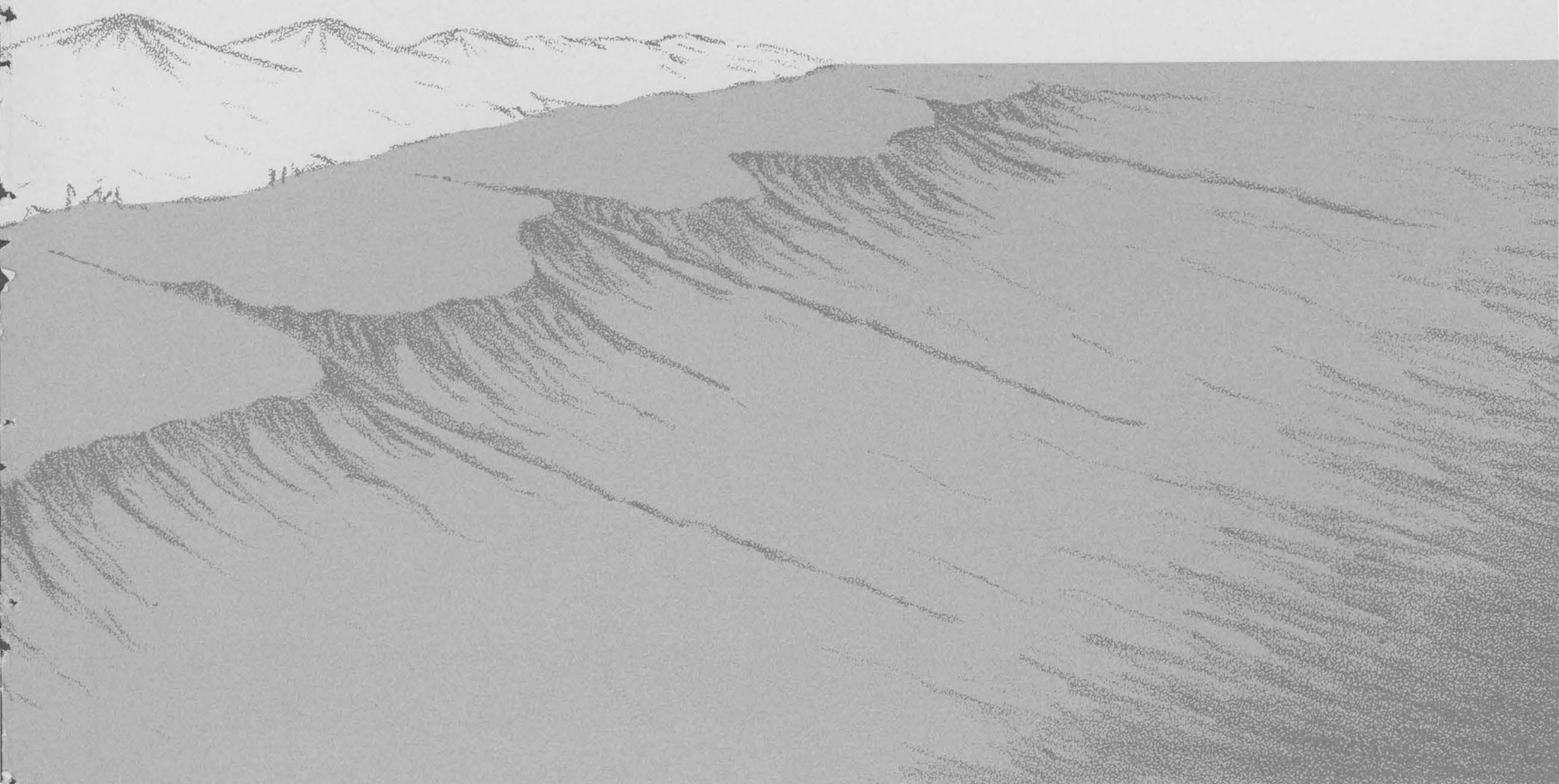
Atlantic Continental Shelf and Slope of the United States



Physiography

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-C

Atlantic Continental Shelf and Slope of The United States—Physiography

By ELAZAR UCHUPI

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Description of the submarine physiography of the continental margin between Nova Scotia and the Florida Keys

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By ELAZAR UCHUPI, Woods Hole Oceanographic Institution

ABSTRACT

The continental margin from Nova Scotia to the Florida Keys exhibits a variety of physiographic forms. On the basis of surface morphology it can be divided into three zones. In the northern zone, the continental shelf extending from Nova Scotia to Nantucket Island, has broad basins separated by shallow flat-topped banks, undulating swells, and irregularly crested ridges; some of the basins reach depths greater than 200 meters. This type of shelf topography is characteristic of shelves off glaciated areas and terminates at or near the southern limit of Pleistocene glaciation. Seaward of the shelf most of the continental slope is deeply entrenched by submarine canyons. At the foot of the slope is a large sedimentary apron known as the continental rise.

The central zone from Nantucket Island to Cape Lookout also consists of continental shelf, slope, and rise. Although smoother than in the northern zone, the surface of the shelf is disrupted by sand swells, channels, coral mounds, and terraces. Most of these features may be related to lower stands of sea level during the Pleistocene. The continental slope in this zone is as deeply entrenched by submarine canyons as the slope in the northern zone. The continental rise seaward of the continental slope is similar to that in the northern zone.

The continental margin in the southern zone from Cape Lookout to the Florida Keys is more complicated than the areas farther north. The continental slope is relatively smooth and has gradients as high as 20°—five times steeper than the slope farther north. The area landward of the slope does not consist of a simple continental shelf as it does farther north but instead consists of a shelf, a marginal plateau (the Blake Plateau), a trough (the Straits of Florida), and the Bahama Banks. In this sector of the continental margin, the topographic position occupied by the continental rise farther north is occupied by the broad flat-bottomed Blake Basin and Blake Ridge. East of Nantucket Island, topographic differences are believed to be due to glacial erosion, which has deepened the normal shallow shelf; south of Cape Lookout, they are believed to be due to folding or faulting, erosion by the Gulf Stream, and calcareous accretion.

INTRODUCTION

GENERAL STATEMENT

The submarine topography of the continental margin (fig. 1) offers abundant information on the geologic history of this complex part of the earth's crust. Description of the topographic provinces of the margin from Nova Scotia to the Florida Keys and a discussion of the origin of these provinces are the prime objectives of this report. This paper is one of a series on the marine geology of the continental margin off the Atlantic coast of the United States. Emery (1966) discussed the general aspects of the investigation, and Pratt (1968) described the physiography and sediments of the adjacent deep-sea basins. Description of the topographic provinces of the continental margin from Nova Scotia to the Florida Keys is based principally on the three charts included with this report and on more than 5,000 kilometers of PDR (Precision Depth Recorder) traces obtained during the present investigation. Physiographic interpretations presented in this paper are based largely on published reports. The conclusions are tentative and may be affected by the continuous seismic studies to be undertaken by this and other projects.

Studies of the sea bottom along the east coast of United States and Canada were initiated well over a century ago. As early as the middle of the 19th century, leadline soundings were taken by the U.S. Coast and Geodetic Survey and the British Admiralty along the coast, on offshore banks, and on the continental shelf. Later these surveys were extended seaward to include the continental slope, continental rise, and the abyssal plains. Data from these surveys were used by Agassiz (1888) to compile a topographic map of the continental margin from the Gulf of Maine to the Florida Keys. Because of the great length of time required to make wire soundings, the concentration of soundings was so low that it prevented accurate determination of the diagnostic details of the continental margin. Since the development of echo-sounding devices and accurate navigational methods, enough soundings have been collected for a regional study of the continental margin.

The first detailed investigation of the physiography of the continental margin was that of Veatch and Smith (1939), who used soundings collected during hydrographic surveys by the U.S. Coast and Geodetic Survey to compile a series of charts from Block Island to Cape Henry, Va. Later, Murray (1947) described

[1] Contribution 1567 of the Woods Hole Oceanographic Institution, based on work done under a program conducted jointly by the U.S. Geological Survey and the Woods Hole Oceanographic Institution and financed by the U.S. Geological Survey.

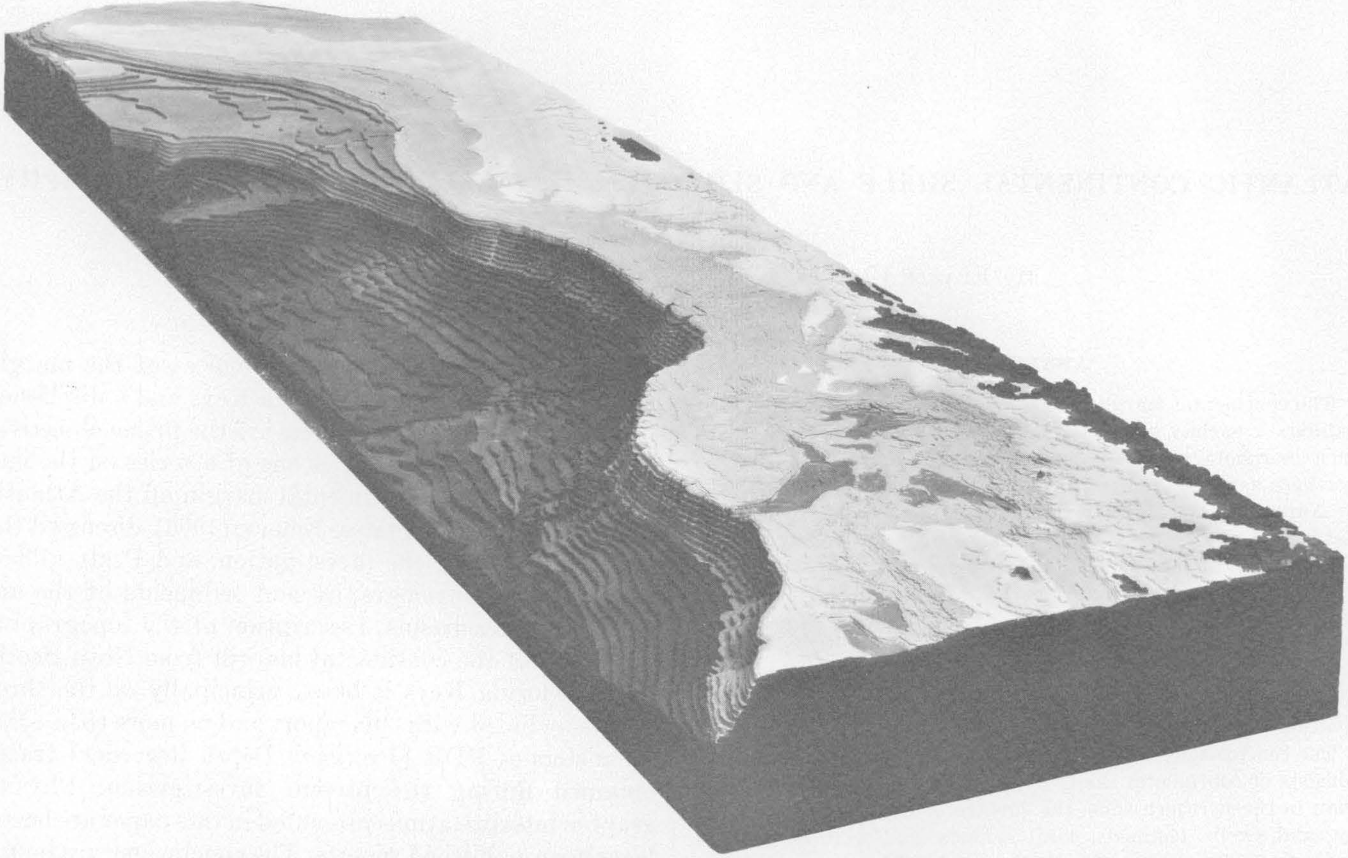

FIGURE 1.—Model of the continental margin from Nova Scotia to the Florida Keys. Vertical exaggeration approximately × 20.

the topography of the western boundary of the Gulf of Maine, and Jordan and Stewart (1961) and Jordan, Malloy, and Kofoed (1964) the topography south of the Florida Keys. These investigations were based on hydrographic surveys by the U.S. Coast and Geodetic Survey. Other local studies of the continental margin include those of Hurley, Siegler, and Fink (1962) and Hurley (1964) on the Straits of Florida, and Pratt and Heezen (1964) on the Blake Plateau. Heezen, Tharp, and Ewing (1959) included the continental margin along the east coast of North America in their study of the bathymetry of the North Atlantic Ocean, and Jordan (1962b) briefly described the physiography of the continental margin off the east coast, as well as off the gulf coast and off the west coast of the United States.

The three charts (pls. 1, 2, 3) included with this report are based on hydrographic surveys of the U.S. Coast and Geodetic Survey and the Canadian Hydrographic Service. As the sounding data obtained by these two agencies do not extend deeper than 2,200 meters, contours beyond that depth are based on unpublished data from Woods Hole Oceanographic Institution, a chart of Hudson Canyon by Heezen and Tolstoy (Heezen and others, 1959), and a chart of the Blake Plateau by Pratt and Heezen (1964). The number of soundings used to compile each chart is shown in figure 2. Soundings on which the contours are based are corrected for sound velocity. Plates 1 and 2 are based on 780,000 and 325,000 soundings, respectively, and plate 3 on 720,000 soundings.[2]

A 20-meter contour interval was used to a depth of 200 meters, except in the Gulf of Maine where this interval was continued to 400 meters and a 200-meter interval was used beyond that depth. Contours were drawn on the bromide and ozalid copies of the original survey sheets which, unlike the published charts, contain all the soundings made in the original survey. These contours were then reduced photographically to a common scale and the various parts fitted together. The adjacent coastal areas in all three charts were also contoured to

[2] The set of three maps is also available separately (I-451, Map showing relation of land and submarine topography, Nova Scotia to Florida; price $1.50) from the U.S. Geological Survey, Washington, D.C. 20242.

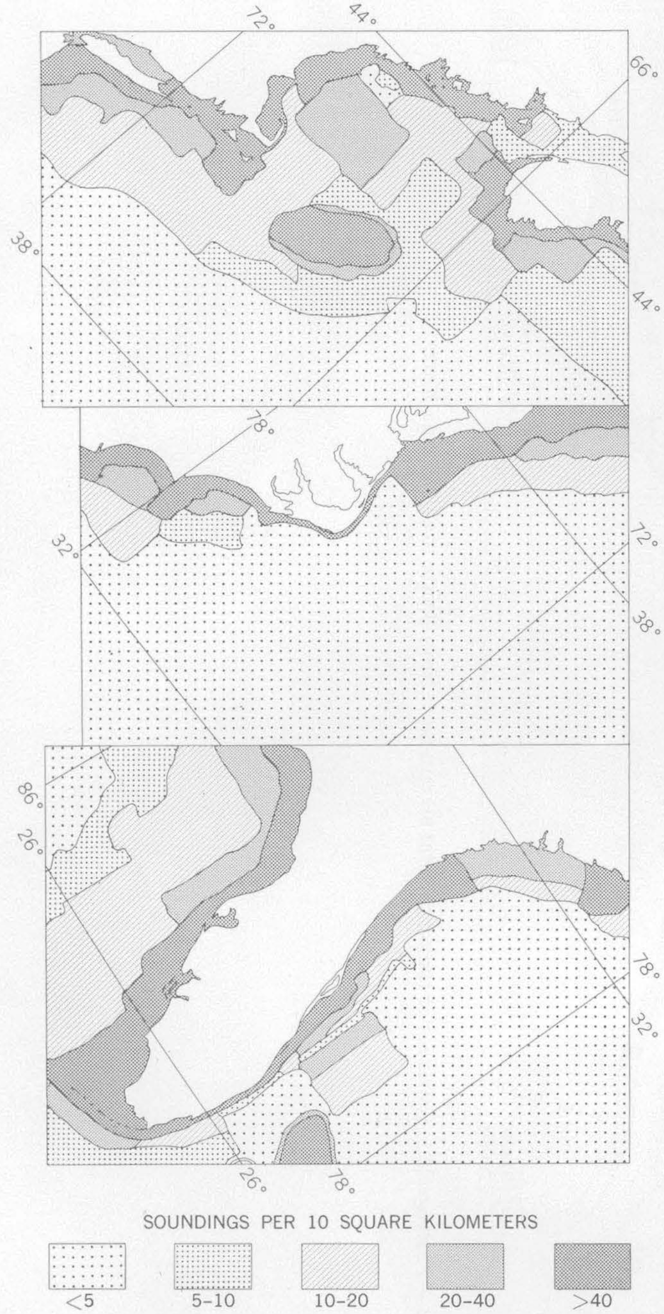

FIGURE 2.—Density of soundings used in construction of charts.

show the relationship between the land and offshore topography. The submarine features shown on these charts strongly reflect the geomorphic development of the continental margin. Gradients given throughout the text were calculated from the charts.

ACKNOWLEDGMENTS

For his suggestions during the preparation of this report the writer wishes to thank Dr. K. O. Emery, Woods Hole Oceanographic Institution. The writer is also indebted to other members of the Woods Hole Oceanographic Institution-U.S. Geological Survey continental margin project for their suggestions and criticisms during this investigation. Special thanks are due to Mr. C. J. Martin of the Canadian Hydrographic Service for furnishing ozalid copies of field sheets from the continental margin off Nova Scotia, the eastern Gulf of Maine, and the Bay of Fundy. Thanks are also extended to Mr. J. W. Kofoed of the U.S. Coast and Geodetic Survey for his help in obtaining copies of the hydrographic surveys made by this agency off the east coast of Florida in 1963. The writer wishes to express his appreciation to Dr. H. B. Stewart, Jr., and Mr. J. W. Kofoed of the U.S. Coast and Geodetic Survey, and Dr. C. A. Kaye of the U.S. Geological Survey for critical reading of the manuscript.

CONTINENTAL MARGIN

GENERAL SETTING

The first-order relief features of the earth's crust are the continents and ocean basins. The transitional zone between these two features has been designated by Heezen, Tharp, and Ewing (1959) as the continental margin. Within the area covered by the three charts included with this report, the continental margin can be broken up into several parallel physiographic provinces (fig. 3). The most striking province is the continental slope, a 1,000- to 4,000-meter-high scarp separating the continents from the ocean basins. At the foot of the continental slope north of Cape Lookout is a thick sedimentary apron known as the continental rise. South of Cape Lookout the continental rise is missing, and its topographic position is occupied by the Blake Basin and Blake Ridge. North of Cape Lookout the continental slope is bordered on the landward side by the continental shelf. From Cape Lookout to the Florida Keys the continental slope is separated from the shelf by the Blake Plateau, Bahama Banks, and the Straits of Florida.

CONTINENTAL SHELF

Along most coasts the continental shelf is a broad and fairly smooth platform extending from shore to the top of the continental slope. In the area from Nova Scotia to the Florida Keys, however, the shelf is more complex and displays a great diversity of topographic forms. On the basis of relief and depth of water, the shelf has been divided into the following provinces: Scotian Shelf, a complex surface of shallow banks and deep basins, off the coast of Nova Scotia; Georges Bank, an area characterized by parallel shoals and troughs and separated from the Scotian Shelf by Northeast Channel and from the East Coast Shelf by Great South

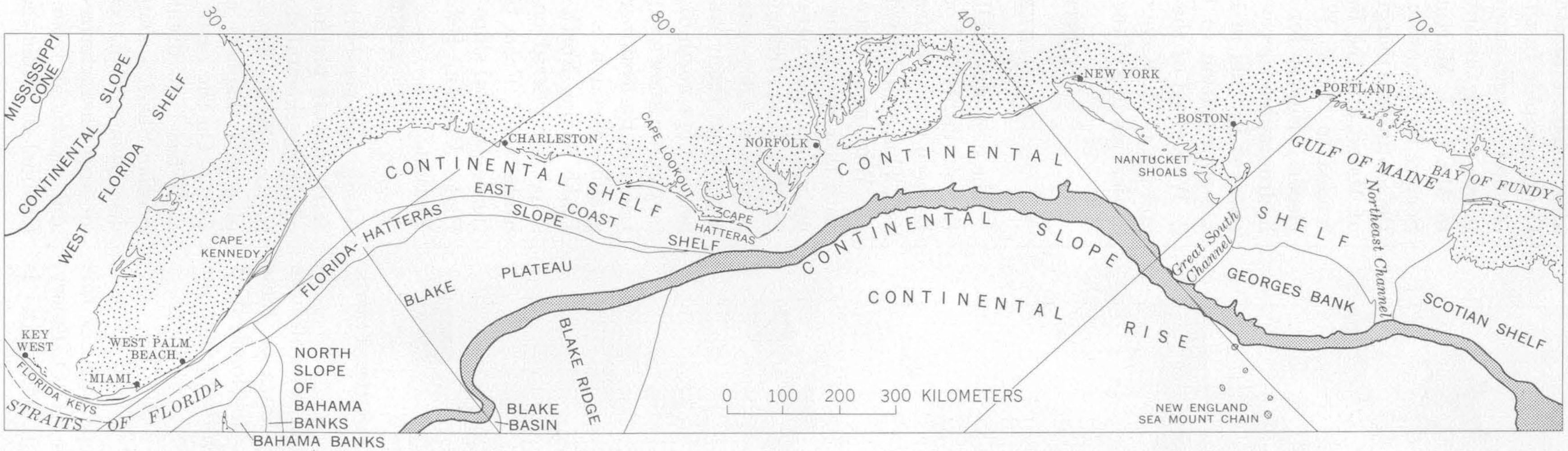

FIGURE 3.—Physiographic provinces of the continental margin from Nova Scotia to the Florida Keys.

Channel; Gulf of Maine, a rectangular depression off the New England coast; and the East Coast Shelf, a shallow platform extending from Nantucket Island to the Florida Keys (fig. 3).

SCOTIAN SHELF

The continental shelf off the coast of Nova Scotia has been designated by Canadian oceanographers as the Scotian Shelf (Heezen and others, 1959, p. 23). The shelf is 690 km long and 110–220 km wide. On the northeast it is flanked by a trough, the Laurentian Channel, which separates it from the Grand Banks (Pratt, 1968, pl. 1). Toward the southwest it terminates against Northeast Channel, a 240-meter-deep trough between Georges and Browns Banks (pl. 1).

Topographically the surface of the Scotian Shelf is complex, consisting of shallow flat-topped banks and fairly deep basins. Features atop the shelf can be divided into four zones. The first zone is an irregular rocky belt that extends from shore out to a distance of 30 km. Numerous channels with reliefs of about 30 meters cross this rough zone and debouch into a chain of basins in the center of the shelf. The topography of this zone is similar to that along the Norwegian coast which Holtedahl (1958) named Skjaergaard. The second zone is a discontinuous low area having 10–60 meters of relief, and it borders the irregular rocky belt on its seaward side south of Mahone Bay (pl. 1) and north of Browns Bank. Both of these zones are developed on the Paleozoic rocks that make up the Nova Scotian peninsula.

Southeast of these zones, in the center of the shelf, is a third zone that consists of a series of basins extending the length of the shelf. They range in depth from 185 meters below sea level in Roseway Basin to 291 meters in Emerald Basin. The sides of these basins are smooth and gentle with declivities that range from 0°06′ to 0°35′. The fourth zone is along the outer edge of the shelf beyond the basins and consists of flat-topped banks separated by low saddles (Heezen and others, 1959, p. 24). Recent seismic refraction profiles across the Scotian Shelf indicate that these banks and the basins on the landward side are floored by unconsolidated to semiconsolidated sediments (Officer and Ewing, 1954). The age of the sediments can be surmised from the Cretaceous and Tertiary fossils recovered from the banks by fishermen (Dall, 1925; Upham, 1894; Verrill, 1878).

The irregular topography atop the Scotian Shelf seems to be typical of glaciated shelves. Similar topographic features have been reported from Norway, Scotland, Labrador, southeast Alaska, Ellesmere Island, southwestern Greenland, western Spitzbergen, and eastern Antarctica (Holtedahl, 1958; Guilcher, 1963). The topography in these regions differs from that on the Scotian Shelf in that the longitudinal troughs parallel to the coasts are deeper than the one off Nova Scotia. For example, near Labrador the longitudinal depression is more than 400 km long and in places exceeds 700 meters in depth (Holtedahl, 1958).

The topography of the Scotian Shelf displays a rough dendritic pattern and suggests the existence of a fluvial cycle before glacial erosion. Subaerial exposure of the shelf may have been caused by eustatic lowering of sea level or unwarping of the shelf. If vertical uplift did take place, it does not seem to have been accompanied by rifting as it was on the continental shelves off Alaska, Norway, and Labrador. Seismic refraction profiles in the area show no evidence of faulting, either parallel or at right angles to the coast. The shallow depression along the coast is a minor corrugation in the Paleozoic terrain and was not formed by rifting. After the fluvial cycle the shelf was glaciated, and the topography was modified to its present form. The flat tops of the banks may have been formed by wave erosion as the sea transgressed the shelf after the ice retreated.

GEORGES BANK

Georges Bank is an immense barrier flanking the seaward side of the Gulf of Maine; it is separated from the Scotian Shelf by Northeast Channel and from the East Coast Shelf to the west by Great South Channel (pl. 1 and fig. 3). This topographic high, 150 km wide and 280 km long, is one of a chain of banks extending from Nantucket Island to the Grand Banks. The core of the bank consists of seaward-dipping Tertiary sediments that crop out along the face of the continental slope (Emery and Uchupi, 1965). Occurrence of Tertiary vertebrate and invertebrate fossils on the crest of the bank suggests that Recent and Pleistocene sediments which rest on these older deposits are thin (Uchupi, 1964).

The southern half of the bank's surface is a smooth plain, similar to that on the East Coast Shelf farther west. To the north, along the crest of the bank and enclosed within the 60-meter contour, is an area of rough topography characterized by a series of parallel northwest-trending shoals and troughs. This shoal and trough area of Georges Bank is a region of strong currents. Average flood and ebb tidal currents are greater than 4 km per hr, and above some of the shoals, speeds as high as 7 km per hr have been measured (Jordan, 1962a; Stewart and Jordan, 1964).

Superimposed on the shoals and troughs is a series of linear sand waves that give the region a sand-dune topography similar to that described from the desert regions of the world (fig. 4). These linear bodies have many forms: Some are sigmoidal in shape, others are branched or shaped like a fishing hook, and still others

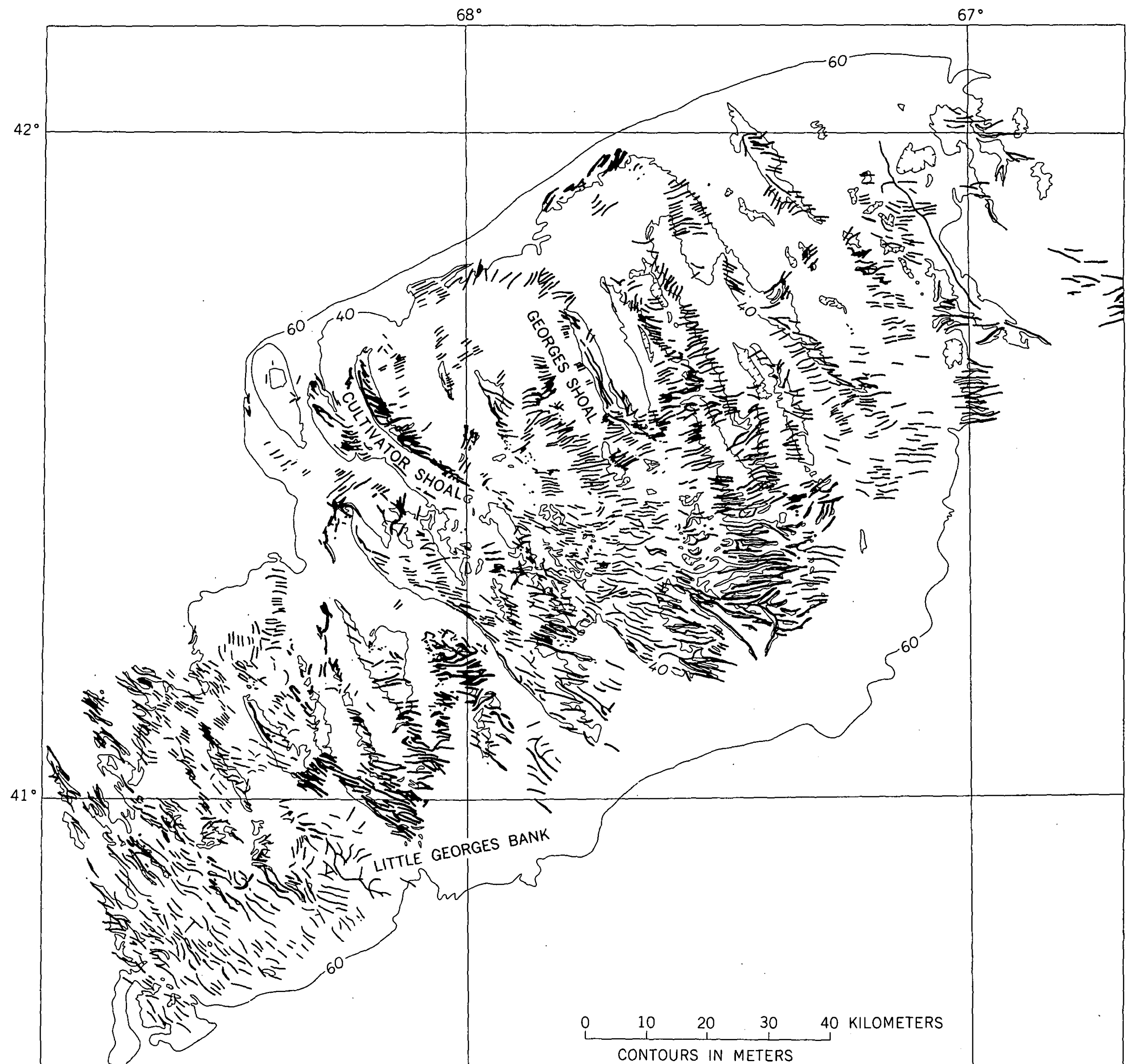

Figure 4.—Distribution of sand waves on Georges Bank. Curved lines indicate crests of sand waves. Based on soundings from U.S. Coast and Geodetic Survey hydrographic surveys.

are crescentic and resemble barchan dunes on land. Some sand waves are parallel to the flood and ebb tidal currents, and others are alined perpendicular to them. Most of the linear sand waves are symmetrical in cross section, but in a few areas asymmetrical sand waves are present (Jordan, 1962a). The asymmetrical waves that occur on the shoal areas generally face away from the Gulf of Maine; that is, the steeper side is toward the open sea. Those that occur between the shoals, face toward the Gulf of Maine, or away from the flood tidal currents (Jordan, 1962a). Exceptions to this orientation are the asymmetrical waves that face the open sea in a large area south of Georges Shoal. These linear sand waves range from 10 to 20 meters high, are about 100–700 meters apart, and are 200 meters to as much as 10 km long.

The two most prominent highs within the ridge and trough area of Georges Bank are Cultivator and Georges

Shoals. Both are asymmetrical, the west side having a gradient of 6° for Georges Shoal and 2° for Cultivator Shoal. The gentler east flank of Georges Shoal has a declivity of 0°11′, that of Cultivator 0°20′. The crest of Georges Shoal is composed of a series of sand waves parallel to the long axis and streaming parallel to the tidal currents at flood and ebb; they are 10–20 meters high and about 7 km long. The sand waves on the flanks of the shoal trend east-west. Stewart and Jordan (1964) found that when the tidal current flows at right angles to the sand waves atop the shoal the entire crest of [each] sand wave is in violent sheet flow at least 1 meter thick. The sand waves along the flank, on the other hand, do not appear to be affected by tidal currents. Stewart and Jordan (1964), who compared the 1930–32 hydrographic surveys with those of 1957–58, found that the sand waves on the crest of Georges Bank have migrated at least 300 meters to the west. They suggested that such migration was due to a westerly flowing current which caused a net transport of sediment placed in suspension by strong tidal currents. According to them, the deeper sand waves do not appear to be active and are probably not related to the present hydrologic regime. The deeper sand waves terminate abruptly against the steeper slope of Georges Shoal, suggesting that the shoal is migrating westward and is slowly burying the earlier structures.

Cultivator Shoal (fig. 5) is similar to Georges Shoal in trend, size, and general depth. It differs in that its northern tip curves to the northeast rather than to the northwest. The sand waves on Cultivator Shoal also differ in that they have rather strong southeasterly to easterly curving tails. They are 4–30 meters high, and the one along the west edge of the shoal is more than 10 km long.

According to Shepard, Trefethen, and Cohee (1934) the sand shoals along the crest of Georges Bank are part of a morainic ridge reshaped into its present form by tidal currents. They also suggested that the troughs between the ridges were excavated by the same currents. A series of gravelly silt samples recovered from just below the surface sediments on Georges Bank by a U.S. Coast and Geodetic Survey vessel whose large anchor had sunk deep into the sediment during a storm might be interpreted as glacial till; however, more recent seismic data (Emery and Uchupi, 1965) suggest that these silty sediments are probably not till, but rather Tertiary sediments that occur just below the Recent and Pleistocene sands. Borings on Georges Shoal indicate that the shoals are composed not of till but of clean sand with some gravel (J. M. Zeigler, oral commun., 1965). The sediments of the shoals and surrounding area have all the characteristics of water-laid deposits; therefore, they probably are glacial outwash deposits laid down near or adjacent to the glacier. Some local relief may be related to their former position in crevasses or other spaces at the ragged edge of stagnant ice. Later when the sea transgressed the area, the submarine topography was modified to nearly its present shape. Further modification of the deposits by tidal currents has led to the formation of sand waves atop the shoals and in the troughs.

GULF OF MAINE

One of the most striking topographic features off the east coast of the United States is the Gulf of Maine, a 90,700 km² rectangular depression having an average depth of 150 meters. It is flanked on the north, northeast, and west by the mainland, on the southwest by the East Coast Shelf, and on the seaward side by Georges Bank and the Scotian Shelf (fig. 3). Northeast of the gulf is the Bay of Fundy, a shallow **U**-shaped trough between Nova Scotia and New Brunswick. Northeast Channel, a 40-km wide and 70-km long trough on the southeast, provides a deep-water connection between the gulf and the open sea. The floor of the Gulf of Maine consists of a series of fairly deep, northwest-, northeast-, and east-trending basins separated by low swells, some of which are capped by flat-topped banks. The basins occupy about 30 percent of the gulf and the topographic highs the remaining 70 percent.

The southern and western sides of the Gulf of Maine are relatively smooth and gentle and have heights of 20–240 meters. In contrast, the northern and eastern sides are very irregular. They have ridges, small pinnacles, and many shallow channels partly filled with sediment (fig. 6).

The sea floor in the center of the gulf is rather complex, consisting of basins, low swells, and flat-topped banks. The most prominent topographic high in this area is Cashes Ledge, a ridge 57 km long and 8–10 km wide near the center of the gulf. Depths along its crest range from 40 to 60 meters except at Ammen Rock, where the ledge shoals to 9 meters. A sample from Cashes Ledge consists of peralkaline granite which resembles petrographically the alkaline granites of New England that generally have been assigned to the White Mountain Plutonic-Volcanic Series (Toulmin, 1957).

Within the gulf are 21 basins with sill depths ranging from 59 to 242 meters (table 1 and fig. 7). The areas at sill depth for these basins range from 30 to 10,400 km² and the volumes from 0.2 to 322 km³ (table 1). This represents 7.6 percent of the total water present in the gulf. Most of these basins are compound (but individual depressions are named in only three); that is, they enclose several areas that are much deeper than their surroundings. For example, six such depressions, Murray,

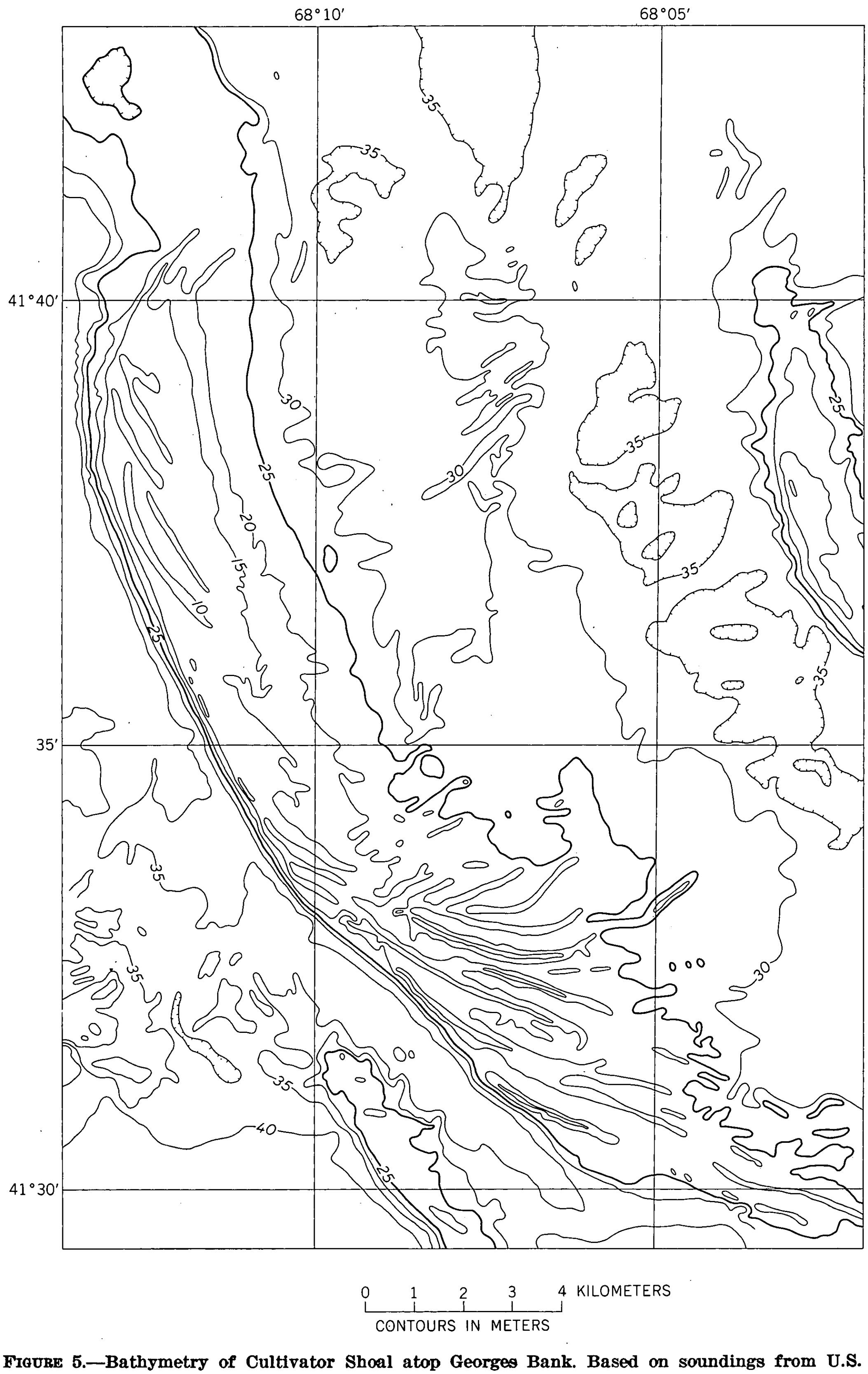

Figure 5.—Bathymetry of Cultivator Shoal atop Georges Bank. Based on soundings from U.S. Coast and Geodetic Survey hydrographic survey.

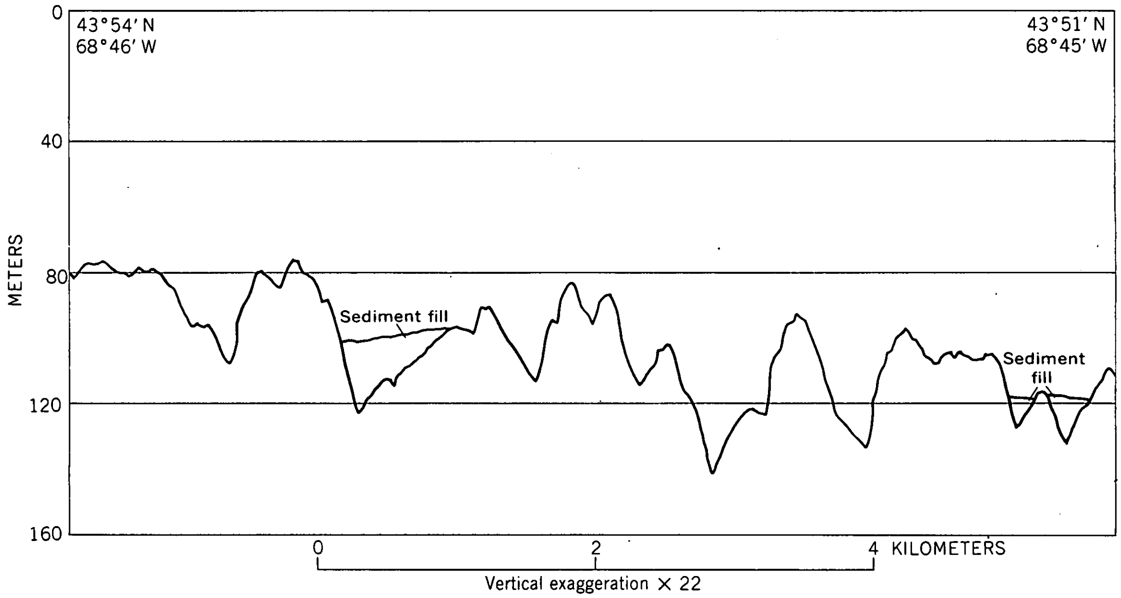

Figure 6.—Trace of a Precision Depth Recorder profile of a series of small channels along the north slope of the Gulf of Maine.

Table 1.—*Depth, area, and volume of basins in the Gulf of Maine*

[From Uchupi, 1965]

Basin	Depth to bottom (meters)	Depth to lowest sill (meters)	Mean depth (meters)	Area of basin at sill depth (km²)	Volume (km³)
Davis, Howell, Murray, Rodgers, Sharrer, Wilkinson	295	188	219	10, 400	322. 4
Blacks, Cashes, Sigsbee	220	165	190	1, 100	39. 6
Jordan, Truxton	311	190	214	8, 070	193. 7
Ammen	221	185	197	760	9. 3
Crowell	304	212	235	1, 310	30. 1
Elizabeth	198	158	178	170	30. 4
Franklin	243	229	236	340	20. 4
Georges	377	242	286	5, 200	228. 8
Lindenkohl	238	223	235	160	1. 9
Little Stellwagen	64	59	62	90	. 3
Owen	157	114	129	210	3. 2
Grand Manan	211	161	183	1, 590	35. 0
Matinicus	227	183	205	600	13. 2
Murr	119	70	77	190	1. 0
Neddick	185	139	149	90	. 9
Platts	180	167	174	1, 240	8. 7
Porpoise	188	154	167	320	4. 2
Scantum	139	127	133	30	. 2
Stellwagen	102	78	89	350	3. 9
Tillies	170	81	105	390	9. 4
Tusket	275	201	228	180	4. 8

Wilkinson, Sharrer, Howell, Rodgers, and Davis Basins occur within the large basin east of Cape Cod (fig. 7). The basin floor between these depressions is irregular, but the deeper sections are flat bottomed. The sediments of the basin floors consist principally of brown silt. This deposit is so transparent to sound that profiles taken with an ordinary echo sounder usually display a strong subbottom reflector (fig. 8; Murray, 1947). This subbottom horizon probably represents a harder sedimentary layer.

Johnson (1925), in a study of the topography of the Gulf of Maine, suggested that it was carved subaerially out of the continental shelf sediments and later drowned. He suggested that the basins in the gulf were stream valleys and that Northeast Channel was the gap of this former drainage system. He also believed that glacial erosion played an insignificant part in the formation of the gulf.

Johnson's study of the morphology of the gulf was based on a few scattered leadline soundings that were inadequate to portray the gulf's diagnostic features. Since then, enough soundings have been obtained by the U.S. Coast and Geodetic Survey and the Canadian Hydrographic Service to outline the topography of the gulf in considerable detail. These new soundings plus the hundreds of bottom samples now available indicate that the geomorphic evolution of the gulf is more complex than Johnson believed. Topographic features in the area are not similar to those found on a maturely dissected coastal plain but are more typical of a glacially eroded topography. Most of the sediments have characteristics similar to known glacial deposits on land, suggesting that glacial erosion and deposition have played a significant role in the formation of the

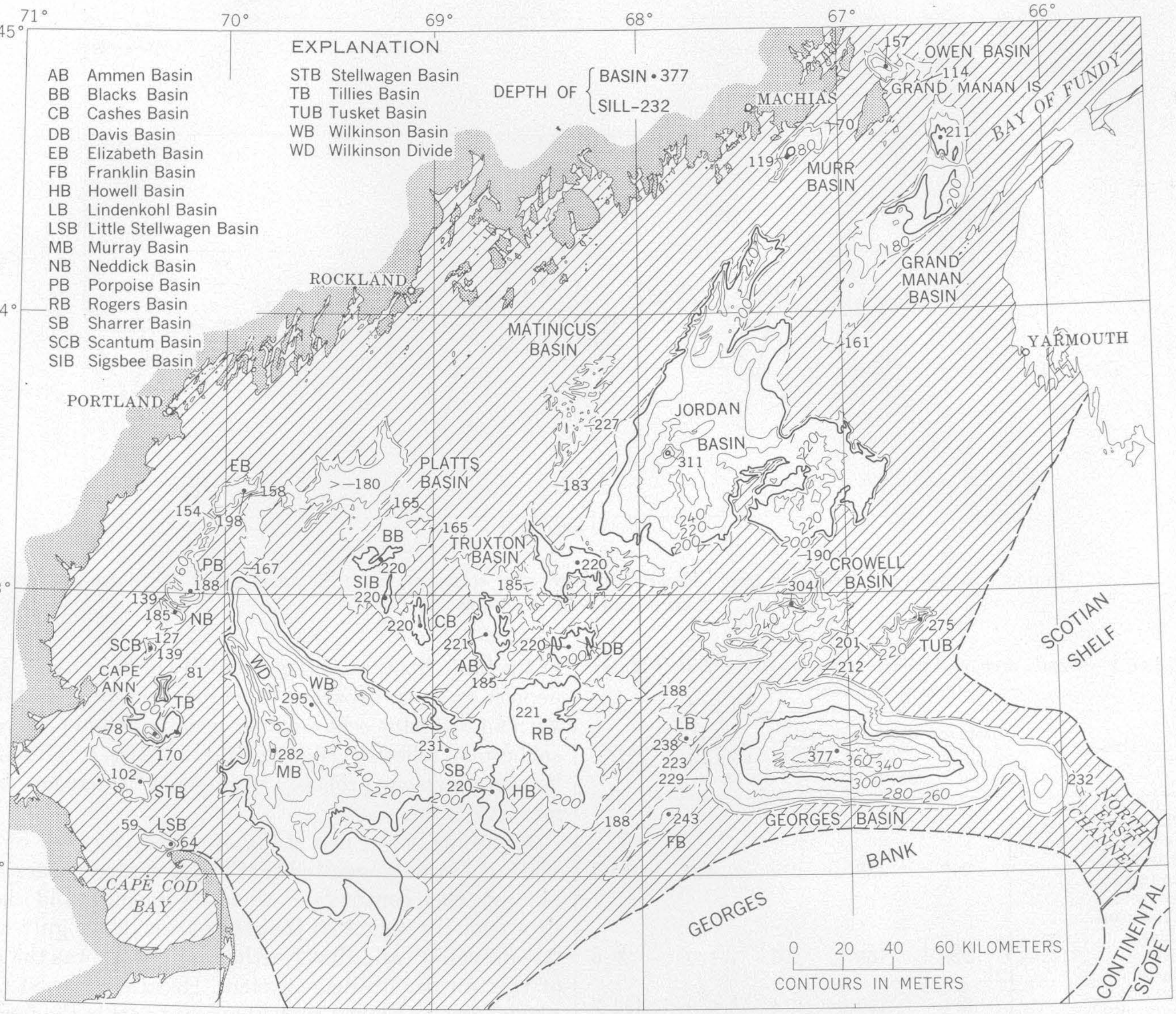

FIGURE 7.—Outline of the basins within the Gulf of Maine. Based on soundings from the U.S. Coast and Geodetic Survey and the Canadian Hydrographic Service. Dashed lines delineate the outlines of the basins. Slanted lines represent the nonbasinal area of the gulf. From Uchupi (1965, fig. 1).

gulf. Thus, the origin of the gulf is probably due to a combination of glacial and fluvial erosion. During the fluvial cycle an inner lowland (Gulf of Maine) and Georges Bank were carved out of the continental shelf strata. The Cretaceous(?) erosional remnants in Cape Cod Bay that were reported by Hoskins and Knott (1961) probably reflect this subaerial cycle. Northeast Channel represents the gap of this drainage system. Later the gulf was glaciated, and the former fluvial topography was modified into its present form. The ice appears to have terminated against Georges Bank and to have reached the sea by way of Northeast Channel as suggested by Torphy and Zeigler (1957). The Pleistocene events that molded the gulf's bottom were probably as complex as those described by Kaye (1964) from nearby Martha's Vineyard.

EAST COAST SHELF

From Great South Channel to the Florida Keys is a seaward-dipping platform extending from shore to the continental slope, the Blake Plateau, and the Florida-Hatteras Slope (fig. 3). The name East Coast Shelf is suggested for this province. This platform is 190 km wide south of New York City, 23 km wide off Cape Hatteras, 132 km wide at lat 31° and 3 km wide off West Palm Beach, Fla. The shelf's declivity ranges from 0°07′

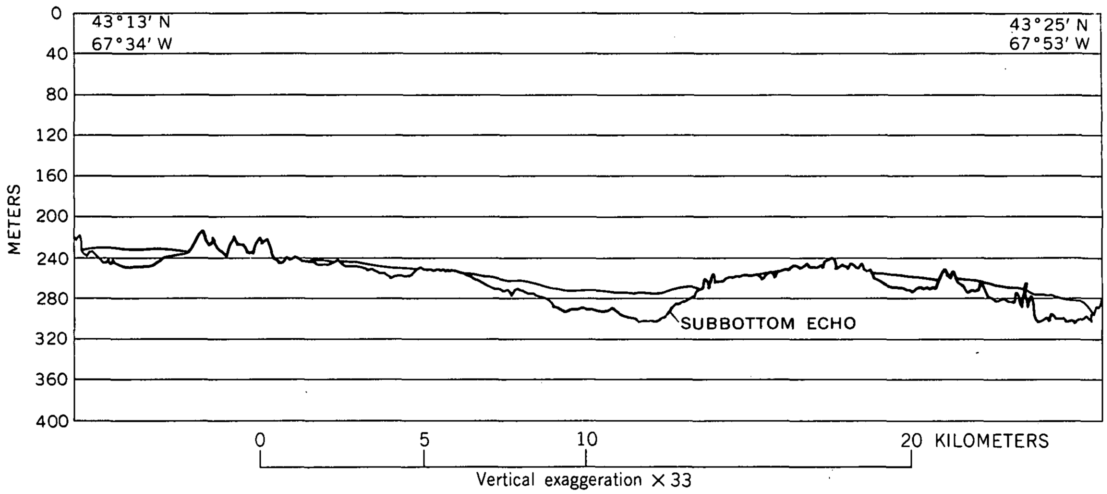

FIGURE 8.—Bottom profile showing subbottom reflector in the deeper parts of Jordan Basin.

off Cape Hatteras to 0°03′ off New York City and 0°02′ off Jacksonville. South of Jacksonville the shelf's gradient increases rapidly and reaches 0°17′ at lat 27°. Between lat 27° and Miami the surface of the shelf is very irregular, narrow and steep (fig. 9). The gradient on this section of the shelf is about 1° and the width is less than 2 km.

From New York to Cape Hatteras, the East Coast Shelf is flanked by the continental slope, from Hatteras to Cape Lookout by the Blake Plateau, and south of Cape Lookout by the Florida-Hatteras Slope. The transition between the shelf and these features is known as the shelf-break (Dietz and Menard, 1951). Off Cape Hatteras the shelf-break is at a depth of 55 meters; it increases to 120–160 meters between Norfolk and Nantucket Island, and to about 70 meters off Jacksonville. South of Jacksonville the shelf-break becomes progressively shallower to a depth of less than 10 meters off the Florida Keys (fig. 10). Variation in depth along the shelf-break is due to sediment upbuilding off Cape Hatteras and to calcareous organic deposition off south Florida.

The shelf's surface is not a smooth plain; it is broken by many minor irregularities, most of which have less than 10 meters of relief. These features can be divided into two groups: (1) erosional forms cut into the shelf, such as channels and terraces, and (2) depositional forms that rise above its general level, such as sand swells and coral reefs.

One of the largest erosional features is a channel that extends from the mouth of Hudson River to the head of Hudson Canyon. It is about 170 km long, 27 km wide at its mouth, and has an average gradient of 0°04′. The channel was cut by the Hudson River during the Pleistocene Epoch, when sea level was near the shelf-break. Throughout most of its length the channel consists of a series of troughs separated by low swells; some of these troughs have a relief of 40 meters.

Between Long Island and Martha's Vineyard are several shallow channels, but they do not seem to extend across the shelf. The broad and gentle depression along the shelf's edge south of Block Island is another example of erosion cutting into the shelf. The shape of this depression and the occurrence of slump hummocks at the base of the continental slope suggest that it may have been formed by some sort of mass movement. According to Moore and Curray (1963), movement along the east-west fracture zone that transects this part of the continental margin may have been responsible for formation of the depression. They suggested that the indentation is probably preserved because of nondeposition due to a low rate of sediment supply.

Great South Channel, separating the East Coast Shelf from Georges Bank, is another erosional feature on the shelf. During the past, the channel probably extended farther south and connected with the head of Hydrographer Canyon. Later its outer end was buried, thus separating it from the canyon.

Another erosional feature on the shelf is a series of terraces that are ancient beaches formed during the last transgression of the sea (table 2). These terraces occur from New York to Miami and are at virtually uniform depths.

The most striking of the depositional features atop the shelf are the large numbers of sand shoals in the vicinity of Nantucket Island (fig. 11). The features are similar to and display as many forms as those on Georges Bank (fig. 12). The whole area is characterized

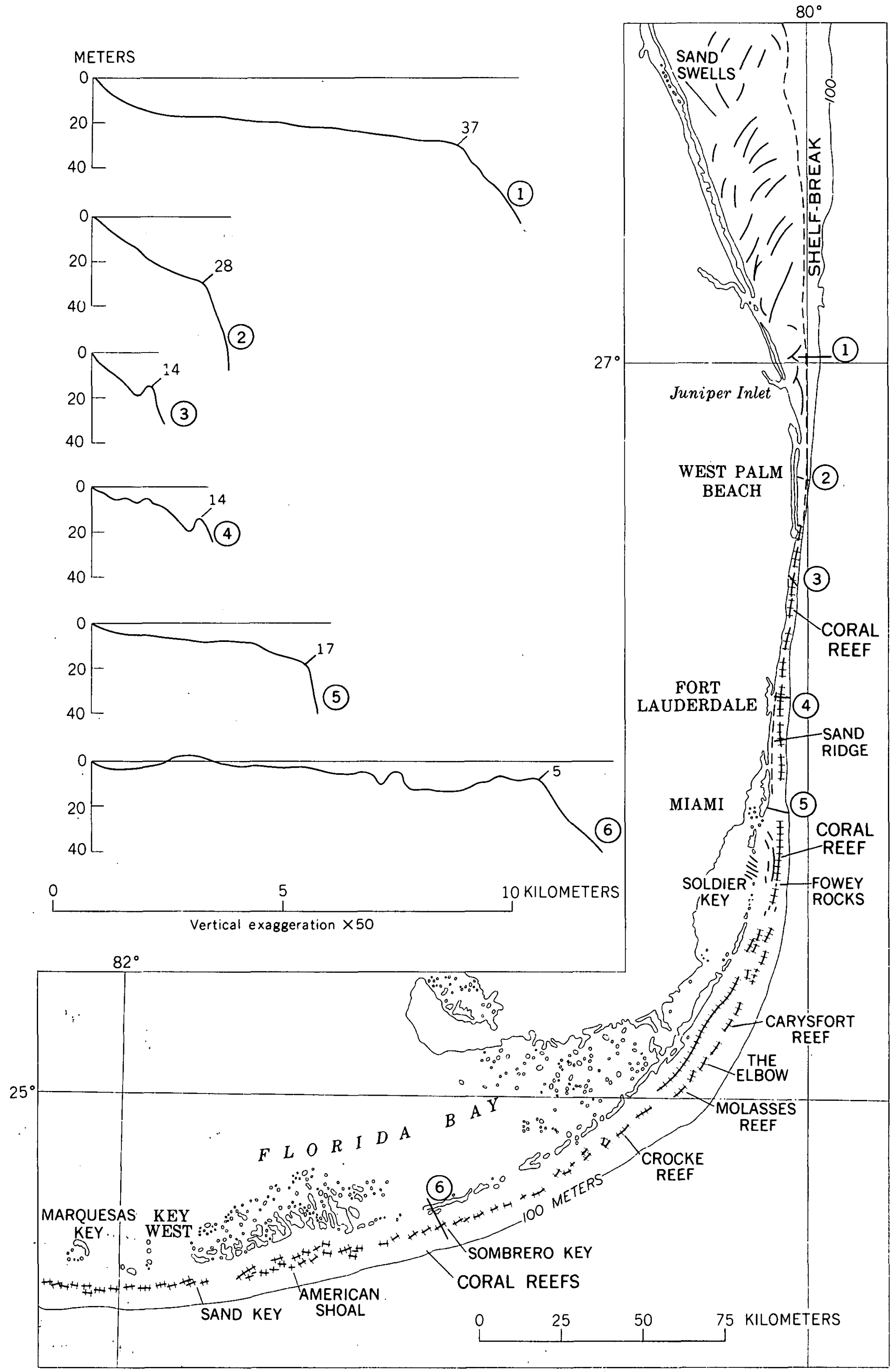

FIGURE 9.—Morphology of the continental shelf from Juniper Inlet to Marquesas Key, Fla., with representative profiles. Circled numbers indicate locations of the profiles. Based on U.S. Coast and Geodetic Survey hydrographic surveys.

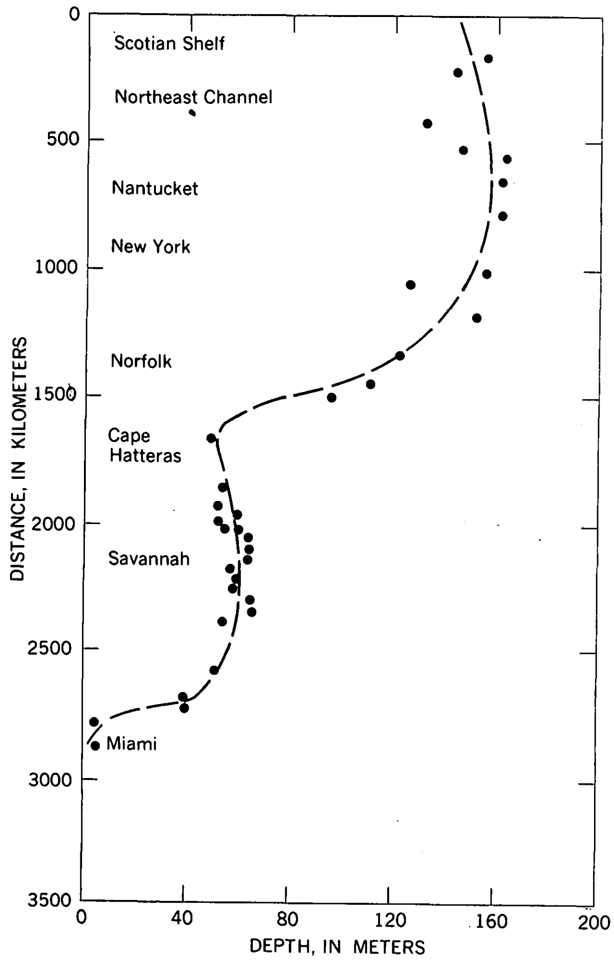

FIGURE 10.—Variation in depth along the shelf-break from Nova Scotia to the Florida Keys. Dots show depth of shelf-break along Precision Depth Recorder profiles obtained during present survey; dashed line shows average depth.

by a complex dunelike topography reflecting the strong tidal currents. On the crest of the shoals and in the troughs between them are innumerable small linear sand waves, most of which are alined at right angles to the flood and ebb tidal currents. A few of the larger sand waves along the crest of the shoals, however, are parallel to the tidal currents at flood and ebb. Because of its shifting shoals, some of which are only 1 meter below sea level, this area is probably one of the greatest hazards to navigation along the east coast of the United States.

Most shoals in Nantucket Shoals may consist of reworked glacial sediments, similar to those on Georges Bank, but the sand shoals along the eastern edge may have a different origin. A boring in one of the shoals there showed that it consists of medium to fine sand with traces of silt and gravel (Zeigler and others, 1964;

TABLE 2.—*Depth to outer edge of terraces of the continental shelf, slope, and Florida-Hatteras Slope (in meters)*

[Based on Precision Depth Recorder records obtained during the present survey]

Martha's Vineyard, Mass.	Atlantic City, N.J.	Onslow Bay, N.C.	Savannah, Ga.	Cape Kennedy, Fla.	Miami, Fla.
-------	-------	-------	-------	-------	10
-------	-------	-------	-------	-------	15
-------	20	20	-------	20	18
-------	-------	-------	25	25	-------
-------	-------	30	-------	30	-------
35	-------	-------	33	-------	33
-------	40	40	40	40	-------
43	-------	45	45	-------	-------
-------	-------	-------	50	50	-------
55	-------	-------	55	-------	-------
63	-------	63	-------	-------	62
-------	-------	-------	67	65	-------
-------	-------	70	-------	-------	70
80	83	80	80	-------	80
-------	95	-------	-------	-------	-------
-------	-------	100	-------	-------	-------
-------	120	120	-------	-------	-------
125	-------	-------	-------	-------	-------
-------	130	-------	-------	-------	-------
-------	140	-------	-------	-------	-------
158	-------	-------	-------	-------	-------
-------	-------	170	-------	-------	-------
-------	175	-------	-------	-------	-------
-------	-------	200	-------	-------	-------
210	-------	-------	-------	-------	-------

Groot and Groot, 1964). Beneath the sandy shoal is a silt bed of unknown thickness that contains abundant Eocene spores and pollen; the upper meter or so has undergone considerable reworking. The sandy sediments making up the shoal contain Quaternary spores, pollen, dinoflagellates, and reworked Cretaceous and Tertiary spores and pollen (Groot and Groot, 1964). The dinoflagellates indicate that the sand was deposited in a marine environment. A shell of *Crepidula fornicata* within the reworked silt zone has a carbon-14 date of 11,465±400 years B.P. (Before Present), indicating that shoal sands are younger than 11,465 years (Zeigler and others, 1964). This species is found living at the present time from the intertidal zone to a depth of 20 meters. Probably the source of the sand was Cape Cod. During the smoothing of the eastern shore of the outer arm of Cape Cod by wave erosion in postglacial time, a large volume of sediment was transported by littoral drift, some north and some south. The northerly transport formed the Provincetown spit at the tip of the Cape Cod peninsula, whereas some of the sediment transported south was deposited east of Nantucket Island. Reworking of the sediments by tidal currents resulted in the present bottom topography.

Among other depositional features on the shelf are the ridge southwest of Martha's Vineyard and the shallow banks east of Block Island (pl. 1). They are probably seaward extensions of the morainic ridge that lies

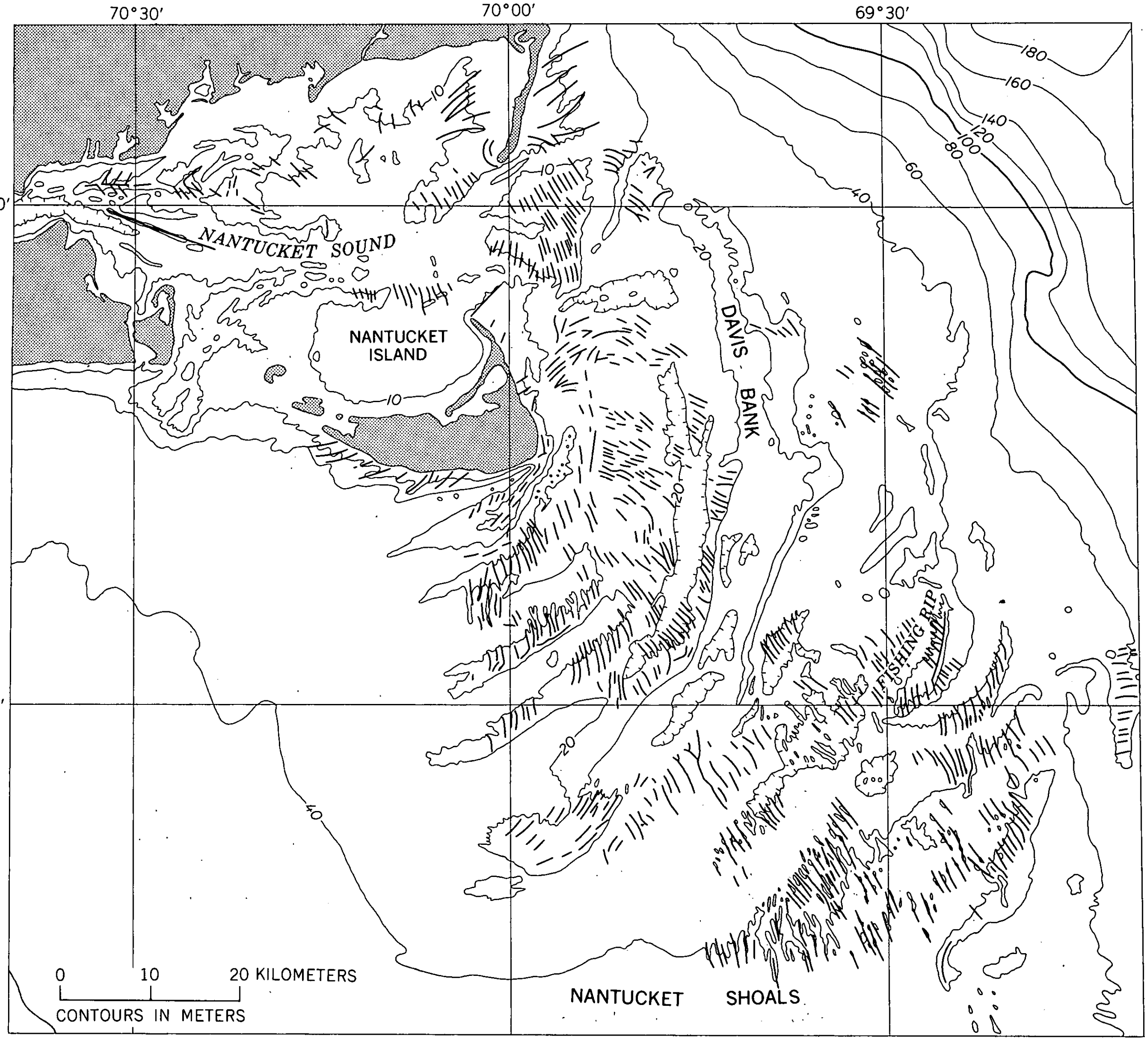

FIGURE 11.—Distribution of sand shoals and sand waves on Nantucket Shoals and Nantucket Sound. Curved lines indicate crests of sand waves. Based on soundings from U.S. Coast and Geodetic Survey.

along the southwest side of Martha's Vineyard. The banks east of Long Island may be seaward extensions of the Harbor Hill and Ronkonkoma moraines. Another depositional form on the shelf has been called Hudson Apron by Veatch and Smith (1939, p. 14); it is a generally smooth region on either side of the submarine extension of the Hudson River that is known as Hudson Channel. This channel meanders across the surface of the apron. The seaward side of the apron is truncated by two terraces, 100 and 160 meters deep (these are the Franklin and Nicholls terraces—also called shores—of Veatch and Smith, 1939, p. 42, 44, and charts 1 and 2); this side of the apron is also deeply entrenched by Hudson Canyon. Seismic reflection profiles indicate that the apron is a deltaic structure that was deposited during the Pleistocene (Ewing, Le Pichon, and Ewing, 1963, p. 6312).

Included with the depositional forms atop the shelf are the low circular algal banks along the Carolina coast that extend from shore to the outer edge of the continental shelf (Pearse and Williams, 1951), and the active and dead coral reefs south of West Palm Beach (fig. 9). Other depositional forms on the shelf are the southeast-trending shoals seaward of the cuspate forelands of Capes Hatteras, Lookout, Fear, and Kennedy.

The most unusual depositional forms on the shelf are

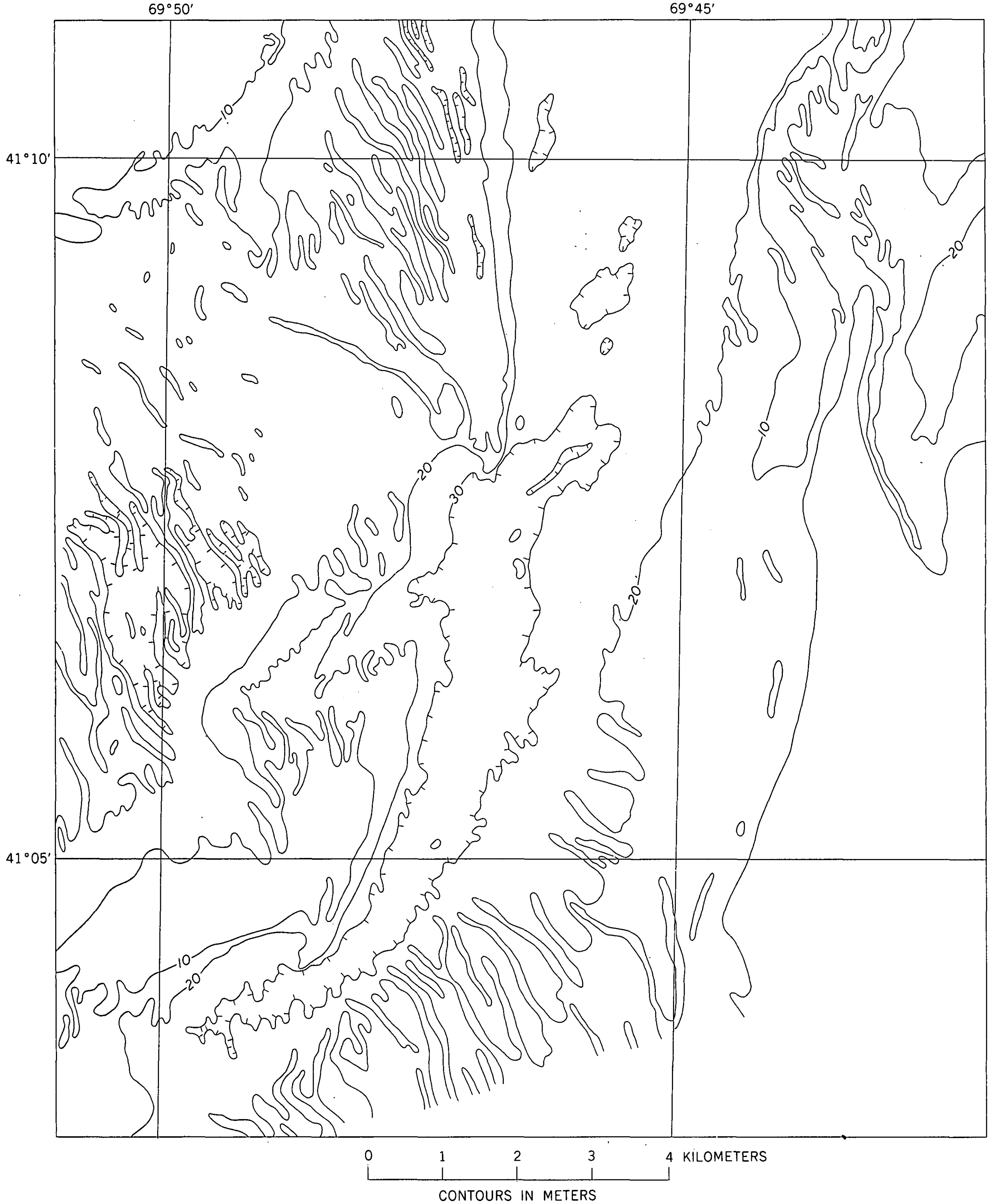

FIGURE 12.—Detailed map of a section of Nantucket Shoals showing several sand shoals with sand waves along their crests and flanks. Based on soundings from U.S. Coast and Geodetic Survey.

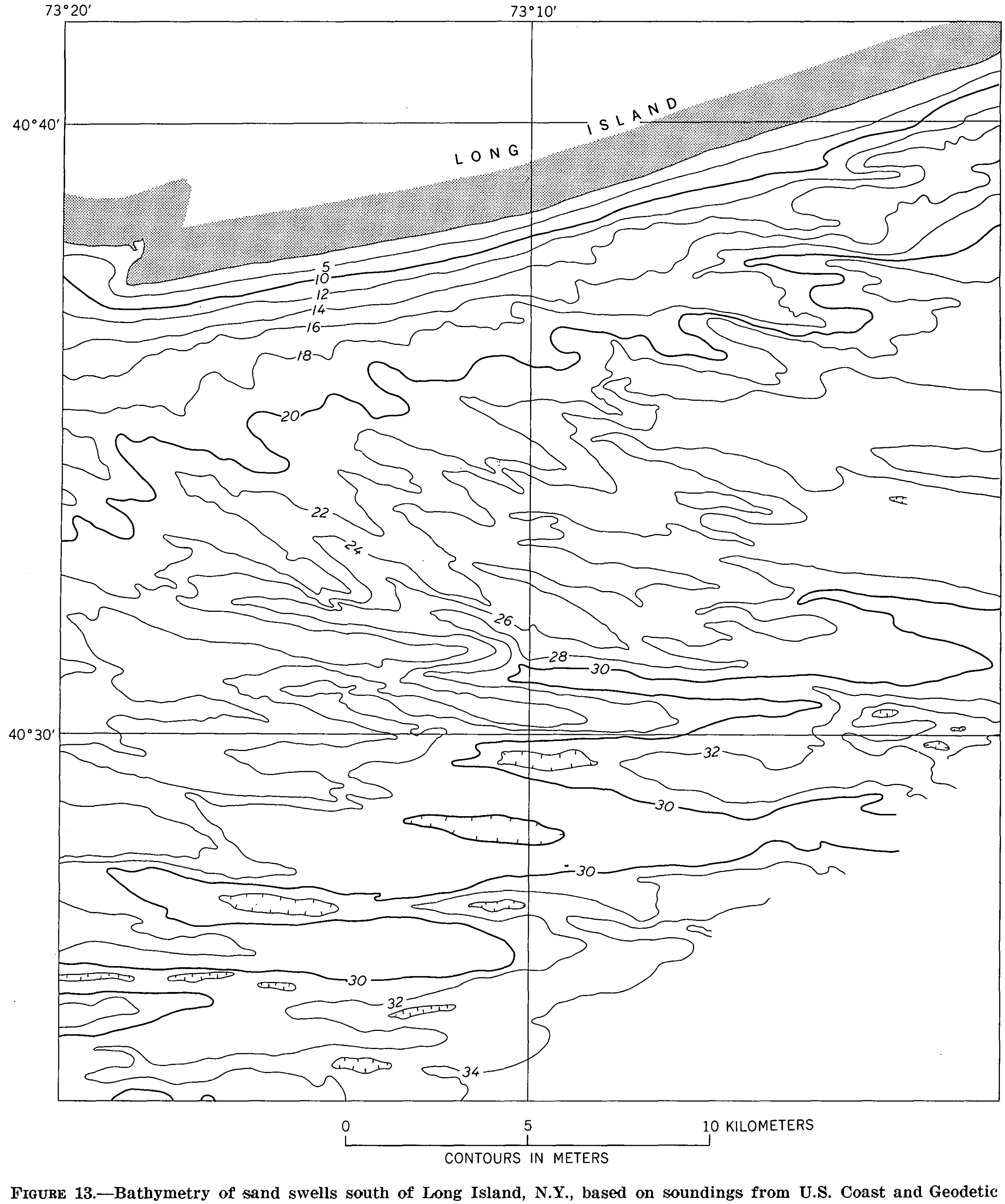

FIGURE 13.—Bathymetry of sand swells south of Long Island, N.Y., based on soundings from U.S. Coast and Geodetic Survey.

linear sand bodies that can be traced almost the whole width of the shelf. On the landward side they seem to terminate at a depth of 10–12 meters (fig. 13). They are about 4 km wide and tens of kilometers long, are symmetrical and broad in cross section, and have side slopes of 1° and 2°. They seem to be present in all the sandy areas of the shelf and absent where gravelly sediments are dominant, as in the 40-meter terrace along the south flank of Hudson Channel of Veatch and Smith (1939). East of the channel they are alined in an east-west direction, but farther south they trend northeast-southwest. The term "sand swells" is suggested for these features.

The few soundings available between Cape Hatteras and Cape Fear suggest that sand swells are present here, too. In Long Bay between Cape Fear and Cape Romain, the swells have a complex orientation diverging like the spokes of a wheel (fig. 14). A similar divergence can be observed in the broad reentrant between Cape Romain and Cape Kennedy. From Cape Kennedy to Juniper Inlet, however, the sand swells near the coast trend in a V north-south direction (fig. 9).

Shepard (1963, p. 214) suggested that the linear sand bodies north of Norfolk, Va., are drowned barrier beaches. In a study of one of the ridges south of Cape Henry, Sanders (1962) found that it was composed of coarse brown sand along the crest and fine gray sand along the flanks. He suggested tentatively that the ridge is one of the coastal beach-dune complexes that were formed at various Pleistocene stillstands of sea level. If the origin suggested by Shepard (1963, p. 214) and Sanders (1962) is true, there has been a drastic change in the alinement of the shoreline in recent times. An alternative explanation is that the linear sand bodies are forming now during intense storms and remaining inactive between storms; if this explanation is correct, they do not delineate former strandlines as suggested by Sanders and Shepard. As pointed out by Hadley (1964, p. 164), wave-induced oscillatory currents during a storm of gale force 10 on the Beaufort Scale (about 90 km per hour) theoretically may produce currents as high as 4 km per hour at a depth of 180 meters. Such velocities are strong enough to move the sediments present on the shelf.

INTERMEDIATE PROVINCES

The continental shelf north of Cape Hatteras is flanked along its seaward side by the continental slope. South of Cape Hatteras, on the other hand, the shelf is separated from the slope by the Blake Plateau, the Bahama Banks, and the Straits of Florida. As only the western edge of the Bahama Banks is included in the area under investigation, those banks are beyond the scope of this discussion.

BLAKE PLATEAU

The Blake Plateau is a broad platform extending from the northern tip of the Straits of Florida to Cape Lookout, where it merges with the continental slope. Depths on the plateau range from 60 to 750 meters along its western margin and from 800 to 1,000 meters along its outer edge. Along its seaward edge the plateau is flanked by the continental slope, called the Blake Escarpment in this region. It is separated from the Bahama Banks by a smooth 800-meter-high slope that has a gradient of 0°14′; the smooth and rounded nature of this slope suggests that it was formed by sediments prograding in a seaward direction. On the western side the plateau is bordered throughout most of its length by a relatively smooth slope that leads up to the continental shelf. The name Florida-Hatteras Slope is suggested for this feature extending from Cape Lookout to the Florida Keys. Relief on this inner slope ranges from a few meters near Cape Lookout to more than 700 meters off Cape Kennedy.

North of lat 34° the Blake Plateau has the form of a ramp leading from the shelf's edge at a depth of 50–60 meters to the top of the continental slope at a depth of 800 meters (profiles 2 and 3, fig. 15). The ramp becomes progressively narrower and steeper toward the north until it blends with the continental slope (profile 1, fig. 15). Toward the south the plateau widens and decreases in declivity. Between lat 34° and 32° it has a gradient between 0°47′ and 0°20′ and a width of 40–140 km. This segment of the plateau is not as smooth, as shown by the profiles constructed from plate 2. Bottom profiles taken with a Precision Depth Recorder show that this smooth platform is disrupted by giant benches whose seaward edges are at depths of 320 and 280 meters. The benches are separated by slopes about 40 meters high.

South of lat 32° the Blake Plateau consists of a series of broad benches separated by slopes that are 100–200 meters high and that have declivities of about 0°15′ (fig. 16). The outer edges of the benches are at depths of 400, 600, 900, 1,100, and 1,200 meters. The surfaces of the benches are slightly warped and contain many boxlike depressions with steep side slopes. At the base of some of the slopes separating the benches are depressions, some of which are fringed by coral mounds. In the vicinity of the large depression near lat 32° (pl. 2), for example, are at least 200 mounds, some of which are as high as 160 meters (Stetson and others, 1962, p. 1). Seaward of the benches, the plateau is relatively smooth. Within this smooth zone is a northeast-trending spurlike projection for which the name Blake Spur is suggested.

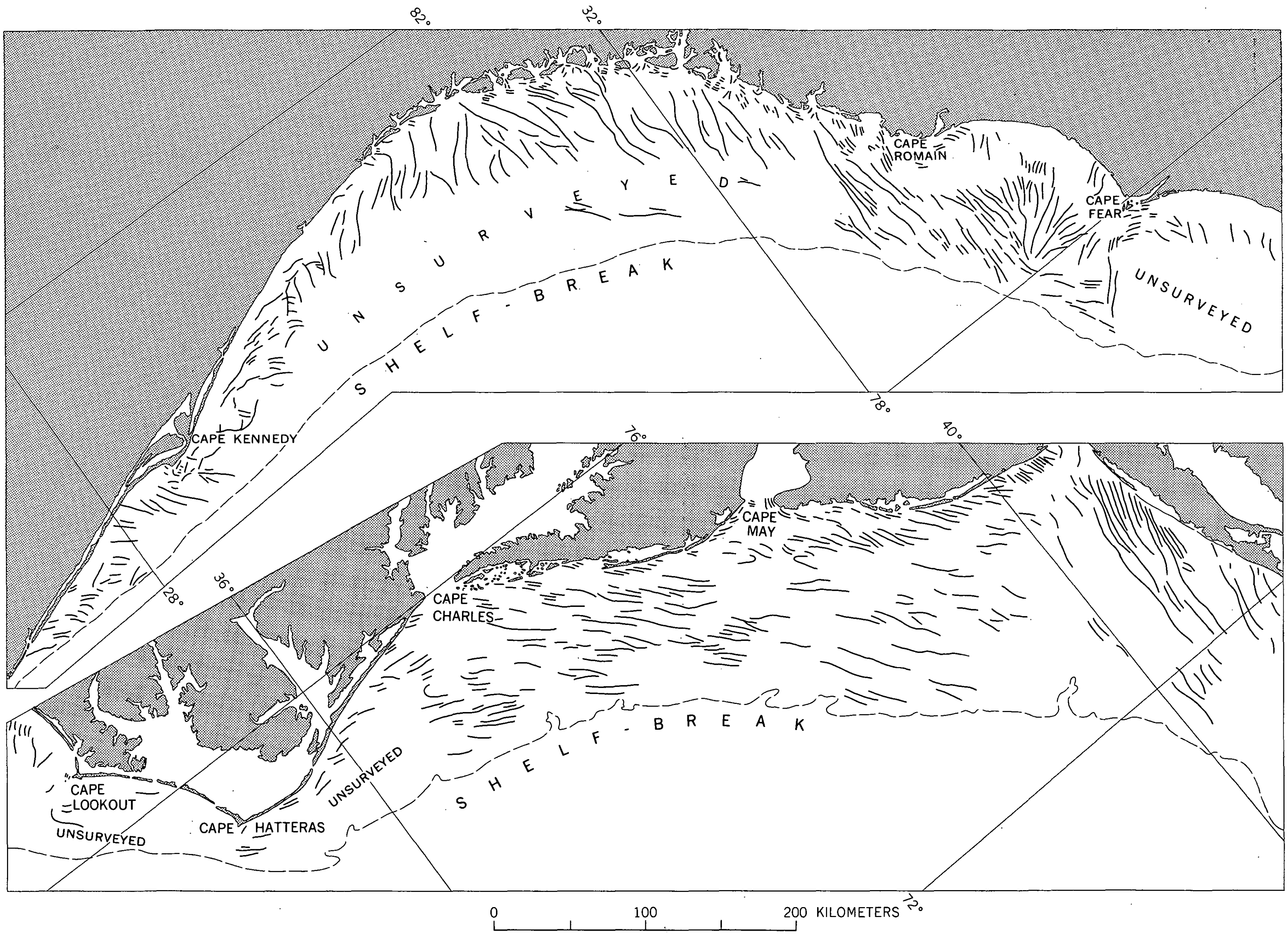

Figure 14.—Sand swells atop the continental shelf from New York to Cape Kennedy: Based on soundings from U.S. Coast and Geodetic Survey. Curved lines indicate crests of sand swells; dashed lines indicate shelf-break.

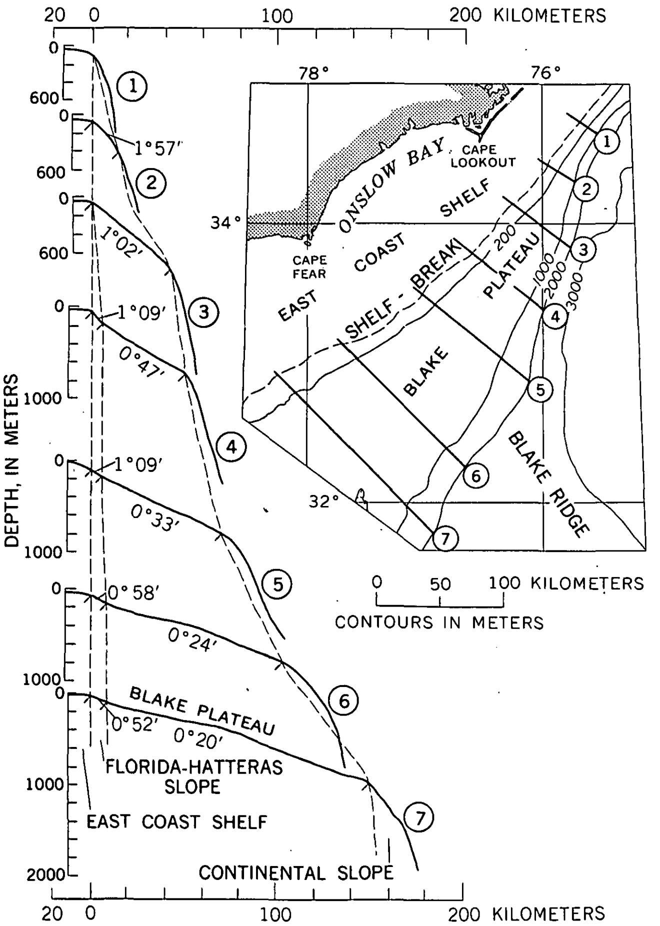

FIGURE 15.—Bottom profiles of the northern edge of the Blake Plateau. Vertical exaggeration × 40.

From lat 32° to lat 28° the Florida-Hatteras Slope has a relief of 340–700 meters. Contact between the slope and the plateau is very ragged: isolated depressions separated by low spurs abut the base of the slope (figs. 17, 18). The depressions are linear and may have resulted from erosion by the Gulf Stream, which closely follows the Florida-Hatteras Slope. Both the depressions and the ridges between them are speckled with low conical hills; a few are as high as 80 meters, but most are less than 30 meters. Bottom samples from this rough zone indicate that the conical hills may be coral mounds similar to those described by Stetson, Squires, and Pratt (1962) from near the eastern edge of the Blake Plateau.

STRAITS OF FLORIDA

The Straits of Florida (pl. 3 and fig. 3) separate the East Coast Shelf from the Bahama Banks. This U-shaped trough ranges in depth from 2,200 meters south of Dry Tortugas (which is about 110 km west of Key West) to 740 meters west of Little Bahama Bank. It ranges in width from 160 km at its western end to 90 km at its northern end. The length of the trough is 860 km. The segment of the Florida-Hatteras Slope forming the western side of the trough is steeper and more irregular than the part of this slope west of the Blake Plateau. Segments of the slope, for example, Pourtales and Mitchell Escarpments (fig. 19) have gradients greater than 10°. Two broad benches, Miami Terrace to the north and Pourtales Terrace to the south, indent the slope (Jordan and Stewart, 1961; Kofoed and Malloy, 1965).

Miami Terrace extends from lat 26°30′ to 25°20′, has a maximum width of 22 km, and ranges in depth from 245 meters along its inner edge to 350 meters along its outer edge (figs. 20, 21). Its surface consists of a smooth inner area separated from an outer rough zone by a narrow channel. PDR records indicate that the rough outer zone is made up of a series of ridges capped by several rectangular blocks that are tilted seaward. Declivity of the landward slope of the terrace averages about 4°, but some parts have gradients as high as 11°. The outer slope of the terrace is more irregular than the inner one but has the same average gradient.

Stratigraphic data from a well near Miami (Puri and Vernon, 1964, pl. 6) suggests that the surface of the Miami Terrace may consist of the shallow-water Oligocene Suwanee Limestone or the lower and middle Miocene Hawthorn Formation. If the terrace is an erosional feature cut near sea level, it must later have been downwarped because its surface is deeper than the maximum lowering (about 160 meters) of sea level during the Pleistocene Epoch (Donn and others, 1962, p. 214). The youngest rocks atop the terrace seem to be Miocene in age; if so, the cutting of the terrace occurred during post-Miocene time.

Pourtales Terrace, which lies south of the Florida Keys, extends from a depth of 180–280 meters and is 10–20 km wide. The terrace loses its identity at lat 25°15′ on the east and long 82°20′ on the west where the seaward and landward slopes of the terrace meet. The inner half of Pourtales Terrace has an average declivity of 0°04′ which increases to 0°35′ along its outer edge (fig. 19). The increase in gradient suggests that the terrace may be tilted to the south. The surface of Pourtales Terrace contains numerous depressions and isolated rises. At the base of the landward slope are a number of rectangular depressions with depths of 260–280 meters; along the outer rim are three nearly circular depressions having depths of 401, 419, and 452 meters. Jordan (1954) believed that they are sinkholes formed by solution of the limestone making up the terrace surface.

The landward slope of the terrace extending from 20–180 meters is 9 km wide and has a gradient ranging from 1° to 0°30′. The seaward slope of Pourtales Ter-

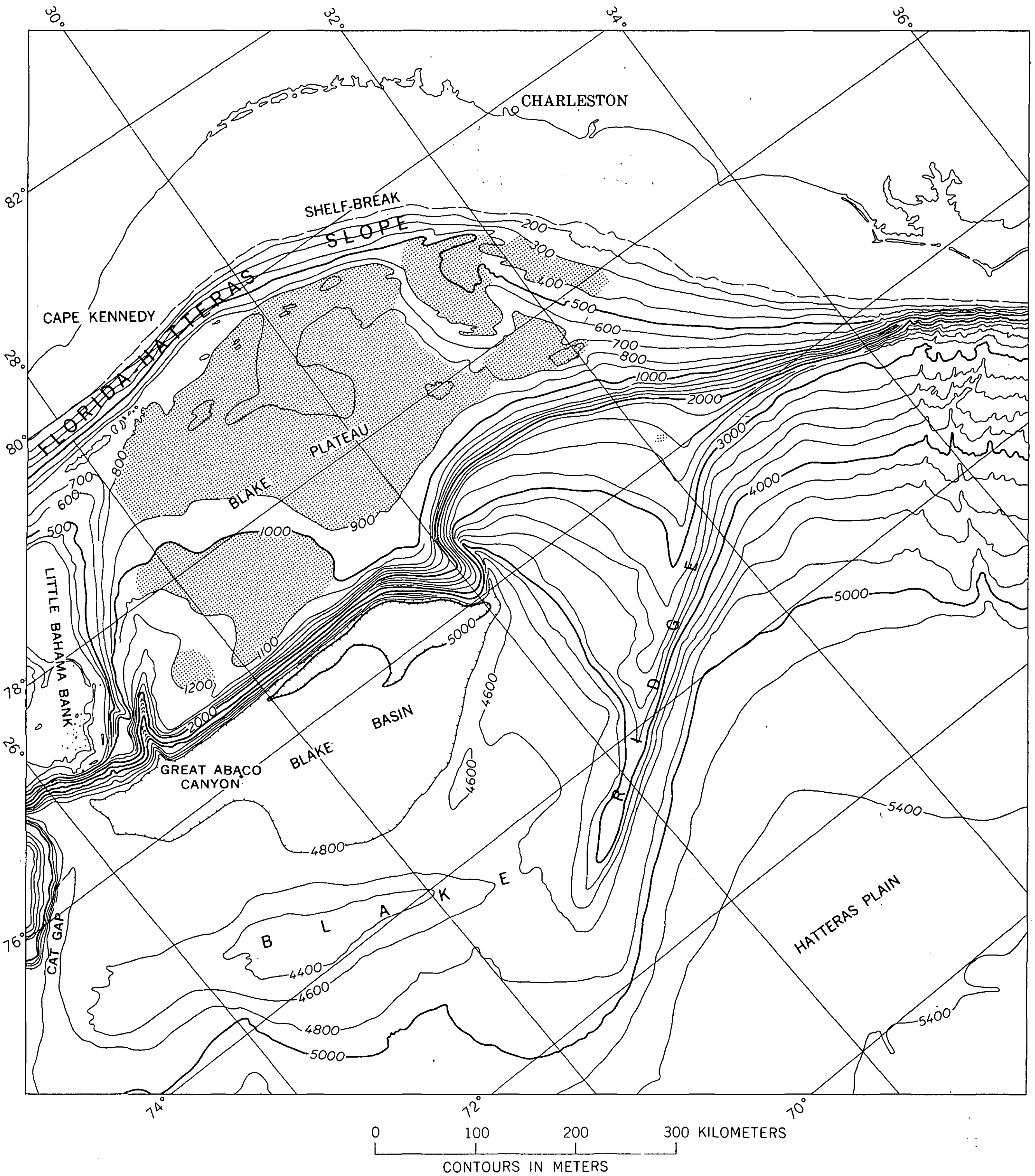

FIGURE 16.—Bathymetry of the Blake Plateau (modified from Pratt, 1967). Shaded areas are benches.

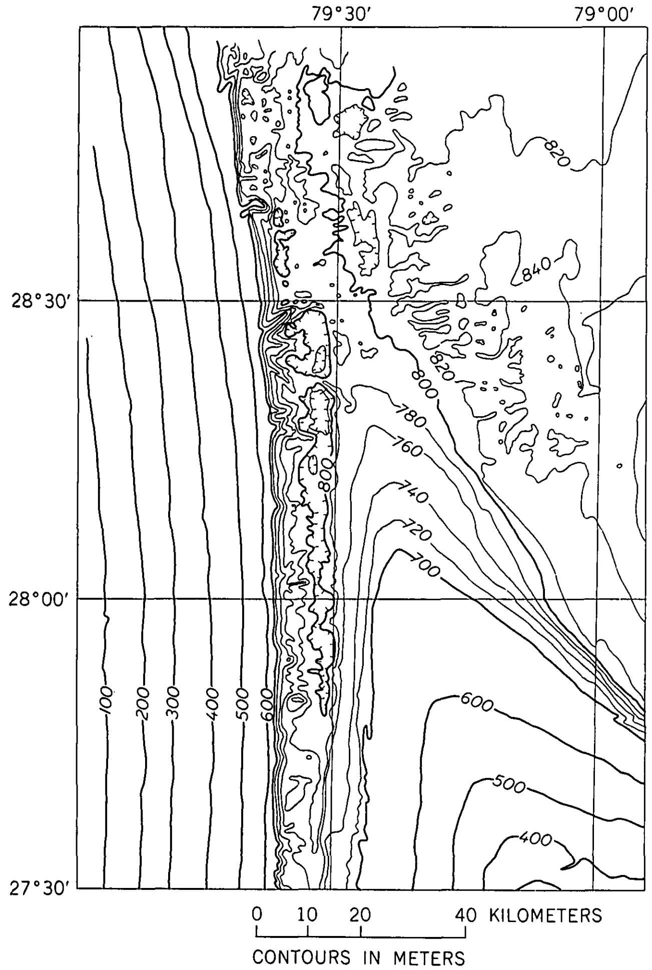

FIGURE 17.—Topography of a part of the rough zone at the base of Florida-Hatteras Slope. Based on soundings from U.S. Coast and Geodetic Survey.

race consists of several segments. Bordering the terrace along most of its length is a steep scarp, Pourtales Escarpment (fig. 19), which is about 200 meters high and has a declivity of 20°. Seaward of this escarpment is a gentle and smooth slope which has a gradient of 0°30′ and closely resembles the inner slope of the terrace. Below this smooth and gentle segment, between long 81° and 82°, is the steep Mitchell Escarpment (fig. 19) which has a declivity similar to that of Pourtales Escarpment.

Lithologic data from a well in Marathon, Vaca Key (fig. 19) (Applin and Applin, 1944), suggest that the limestone making up the surface of Pourtales Terrace is probably the Hawthorn Formation. If the sinkholes on the surface of the terrace were formed above sea level as Jordan (1954) believed, then the terrace has been downwarped at least 300 meters. Atop this subsiding surface were deposited the Pliocene and Pleistocene sediments making up the gentler inner slope of Pourtales Terrace.

Pourtales and Miami Terraces may have been continuous in the past, but prograding of sediments in a seaward direction since they were formed has buried the surface south of Key Largo (fig. 19) and separated them. If the terraces are segments of a single surface, the surface is tilted to the north because depths along its outer edge increase from 337 meters on Pourtales Terrace to 350 meters on Miami Terrace.

The eastern slope of the Straits of Florida is made up of two segments. The first is from the rim of the Bahama Banks to a depth of 200 meters; it is a steep scarp with a declivity of 20°. This segment is similar to the steep scarps south of the Florida Keys and is believed by Newell and Rigby (1957, p. 23) to be a Tertiary coral reef slope although this has not been verified by sampling. Brooks (1964) suggested that it is an erosional cliff formed by wave action during the Pleistocene. Below this steep scarp is the second segment of the eastern slope; it is gentler, has a declivity ranging from 5° to less than 1°, and is cut by several small channels.

Topographically the margins and the center of the floor of the Straits vary considerably both in an east-west as well as in a north-south direction. On the Florida side the boundary of the floor, for the most part, consists of a convex rise separated from the Florida-Hatteras Slope by a narrow V-shaped discontinuous depression (fig. 19). Along the base of the slope on the east side of the straits, an irregular or hummocky zone may be a rocky belt or talus apron derived from the steep slope above (Hurley and others, 1962). The center of the Straits of Florida north of lat 26° is very rough (fig. 18). Such rough topography may be due to coral mounds. South of lat 26° to about 25°30′ is a smooth graded valley that has a gradient of about 0°5′; at lat 25°30′ it joins with a smooth plain (fig. 19). For more than 120 km the plain has no gradient, but near Cay Sal Bank the plain narrows, becomes more irregular, and its declivity increase to 0°04′.

CONTINENTAL SLOPE

The relatively steep scarp that marks the boundary between the continents and the oceans is known as the continental slope. North of Cape Hatteras the slope is bordered on its landward side by the continental shelf, and south of Cape Hatteras it is flanked on the west by the Blake Plateau (fig. 3). East of Bear and Physalia Seamounts and west of Block Canyon (pl. 1) the slope trends in a northeast direction. These two sections of the continental slope are separated by an approximately 210-km segment that trends in an east-west direction along lat 40° N. The change in trend is believed by Drake, Heirtzler, and Hirshman (1963) to have been

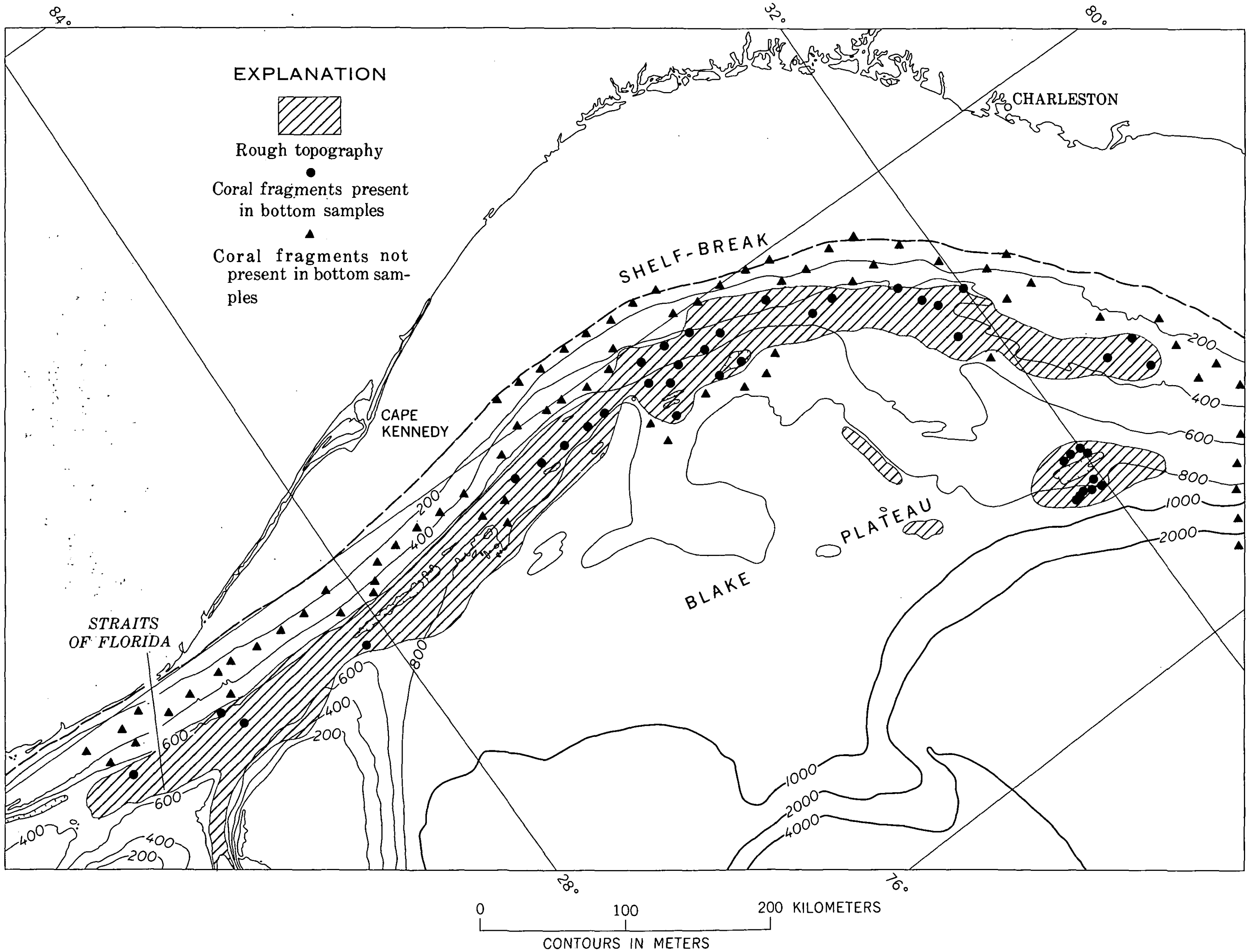

Figure 18.—Zone of rough topography along the western boundary of the Blake Plateau and the northern tip of the Straits of Florida.

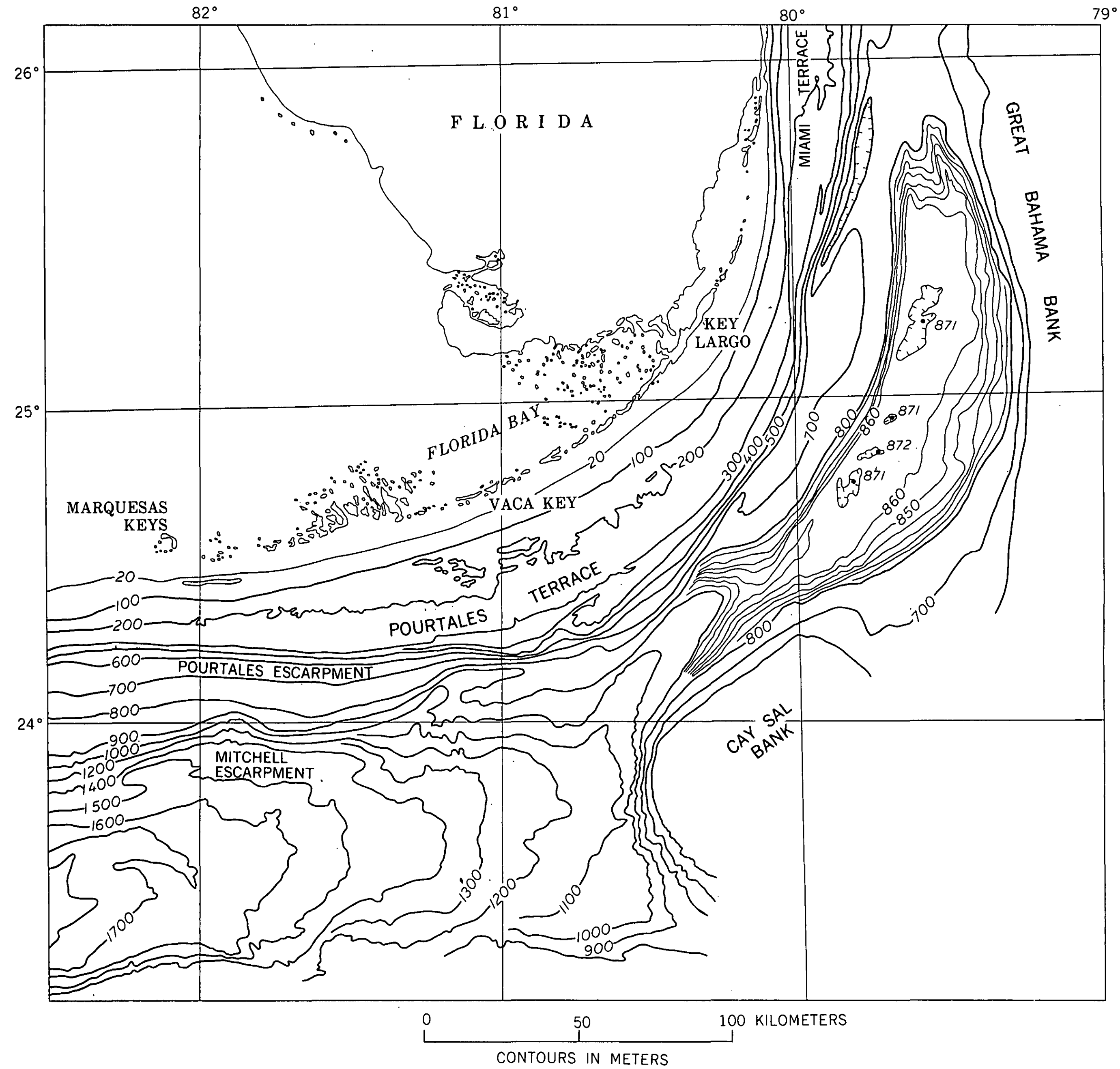

Figure 19.—Bathymetry of the Straits of Florida. Based on U.S. Coast and Geodetic Survey hydrographic surveys.

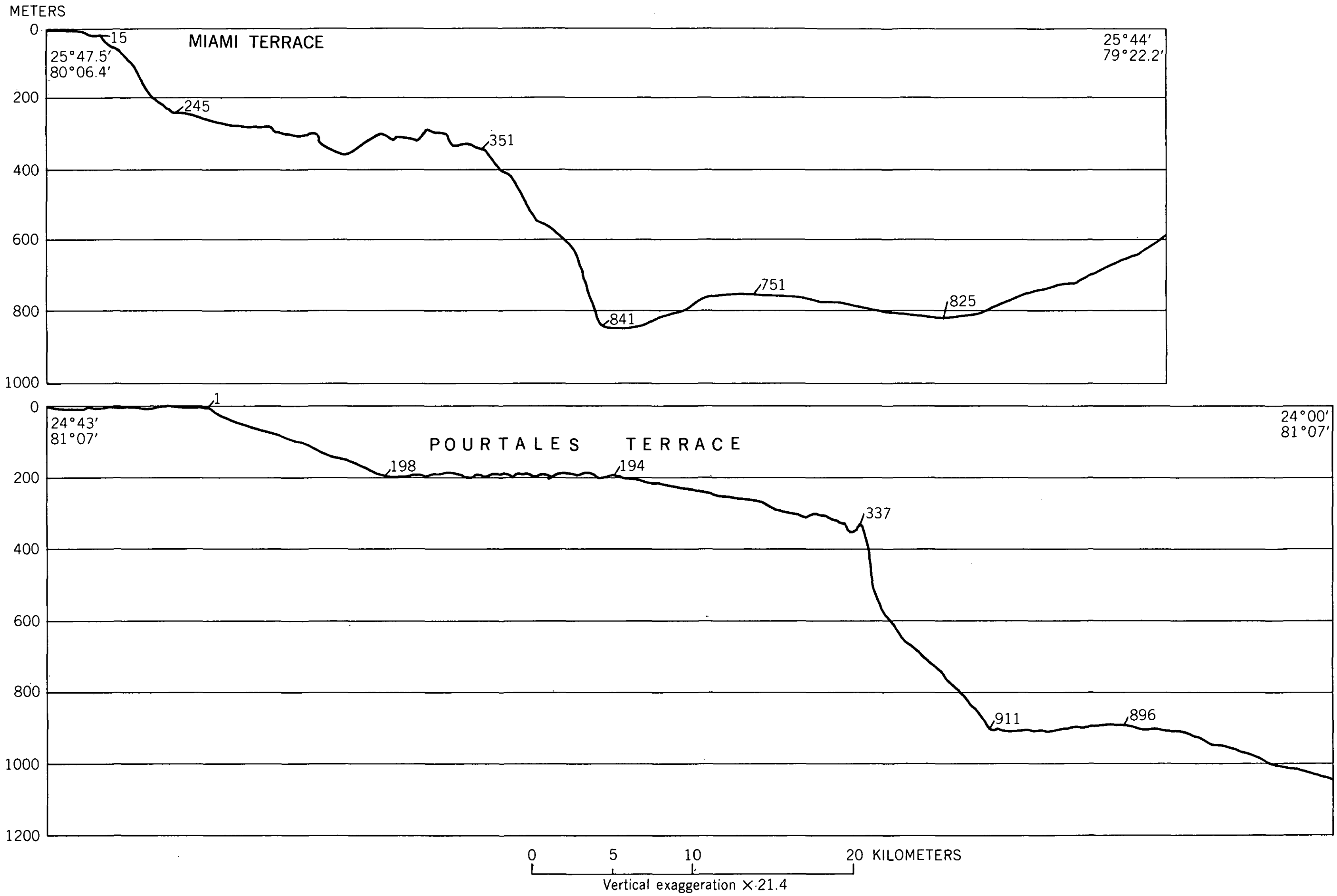

FIGURE 20.—Bottom profiles of Miami and Pourtales Terraces, constructed from U.S. Coast and Geodetic hydrographic surveys.

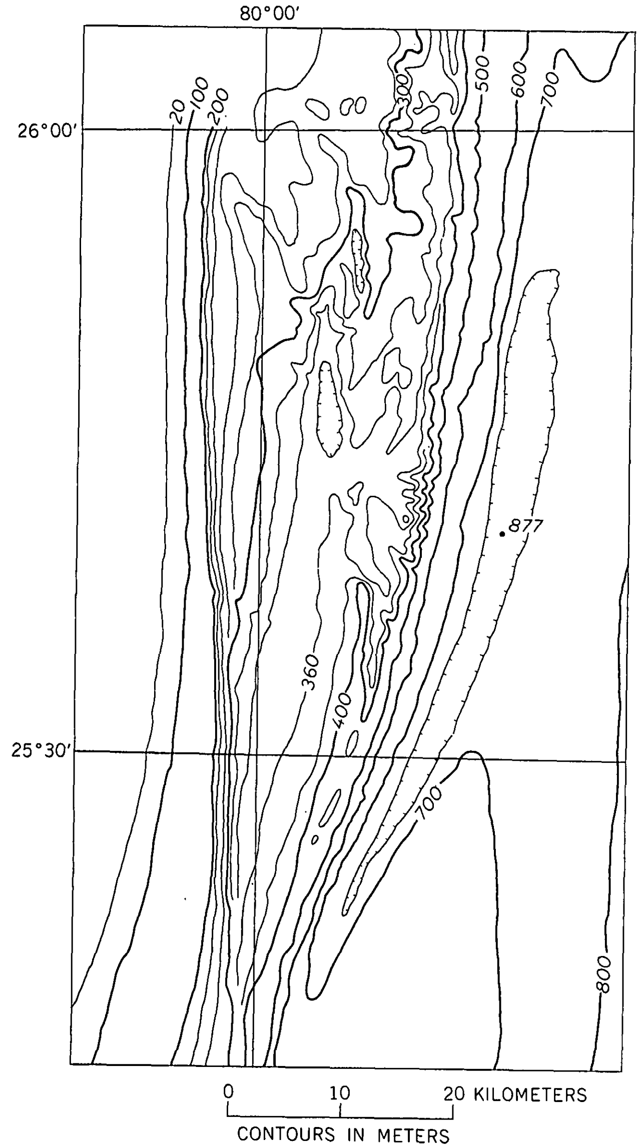

FIGURE 21.—Topography of Miami Terrace. Based on soundings from U.S. Coast and Geodetic Survey.

caused by a right-lateral displacement along an east-west-trending fracture zone. The seaward extension of this structure is marked by the New England Seamount Chain; its shoreward extension is indicated by a conspicuous change in the strike of the Paleozoic and Triassic structures.

The continental slope shows a great diversity in gradient and relief from Nova Scotia to the Bahama Islands (pls. 1, 2, 3). East of long 62°30′ to the edge of the area shown on plate 1, the slope is fairly smooth and has a gradient of 2°35′. On its seaward side it grades imperceptibly into the continental rise at a depth of 3,600–4,000 meters, where the declivity decreases to less than 1° (profile 1, fig. 21). From 62°30′ to Northeast Channel the base of the slope is at a depth of 1,000–1,200 meters (fig. 22). The slope's low relief is believed to be due to the deposition of a large volume of sediment removed from the Gulf of Maine and the Scotian Shelf by proglacial streams and Pleistocene glaciers. Seaward of Georges Bank the slope increases in declivity and relief. Here the slope can be divided into an upper and a lower slope, the upper slope extending from the shelf-break at a depth of 120–160 meters to 400 meters with a declivity of less than 2° and the lower slope extending from 400 to 2,000 meters with a declivity of 6°. Both segments of the slope are cut deeply by submarine canyons and innumerable smaller gullies. The gullies are restricted to the slope, but the canyons indent the outer edge of Georges Bank.

The continental slope between Georges Bank and Hudson Canyon also is made up of two segments. South of Martha's Vineyard the upper slope extends to a depth of 1,000 meters and has a declivity of about 1°, the lower slope, which extends to a depth of 2,200 meters, has a gradient of 3°. Here, as south of Georges Bank, the continental slope is entrenched by submarine canyons. The upper part of the continental slope south of Block Island, has an amphitheaterlike scar, probably formed by slumping. Hudson Canyon, the largest canyon off the east coast of the United States, lies along the western margin of this part of the continental slope. It is continuous both in a landward direction across the shelf and seaward across the continental rise. On the slope Hudson Canyon is 100–600 meters deep and about 12–15 km wide.

From Hudson Canyon to Cape Henry, the continental slope is very irregular and has an average declivity of 4°. Submarine canyons in the slope extend partly into the continental shelf and terminate against the seaward slope of Franklin Terrace (pl. 2). The heads of Wilmington and Baltimore Canyons have pronounced hooks, the origins of which are not known.

South of Cape Henry to lat 34° 30′ the continental slope has a declivity between 4° and 5° and a height of 2,000–2,400 meters. No major canyons are present, but the scarp is cut by innumerable small gullies. Off Cape Hatteras the gullies coalesce toward the base of the slope to form Hatteras Canyon (pl. 2). From lat 34° 30′ to Blake Spur (pls. 2, 3) the top of the slope is at a depth of 1,000 meters and its base is at depths ranging from 2,000 to 2,600 meters. Here the slope descends directly onto the crest of Blake Ridge.

The continental slope south of the Blake Spur has the steepest declivity of any segment off the east coast. This part of the slope, which is known as the Blake Escarpment (pl. 3) (Heezen and others, 1959), has an average gradient greater than 20°. This segment of the continental slope descends directly into the Blake Basin.

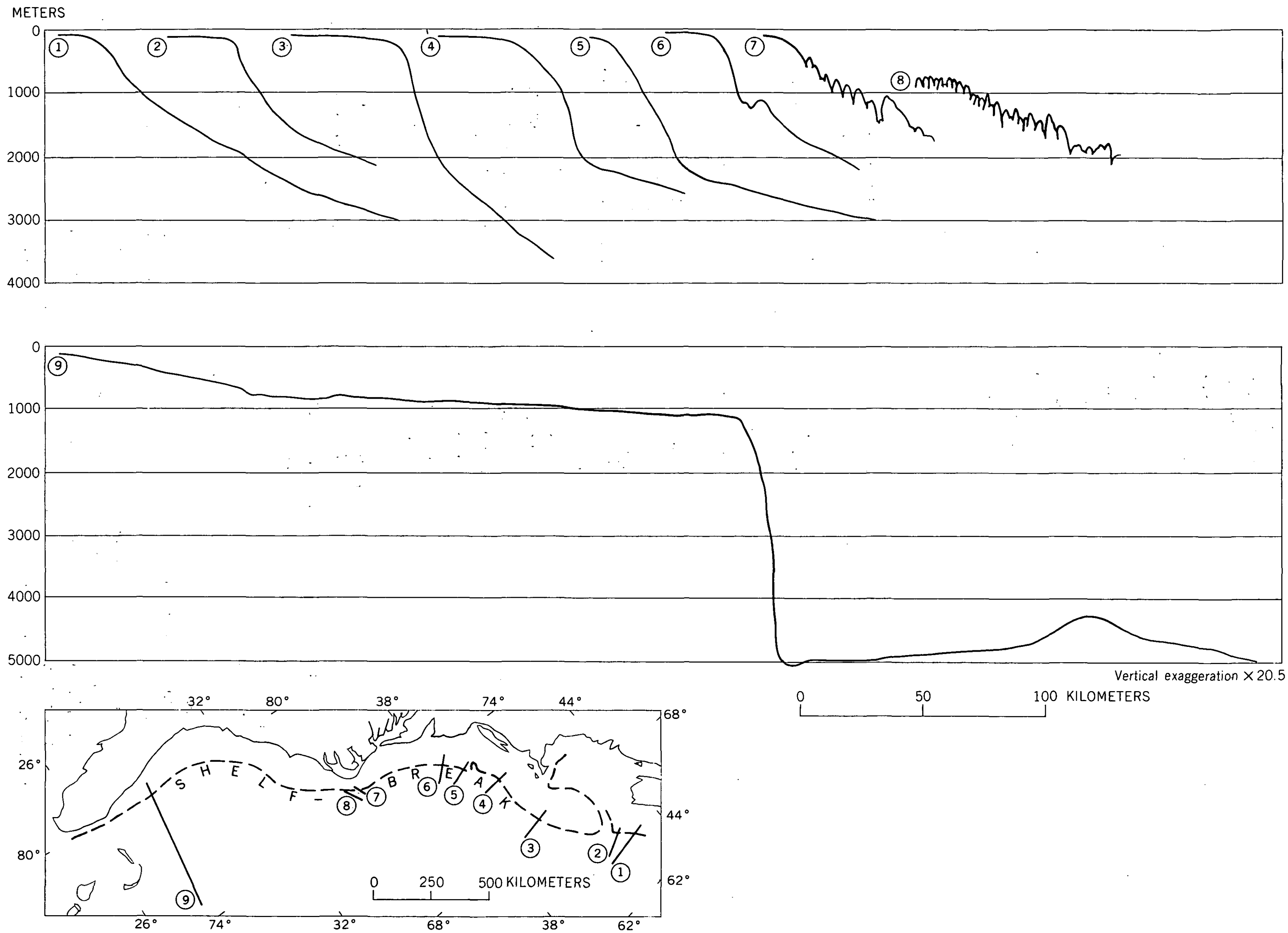

Figure 22.—Bottom profiles of the continental slope. Profiles 7 and 8 are Precision Depth Recorder traces. The other profiles were constructed from plates 1, 2, and 3.

PROVINCES SEAWARD OF THE CONTINENTAL SLOPE

North of Cape Hatteras the continental slope is bordered along its seaward side by the continental rise. East of the Blake Plateau the continental slope is flanked by the Blake Basin and Blake Ridge (fig. 3).

CONTINENTAL RISE

Extending from the base of the continental slope to the western margin of the abyssal plains, north of Cape Hatteras, is a wide sedimentary apron known as the continental rise. It ranges in width from less than 10 km at the foot of the Blake Ridge to almost 800 km off New York City. Within the area covered by the three charts included with this report, the continental rise has an area of 630,000 km². Depths on the rise range from 1,000 to 2,200 meters at the base of the continental slope to about 5,000 meters at the seaward edge of the rise. The continental rise has a generally abrupt contact with both the slope and the abyssal plains. Relief on the rise is generally less than 40 meters, but some sections have as much as 300 meters of relief (Heezen and others, 1959, p. 27).

Most of the canyons on the continental slope have channellike extensions that cross the continental rise and debouch on the abyssal plains farther east. Some of the channels appear to have leveelike ridges along their banks. Perhaps the best surveyed area of the rise is near Northeast Channel where the submarine *Thresher* sank in 1963. The unprecedented number of soundings taken in the area clearly show a series of channels extending from the base of the slope to the middle of the continental rise (fig. 23). The channels are about 40 fathoms deep (72 meters) and are flat bottomed. The channel divides are about 4 km broad and have rounded shoulders. Near the base of the continental slope the longitudinal profiles of the channels have gradients of about 1° and the side walls have gradients of about 8°. The channels are slightly asymmetrical because the bank on the right (looking downstream) is steeper.

South of Georges Bank a chain of seamounts extends across the Continental Rise and the Sohm Plain, forming an arc more than 1,800 km long. The seamounts seem to be on the fracture zone that has displaced the continental slope a distance of 210 km along lat 40°. (See p. C25.) The occurrence of Eocene calcareous algae on Bear and Mytilus Seamounts (Northrop and Ziegler, 1959; Northrop and others, 1962) suggests that the crests of the seamounts must have been at or near sea level during the Eocene. If the algae are in place, they also indicate that the fracture zone must have been active as late as Eocene time.

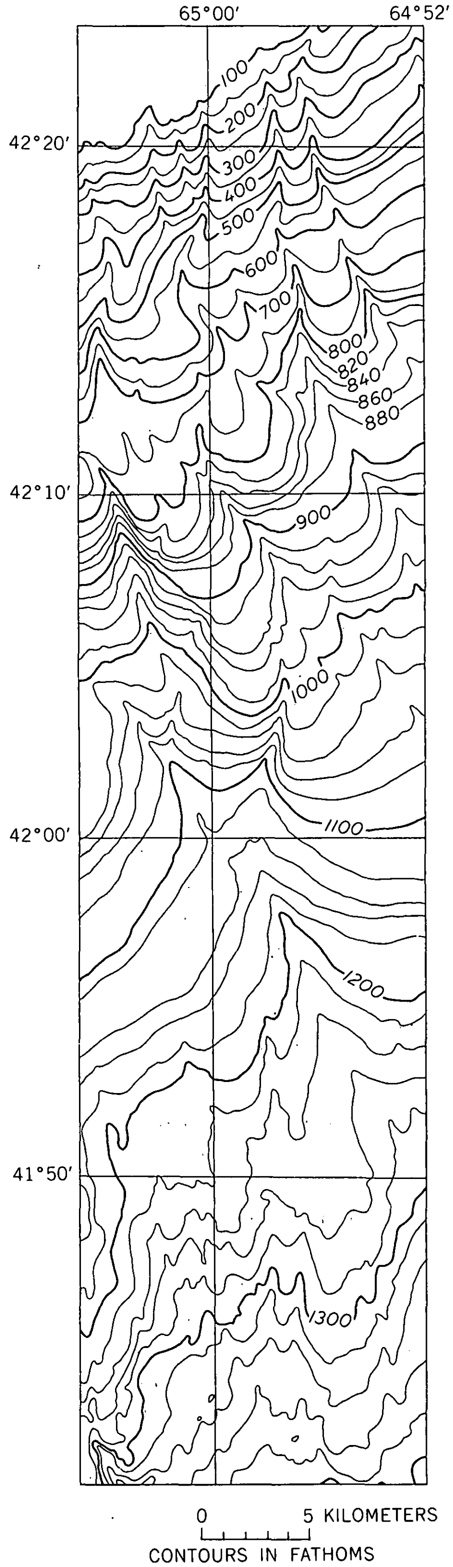

FIGURE 23.—Bathymetry of the continental slope and rise near Northeast Channel. Based on U.S. Coast and Geodetic Survey hydrographic survey and U.S. Navy *Thresher* Search plotting sheet.

BLAKE BASIN AND BLAKE RIDGE

East of the Blake Plateau the continental slope is bordered by a marginal basin (Blake Basin) and an outer ridge (Blake Ridge). Blake Basin has an area of 57,000 km^2 and a maximum depth of 5,046 meters. The basin is widest and shallowest near Great Abaco Canyon, and it narrows and deepens toward the north (fig. 16). The center of the basin is occupied by a narrow abyssal plain. The plain and the continental slope are in sharp contact in most places, but in some areas they are separated by a hummocky zone that is probably formed by material displaced from farther upslope (Heezen and others, 1959). A fan at the mouth of Great Abaco Canyon blocks the basin on the south and prevents it from draining into Hatteras Plain by way of Cat Gap (fig. 16).

Blake Ridge separates Blake Basin from the Hatteras Plain (fig. 15). The ridge can be divided into a northwest segment and a northeast-trending segment. The northeast-alined segment is separated from the continental slope by Cat Gap. Its slopes are gentle, and it is symmetrical in cross section. The northwest-trending segment abuts the slope. It is asymmetrical in cross-section, the northern side having a declivity of 2° and the southern side having less than 0°30′. Continuous seismic reflection profiles across the ridge indicate that the ridge consists of a prism of sediments and that the oceanic basement passes directly underneath without any structural effect (Ewing, Ewing and Worzel, 1963; Clay and others, 1964).

SUMMARY

The topographic features of the continental shelf, slope, and rise are interrelated and can be grouped from north to south into three distinct regions or zones. In the first, from Nova Scotia to the Nantucket Shoals area, the position normally occupied by a gently seaward-sloping continental shelf, contains (1) the Gulf of Maine, and (2) several large shallow banks, namely Georges, Browns, La Have, and Emerald Banks (pl. 1). East of Northeast Channel the continental slope trends generally northeast-southwest and is smooth, but between Nantucket Shoals and Northeast Channel it trends east-west and is dissected by submarine canyons and interrupted by the eastern end of the New England Seamount Chain. The continental rise laps high onto the slope as a result of the seaward movement of great volumes of sediment deposited by both proglacial and Pleistocene streams debouching through Northeast Channel.

In the second or central zone, from the Nantucket Shoals area to Cape Lookout, the continental shelf is a moderately smooth seaward-sloping surface or plain having sand swells, channels, terraces, and coral mounds. The continent slope is generally steep and is dissected by several submarine canyons. South of Nantucket Shoals and west to Block Canyon (pl. 1), the slope trends east-west along a major fracture zone, but west of Block Canyon it trends again approximately northeast-southwest. In this central zone the continental rise is cut by channels that extend seaward from the several submarine canyons of the continental slope. Hudson Canyon and the so-called Hudson channel on the shelf and the channels on the rise constitute the only discrete valley system that can be traced continuously from land across the entire continental margin.

In the third or southern zone, from Cape Lookout south to the Florida Keys, the continental margin is again atypical. Between Cape Lookout and Cape Kennedy, the shelf is separated from the continental slope by the Blake Plateau, an intermediate-level surface with some topographic irregularities. Throughout most of its length, the Blake Plateau is separated from the shelf by the Florida-Hatteras Slope (pl. 3). The upper part of this slope is smooth, but at its base is a narrow trough consisting of a chain of basins separated by low ridges. The trough contains scattered low hills that are believed to be coral mounds. Seaward of this rough zone the Blake Plateau is made up of broad benches. Between the benches are depressions, some of which are fringed by coral mounds. East of the Blake Plateau the continental slope—called the Blake Escarpment in this region—drops off steeply into the Blake Basin. The continental rise diminishes in width south of Cape Hatteras and disappears at its intersection with the Blake Ridge and Blake Basin.

South of Cape Kennedy the shelf is bordered along its seaward side by a trough, the Straits of Florida. Two broad terraces, Miami and Pourtales Terraces, both of which are believed to be cut into Miocene limestone, indent the western slope of this trough.

Topographic differences of the continental margin from Nova Scotia to the Florida Keys reflect in part the agents responsible for molding its surface. The rather deep and irregular continental shelf east of Cape Cod and the low relief of the continental slope east of Georges Bank probably resulted from glacial erosion, transport of much of the sediment through Northeast Channel, and its deposition on the continental rise southeast of Georges and Browns Banks. The present form of the continental margin from Georges Bank to Cape Hatteras resulted from fluvial erosion and deposition on the shelf, submarine erosion on the slope, and deposition on the continental rise during the Pleistocene. Farther south, faulting and (or) folding, erosion by the Gulf

Stream, and calcareous accretion have had an important role in molding the continental margin.

The latest modifications of the continental margin were caused by the rise in sea level in post-Wisconsin time. During this transgression a series of terraces were cut on the shelf and slope, and the glacial deposits on Georges Bank and Nantucket Shoals underwent considerable reworking. Since sea level rose to its present geographic position, tidal currents have further modified these deposits. The sand swells on the East Coast Shelf may have been formed during a rise in sea level in post-Wisconsin time or are being formed now during unusually intense storms. The presence of terraces and the well-preserved glacially eroded topography on the shelf east of New York indicate that deposition on the continental margin has been negligible in post-Pleistocene time.

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