Characteristics of Estuarine Sediments of The United States

GEOLOGICAL SURVEY PROFESSIONAL PAPER 742

Prepared in cooperation with the U.S. Federal Water Pollution Control Administration

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By DAVID W. FOLGER

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A compilation of data, essentially an atlas, on texture and composition of bottom sediments, including geologic and hydrologic factors that influence them, in 45 estuaries

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CHARACTERISTICS OF ESTUARINE SEDIMENTS OF THE UNITED STATES[1]

By David W. Folger

ABSTRACT

The texture and composition of bottom sediments in the estuarine zones of the United States are a function of the geologic, bathymetric, and hydrologic settings in which they were deposited. On the northeast and northwest coasts, where sediment supply has been inadequate to fill many of the deep drowned river valleys or glacially scoured estuaries, clay and silt in the deep central parts of the bays most commonly grade shoreward and seaward into sand. On the Oregon and northern California coasts, where both sediment supply and tidal range are large, clay and silt are commonly swept from the deep channels and deposited on marginal tidal flats. On the gulf coast, where tidal ranges are small and where rivers transport abundant fine material to the coast, estuaries are generally shallow. Silt and clay near the center of these bar-built estuaries and lagoons grade into sand around the margins. Deltas are common in many of the gulf coast bays and have, in several, prograded across the estuarine zone onto the continental shelf.

Most bottom sediments that accumulate in the estuarine zone consist of terrigenous detritus, biogenic debris, and pollutants. Organic carbon generally makes up less than 5 percent of the bottom sediments except in swampy areas, fjords, or where pollutants are abundant. Inorganic constituents are mostly quartz, feldspar, and clay minerals. In general, illite and chlorite are the most abundant clay minerals on the northeast coast; kaolinite predominates on the southeast Atlantic coast and in the eastern Gulf of Mexico; and montmorillonite is common along the coasts of the western Gulf of Mexico and the Pacific Ocean. Shell debris is locally abundant in many areas but is dominant only in areas far from terrigenous sources.

INTRODUCTION

SCOPE AND PURPOSE OF THE STUDY

The available information concerning the characteristics of sediments deposited in 45 estuaries, lagoons, embayments, and deltas of the United States has been assembled, summarized, and presented in this report (fig. 1); 17 of the areas are on the Atlantic coast, 20 on the gulf coast, and eight on the Pacific coast. This compilation of summaries represents much of the available data on the estuarine zone and thus provides an opportunity to compare coastal sedimentary deposits and the processes responsible for them.

This study was undertaken by the U.S. Geological Survey and Woods Hole Oceanographic Institution in cooperation with the U.S. Federal Water Pollution Control Administration as part of the response to Public Law 89–753, which instructed the U.S. Secretary of the Interior to assemble, coordinate, and organize all existing pertinent information on sedimentation in estuarine zones, and to identify the problems and areas where further research and study are required.

SOURCES OF INFORMATION

Information in this report has been drawn from published sources and unpublished material—including M.S. theses, Ph. D. theses, and a few raw data that mostly deal with organic carbon concentrations and clay mineralogy. U.S. Geological Survey water-supply papers and U.S. Coast and Geodetic Survey (U.S.C. & G. S.) tide tables were used throughout the report and therefore have not been cited. For simplicity of presentation, source material for each area is listed only briefly at the end of the summary section on the area, but reference to specific sources is given for the illustrations and complete references are listed at the back of the report.

FORMAT

The data for each area are presented in the following format:

Setting
- Geology
- Bathymetry
- Hydrology

[1] Contribution 2482 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 in cooperation with the U.S. Federal Water Pollution Control Administration and financed mostly by the U.S. Federal Water Pollution Control Administration.

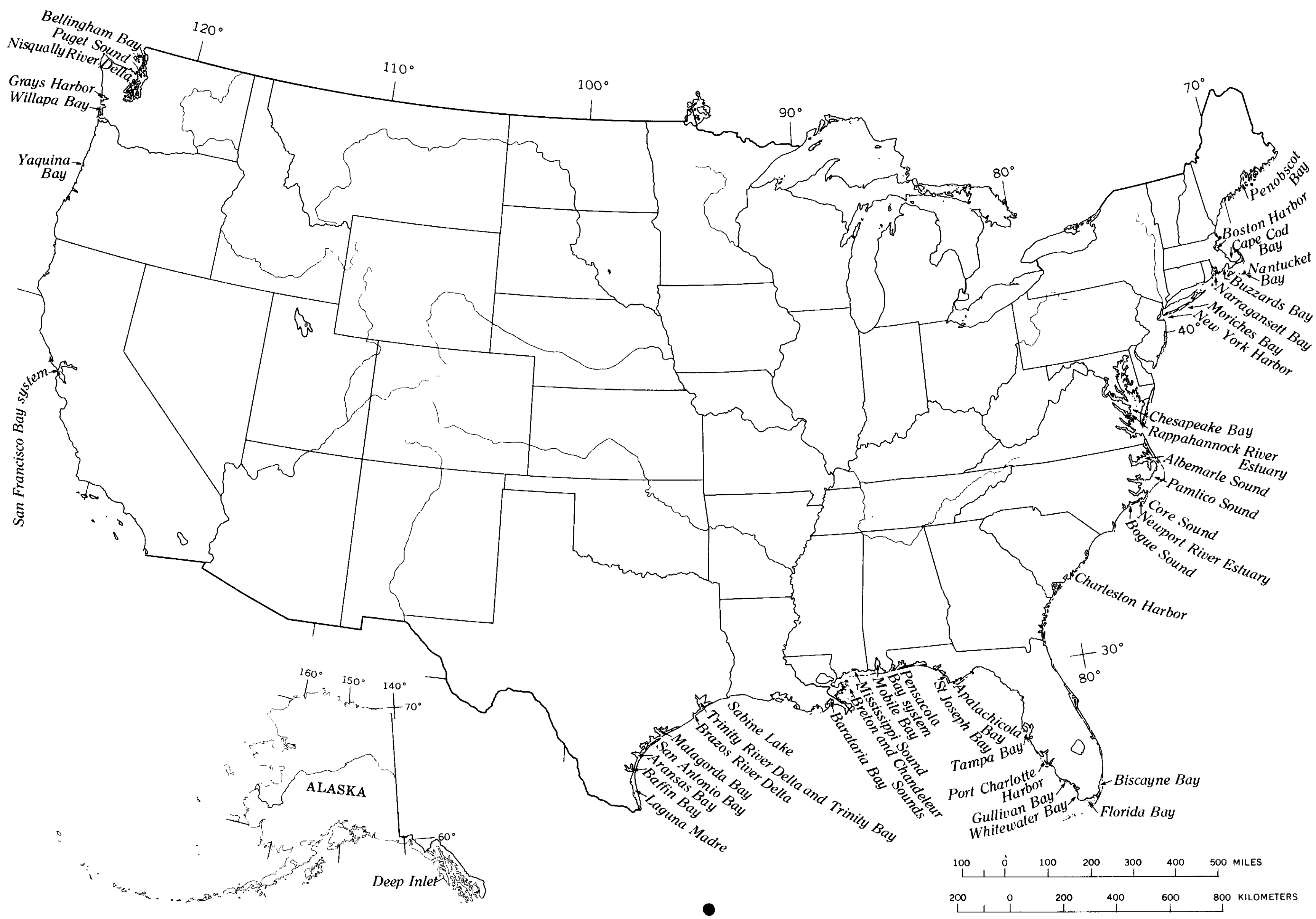


FIGURE 1.—Map of the United States showing the estuaries, lagoons, embayments, and deltas described in this report.

Sediment texture
- Bottom
- Subbottom

Sediment composition
- Organic carbon
- Mineralogy
- Other

References

Illustrations that accompany each summary generally represent bathymetry, sediment texture, and organic carbon distribution in the bottom sediments. Geologic cross sections and maps showing the distribution of calcium carbonate or other mineral constituents are included where sufficient data are available.

SETTING

The geologic, bathymetric, and hydrologic characteristics of each area are discussed because each affects directly the composition and distribution of sediment. Specifically, the summary of geology includes the type and age of the sedimentary and other rocks contiguous with and underlying the area; hydrology includes the mean rate of fresh-water inflow, salinity distribution, tidal range, and current velocities; bathymetry is presented in feet rather than meters, because most available maps have been adapted or taken directly from U.S. Coast and Geodetic Survey charts.

SEDIMENT TEXTURE

Most statistical data concerning sediment texture were derived from mechanical analyses of sediment samples. In several areas, however, estimates of texture are based in part on optical examination. Textural classes presented in the illustrations are based mostly on sample median and mean diameters and, in a few areas, on modal diameters. Where only numerical data are available, values have been grouped into classes according to a slightly modified form of Inman's (1952) classification; where textural data from several references are available, the most compatible information has been used. Maps of sediment sorting, skewness, and kurtosis were considered too specific for the scope of this report and have not been included.

SEDIMENT COMPOSITION

In most of the studies summarized herein, the organic constituents of sediments were recorded as either carbon or nitrogen. Total organic matter (weight loss after treatment with hydrogen peroxide) and oxidizable organic matter were also reported. Organic carbon and (or) organic matter are, therefore, the only parameters cited in this report that indicate the amount of natural organic material and organic pollutants retained by the sediments. Techniques used to measure organic carbon content include those of Popoff (1927), Krogh and Keys (1934), Allisson (1935), Niederl and Niederl (1942), Dennen (1957), Walkely-Black (in Jackson, 1958, p. 219), and Curl (1962). Gas analyzers that were used for these measurements include Leco, Beckmann, and Coleman.

The distribution of various mineral species in the estuarine zone has been investigated thoroughly in only a few areas. Most available data are summarized in the text, but for most areas only the distribution of minerals composed of calcium carbonate is presented graphically.

ACKNOWLEDGMENTS

Many thanks are due R. H. Meade of the U.S. Geological Survey, who assembled much of the information used in this report and offered helpful suggestions and guidance in preparing the manuscript. J. C. Hathaway of the U.S. Geological Survey and Susan Kadar of Woods Hole Oceanographic Institution provided many useful raw data that were collected during recent joint U.S. Geological Survey-Woods Hole Oceanographic Institution continental shelf surveys. D. S. Gorsline of the University of Southern California, H. G. Goodell of Florida State University, and B. W. Nelson of the University of South Carolina also supplied helpful information. Frances Williams of Woods Hole Oceanographic Institution prepared the illustrations.

AREA SUMMARIES

PENOBSCOT BAY, MAINE

SETTING

Geology.—Lower and middle Paleozoic metasedimentary rocks and granite are exposed on the islands and on the western shore of Penobscot Bay; silicic intrusive rocks crop out on the eastern side. Thin patchy deposits of Pleistocene glacial till occur mostly in depressions and valleys.

Most data concerning sediment distribution in the estuary are limited to the western part. The thickness of unconsolidated material varies from zero (in areas where bedrock is exposed) to a maximum of approximately 150 feet (46 m (meters)) northwest of Vinalhaven Island. Southwest of the island, however, in the deepest part of the bay, little sediment has accumulated.

Bathymetry.—The smooth bottom near the head of the estuary, which is cut by channels 2 to 18 feet (0.6–5.5 m) deep and as much as 90 feet (27 m) wide, grades southward into predominantly irregular topography. The bay deepens to a maximum depth of about 540 feet (165 m) southeast of Rockland, and it shoals southward from there (fig. 2).

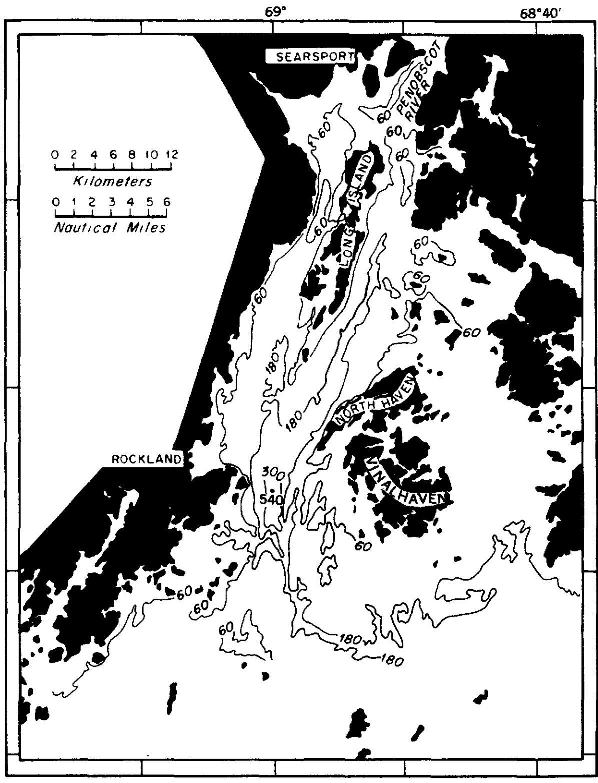


FIGURE 2.—Bathymetry (in feet) of Penobscot Bay, Maine (from Ostericher, 1965).

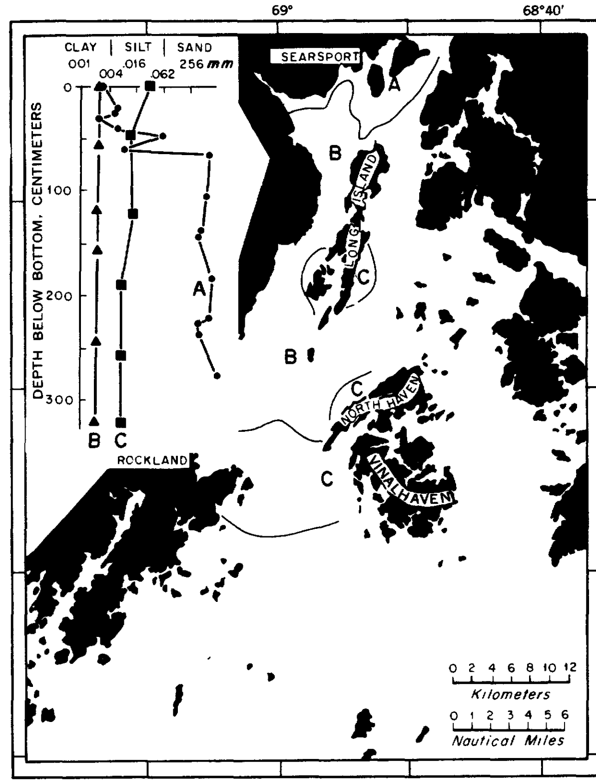
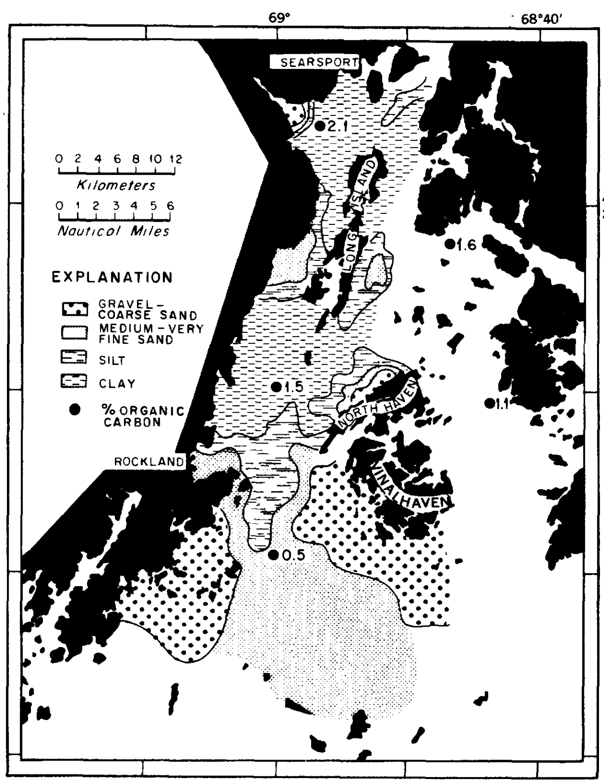


FIGURE 4.—Subbottom sediment texture, Penobscot Bay, Maine. Interpreted from data of Ostericher (1965). In area A, bottom clay grades down into sand; in area B, clay predominates to the depth of core penetration; in area C, silt or sand at the bottom becomes finer with depth.



Hydrology.—Average fresh-water discharge at the mouth of the Penobscot River is approximately 470 m^3/sec (cubic meters per second). Except during periods of high runoff, salinity ranges from about 25 parts per thousand at the head of the bay to 32.5 parts per thousand at the mouth; the latter salinity is typical of Gulf of Maine water. The mean tidal range exceeds 10 feet (3 m), and currents in the bay are dependent primarily on the tidal cycle. Flow velocities at the surface during the ebb tide exceed those during flood, while at the bottom the situation is reversed. Off Rockland, a maximum current velocity of 1.0 knot (50 cm/sec (centimeters per second)) was measured at the surface and 0.7 knot (35 cm/sec) at the bottom. Higher values are common in restricted channels. During winter months sea states may become severe in unprotected areas of the bay.

FIGURE 3 (left).—Texture and organic carbon content of bottom sediments in Penobscot Bay, Maine. Grain-size distribution of sediment is based on data of Ostericher (1965); carbon values are from Hathaway (1971).

SEDIMENT TEXTURE

Bottom.—Silty clay and clay predominate throughout most of the estuary, but sand is abundant near mouths of rivers and close to shore. The very fine sediment at the head of the bay grades southward into silt and subsequently to sand at the mouth of the bay (fig. 3).

Subbottom.—Only the upper 10 feet (3 m) of section has been cored. At the head of the bay, the predominant silt and clay at the surface grades down into sand. Most sediment, however, is silty clay (smallest particle size measured is 2 microns) throughout the estuary to the depth of core penetration. Silt persists with depth only in the mouth of the estuary and in a few nearshore areas (fig. 4).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Leco gas analyzer).—Measurements have been made for only five samples (fig. 3). Fine material deposited near the mouth of the Penobscot River contains the greatest amounts of organic carbon (2.1 percent), and sands south of Vinalhaven Island contain less than 1 percent.

Mineralogy.—In samples collected at the locations shown in figure 3, quartz and feldspar are the most abundant minerals (70 percent) in the sediment fraction coarser than silt. In the fine sediment, illite, chlorite, and minor kaolinite make up 70 to 80 percent of the minerals present.

Color, burrowing, and age.—Silt and clay are mostly olive gray; sandy layers are lighter in color. Throughout the bay, wood fragments are common and shell detritus is generally confined to thin zones. Burrowing is most common near the head of the bay. Wood lying close to or in a prominent acoustic subbottom reflector 10 to 50 feet (3–15 m) below the bottom has been dated as 7,390 ± 500 years old.

REFERENCES

R. L. Cory (unpub. data of the U.S. Naval Hydrographic Office, 1959), Hathaway (1971), Ostericher (1965).

BOSTON HARBOR, MASSACHUSETTS

SETTING

Geology.—Boston Harbor is a topographic basin underlain by Paleozoic clastic sedimentary rocks interbedded with andesitic volcanic rocks. Bedrock surrounding the harbor is covered with as much as 200 feet (61 m) of glacial drift.

In the harbor itself, glacial detritus ranges in thickness from zero (bedrock is exposed on several islands) to more than 100 feet (30 m). Overlying Holocene black mud, present over most of the area, ranges in thickness from less than 10 feet (3 m) to more than 40 feet (12 m).

Bathymetry.—The bottom is generally smooth, but rises abruptly to the shores of the many islands, which consist mostly of drumlin till. The depth averages less than 20 feet (6 m), but is maintained by dredging at a depth of approximately 40 feet (12 m) in the major ship channels (fig. 5).

Hydrology.—The Charles, Mystic, and Chelsea Rivers contribute fresh water to the inner harbor at an approximate rate of 10 to 20 m^3/sec. Salinities range from 1 part per thousand near the river mouths to more than 32 parts per thousand between the islands farthest from land. The average tidal range is about 9 feet (2.7 m). The greatest current velocity approaches 2 knots (100 cm/sec) between Deer Island and Long Island, but in most areas velocities are less than 1 knot (50 cm/sec).

SEDIMENT TEXTURE

Bottom.—Clayey silt predominates throughout most of the harbor. Coarsest material is limited to areas adjacent to the mainland and to the islands (fig. 6).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Dennen (1957) spectrographic technique).—In 98 percent of

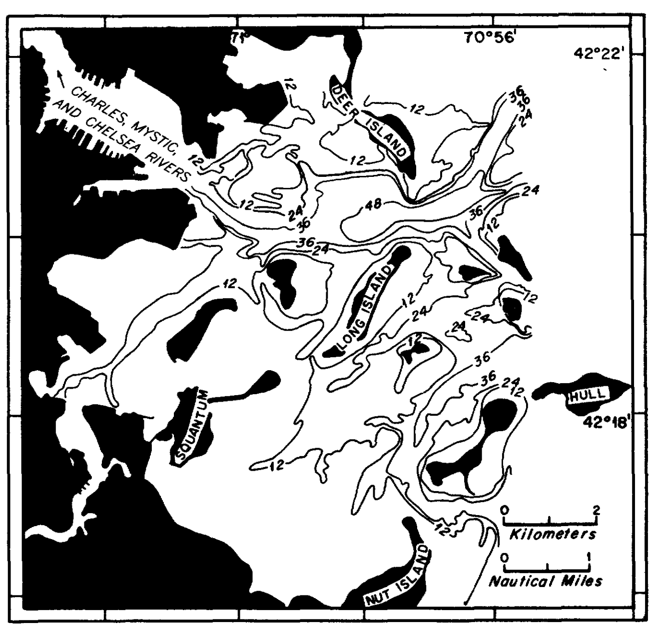


FIGURE 5.—Bathymetry (in feet) of Boston Harbor, Mass. (from U.S.C. & G.S. Charts 240 and 246.)

FIGURE 6.—Texture of bottom sediments in Boston Harbor, Mass. Modified from Mencher, Copeland, and Payson (1968).

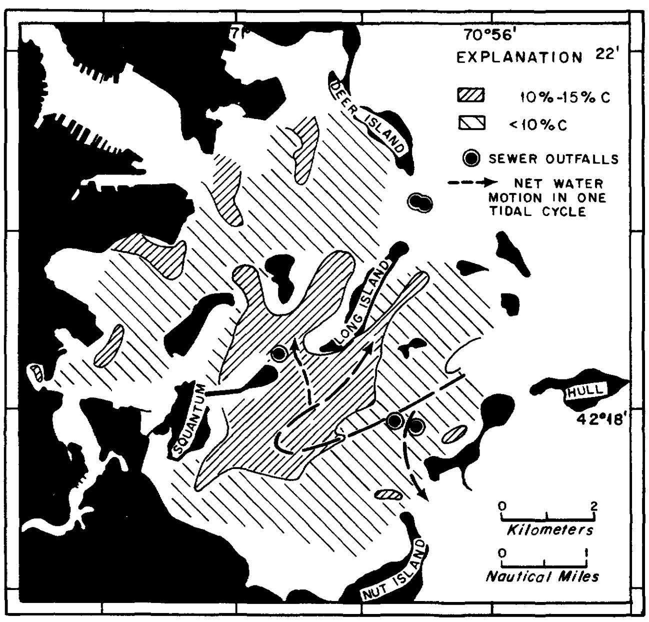


FIGURE 7.—Organic carbon content of bottom sediments in Boston Harbor, Mass. Modified from Mencher, Copeland, and Payson (1968).

the sediment, organic carbon content ranges from 1 to 15 percent. Coal and coke fragments predominate in the organic matter of the 62– to 1,000–micron size fraction, whereas finely divided organic material, probably mostly composed of sewage, is concentrated in the silt and clay fractions. The distribution of organic carbon is related both to the location of sewage outfalls and to the water circulation in the harbor (fig. 7).

Mineralogy.—Sand consists of 80 to 90 percent rounded clear quartz grains and 5 to 10 percent black frothy coke and coal fragments. Silt grains are almost entirely angular vitreous quartz. The finest material is composed of chlorite, illite, and probably muscovite plus some quartz and feldspar.

The Holocene mud is soupy to gelatinous and is black to dark gray; shell detritus forms 1 to 30 percent of it. Mussel banks are common.

REFERENCES

Bumpus and Day (1952), Bumpus and others (1953), Mencher, Copeland, and Payson (1968).

CAPE COD BAY, MASSACHUSETTS

SETTING

Geology.—Crystalline rocks (Dedham Granodiorite) crop out on the western margin of Cape Cod Bay and have been cored on Cape Cod. These rocks are overlain by patchy deposits of semiconsolidated and consolidated sediments and a thick section of glacial debris. The present configuration of the bay was determined largely by glacial processes superimposed on an erosional surface of low relief.

Sediments in the bay include thin, unconsolidated Pleistocene and Holocene detritus, glacial till, and unconsolidated Tertiary and Cretaceous(?) deposits. This sedimentary section ranges in thickness from less than 100 feet (30 m) at the western margin of the bay to approximately 550 feet (166 m) near the eastern margin.

Bathymetry.—The smooth bottom of the bay has an average depth of over 100 feet (30 m) and a maximum depth of 220 feet (66 m). A well-defined shelf borders the western side; and two northeast-trending ridges, probably recessional moraines, extend across the bay (fig. 8).

Hydrology.—Fresh-water inflow to the bay is very small and salinities are essentially the same as those in the open sea except in a few protected embayments along the coast. Mean tidal range is approximately 9 feet (2.7m).

SEDIMENT TEXTURE

Bottom.—Sand and gravel are most abundant along the margins of the bay. To seaward, medium to fine sand grades into clay and silt in deeper water. Sand occurs locally throughout the area, especially on topographic highs where fine material has been winnowed out. Silt and clay are mostly restricted to protected embayments near shore and to the deep central part of the bay (fig. 9).

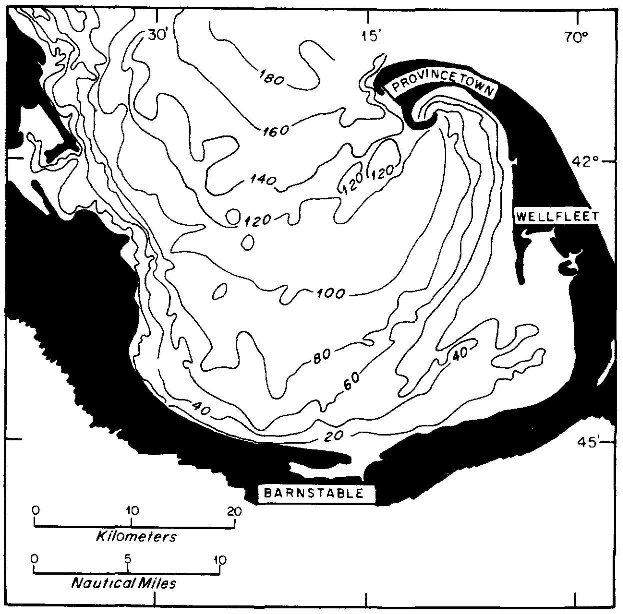


FIGURE 8.—Bathymetry (in feet) of Cape Cod Bay, Mass. (from Hough, 1942.)

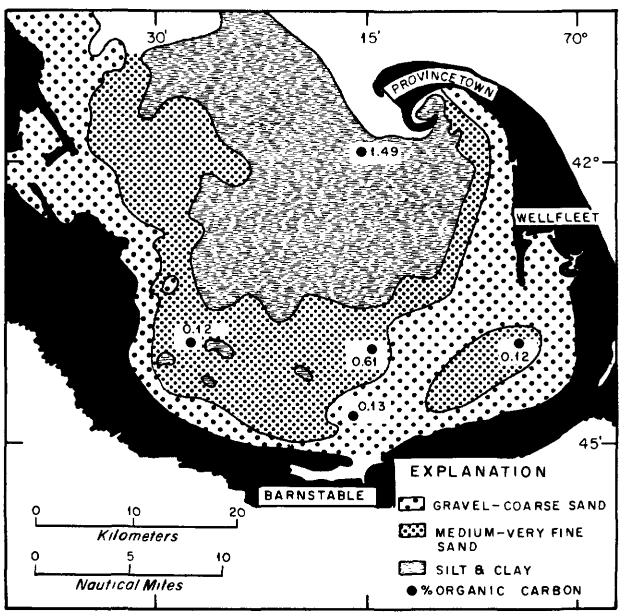


FIGURE 9.—Texture (modified from Hough, 1942) and organic carbon content (from Hathaway, 1971) of bottom sediments in Cape Cod Bay, Mass.

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Leco gas analyzer).—Of the five measurements available, four were made in areas where sand predominates. Of these four, the highest measurement of organic carbon content was 0.6 percent, and the other three were less than 0.2 percent. The one value in a sample taken in the silt-clay area was 1.5 percent.

Mineralogy.—Analyses have been made only at the five locations shown in figure 9. Coarse sand and gravel consist of quartz (90–95 percent) and feldspar (5–10 percent); fine to medium sands are 75 percent quartz and feldspar plus 25 percent illite and chlorite; and the clay and silt is 45 percent quartz and feldspar and 55 percent layered silicates.

Color.—The finest sediment is generally brownish green to black, and sands are light brown. Shell debris is sparse.

REFERENCES

Hathaway (1971), Hoskins and Knott (1961), Hough (1942), Oldale (1969).

NANTUCKET BAY, MASSACHUSETTS

SETTING

Geology.—Nantucket Bay is bordered on the south and east by detritus deposited as part of the terminal moraine of Wisconsin Glaciation. A postglacial cuspate spit isolates the bay on the northwest from Nantucket Sound. Pleistocene(?) marine rocks crop out near the east end of Nantucket Island and probably underlie the reworked glacial material which covers the entire bottom of the bay. Basement depth is approximately 1,500 feet (460 m).

Bathymetry.—Shoals are abundant throughout the bay and water depths are generally less than 20 feet (6 m). The depth reaches a maximum of about 30 feet (10 m) in the channel at the harbor entrance (fig. 10).

Hydrology.—Only a few small streams flow into the bay. Available salinity measurements, however, vary little from 31 parts per thousand throughout the entire bay. The mean tidal range is about 3 feet (0.9 m). Maximum velocities of tidal flow are between 0.6 and 4 knots (30–200 cm/sec.).

SEDIMENT TEXTURE

Bottom.—Gravel, composed of both shell fragments and glacial material, occurs near the harbor entrance and in the channel that leads into the central harbor. Very coarse sand is associated with shoals that extend from cusps on the northwest and southeast sides of the bay. Grain size decreases uniformly to silt and clay where depths are greater in the widest parts of the bay. Material less than 32 microns in diameter generally is present in areas deeper than 16 feet (5 m) (fig. 11).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed with the Leco gas analyzer).—High concentrations of organic carbon (2–3 percent) occur in the deepest areas of the three basins. Where eel grass is particularly abundant anomalously high values (10–20 percent) apparently

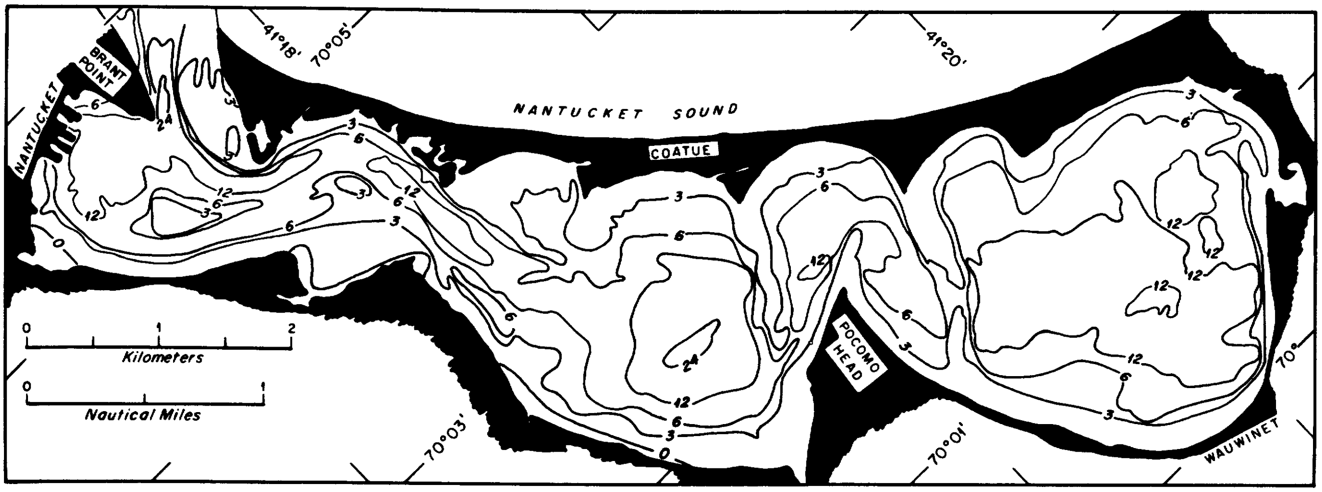


FIGURE 10.—Bathymetry (in feet) of Nantucket Bay, Mass. Modified from Lidz (1965).

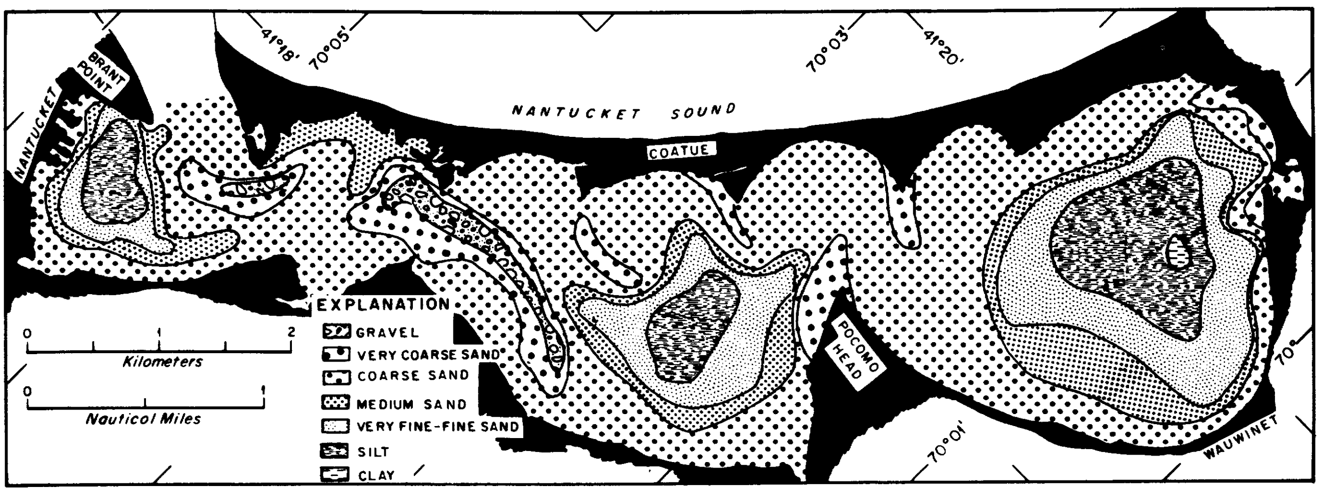


FIGURE 11.—Texture of bottom sediments in Nantucket Bay, Mass. Modified from Lidz (1965).

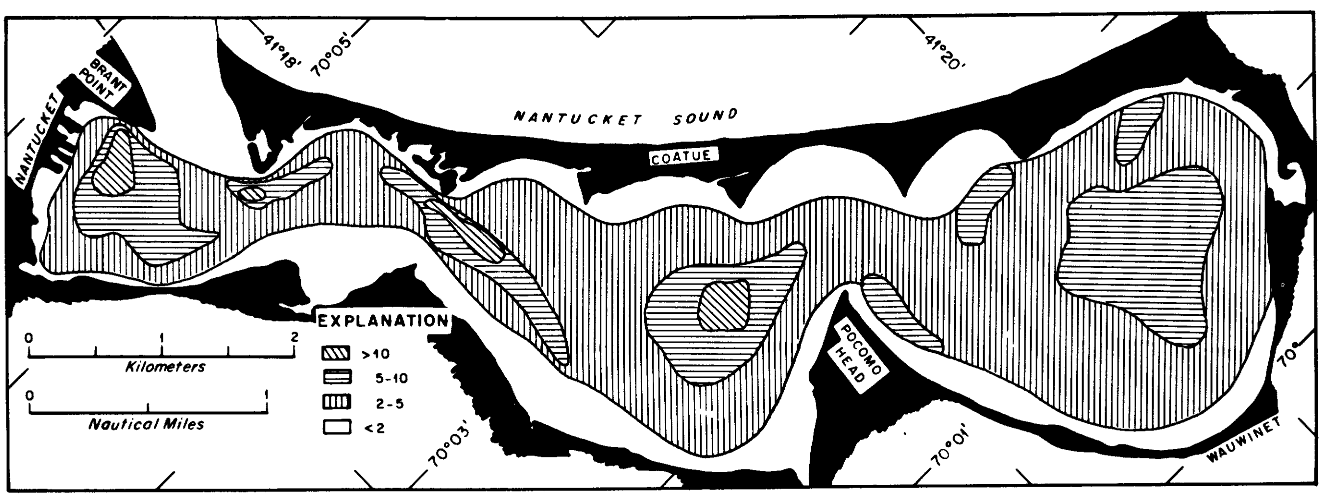


FIGURE 12.—Calcium carbonate content (in percent) of bottom sediments in Nantucket Bay, Mass. (from Lidz, 1965).

may be present, but most are less than 3 percent. Sand, which covers most of the bottom, generally contains less than 1 percent organic carbon.

Mineralogy.—Quartz constitutes approximately 90 percent and feldspar 10 percent of the light-mineral fraction. Heavy minerals, mostly magnetite and ilmenite, make up a maximum of 3 percent of the total assemblage. Layered silicates, in contrast to their abundance in most bays and estuaries in the area, are notably sparse. Carbonates that consist mostly of large shell fragments and Foraminifera are most abundant in the silts and clays and locally in gravel (fig. 12).

Color.—Sediment color varies from white to light gray in quartz sands to dark greenish gray in muds. A reddish color in some sands may be relict or may be due to staining by iron-rich water flowing into the bay from contiguous swamps.

REFERENCES

Lidz (1965), Oldale (1969), D. W. Folger and L. G. Toner (unpub. data, 1970).

BUZZARDS BAY, MASSACHUSETTS

SETTING

Geology.—Thick glacial deposits overlie the Dedham Granodiorite which crops out intermittently on the northwestern shore of Buzzards Bay. A terminal moraine of Wisconsin Glaciation forms the Elizabeth Islands and isolates the bay from Vineyard Sound. Few subsurface data are available within the bay. Basement was cored at a depth of about 300 feet (90 m) below the bottom in Woods Hole Harbor. Geophysical profiles within the bay itself indicate that crystalline rocks are present between about 30 and 200 feet (9–60 m) below the bottom. Most of the sedimentary material is probably Pleistocene glacial debris, but available seismic velocity data do not preclude the presence of older strata. No data are available on the thickness of Holocene sediments.

Bathymetry.—Most of the bay is less than 50 feet (15 m) deep, but depressions near the mouth reach a depth of 140 feet (42 m). The dissected, hummocky topography on the northwest side of the bay becomes smoother with increasing distance from the mainland (fig. 13).

Hydrology.—Fresh-water inflow from a few small streams on the mainland is small. Variations in salinity are accordingly also small and generally range from 29.5 to 32.5 parts per thousand. Semidiurnal

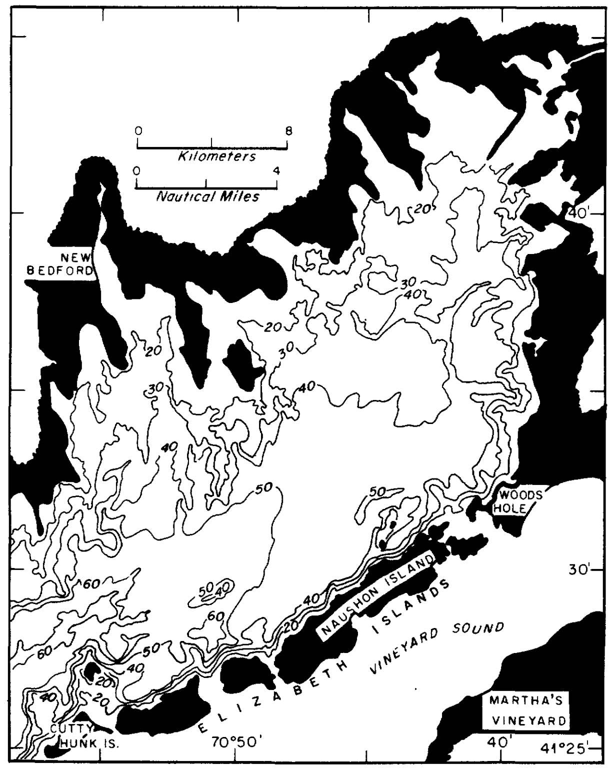


FIGURE 13.—Bathymetry (in feet) of Buzzards Bay, Mass. (from Moore, 1963).

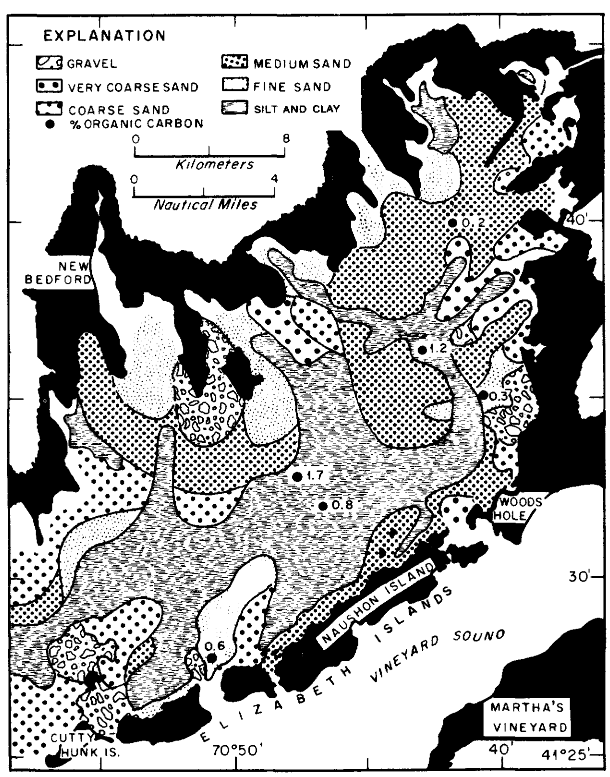


FIGURE 14 (right).—Texture (modified from Moore, 1963) and organic carbon content (from Hathaway, 1971) of bottom sediments in Buzzards Bay, Mass.

tides have a range of about 3 to 4 feet (0.9–1.2 m). Tidal currents in the bay are mostly less than 1 knot (50 cm/sec). Velocities are higher only in channels between islands on the margin of the bay.

SEDIMENT TEXTURE

Bottom.—The sediments in the southeastern part of the bay where topography is smoothest are primarily silts and clays. Fine detritus has also been trapped near shore in embayments. The complex distribution of sand is apparently due to current and wave action. Gravel occurs near shore in shallow water (fig. 14).

SEDIMENT COMPOSITION

Organic carbon.—The total organic content in 20 sediment samples collected in 1934 averaged approximately 2 percent. The technique used to obtain this value was not reported.

Six recent measurements (Leco gas analyzer) are less than 0.3 percent organic carbon in sand samples and range from 0.8 to 1.7 percent in silt and clay samples (fig. 14).

Mineralogy.—In the few samples analyzed, sand is composed of quartz (as much as 90 percent) and feldspar (as much as 30 percent). Illite makes up approximately 50 percent of the clay and silt.

REFERENCES

Hathaway (1971), Hough (1940), Moore (1963), Murray (1968), Oldale (1969).

NARRAGANSETT BAY, RHODE ISLAND

SETTING

Geology.—Narragansett Bay is located in a structural depression (Narragansett basin) filled with Carboniferous sedimentary and metasedimentary rocks. Precambrian and lower Paleozoic rocks crop out on the western shore. The position of the three main channels is controlled by bedrock valleys.

Bathymetry.—North of Prudence Island the smooth bottom averages 20 feet (6 m) in depth. Two dredged channels are maintained at a depth of approximately 24 feet (7 m). To the south topography is rougher, especially in the narrow channels (fig. 15). A maximum depth of more than 150 feet (45 m) occurs in the narrow channel at the bay mouth, between Conanicut Island and Newport Neck.

Hydrology.—The volume of fresh water flowing into the bay is not great. Mean flow rate for the Taunton River is approximately 29 m³/sec. Measurements of salinity vary between approximately 15 parts per thousand at Fall River to 33 parts per thousand near the bay mouth. Tidal current velocities are generally

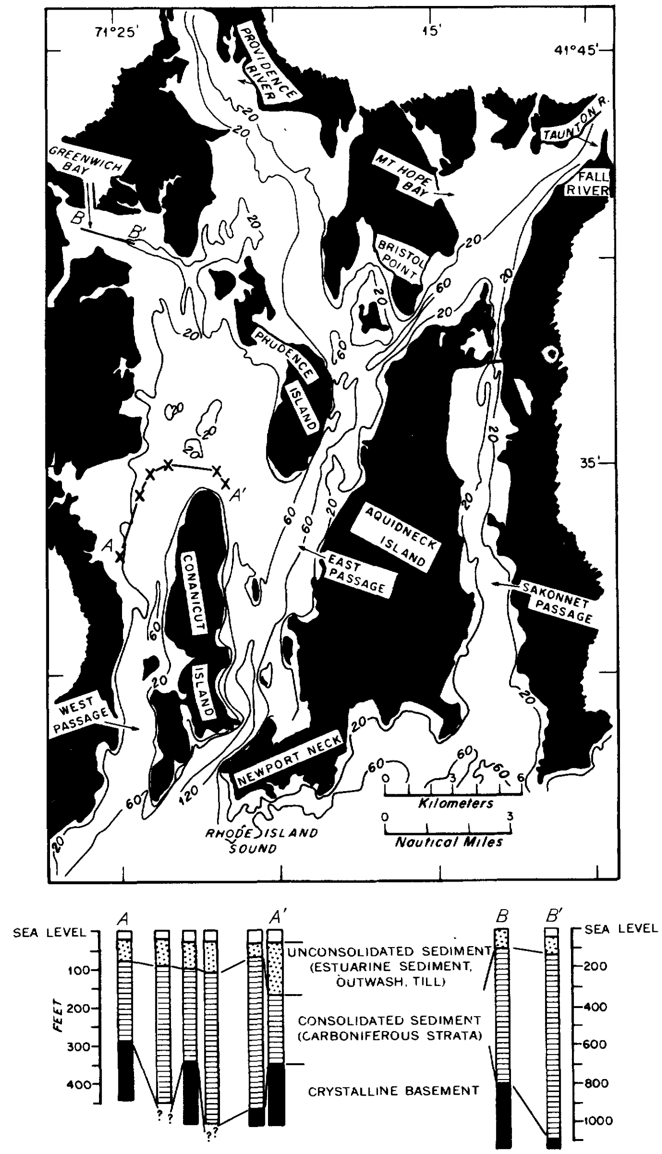


FIGURE 15.—Bathymetry (in feet) of Narragansett Bay, R.I. (from McMaster, 1960). Columnar sections *A–A'* and *B–B'* are based on geophysical data of Birch and Dietz (1962).

between 0.5 and 1.0 knot (25–50 cm/sec), but in narrow channels they approach 3 knots (150 cm/sec).

SEDIMENT TEXTURE

Bottom.—In the upper bay, silts and clays predominate in the deeper area whereas sand is more abundant near shore. Clay, however, rarely constitutes more than half the total sediment, and gravel, though ubiquitous, is rarely volumetrically important. Sand predominates in all three passages from the southern part of the bay

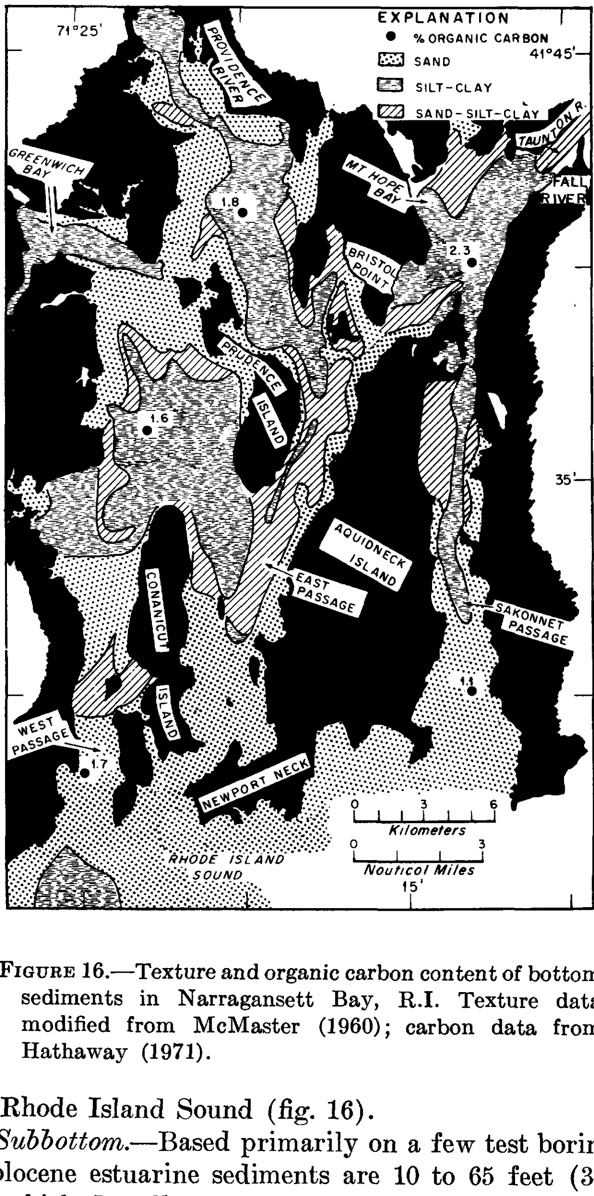


FIGURE 16.—Texture and organic carbon content of bottom sediments in Narragansett Bay, R.I. Texture data modified from McMaster (1960); carbon data from Hathaway (1971).

to Rhode Island Sound (fig. 16).

Subbottom.—Based primarily on a few test borings, Holocene estuarine sediments are 10 to 65 feet (3–20 m) thick. Locally, plant remains and shell fragments are abundant. Poorly sorted underlying unconsolidated sediment, approximately 60 to 160 feet (18–50 m) thick, is probably made up principally of glacial till and outwash. The thickness of Carboniferous basement strata, based on seismic refraction measurements (fig. 15), ranges from approximately 160 feet (50 m) to at least 1,000 feet (333 m).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Leco gas analyzer).—Few measurements of organic carbon content are available. The greatest value (2.3 percent) was recorded from the deepest part of Mt. Hope Bay. The only other values available for sediments of the upper estuary are 1.8 percent and 1.6 percent. In Sakonnet Passage and West Passage, values for two samples are 1.1 percent and 1.7 percent, respectively (fig. 16).

Mineralogy.—In the northern part of the bay, layered silicates make up between 50 and 70 percent of the minerals present in the few samples analyzed. Quartz and feldspar make up the remainder. In one sample collected in West Passage, where coarser textured sediment predominates, quartz and feldspar constitute 70 percent of the minerals.

REFERENCES

Berg (1963), Birch and Dietz (1962), Hathaway (1971), McMaster (1960), Towe (1959), Upson and Spencer (1964), Wilson (1967).

MORICHES BAY, NEW YORK

SETTING

Geology.—The irregular shoreline on the northwest side of Moriches Bay consists of detritus deposited as part of the outwash plain of Wisconsin Glaciation. On the southeast the bay is isolated from the Atlantic Ocean by a barrier island which is periodically cut by an inlet.

Bathymetry.—At high tide, the flat-floored bay has an average depth of 4 feet (1.2 m) and a maximum depth of less than 8 feet (2.4 m). A delta formed by material transported landward through Moriches Inlet divides the bay into two basins. Irregular shoals that project from the barrier island are washover fans and former inlet deltas (fig. 17).

Hydrology.—Sluggish water circulation within the bay is controlled by tides and runoff. Waters are well mixed vertically. Most drainage is introduced by the Forge River, but seepage is responsible for most fresh water present in the bay. Average salinity when Moriches Inlet is open is 27 parts per thousand, and when closed, about 12 parts per thousand.

SEDIMENT TEXTURE

Bottom.—Clayey silt is present in the deepest, central parts of the lagoon and is surrounded by a narrow marginal zone consisting of a mixture of sand, silt, and clay. Shallow areas adjacent to the barrier islands are sand. Clayey silt covers much of the bottom of the Forge River estuary (fig. 18).

SEDIMENT COMPOSITION

Organic matter (dry weight loss after sample digestion with H_2O_2).—Lowest values of organic matter content, which occur near shore in sand, increase toward the center of the lagoon in clayey silts. Highest concentrations (28.7 percent maximum in Seatuck Cove) are present in the drowned stream channels where duck farms are located (fig. 19).

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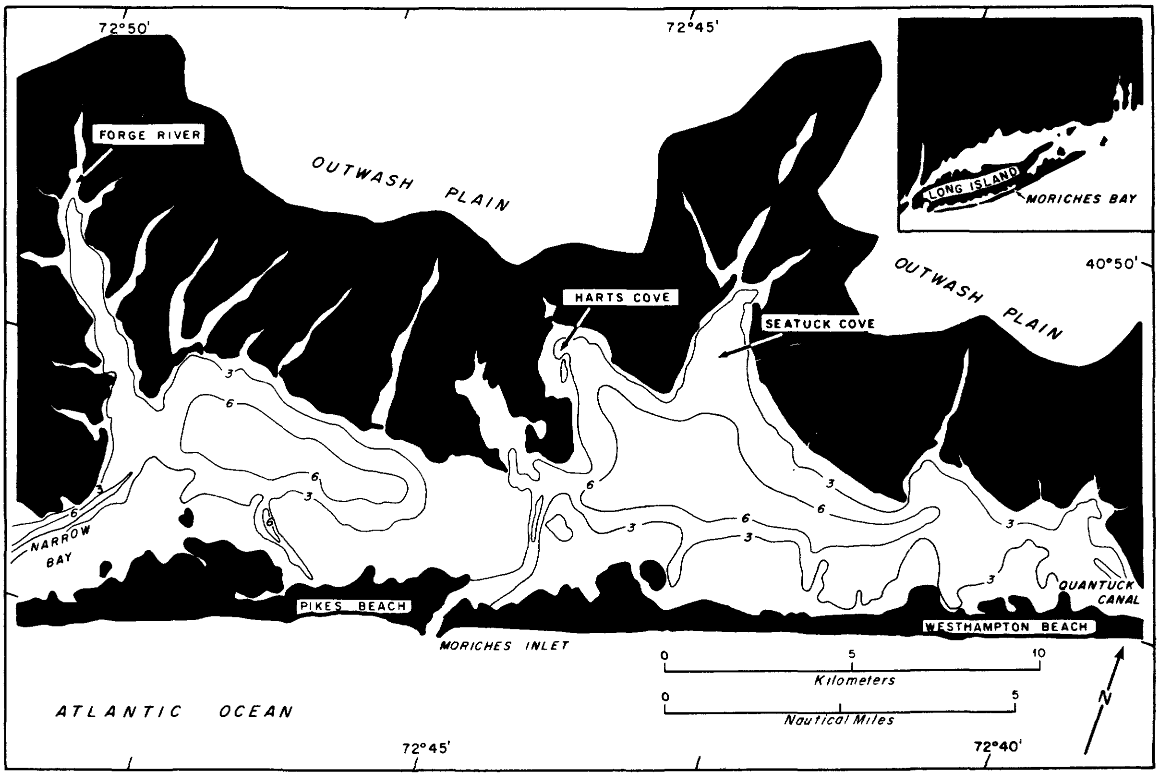

FIGURE 17.—Bathymetry (in feet) of Moriches Bay, N.Y. (from Nichols, 1964).

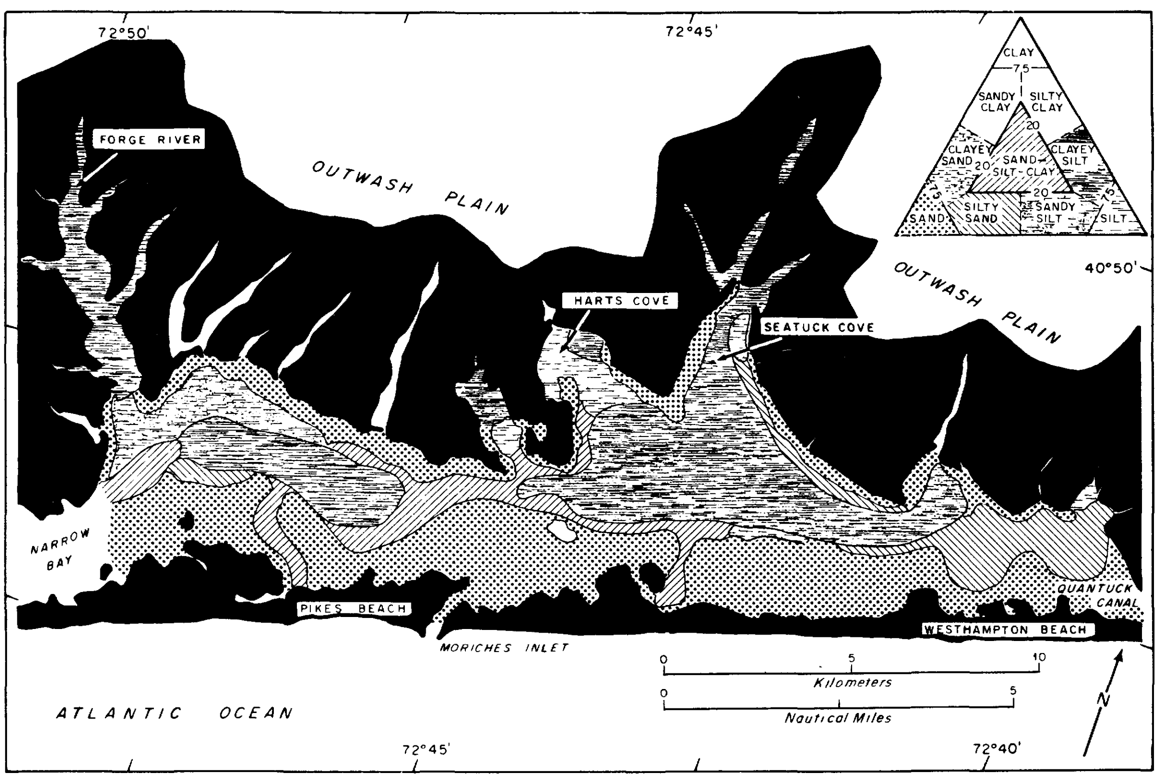

FIGURE 18.—Texture of bottom sediments in Moriches Bay, N.Y. Modified from Nichols (1964).

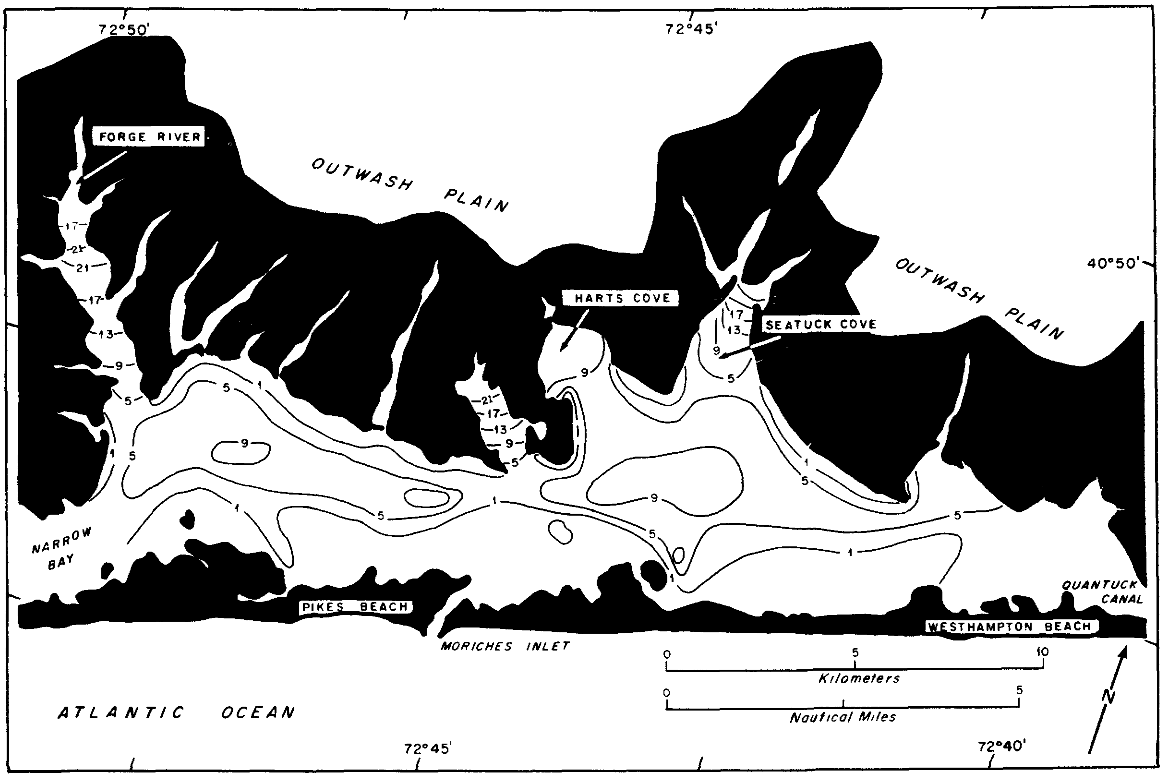

FIGURE 19.—Total organic matter content (in percent) of sediments in Moriches Bay, N.Y. (from Nichols, 1964).

Mineralogy.—The principal clay minerals—illite, kaolinite, and montmorillonite—occur respectively in the following ratios: 7–3–trace in an estuary, 3–7–0 in a cove, 8–2–trace in midbay, and 8–0–2 on a barrier shoal. In the sand fraction, components are: 90 percent quartz, 2 percent muscovite, 3 percent plagioclase feldspar and small amounts of apatite, biotite, potash feldspar, chlorite, chert, and rock fragments. Other components of sediment coarser than 0.062 mm are shown in table 1. Heavy minerals (as much as 4 percent in inlets) include magnetite, garnet, tourmaline, kyanite, and hornblende.

TABLE 1.—*Average composition, in percent, of the coarse fraction of sediments in each environment in Moriches Bay, N.Y.*

[Modified from Nichols (1964)]

Environment	Shell	Foraminifera	Wood	Minerals	
				Light	Heavy
Midbay	2.3	0.06	3.7	78.8	0.8
Open cove	5.6	.1	8.5	60.2	.6
Estuary			33.2	57.8	.8
Bay margin	.5	.05	.1	97.8	1.2

	Mica	Ferruginous aggregates	Diatoms
Midbay	13.7	0.2	0.5
Open cove	20.2	3.8	1.0
Estuary	7.5	.3	.3
Bay margin	.5	.2	.4

Internal structures.—Sands on the margins of the estuary are homogeneous and contain no layering. In midbay, indistinct mottling of the sediments reflects the effects of burrowing organisms.

Color, pH, Eh.—In midbay, clayey silts have an average pH of 7.8 at the surface and 7.0 at a depth of 1 cm (centimeter). Eh below the surface ranges from −0.5 to −2.5 volts. In drowned stream channels where organic material is most abundant, pH values are 6.7 at the surface and 6.2, 6.4, and 6.4 at depths of 1 cm, 15 cm, and 30 cm, respectively. These sediments are generally black, have an H_2S odor, and contain small pyrite grains. Sands on the margin of the bay have neutral pH and positive Eh.

Coarse fraction.—Components of the coarse fraction of the sediments are shown in table 1.

REFERENCE

Nichols (1964).

NEW YORK HARBOR, NEW YORK AND NEW JERSEY

SETTING

Geology.—Glacial debris, probably mostly part of the terminal moraine of Wisconsin Glaciation, borders the Lower Bay and Raritan Bay on the northwest (Staten Island) and on the south along segments of the New Jersey coastline (fig. 21). Cretaceous deposits crop out along cliffs on the southwestern shore. Sandy Hook is a postglacial spit. In the Upper Bay and the Hudson River, Paleozoic crystalline rocks crop out on the east and Triassic intrusives and sedimentary rocks crop out on the west. Unconsolidated sediments that underlie the harbor probably consist mostly of Cretaceous, glacial, and Holocene deposits and range in thickness from zero to approximately 1,000 feet (fig. 20).

Bathymetry.—Dissected topography around the margin of the Lower Bay grades into the smooth bottom which is present over much of the central area. North of the Narrows, rapid shoaling requires frequent dredging. Depths are maintained between 40 and 60 feet (12–18 m) (fig. 21).

Hydrology.—The Hudson River accounts for 90 percent of the total fresh-water inflow of 740 m^3/sec into the bay. The Raritan and Passaic Rivers bring in most of the remaining 10 percent. In the Upper Bay the mean tidal range is about 3 to 4 feet (0.9–1.2 m); flood currents in the area flow at velocities of 0.8 to 1.8 knots (40–90 cm/sec) and ebb currents flow from 0.6

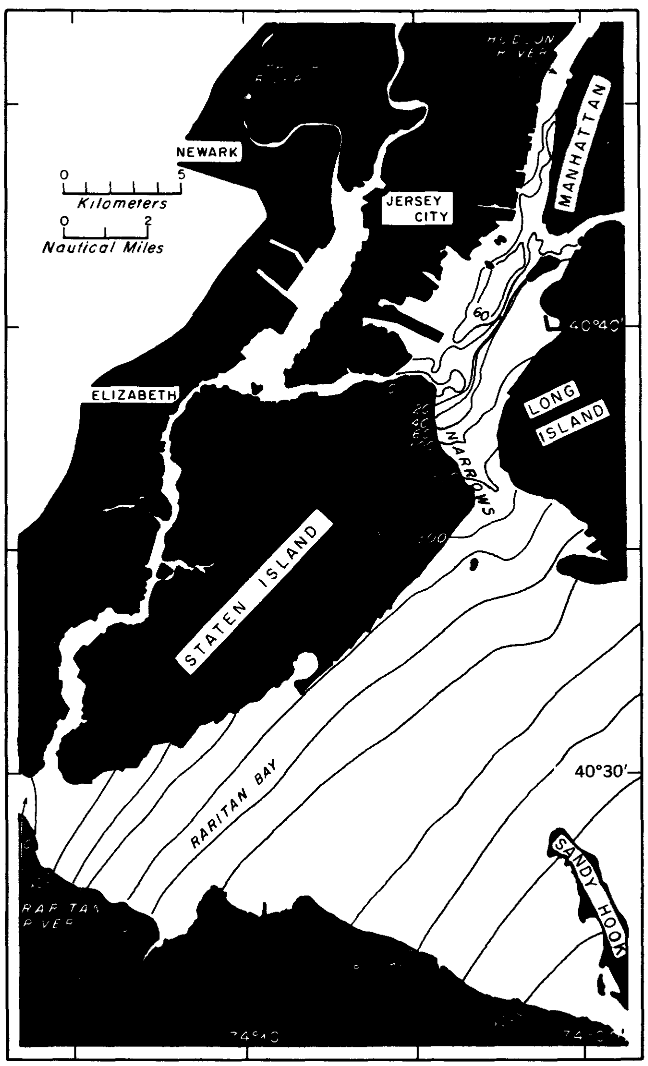

FIGURE 20.—Depth (in feet) below sea level to crystalline rock or consolidated sediments in New York Harbor, N.Y. and N.J. (from Crawford and others, 1951).

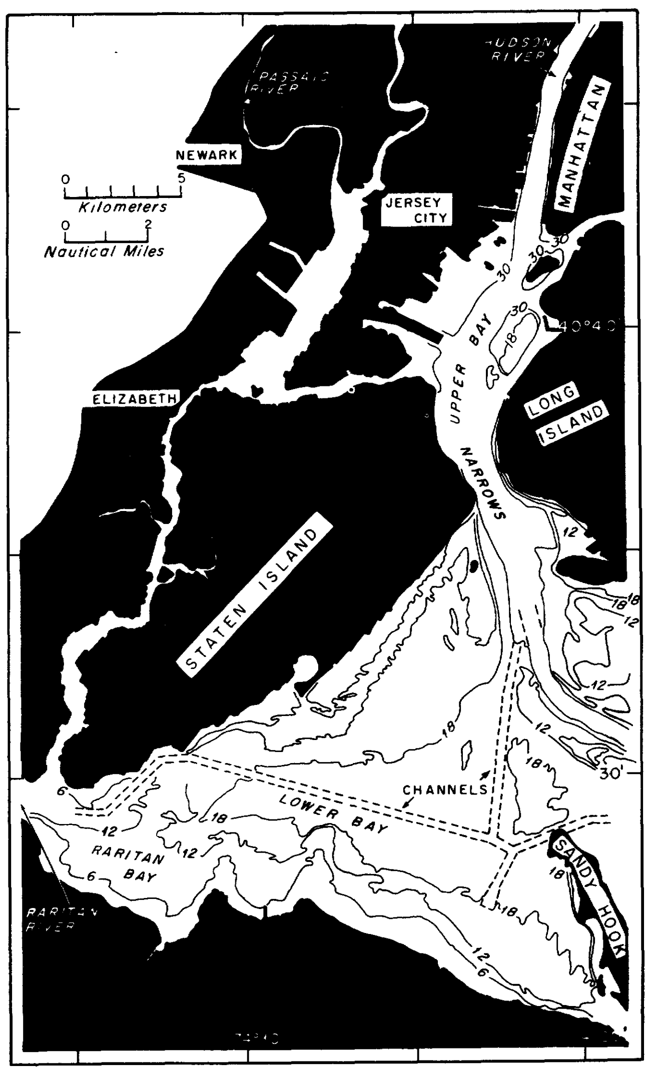

FIGURE 21.—Bathymetry (in feet) of New York Harbor, N.Y. and N.J. (from U.S.C. & G.S. Chart 369).

to 2.5 knots (30–125 cm/sec). South of Manhattan the estuary is well mixed vertically; to the north it is only partly mixed.

SEDIMENT TEXTURE

Available data concerning sediment distribution in the area are sparse. Most of the analyzed samples used in this study were collected in Raritan Bay with a Petersen grab sampler. A few samples were taken in the northern part of the Lower Bay and in the Hudson River off Manhattan.

Bottom.—Sand is present throughout most of the Lower Bay. Silt and clay are predominant near the mouths of the Raritan and Hudson Rivers and in an area west of Sandy Hook. The median diameter of most of the sand in Raritan Bay ranges from 0.1 to 0.5 mm (millimeter) (fine to medium sand), and that of finer material near Sandy Hook is about 0.03 mm (coarse silt). A few analyzed sediment samples from the Hudson River off Manhattan have median diameters between 0.008 and 0.060 mm, encompassing almost the whole silt range (fig. 22).

Subbottom.—North of the Battery, which is at the south end of Manhattan, the few analyzed samples did not show significant textural variations to a depth of 7 feet (2 m) below the bottom.

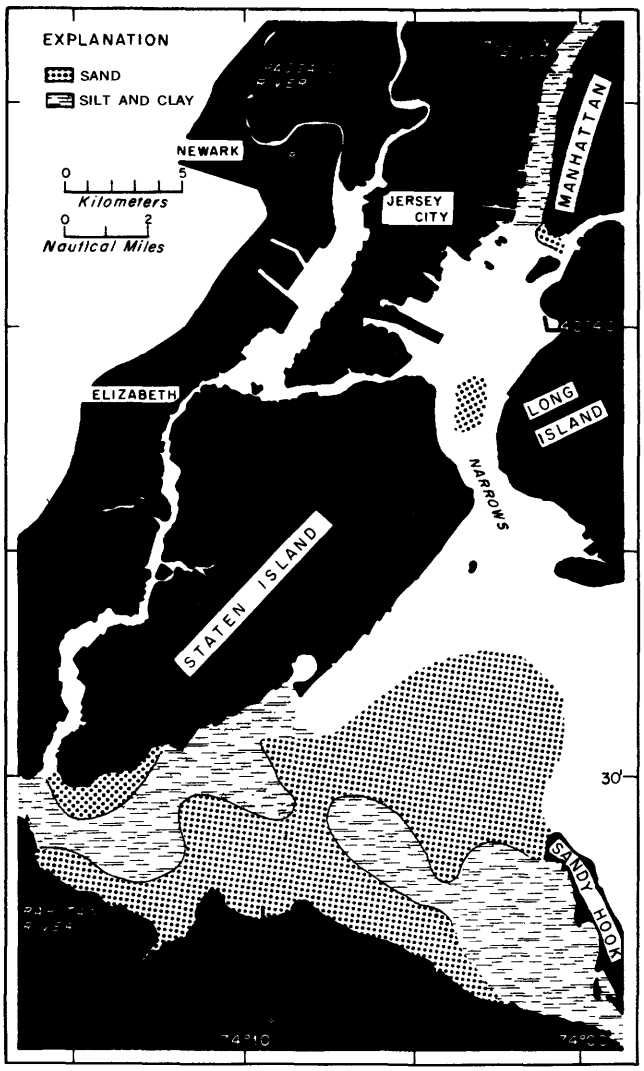

FIGURE 22.—Texture of bottom sediments in New York Harbor, N.Y. and N.J. Modified from DeFalco (1967), Duke (1961), and Panuzio (1965).

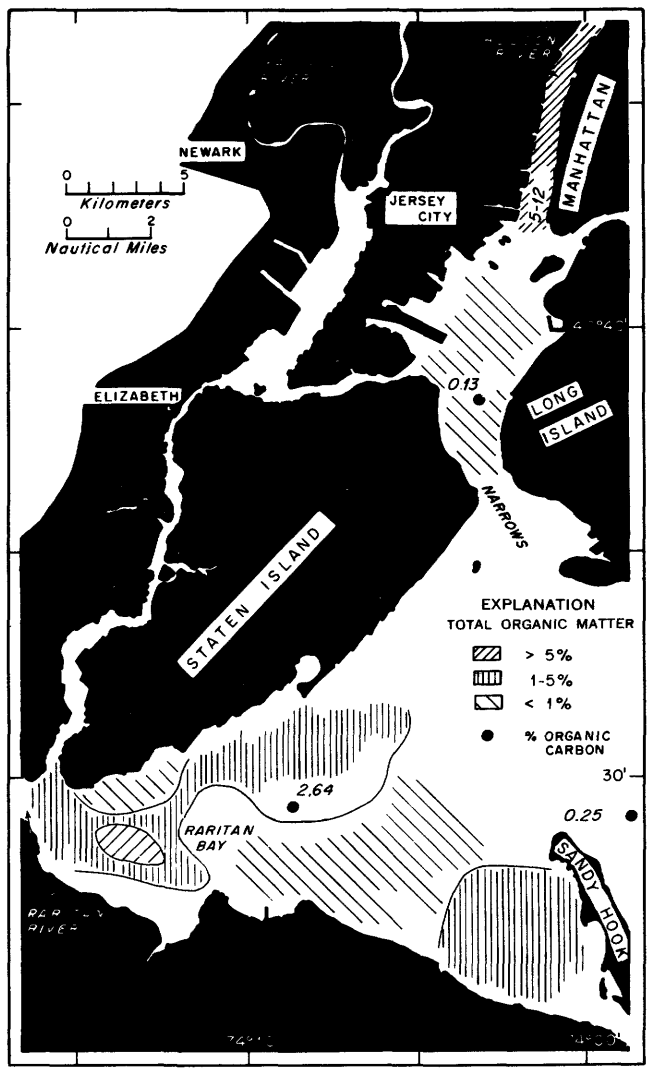

FIGURE 23.—Total organic matter and organic carbon content of bottom sediments in New York Harbor, N.Y. and N.J. Data on total organic matter content is modified from DeFalco (1967); organic carbon content in the Hudson River from Panuzio (1965); and concentrations of organic carbon elsewhere from Hathaway (1971).

SEDIMENT COMPOSITION

Organic matter.—Values for total organic matter measured in sediment samples of Raritan Bay were based on dry weight loss after treatment with H_2O_2 (fig. 23). A few values for organic carbon measured by the Leco gas analyzer are also shown. The method used for measuring organic carbon concentrations in the Hudson River was not specified.

The highest concentrations of organic matter in the Raritan and Lower Bays are associated with the silt and clay near the mouth of the Raritan River and near Sandy Hook. Sands throughout the areas generally contain less than 1 percent organic matter. The highest values (5–12 percent organic carbon) were reported in shoal areas in the Hudson River. Much of the coarse organic debris consists of amphipod tubes, wood, and coal.

Mineralogy.—Over 90 percent of the sand in the few samples analyzed consisted of quartz and plagioclase feldspar. Illite, montmorillonite, and quartz predominate in the finer material.

Carbonate.—Shells and shell fragments (mostly oyster shells) make up 0.1 to 40 percent of the sediment.

REFERENCES

Crawford, Powers, and Backus (1951), DeFalco (1967), Duke (1961), Hathaway (1971), Panuzio (1965), U.S. Public Health Service (1965), Wilson (1967).

CHESAPEAKE BAY, MARYLAND AND VIRGINIA

SETTING

Geology.—Chesapeake Bay lies totally within the Atlantic Coastal Plain. Sedimentary strata underlying the bay and exposed on its shores consist mostly of unconsolidated gravel, sand, clay, and marl of Cretaceous, Tertiary, and Quaternary age. The complex dendritic drainage system of the Susquehanna River was drowned in the postglacial advance of the sea; this formed the largest estuary on the Atlantic coast. The shoreline is a classic example of a ria or youthful coast.

Bathymetry.—The bay has a mean depth of less than 25 feet (7.6 m). The deepest area (about 175 feet or 53 m), between the mouths of the Chester and Choptank Rivers, is part of a sinuous channel that extends the length of the bay and may be part of the unfilled ancient Susquehanna River valley (fig. 24).

Hydrology.—The Susquehanna River accounts for about half the average total fresh-water inflow (2,000 m^3/sec) brought to the bay by nine main rivers. Salinity ranges from zero at the head of the estuary to about 33 parts per thousand at the mouth. Average tidal range is about 3 feet (1 m) at Norfolk and declines to about 1.5 feet (0.5 m) near the Potomac River mouth. Current velocities may be as high as 3 knots (150 cm/sec) but most often are less than 1 knot (50 cm/sec). Water is generally saturated with dissolved oxygen except in summer when it becomes depleted in the deep areas.

SEDIMENT TEXTURE

Bottom.—Data are taken mostly from Ryan's (1953) reconnaissance map that was based on analyses of 209 bottom samples collected during 15 transects of the bay. The results of more recent studies of sediment texture, (Biggs, 1967; Harrison and others, 1964; Virginia Institute of Marine Science, 1967; Young, 1968) are incorporated onto Ryan's map on the basis either of the median or arithmetic mean sediment diameter reported (fig. 25). Clayey and sandy silt, present over most of the central parts of the bay, is bounded toward shore by fine to medium sand. Gravel and coarse sand are sparse except near the mouth of the bay.

SEDIMENT COMPOSITION

Organic carbon (samples analyzed with the Leco gas analyzer or by the Niederl and Niederl (1942) techniques).—Closely spaced samples have been analyzed only in the areas off the Patuxent River mouth and between the mouths of the Rappahannock and Potomac Rivers. Others, located along the bay axis, were collected at about 10-nautical-mile (16 km (kilometers)) intervals. Highest concentrations of organic carbon (7 percent)) occur in sediments of the northern bay (fig. 26). Coal fragments are abundant on the bottom for a distance of approximately 20 miles (37 km) south of the Susquehanna River mouth; these probably account in part for the high values. South of the Patuxent River, few samples contain more than 2 percent organic carbon.

Mineralogy.—The sand fraction of the sediment consists mostly of quartz, and equal amounts of feldspar occur locally. In the finer material, layered silicates (mostly illite, chlorite, and mixed-layer clay) locally constitute as much as 50 percent of the minerals. Rock fragments are abundant in a few places, mostly near the bay mouth. A wide variety of heavy minerals—the most common of which include hornblende, garnet, and hypersthene—generally constitute less than 3 percent of the sediment by volume.

pH, Eh, and color.—In sediments located between the mouths of the Rappahannock and Potomac Rivers, pH in surface sediments ranges from 7.0 to 8.3. Below the bottom, values range from 6.8 to 8.3. The lowest values occur in black soupy mud common along the axis of the central bay. Iron sulfide minerals appar-

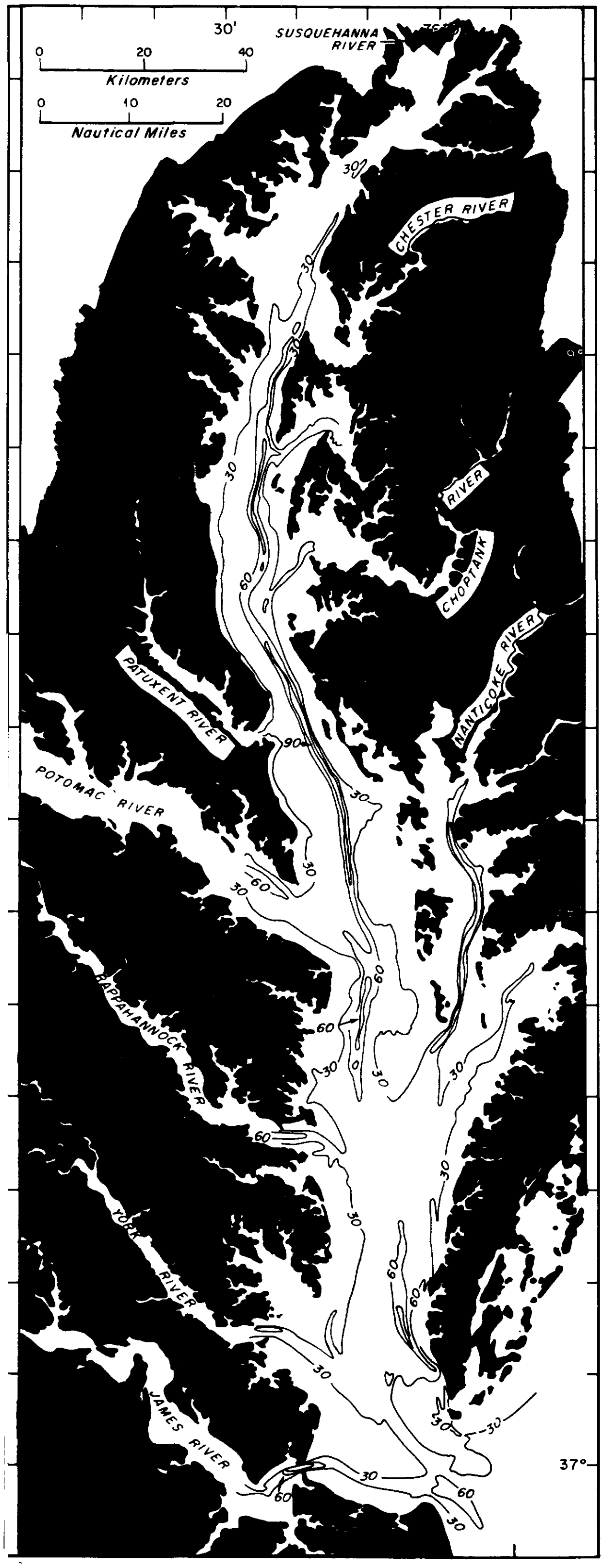

FIGURE 24.—Bathymetry (in feet) of Chesapeake Bay, Md. and Va. (from Ryan, 1953).

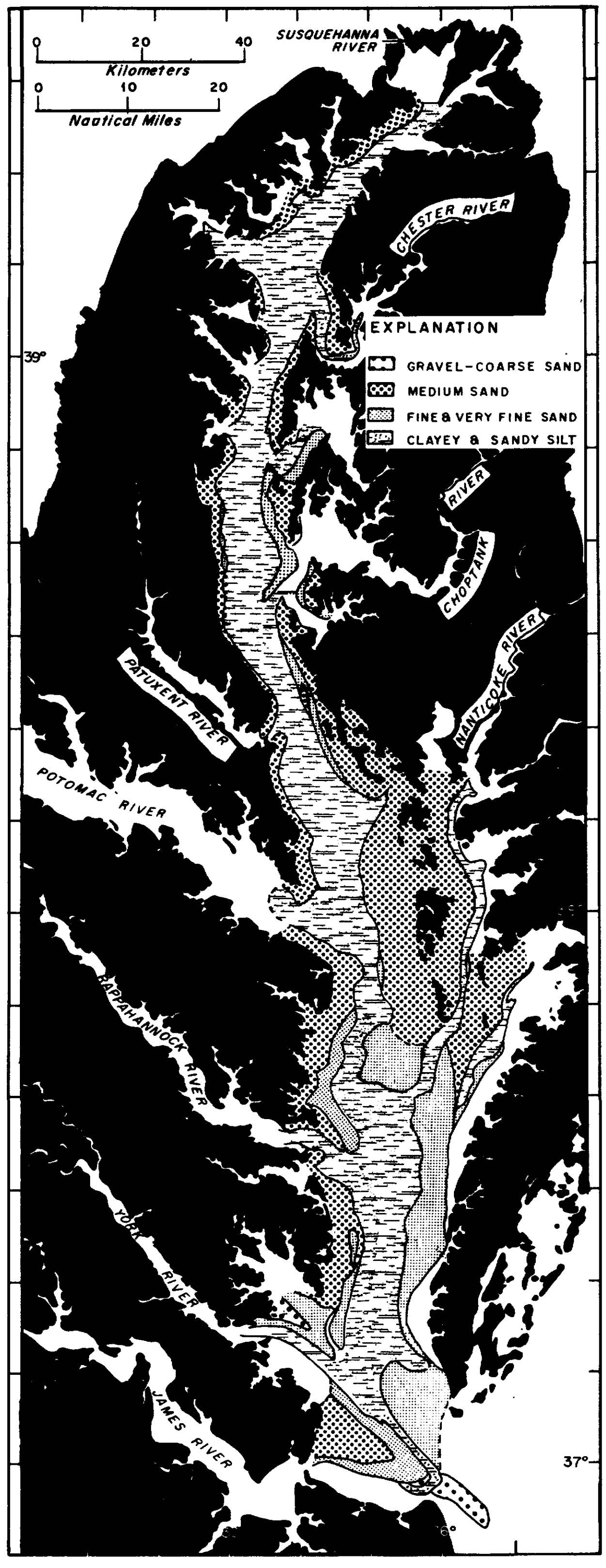

FIGURE 25.—Texture of bottom sediments in Chesapeake Bay, Md. and Va. Modified from Ryan (1953), Biggs (1967), Harrison and others (1964), Virginia Institute of Marine Science (1967), Young (1968).

ently are responsible for the black color. Eh values in the top inch of black sediment are commonly lower than −150 millivolts.

FIGURE 26. (left)—Percentage of organic carbon content of bottom sediments in Chesapeake Bay, Md. and Va. •, from Hathaway (1971); ▲, from Harrison and others (1964), Virginia Institute of Marine Science (1967), and Young (1968); contours from Biggs (1967).

REFERENCES

Biggs (1967), Harrison, Lynch, and Altschaeffl (1964), Hathaway (1971), Powers (1954, 1957), Pritchard (1952), Ryan (1953), Schubel (1968), Virginia Institute of Marine Science (1967), Wilson (1967), and Young (1968).

RAPPAHANNOCK RIVER, VIRGINIA

SETTING

Geology.—The estuary channel of the Rappahannock River cuts into Quaternary, Tertiary, and Cretaceous sedimentary rocks of the Atlantic Coastal Plain. Most of the sediment that is presently accumulating here is transported by the Rappahannock River from the weathered crystalline rocks of the Blue Ridge and Piedmont provinces.

Bathymetry.—In the lower estuary (fig. 27), shallow water on the margins deepens rapidly into the narrow central channel where water depths reach almost 80 feet (24 m). In the upper estuary, depths range from 20 to 40 feet (6–12 m).

Hydrology.—Fresh-water inflow ($\approx$ 70 m^3/sec) is primarily derived from the Rappahannock River. Salinity increases from an average of 1 part per thousand at Tappahannock to 18 parts per thousand at the mouth of the estuary in the summer. The mean tidal range is about 1.1 feet (0.3 m) at the mouth and 2.3 feet (0.7 m) near the head. The maximum tidal currents observed are 1.4 knots (70 cm/sec) at ebb tide and 1.1 knots (55 cm/sec) at flood tide. Velocities decrease downstream. The water has a pH that ranges from 6.5 to 7.0.

SEDIMENT TEXTURE

Bottom.—Distribution of sediment (fig. 28) is interpreted from descriptions of sediments collected during nine transects of the estuary. No quantitative data such as the median diameter are available. Sand is most abundant in the estuary along the margin and over a wide area near the mouth. Silt in the deep channel near the mouth gives way to clay with increasing distance upstream.

Subbottom.—Numerical textural data on subbottom sediments are unavailable. The geologic cross section near Grey's Point (fig. 28) is based on descriptions of sediments penetrated by test borings drilled prior to the construction of a bridge.

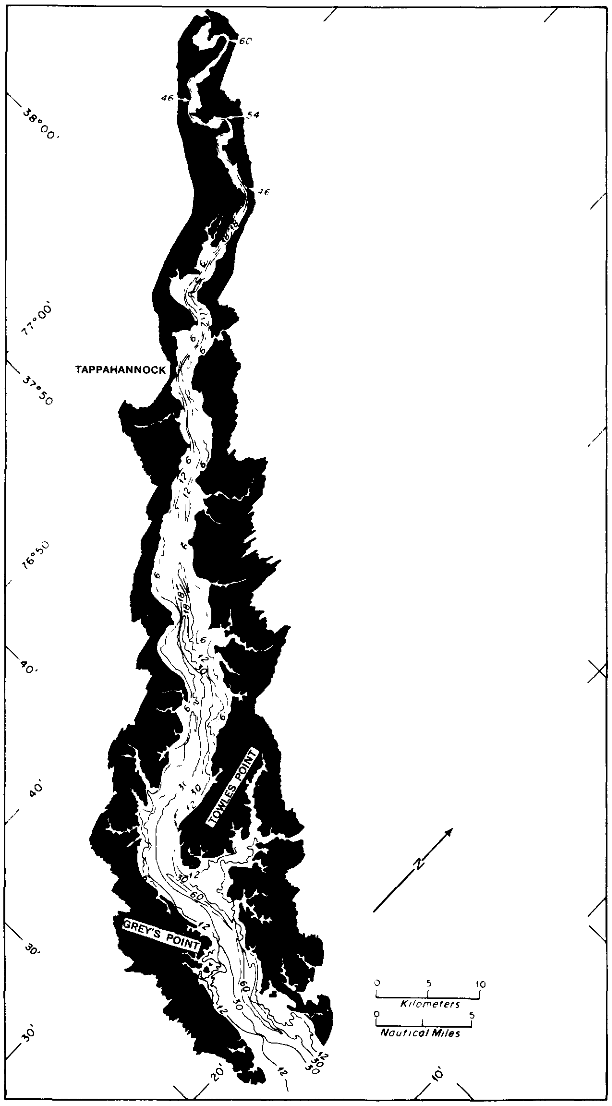

FIGURE 27.—Bathymetry (in feet) of the Rappahannock River Estuary, Va. (from U.S.C. & G.S. Charts 534 and 535).

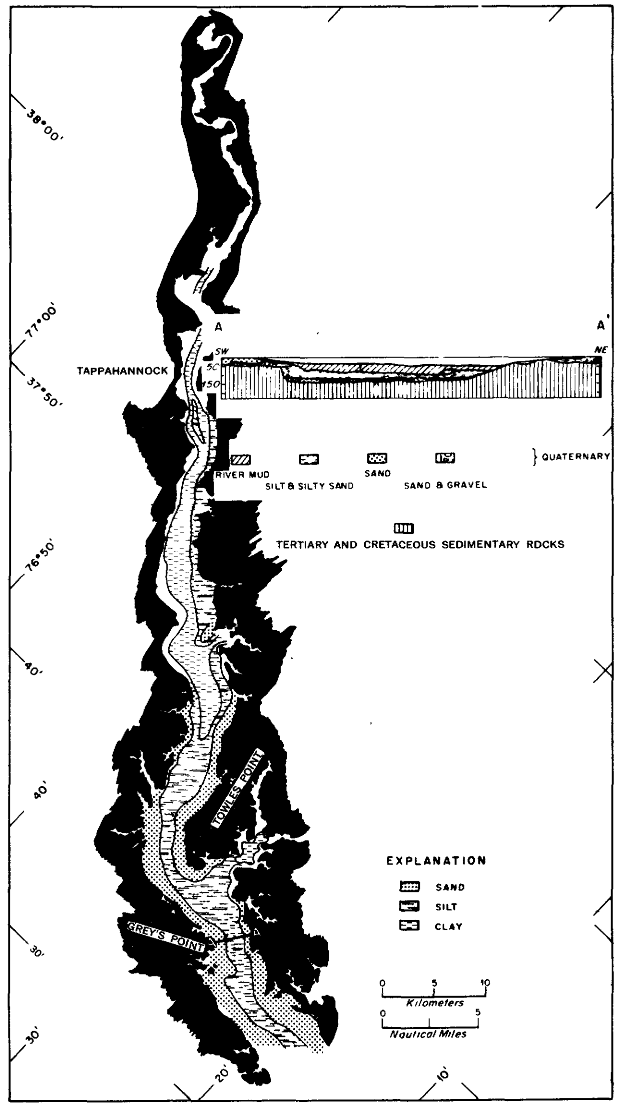

FIGURE 28.—Texture of bottom sediments in Rappahannock River Estuary, Va. Adapted from sediment descriptions of Ellison, Nichols, and Hughes (1965). Geologic cross section modified from Hack (1957).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Leco gas analyzer).—Concentrations of organic carbon in 10 samples collected in the estuary are shown in figure 29. Values range from 1.3 to 2.7 percent.

Mineralogy.—Detailed studies of minerals in the sediments have been confined mostly to the layered silicates. Kaolinite, illite, montmorillonite, and vermiculite are abundant in the upper part of the estuary and become rather evenly mixed between 20 and 40 nautical miles (37–74 km) upstream from the mouth. Chlorite and feldspar are confined to the lower estuary, where most of the layered silicates decline in abundance.

REFERENCES

Boon and MacIntyre (1968), Bue (1970), Ellison, Nichols, and Hughes (1965), Hack (1957), Nelson (1960), Nichols and Poor (1967).

ALBEMARLE SOUND, NORTH CAROLINA

SETTING

Geology.—Coastal Plain sedimentary rocks of Quaternary age are exposed on the mainland shores of Albemarle Sound, except on the western shore where the Yorktown Formation of Miocene age borders the area. An offshore bar which is part of the North Carolina Outer Banks forms the seaward margin.

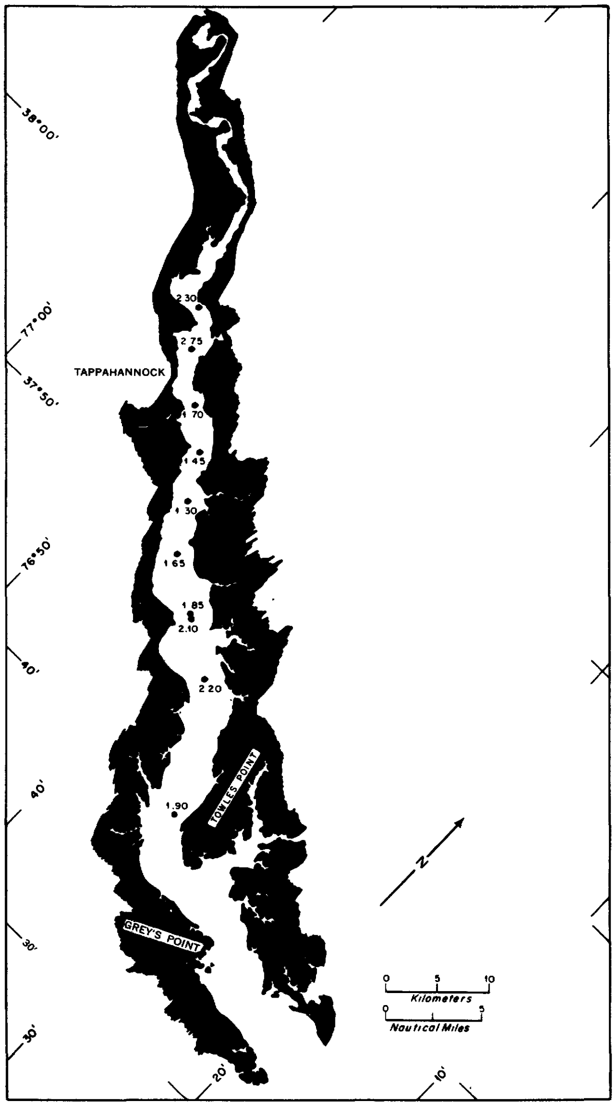

FIGURE 29.—Organic carbon content (in percent) of bottom sediments in the Rappahannock River Estuary. Data from Boon and MacIntyre (1968).

Bathymetry.—Depths increase rapidly with distance from shore to the relatively flat floor of the sound (fig. 30). The maximum depth is almost 30 feet (9 m) but most of the bottom of the central area of the bay is about 18 feet (5.4 m) deep. In Croatan Sound, which connects Albemarle Sound with Pamlico Sound to the south, depths are less than 12 feet (3.6 m).

Hydrology.—Fresh-water inflow from the Roanoke and Chowan Rivers averages about 380 m^3/sec. Average salinities range from zero at the western end of the sound to about 5 parts per thousand at the eastern end. Values are normally 10–15 parts per thousand in Croatan Sound, except in the spring when concentrations drop to 3 parts per thousand. Tidal influence on the water level is slight due to the narrow channels that connect the bay with the open sea.

SEDIMENT TEXTURE

Bottom.—Most of the available data on sediment texture were obtained by microscopic estimates of grain size. The coarsest sediments, which consist mostly of fine to medium sand, are concentrated around the margins of the sound and grade bayward to silt and clay in the deepest areas. Some coarse material is probably carried into the sound by the Roanoke River but most is derived from erosion of Quaternary sediments on the shores of the sound. Widespread sand deposits at the eastern end of the bay and in Croatan Sound were probably derived in large part from the Outer Banks (fig. 31).

SEDIMENT COMPOSITION

Organic carbon (samples were analyzed by the Leco gas analyzer).—Eleven samples were analyzed for concentrations of organic carbon; 0.1 to 1.4 percent was found in sands, and 1.6 to 2.6 percent was found in silts and clays of the central bay. Values exceeding 3 percent were found in sediments in the Chowan River and in a smaller drowned stream channel that probably receives much organic matter from adjacent swamps. One sample of peat recovered from the Alligator River contained 28 percent organic carbon (fig. 31).

Mineralogy.—Quartz is the most abundant constituent of the sand; feldspars are rare and constitute less than 1 percent. Heavy minerals include amphiboles, epidote, garnet, ilmenite, magnetite, pyroxenes, staurolite, and zircon. The fine fraction consists mostly of kaolinite, illite, dioctahedral vermiculite, and chlorite. Kaolinite, which accounts for as much as 80 percent of the fine fraction, is relatively more abundant here than in any other estuary from which sediments have been analyzed on the Atlantic coast. Chlorite is present in concentrations as high as 20 percent and is apparently being transported into the estuary from the continental shelf.

Carbonate minerals make up less than 0.3 percent of the 11 samples analyzed.

Bottom sediments here are more yellowish than those in other estuaries on the Atlantic coast. The color is apparently due to influx of fine material carried to the area by the Roanoke River prior to the construction of the Kerr Reservoir dam, which now is located about 90 nautical miles (160 km) west-northwest of the sound.

REFERENCES

Hathaway (1971), Pels (1967), Smith (1967), Stanley (1969), Wilson (1967).

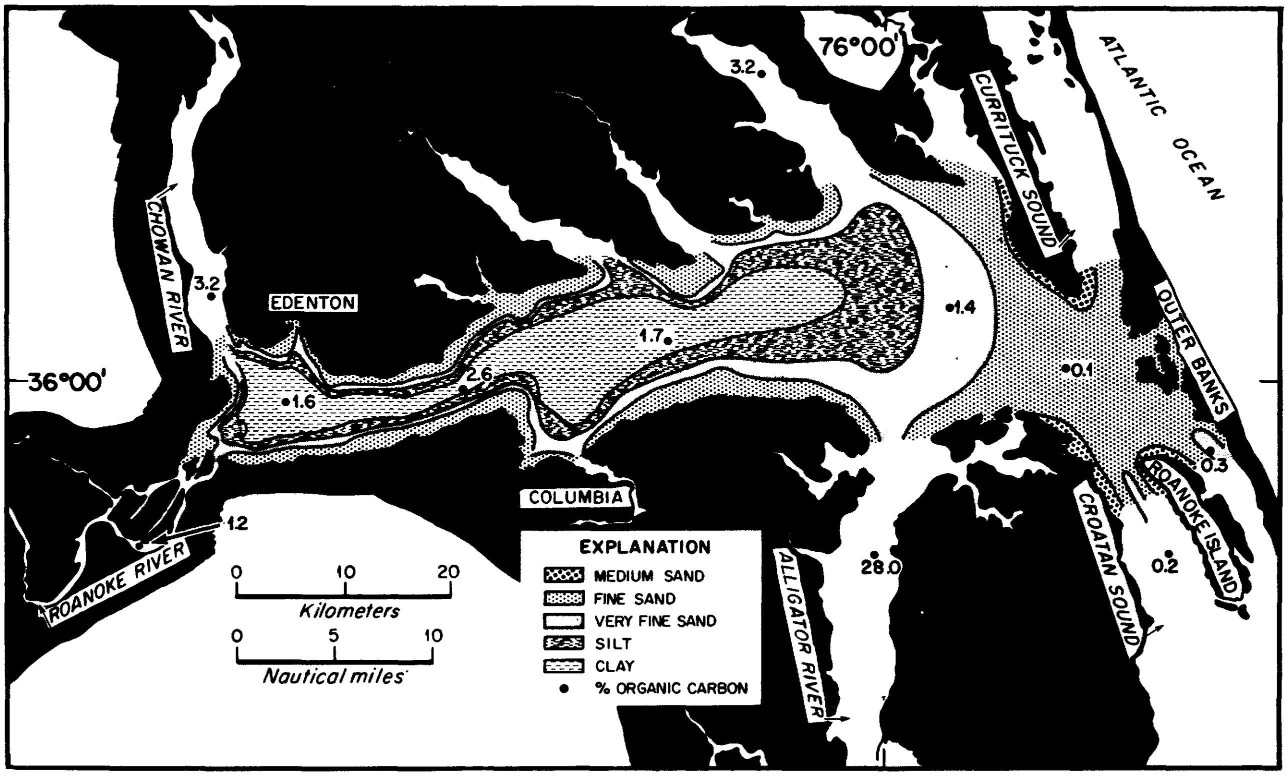

FIGURE 30.—Bathymetry (in feet) of Albemarle Sound, N.C. (from Pels, 1967).

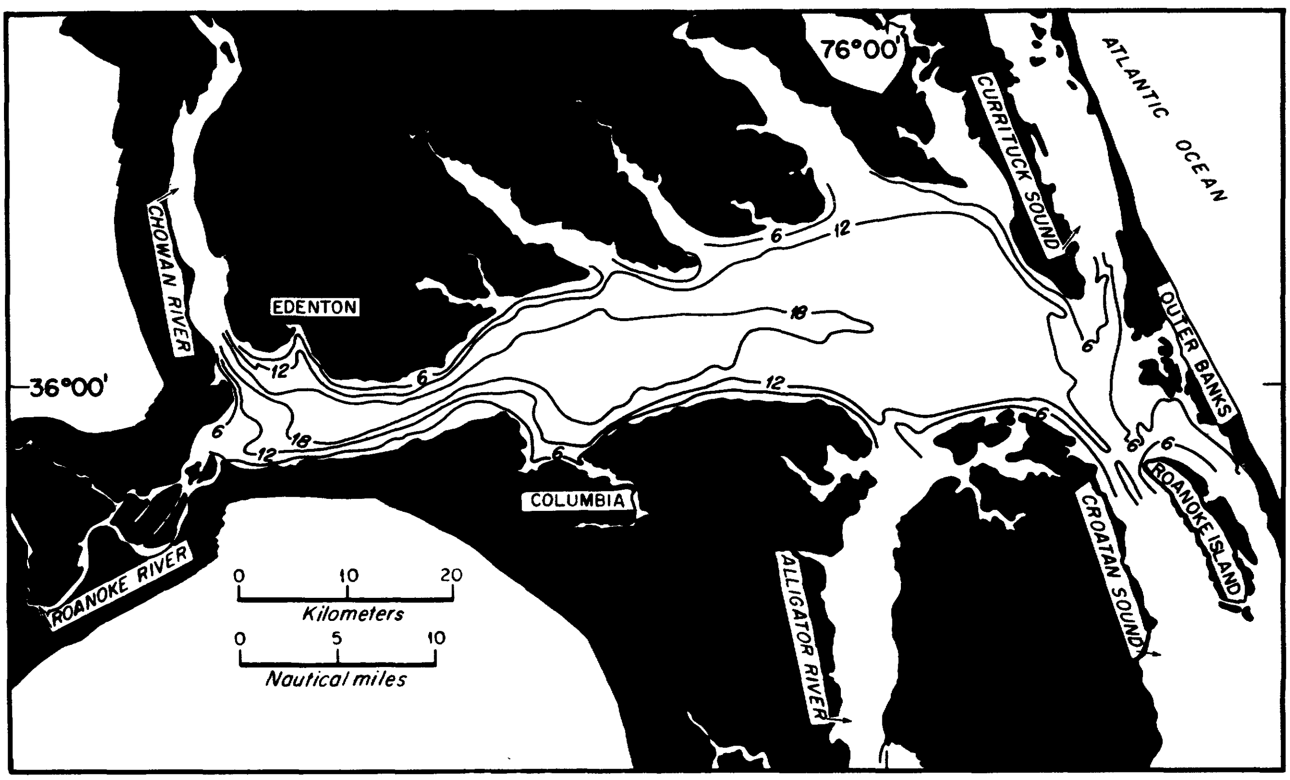

FIGURE 31.—Texture (modified from Pels, 1967) and organic carbon content (from Hathaway, 1971) of bottom sediments in Albemarle Sound, N.C.

PAMLICO SOUND, NORTH CAROLINA

SETTING

Geology.—West of Pamlico Sound, Quaternary sand and clay overlie Tertiary and Cretaceous sediments of the Atlantic Coastal Plain. A postglacial barrier island system, broken by inlets, isolates the bay from the Atlantic Ocean.

Bathymetry.—Bluff Shoal (fig. 32) divides the sound into two broad basins. Bottom topography in the northern area dips smoothly toward the center to a maximum depth of approximately 24 feet (7 m). In the southern part, shoals project from the western shore well into the bay. A tidal delta extends into the sound from Ocracoke Inlet (fig. 32).

Hydrology.—Average fresh-water inflow to the southern part of the sound from the Neuse and Pamlico Rivers is 290 m³/sec. Salinities at the mouths of these rivers is most often between 10 and 15 parts per thousand. To the north, inflow to Albemarle Sound from the Roanoke and Chowan Rivers averages 380 m³/sec. Some of this fresh water enters Pamlico Sound and reduces the salinity near Roanoke Island to a minimum of about 3 parts per thousand in the spring. Salinities at the inlets are generally between 26 and 33 parts per thousand. Currents within the sound are controlled mostly by wind and are generally less than 0.5 knot (25 cm/sec). Velocities are as much as about 2 knots (100 cm/sec) in the inlets. Water is slightly acidic in the western part of the sound adjacent to swamps and becomes slightly alkaline to the east.

SEDIMENT TEXTURE

Bottom.—Fine sand covers most of the bottom. Toward the central deep area of the northern basin, silt becomes abundant; whereas in the southern part, the finer sediments are confined mostly to the channels that extend into the bay from the river mouths. Medium sand covers most shoals and extends basinward from inlets as tidal-channel deltas and from the barrier

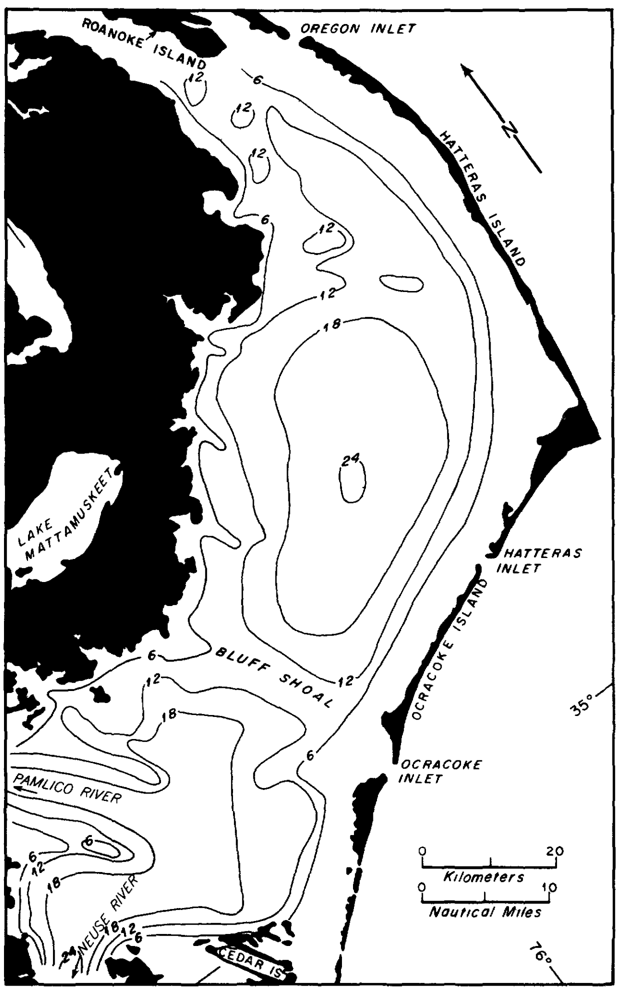

FIGURE 32.—Bathymetry (in feet) of Pamlico Sound, N.C. (from Pickett, 1965).

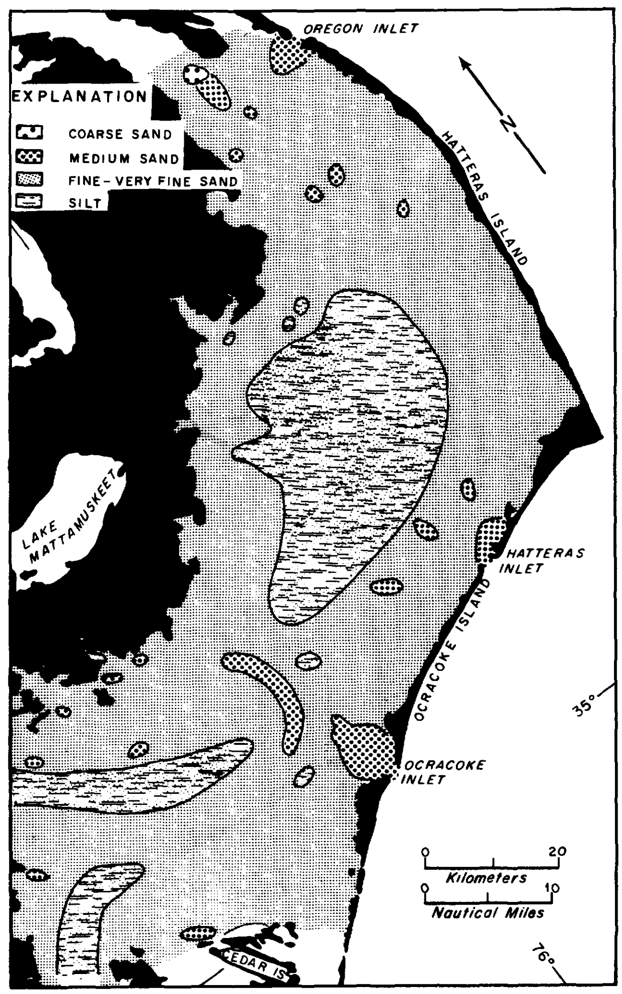

FIGURE 33.—Texture of bottom sediments in Pamlico Sound, N.C. (from Pickett, 1965).

islands as washover fans (fig. 33).

Subbottom.—No quantitative data are available. Cores were taken to a maximum depth of 1 foot (0.3 m). Sediments seem to be fairly homogeneous to that depth in the central part of the bay and near river mouths.

SEDIMENT COMPOSITION

Organic carbon.—Concentrations shown by the shaded areas in figure 34 are based on analyses by the Walkely-Black (in Jackson, 1958) method. The discrete values presented were obtained with the Leco gas analyzer. Both methods reveal a general increase in carbon concentration toward the center of the northern part of the bay and toward the axes of the drowned Neuse and Pamlico River channels where the finer sediment is concentrated. Most of the organic material is apparently due to indigenous biologic activity, although some peat evidently underlies a thin veneer of sand at the southern end of the bay.

Mineralogy.—The sand fraction is mostly composed of quartz. Kaolinite content decreases to the east with increasing distance from the river source areas, whereas illite content increases. Chlorite and a trace of montmorillonite are also present. Heavy minerals make up about 1 percent of the coarse fraction and include ilmenite, epidote, garnet, and hornblende. Fifty percent of the opaque fraction consists of ilmenite. Garnet content decreases westward from its apparent source, the barrier islands.

Calcium carbonate.—Highest concentrations of calcium carbonate, mostly shell detritus, are associated with the fine sediments in the northern basin and near the river mouths, and with the medium sands of tidal-channel deltas at inlets (fig. 35).

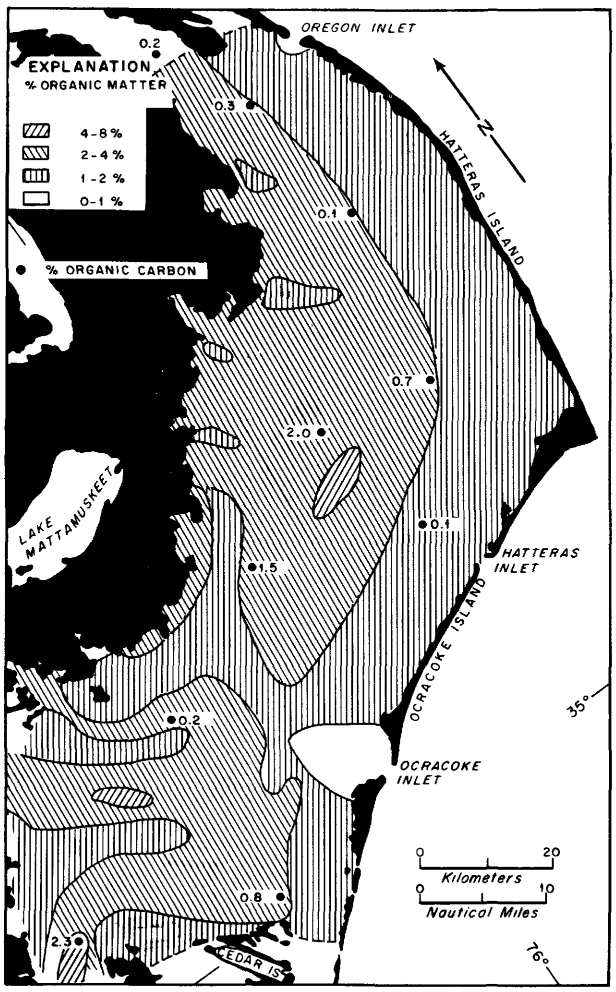

FIGURE 34.—Oxidizable organic matter and organic carbon content of bottom sediments in Pamlico Sound, N.C. Oxidizable organic matter data are from Pickett (1965); organic carbon data are from Hathaway (1971).

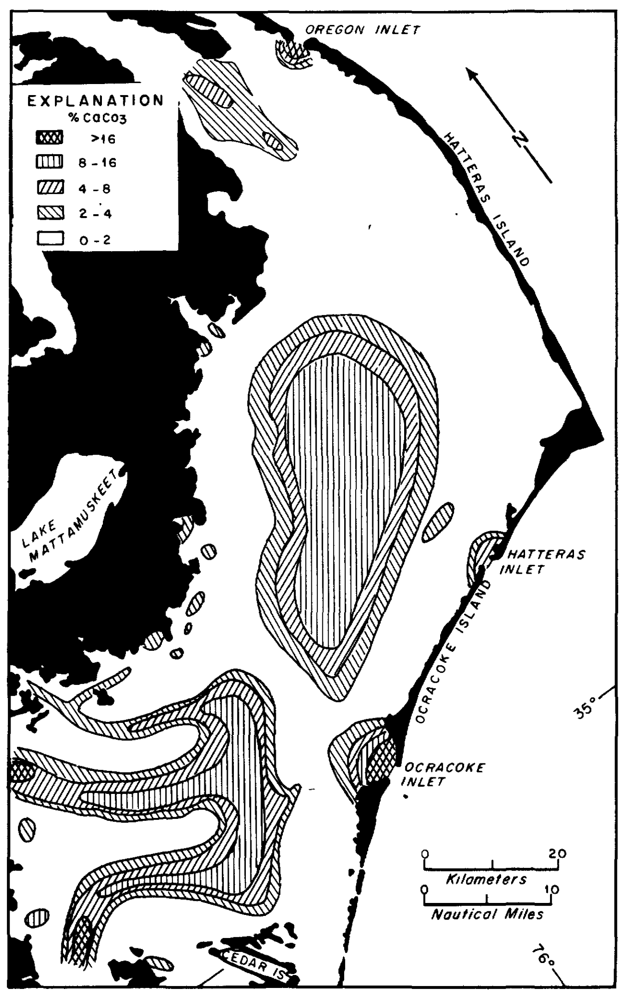

FIGURE 35.—Calcium carbonate content of bottom sediments in Pamlico Sound, N.C. (from Pickett, 1965).

REFERENCES

Bue (1970), Duane (1962), Hathaway (1971), Pickett (1965), Pickett and Ingram (1969), Roelofs and Bumpus (1954), Williams and others (1967), Wilson (1967).

CORE SOUND, NORTH CAROLINA

SETTING

Geology.—Core Sound is flanked by sand and clay of Pleistocene and Holocene age which overlie the unexposed Yorktown Formation of Miocene age. Core Banks, a series of post-Pleistocene barrier islands, isolate the sound from the Atlantic Ocean.

Bathymetry.—Many shoals are present around the margin and in the central area of the bay (fig. 36). Mean depth is between 3 and 4 feet (0.9–1.2 m) and the maximum depth is 11 feet (3.3 m).

Hydrology.—Brackish water in the sound is probably derived mostly from Pamlico Sound immediately to the north. Salinities range from about 25 parts per thousand north of Cedar Island to 35 parts per thousand near the southern margin of the area shown in figure 36. Tidal range is 0 to 3 feet (0.9 m), depending on wind conditions. Currents in the inlets may attain 1 knot (50 cm/sec), but water motion within the bay is generally sluggish.

SEDIMENT TEXTURE

Bottom.—Texture of bottom sediments was evaluated by mechanical analysis and microscopic examination of samples. Most of the bottom is covered by fine sand. Medium sand is only abundant near the barrier island and on some shoals near the shore margin. Silt is concentrated only in the deepest parts of the bay center and in the protected mouths of creeks (fig. 37).

SEDIMENT COMPOSITION

Mineralogy.—Light minerals in the sand fraction consist mostly of quartz with a trace of feldspar. Heavy minerals, mostly magnetite and zircon, make up less than 1 percent of the sand. Carbonate concentrations range from less than 3 percent near the barrier islands to 12 percent south of Cedar Island where shells and shell debris are most abundant (fig. 38).

REFERENCE

Skean (1959).

NEWPORT RIVER ESTUARY, NORTH CAROLINA

SETTING

Geology.—Quaternary sand and clay of the Atlantic Coastal Plain are exposed in cliffs 5 to 15 feet (1.5–4.5 m) high around much of the Newport River Estuary.

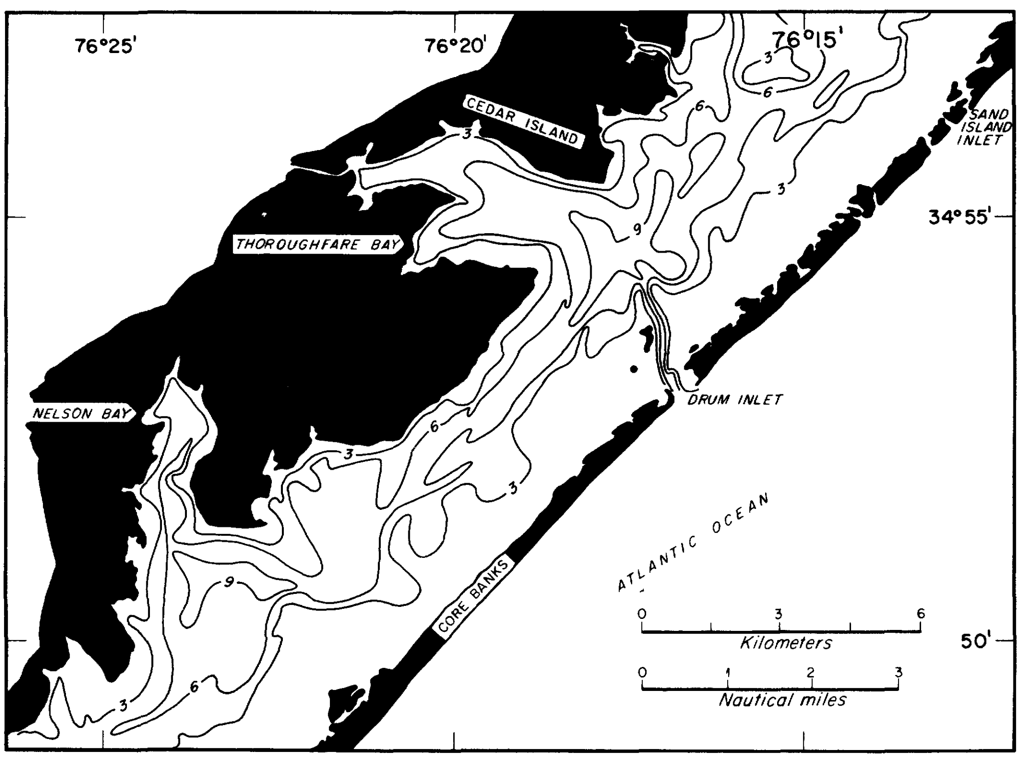

FIGURE 36.—Bathymetry (in feet) of Core Sound, N.C. (from Skean, 1959).

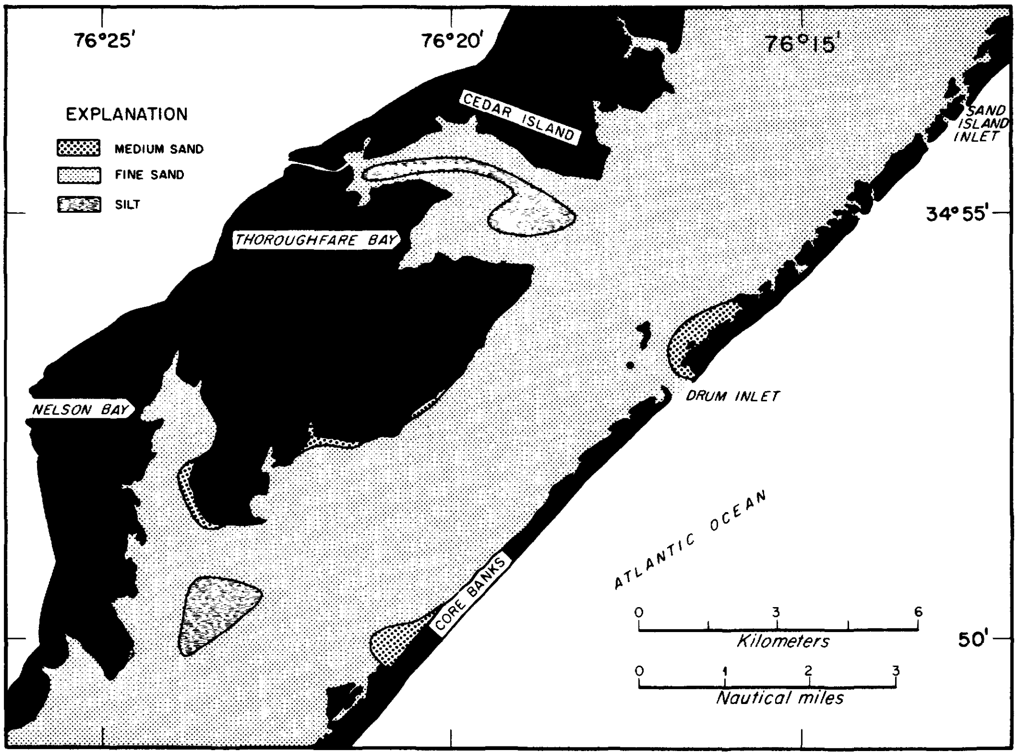

FIGURE 37.—Texture of bottom sediments in Core Sound, N.C. (from Skean, 1959).

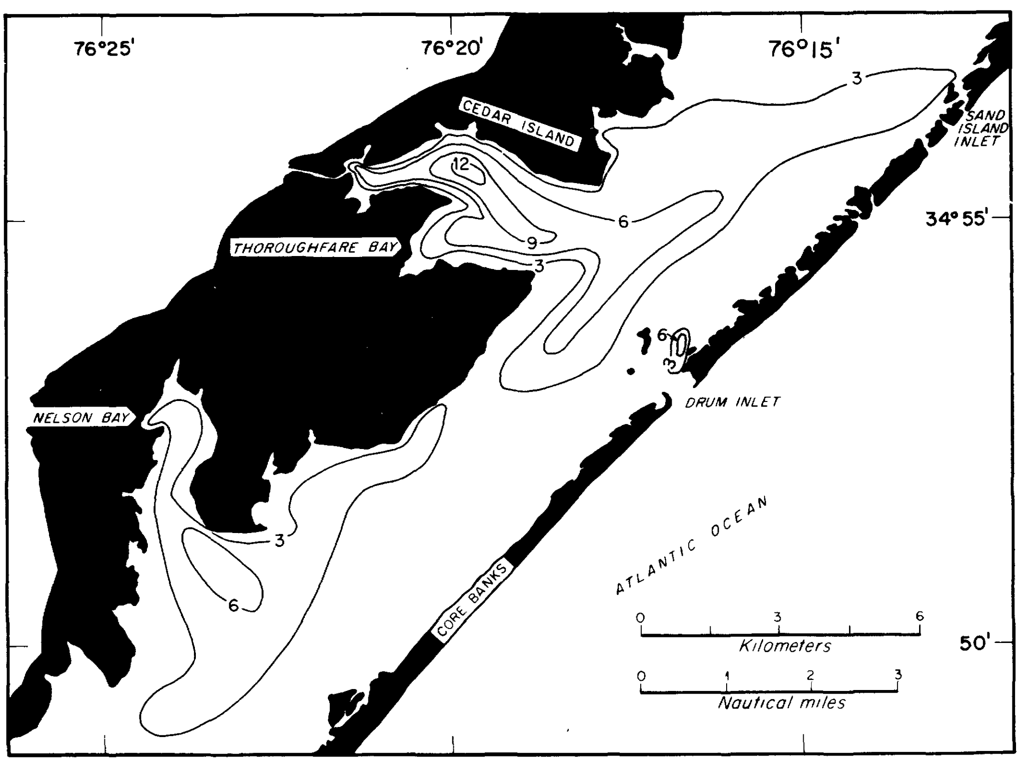

FIGURE 38.—Calcium carbonate content (in percent) of bottom sediments in Core Sound, N.C. (from Skean, 1959).

Bathymetry.—West of Core Creek most of the flat estuary bottom is less than 6 feet (1.8 m) deep. East and south of Core Creek the bathymetry is complicated by natural and dredged channels, which reach a maximum depth of about 18 feet (5.4 m). Shallow water covers oyster and mussel reefs near the head of the estuary (fig. 39).

Hydrology.—No data are apparently available on the inflow of fresh water from the Newport River or from the many small creeks to the estuary. Salinity in the bay is reported to range from about 24 to 35 parts per thousand. Tidal ranges are between 2 and 3 feet (0.6–0.9 m), and maximum tidal currents through Beaufort Inlet are about 1 knot (50 cm/sec). Water circulation in the bay is often dominated by wind-generated currents.

SEDIMENT TEXTURE

Bottom.—Texture was evaluated by mechanical analysis and by microscopic examination. Most of the bottom is covered by fine sand. In the upper estuary, clayey silt in the center grades shoreward into silty sand around the margins (fig. 40). Material greater than 2 mm in diameter is composed almost entirely of shell fragments.

SEDIMENT COMPOSITION

Mineralogy.—The light minerals of the sand fraction consist of quartz (94 percent), plagioclase (3 percent), and orthoclase (3 percent). Heavy minerals account for less than 1 percent of the sand fraction and consist mostly of ilmenite, rutile, and zircon. Illite and chlorite are the most abundant clay minerals. Calcium carbonate is present in concentrations of less than 5 percent throughout most of the estuary, except in oyster and mussel shoals where values are locally high (fig. 41).

REFERENCE

Johnson (1959).

BOGUE SOUND, NORTH CAROLINA

SETTING

Geology.—Quaternary sediments mantle the adjacent Atlantic Coastal Plain north of Bogue Sound. A single barrier island isolates the sound from the Atlantic Ocean to the south.

Bathymetry.—Depths in the shallow lagoon average 2 to 3 feet (0.6–0.9 m). Deepest natural areas, excluding the two inlets, reach 12 to 16 feet (3.6–4.5 m). The

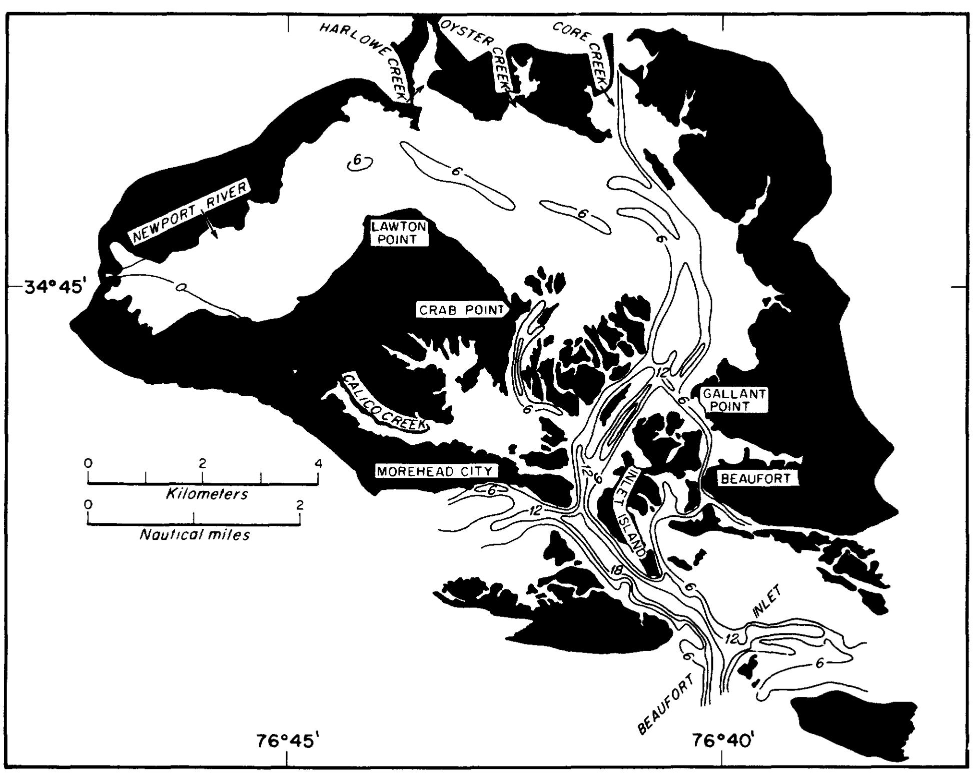

FIGURE 39.—Bathymetry (in feet) of Newport River Estuary, N.C. (from Johnson, 1959).

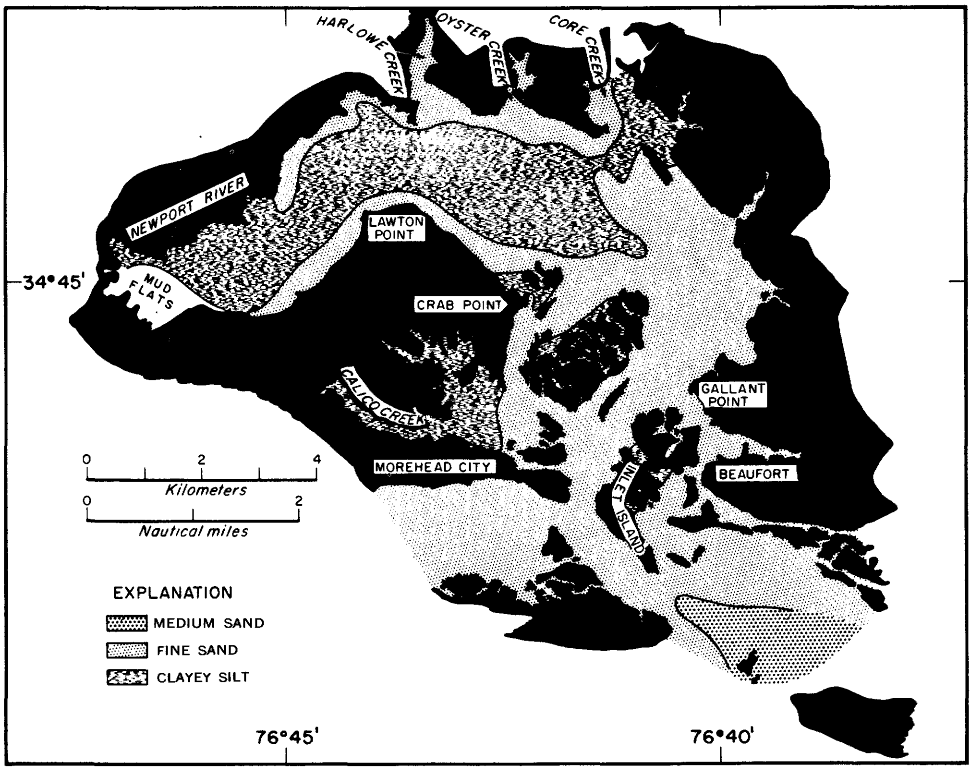

FIGURE 40.—Texture of bottom sediments in Newport River Estuary, N.C. Modified from Johnson (1959).

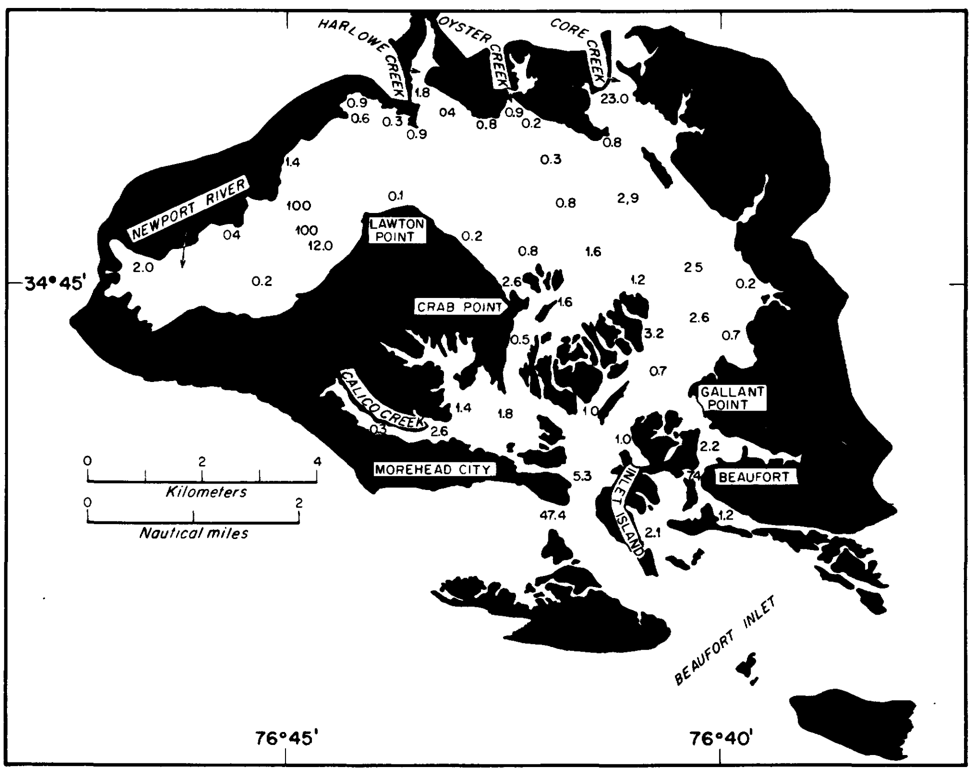

FIGURE 41.—Calcium carbonate content (in percent) of bottom sediments in Newport River Estuary, N.C. (from Johnson, 1959).

Intracoastal Waterway, which is dredged to a depth of 15 feet (4.5 m), extends along the northern margin of the sound and is flanked by piles of dredge spoil, which often break the surface (fig. 42).

Hydrology.—Fresh-water drainage from the two principal rivers in the area moves mostly out to sea through the inlets at each end of the sound. Salinities in the sound therefore are generally between 31 and 33 parts per thousand, although values as high as 36 parts per thousand have been recorded from shallow areas during dry periods when local runoff is low. Diurnal tides have a range of 1 to 3.5 feet (0.3–1.1 m), but wind under certain conditions may cause the water level to vary by as much as 5 or 6 feet (1.5–1.8 m). Tidal currents in the sound are generally less than 0.5 knot (25 cm/sec), but velocities in the inlets may be as high as 3 knots (150 cm/sec).

SEDIMENT TEXTURE

Bottom.—Most sediment at the few locations sampled consists of fine sand (fig. 43). Medium sand is accumulating only near Beaufort Inlet. Sediment coarsens slightly toward the center of the bay, which is less well protected from wave action. Over most of the sound, clay constitutes less than 5 percent of the total sediment; only in a few local areas along the margins does clay content exceed 15 percent (fig. 44).

SEDIMENT COMPOSITION

Organic matter (sample analyses by the Walkely-Black (in Jackson, 1958) technique).—Concentrations of oxidizable organic matter are generally less than 0.5 percent in midbay. In the small estuaries along the northern margin of the sound, values close to 3 percent have been measured (fig. 45).

Mineralogy.—Quartz dominates the sand fraction. Clay-sized components in order of relative abundance consist of quartz, kaolinite, illite, mixed-layer clays, montmorillonite, and a small amount of chlorite.

REFERENCES

Batten (1962), Brett (1963), Daniels and Owen (1968).

CHARLESTON HARBOR, SOUTH CAROLINA

SETTING

Geology.—Sediments exposed on the Atlantic Coastal Plain in the area of Charleston Harbor are Quaternary in age. Most terrigenous detritus deposited in the harbor itself was eroded locally until the Santee River was diverted about 40 nautical miles (74 km) north of Charleston into the Cooper River in 1942. Fine sediment is now being transported by the Santee-Cooper system into the estuary from the upper Coastal Plain and the Piedmont.

Bathymetry.—Although natural deep areas of the harbor still exist, the large inflow of the Cooper River since 1942 has resulted in rapid shoaling, which has required continuous dredging. The bathymetry of much of the harbor bottom is therefore due to the man-made effects of dredging and dumping of spoil (fig. 46).

Hydrology.—The tidal Wando and Ashley Rivers contribute little fresh water to the estuary except from local runoff. Discharge from the Santee-Cooper system is regulated at about 425 m^3/sec by the Pinopolis Dam at Moultrie Reservoir, approximately 22 miles (35 km) north of Charleston. The limit of salt-water intrusion in the Cooper River is about 20 miles (37

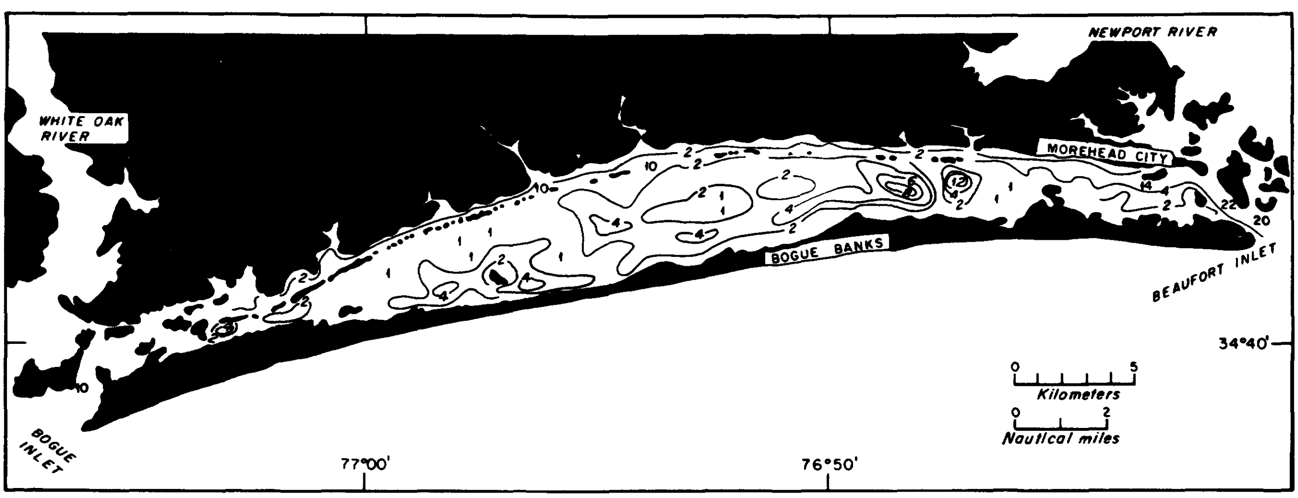

FIGURE 42.—Bathymetry (in feet) of Bogue Sound, N.C. (from Brett, 1963).

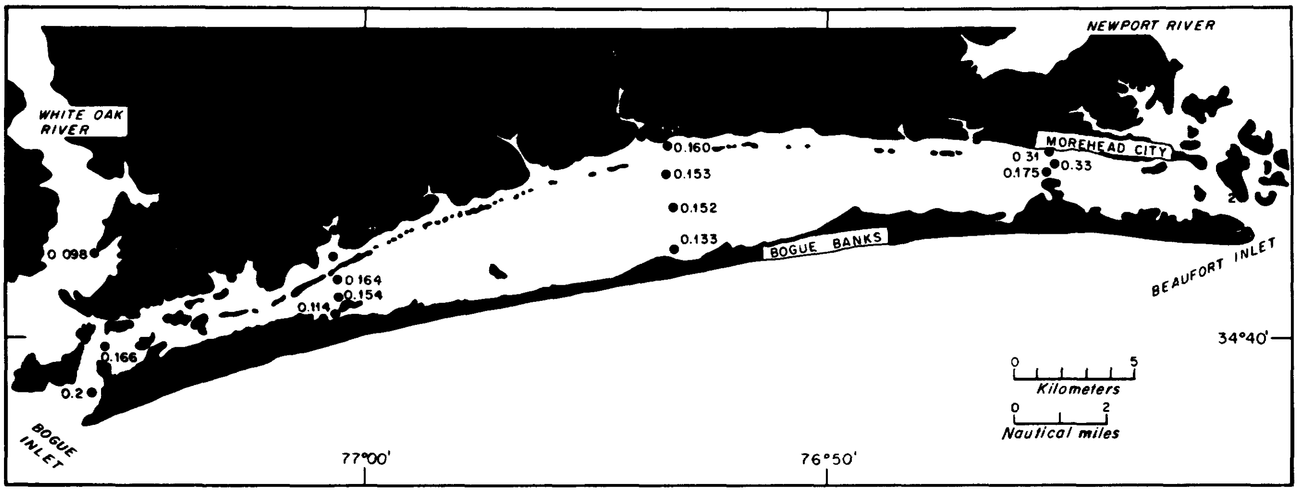

FIGURE 43.—Median diameter (in millimeters) of bottom sediments in Bogue Sound, N.C. (from Brett, 1963).

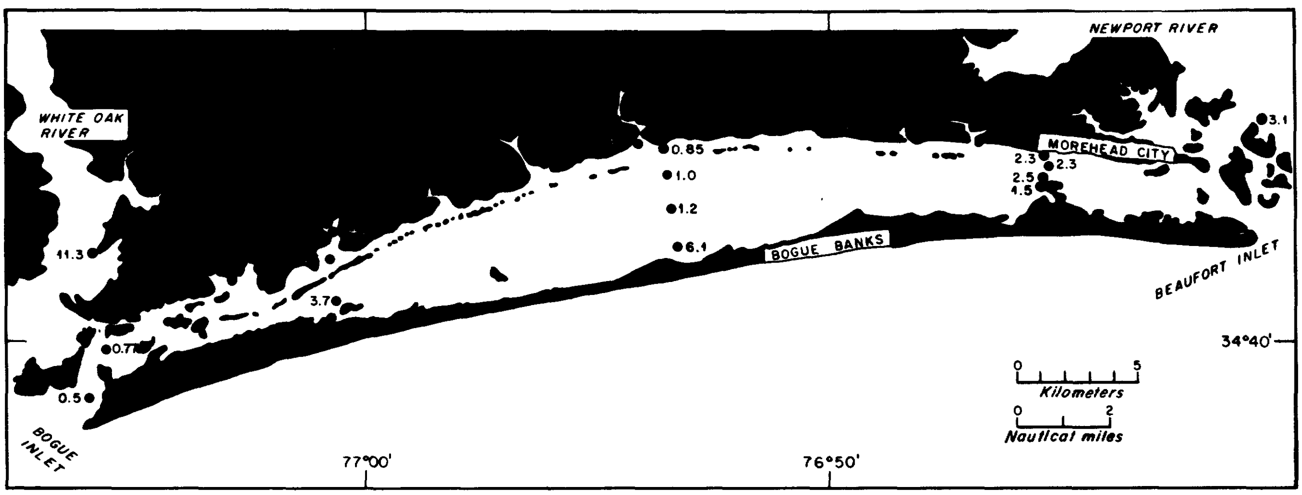

FIGURE 44.—Clay content (in percent) of bottom sediments in Bogue Sound, N.C. (from Brett, 1963).

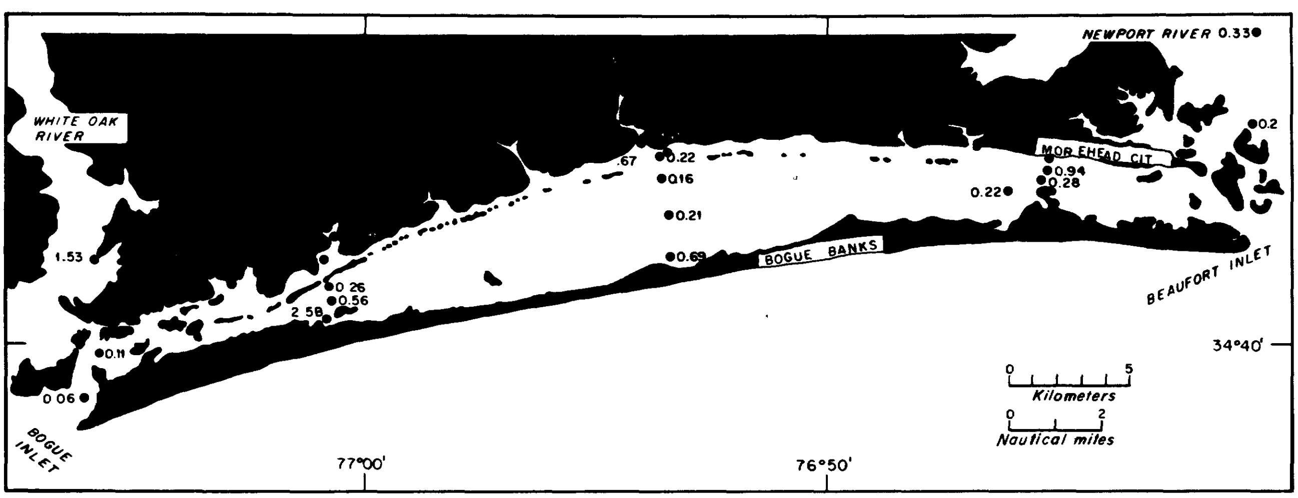

FIGURE 45.—Oxidizable organic matter content (in percent) of bottom sediments in Bogue Sound, N.C. (from Brett, 1963).

FIGURE 46.—Bathymetry (in feet) of Charleston Harbor, S.C. (from U.S.C. & G.S. Chart 470).

FIGURE 47.—Median diameter of discrete sediment samples (from U.S. Army, Corps of Engineers, 1954) and distribution of shoals composed mostly of clay (from U.S. Army, Corps of Engineers, 1966) in Charleston Harbor, S.C., and on the continental shelf outside the harbor.

km) upstream from the jetties at the harbor mouth. Greatest dilution of salt water occurs on the western side of the estuary. The mean tidal range measured between Drum Island and Shutes Folly Island is 5.1 feet (1.5 m). Maximum current velocities under normal conditions are 2.5 to 3.0 knots (125–150 cm/sec).

SEDIMENT TEXTURE

Bottom.—Clay, presently accumulating in the channels, forms most of the shoals. Much of this material may have been dredged previously. Areas of shoal formation as of 1966 are shown in figure 47. Where river-transported fine detritus is not accumulating, such as near the estuary mouth, the sediment is mostly sand.

SEDIMENT COMPOSITION

Organic carbon (values obtained with a Beckmann

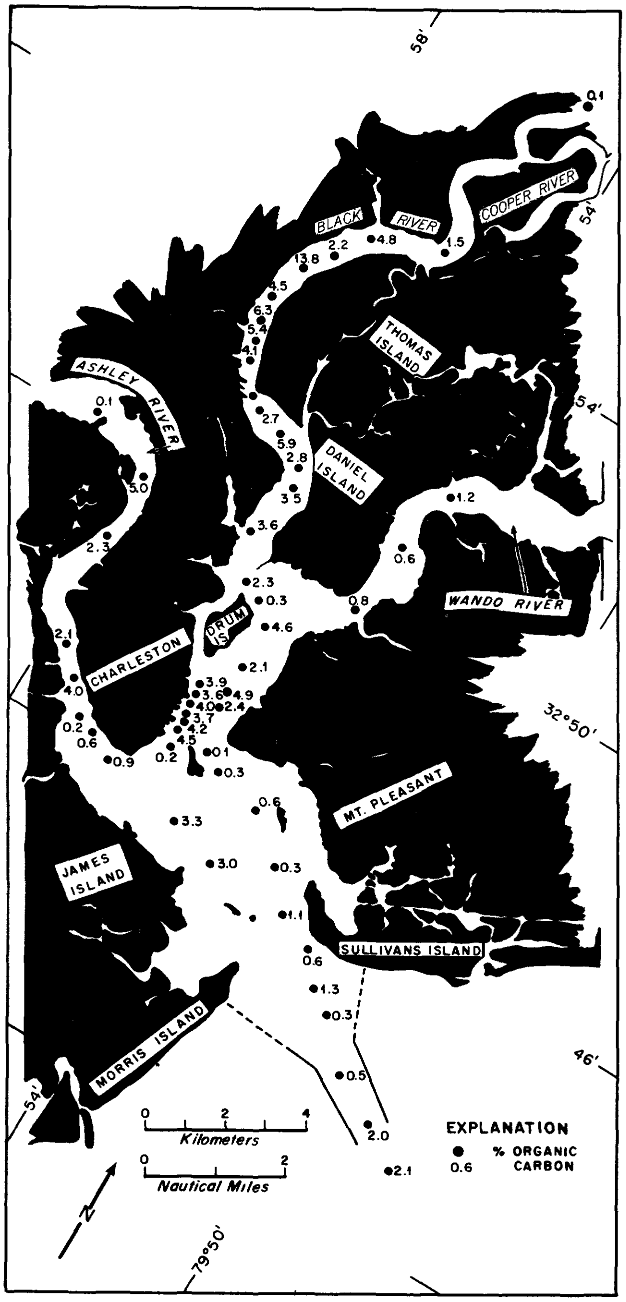

FIGURE 48.—Organic carbon content of bottom sediments in Charleston Harbor, S.C. (from U.S. Federal Water Pollution Control Administration, 1966).

gas analyzer).—Owing to the abundance of raw sewage presently being dumped into the estuary and to the changing pattern of fine sediment deposition, organic carbon concentrations probably change rapidly on the bottom. North of Charleston Harbor area values are less than 0.1 percent in sediments of the Cooper River. Adjacent to and downstream of the city, values are generally between 3 and 5 percent, although a maximum of almost 14 percent was recorded. High concentrations in the Ashley River are probably due mostly to the introduction of untreated industrial wastes, whereas those in the Cooper River area are due mostly to raw sewage (fig. 48).

Mineralogy.—Bottom sediments are composed principally of quartz, feldspar, and layered silicates. The sand fraction, mostly quartz and feldspar, is probably being transported into the estuary mainly from the continental shelf. Silt and clay—principally composed of kaolinite, montmorillonite, and illite—are being brought in mainly by the Santee-Cooper River system. Kaolinite/montmorillonite ratios of about 1, which occur in the western part of the estuary, apparently reflect well-mixed sediments of both Piedmont and Coastal Plain origin. An average ratio of 0.7 in the eastern area reflects a predominance of Coastal Plain material. Heavy minerals range from 1 to 7 percent by weight of the total assemblage but are most commonly less than 3 percent. The most abundant of these—hornblende, ilmenite, and epidote—are probably carried into the estuary from the continental shelf.

Color.—Reddish-tan sediments in the Cooper River grade into gray and black soupy muds in the harbor that contain sewage, petroleum, and industrial waste products. These pollutants have constituted as much as 30 or 40 percent of the fine sediments which have accumulated over the last 20 years.

REFERENCES

U.S. Federal Water Pollution Control Administration (1966), Neiheisel and Weaver (1967), U.S. Army Corps of Engineers (1954, 1966).

BISCAYNE BAY, FLORIDA

SETTING

Geology.—Quaternary deposits are exposed around Biscayne Bay. With the exception of a thin stratum that contains quartz sand (Pamlico Sand), these deposits are primarily carbonate. The Key Largo Limestone of Pleistocene age forms most of the keys and shoals which isolate the bay from the Atlantic Ocean. A thick section of Tertiary and Cretaceous rocks, also mostly carbonate, underlies the younger sediments.

Bathymetry.—Water depths in most of the bay are less than 12 feet (3.6 m). A complex series of shoals (Featherbed Bank) oriented roughly east-west divides the bay into two parts. Slopes in both areas dip uniformly from the western shore toward the middle of the basin, but a complex of banks forms the northeast margin. Topography is more uniform on the southeast flank. The maximum depth in the bay (21 feet or 6.4 m) is in a channel south of Key Biscayne (fig. 49).

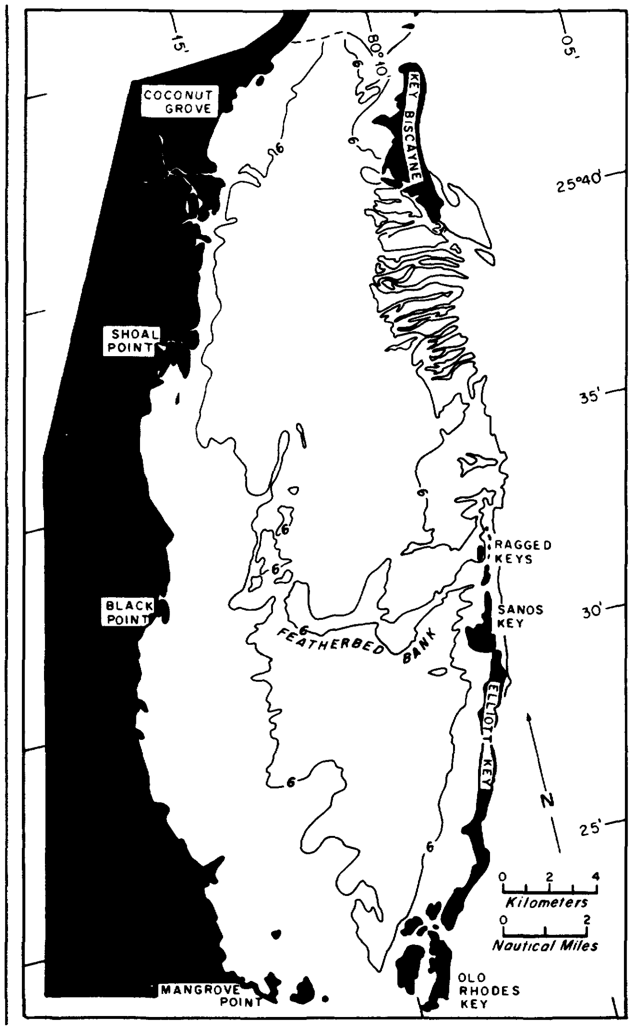

FIGURE 49.—Bathymetry (in feet) of Biscayne Bay, Fla. (from Bush, 1958).

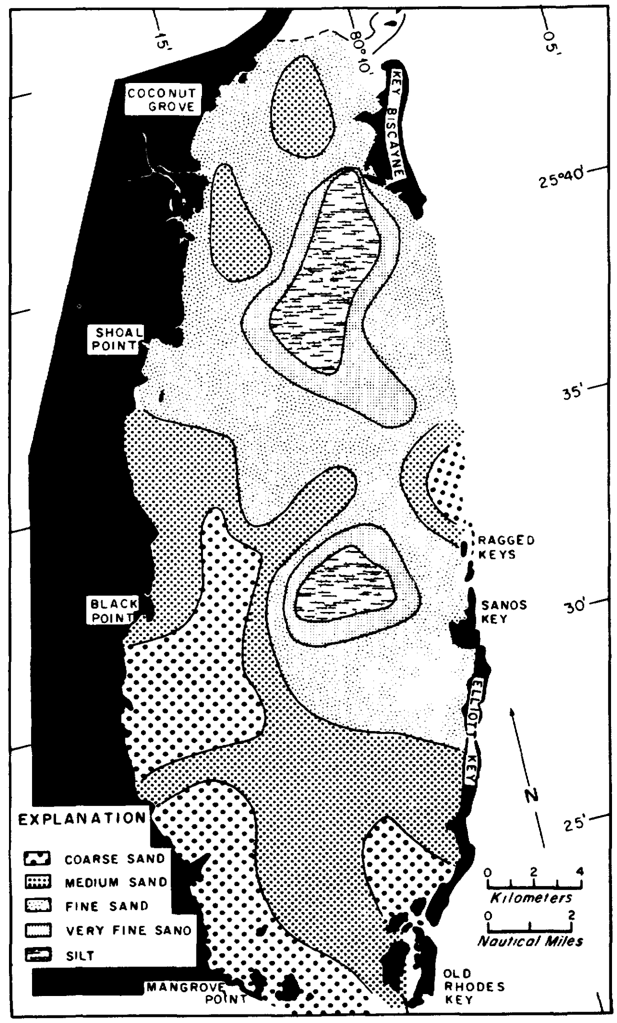

FIGURE 50.—Texture of bottom sediments in Biscayne Bay, Fla. Modified from Bush (1958).

Hydrology.—Fresh-water inflow is derived mainly from the Miami and Little Rivers, the Tamiami Canal, and other dredged canals which lie mostly northwest of the bay. Salinities range from about 3 parts per thousand at the mouth of the Miami River, north of the map area, to 39 parts per thousand at Featherbed Bank. Tidal range is only 2 to 2.5 feet (0.6–0.7 m), but wind and rainfall often obscure normal tidal fluctuations. In the channels, currents may attain velocities of 2 knots (100 cm/sec) at flood tide and 3 knots (150 cm/sec) at ebb tide.

SEDIMENT TEXTURE

Bottom.—Fine sand is most abundant in the northern part of the bay and medium to coarse sand predominates in the southern part (fig. 50). The size distribution, however, is bimodal due to the presence of two constituents—namely, well-sorted quartz sand (fig. 51) and fragments of detritus composed of calcium carbonate (fig. 52). Silt deposits are located in two areas, southeast of Biscayne Island and west of Ragged Keys.

SEDIMENT COMPOSITION

Mineralogy.—Fine quartz sand (fig. 51), probably derived mostly from the Pamlico Sand, and fragments of calcium carbonate (fig. 52), derived from indigenous organisms (principally the calcareous alga *Halimeda*), make up most of the sediment. Heavy minerals, mainly epidote, constitute less than 0.1 percent of the sediment. Clay minerals are rare.

REFERENCES

Bush (1958), Wanless (1969).

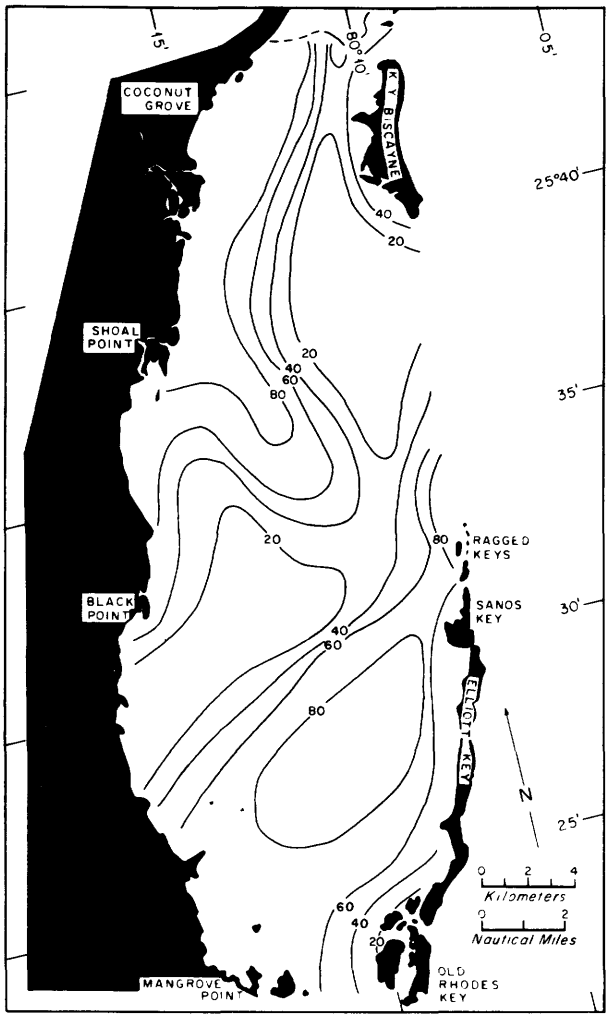

FIGURE 51.—Quartz content (in percent) of bottom sediment in Biscayne Bay, Fla. (from Bush, 1958).

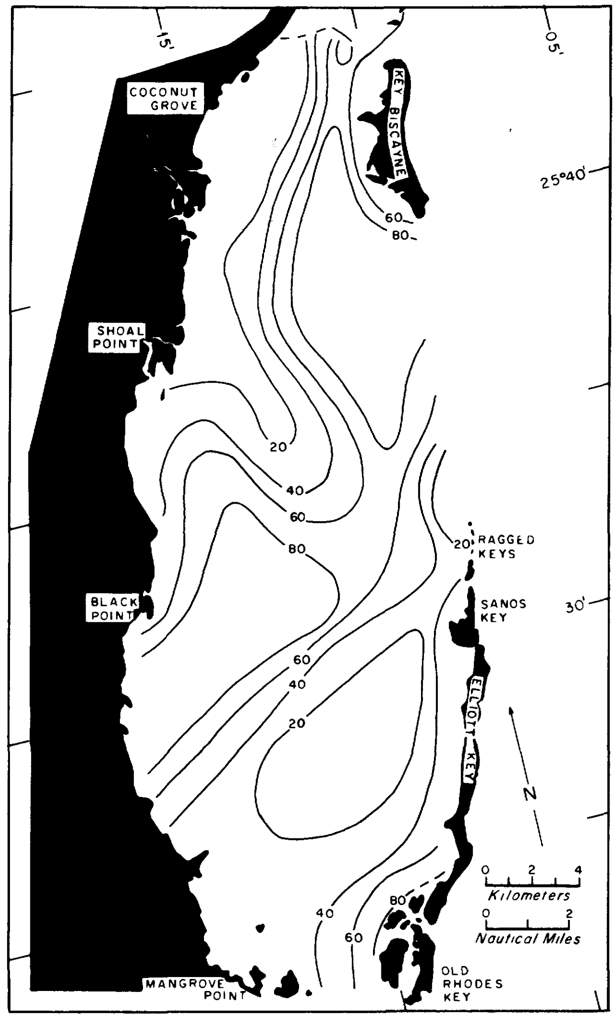

FIGURE 52.—Calcium carbonate content (in percent) of bottom sediments in Biscayne Bay, Fla. (from Bush, 1958).

FLORIDA BAY, FLORIDA

SETTING

Geology.—Florida Bay is bounded on the north by coastal fresh- and brackish-water swamps of the Everglades and on the southeast by the Florida Keys which consist of elevated Pleistocene coral reefs (Key Largo Limestone). In the bay the Miami Oolite (Pleistocene) underlies unconsolidated Holocene sediments that range in thickness from a few inches where water depth is greatest to approximately 5 or 6 feet (1.5–1.8 m) where mud banks are present (fig. 53).

Bathymetry.—The bottom slopes gently from a depth of approximately 3 feet (1 m) in the northeastern part of the bay to about 8 or 10 feet (2.4–3 m) along the western margin. Average water depth is roughly 6 feet (1.8 m), except where tidal currents have cut channels into bedrock to depths as great as 15 feet (4.5 m). Many mud banks are exposed during periods of low water (fig. 53).

Hydrology.—Fresh-water inflow from the Everglades to the bay increases near the end of the rainy season, which lasts usually from June to December. Maximum dilution therefore occurs between December and February, when salinities may be as low as 10 parts per thousand in the northern part of the bay. During the dry months of the year, salinities throughout the whole bay average 35–40 parts per thousand, but in local restricted areas values as high as 70 parts per thousand have been recorded. The mixed semidiurnal tides have a range at Cape Sable of almost 3 feet (1 m); but in the interior of the bay, tidal range is less than 1 foot (0.3 m). Currents, often mainly the

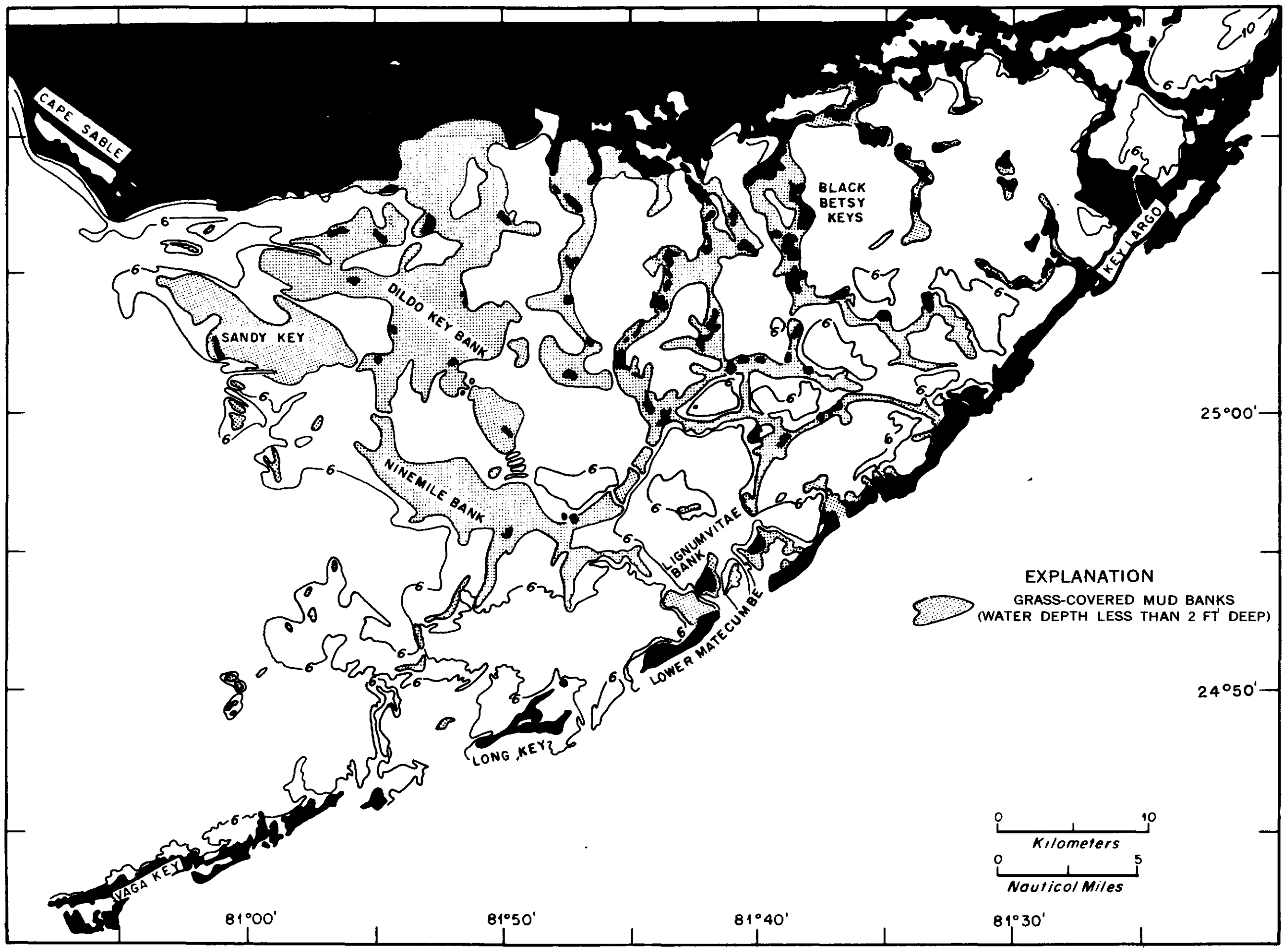

FIGURE 53.—Bathymetry (in feet) of Florida Bay, Fla. (from Ginsburg, 1956).

result of wind, are greatest in the passes where they reach 3 to 4 knots (150–200 cm/sec). Throughout most of the bay, however, current velocities are less than a few tenths of a knot.

SEDIMENT TEXTURE

Bottom.—The average texture of most bottom sediments throughout the bay is rather uniform, though grain size may vary greatly in small areas. The average median diameter of bottom sediments in the eastern part of the bay is 0.025 mm, and in the western part, 0.028 mm. On the exposed edges of banks, sediment is generally sand; but throughout most of the deep areas and on protected parts of the banks, silt and clay predominate. Average sediments on the mud banks in the western bay are 70 percent silt and clay (less than 0.062 mm diameter) and 30 percent sand.

Subbottom.—Sediment texture below the bottom to a depth of 4 feet (1.2 m) differs little from that on the surface; silt and clay (less than 0.062 mm diameter) range from slightly over 50 percent to 100 percent.

SEDIMENT COMPOSITION

Organic carbon.—Average values for organic carbon at the bottom are 2.1 percent in the western part and 3.5 percent in the eastern part, but concentrations as high as 30 percent have been recorded from cores taken where plant detritus is particularly abundant. Below the upper few inches of oxidized sediment, an H_2S odor is notable in most sediments.

Mineralogy.—The sediment consists of approximately 90 percent carbonate particles, and the remainder is mostly quartz, opaline sponge spicules, and organic matter. Average estimates of the carbonate mineralogy of bottom sediments in the western and eastern parts of the bay, respectively, are: aragonite, 59–67 percent; high-magnesium calcite (4–19 percent $MgCO_3$), 19–37 percent; low-magnesium calcite, 14–17 percent. The coarse fraction consists almost entirely of mollusk shells, foraminifer tests, and detrital quartz. Dolomite is present in low concentrations (less than 5 percent) as discrete particles smaller than 0.062

mm. Physical properties, mineralogy, and chemistry of Florida Bay sediments are summarized in table 2.

TABLE 2.—*Physical, mineral, and chemical characteristics of sediments in Florida Bay, Fla.*

[Modified from Scholl (1966). Values are given as weight percent except as otherwise indicated]

Sediment characteristic	Western Florida Bay		Eastern Florida Bay	
	Average	Range	Average	Range
Mass properties and grain-size distribution				
Mass properties:				
Water content (dry weight basis)	71.5			
Porosity (volume percent)	65.9			
Grain density (g/cc)	2.71			
Bulk density (g/cc)	1.58			
Grain-size distribution:				
Median diameter (mm)	.028		0.025	
Trask sorting coefficient	6.81			
0.125-mm diam sand			51	15–90
0.062-mm diam sand	30	1–52		
0.062–0.001-mm diam silt-clay	48	9–70		
<0.001-mm diam subclay	22	5–50		
Carbonate mineralogy				
Subsurface and surface sediments:				
Aragonite	59	35–77	46	20–78
High-Mg calcite	27	3–54	37	0–51
Low-Mg calcite	14	1–29	17	4–80
Surface sediments:				
Aragonite	59	41–70	67	40–100
High-Mg calcite	26	10–47	19	0–39
Low-Mg calcite	15	10–20	16	0–44
General sediment chemistry				
Ca/Mg	25	6–41		
Sr/Ca×10³	8.7	6.3–11.7		
Sr			0.42	0.20 –0.64
Mg			1.4	.06 –4.1
Mn			.006	.0005– .04
Ba			.002	.001 – .004
Calcareous minerals	87	81–90		
Noncalcareous minerals	9	8–13		
Organic matter	4	2– 6	6.2	
Organic carbon	2.1	1.3– 3.7	3.5	
Organic nitrogen	.15	.29– .09	.1	
Organic carbon/organic nitrogen	17	13-26	27.5	

REFERENCES

Fleece (1962), Ginsburg (1956, 1964), Lloyd (1964), Scholl (1966), Stehli and Hower (1961), Taft (1962), Taft and Harbaugh (1964).

WHITEWATER BAY, FLORIDA

SETTING

Geology.—Southwestern Florida is characterized by a stable flat limestone surface of late Cenozoic age. Bedrock in Whitewater Bay, the Miami Oolite (Pleistocene), underlies 2 to 3 feet (0.6–0.9 m) of unconsolidated sediment composed of peat and calcareous shell debris. Structure contours on the top of the bedrock are shown in figure 54. Mangrove islands are abundant throughout the bay, which is flanked on the northeast by mangrove forests and the Everglades and on the southwest by marshes which form part of Cape Sable.

Bathymetry.—The floor of the bay is flat and averages 4 to 5 feet (1.2–1.5 m) in depth. In channels between mangrove islands, currents have scoured into bedrock to depths of 6 feet (1.8 m).

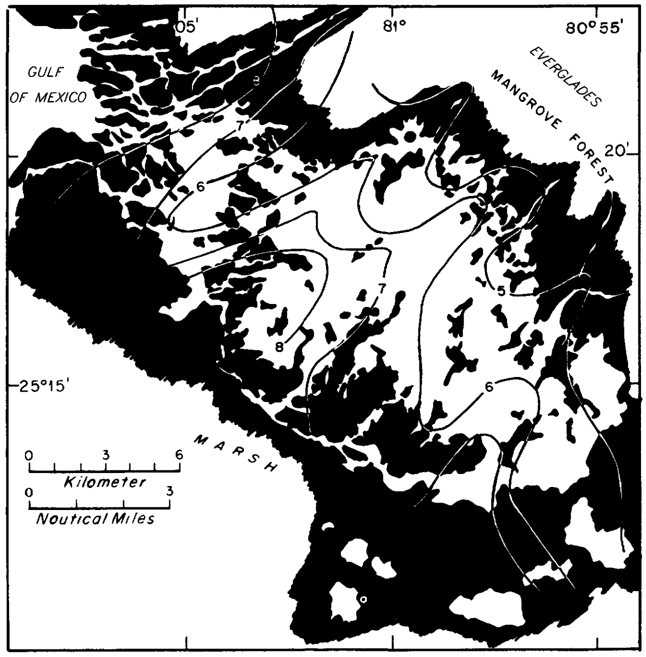

FIGURE 54.—Structure contours (in feet below sea level) on the bedrock surface (Miami Oolite) in Whitewater Bay, Fla. (from Scholl, 1964, and Spackman and other, 1964).

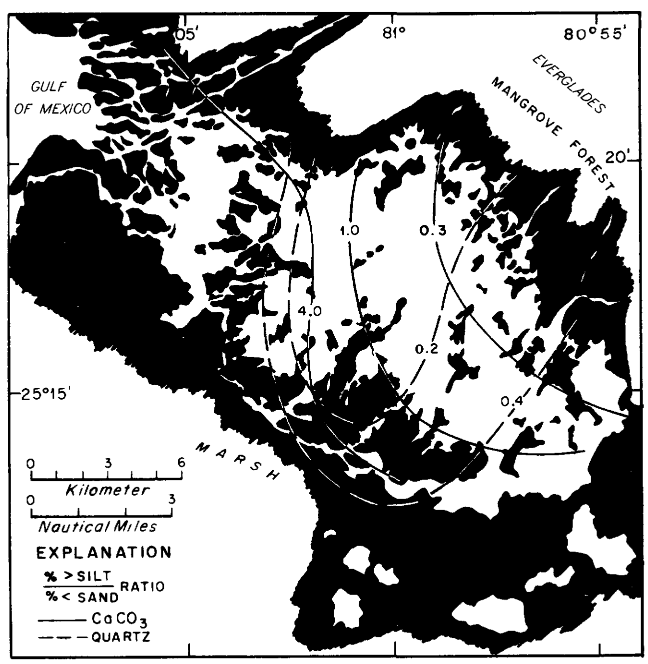

FIGURE 55.—Ratios of sand to silt for the calcium carbonate and quartz fractions of bottom sediments in Whitewater Bay, Fla. Modified from Scholl (1963).

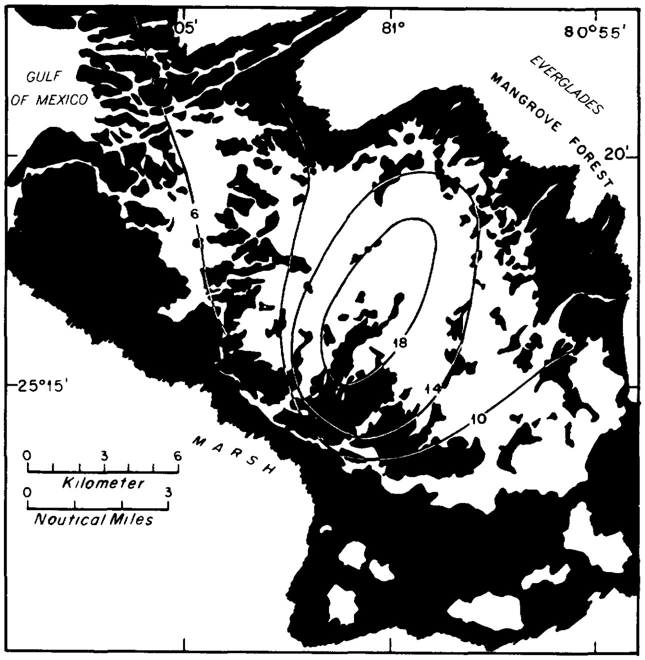

FIGURE 56.—Organic carbon content (in percent) of bottom sediments in Whitewater Bay, Fla. (from Scholl, 1963).

Hydrology.—Four rivers drain into the bay from the Everglades swamp. Runoff fluctuates seasonally. Salinity in the bay ranges from about 1 part per thousand when runoff is greatest to hypersaline conditions (40 parts per thousand) during extended periods of low rainfall. Maximum values during normal dry periods seldom exceed 37 parts per thousand. Water circulation in the bay is roughly counterclockwise and generally is sluggish (less than 0.5 knot or 25 cm/sec).

SEDIMENT TEXTURE

Bottom.—No map of the overall size distribution of the sediments is available. Near the entrance to the bay, bottom sediment is approximately 0.5 mm in median diameter. Within the bay, particle size is controlled primarily by the amount of coarse shell debris present and varies greatly over short distances. Particle-size ratios for the quartz and calcium carbonate fractions are shown in figure 55. Quartz is present mostly as clay and silt. Both ratios indicate a great abundance of fine material within the bay; in contrast, sediments on the shelf nearby contain somewhat coarser material.

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Allisson (1935) method).—Organic carbon is most abundant near the center of the bay (18 percent) (fig. 56). Even higher concentrations, however, occur adjacent to mangrove islands where peat is exposed. Most of this organic material is derived from autochthonous plant debris and sessile algae. Values in bottom sediment of the adjacent continental shelf are about 1 percent.

Mineralogy.—The sediment is composed mainly of aragonite, calcite, and quartz. Detrital dolomite and authigenic pyrite are also present. Carbonates, which are 60 percent aragonite, make up 65 percent of the total sediment, and quartz constitutes 5 to 10 percent.

REFERENCES

School (1963, 1964), Spackman, Scholl, and Taft (1964).

GULLIVAN BAY, FLORIDA

SETTING

Geology.—Surface sediments that cover the low topography of the Florida Peninsula in the area of Gullivan Bay consist of fine, unconsolidated marsh and swamp deposits; these are underlain by the Tamiami Formation (Miocene). The Ten Thousand Islands on the eastern margin of the bay are sand bars made up mostly of shell fragments which are now covered by mangrove forests. The bay is a reentrant on the coastline and is probably structurally controlled. Bay sediments apparently are derived mostly from shoals offshore, swamps and marshes onshore, and eroded Pleistocene terraces.

Bathymetry.—The bottom slopes gently away from shore at a gradient of about 1.5 feet per mile to a maximum depth of about 21 feet (6.3 m) on the western side of the bay. A series of curved en echelon shoals lie offshore (fig. 57).

Hydrology.—Many small ungaged streams drain the swampy terrain adjacent to the bay. Gradients are so low, however, that most water movement is due to tidal action. The mixed semidiurnal tides have an approximate range of 2.5 to 3.5 feet (0.7–1.0 m). Tidal currents in the open bay flow in a counterclockwise direction.

SEDIMENT TEXTURE

Bottom.—The noncarbonate detritus of the bottom sediment consists mostly of very fine to fine sand which is distributed over most of the bay center. Silt is abundant adjacent to the Ten Thousand Islands and in a few offshore areas (fig. 58).

SEDIMENT COMPOSITION

Organic carbon (method of analysis not given).—Concentrations of organic carbon on the shelf are generally less than 1 percent. In channel sediments between the islands, values range from 1 to 4 percent; in the lagoon behind the mangrove islands, from 4 to

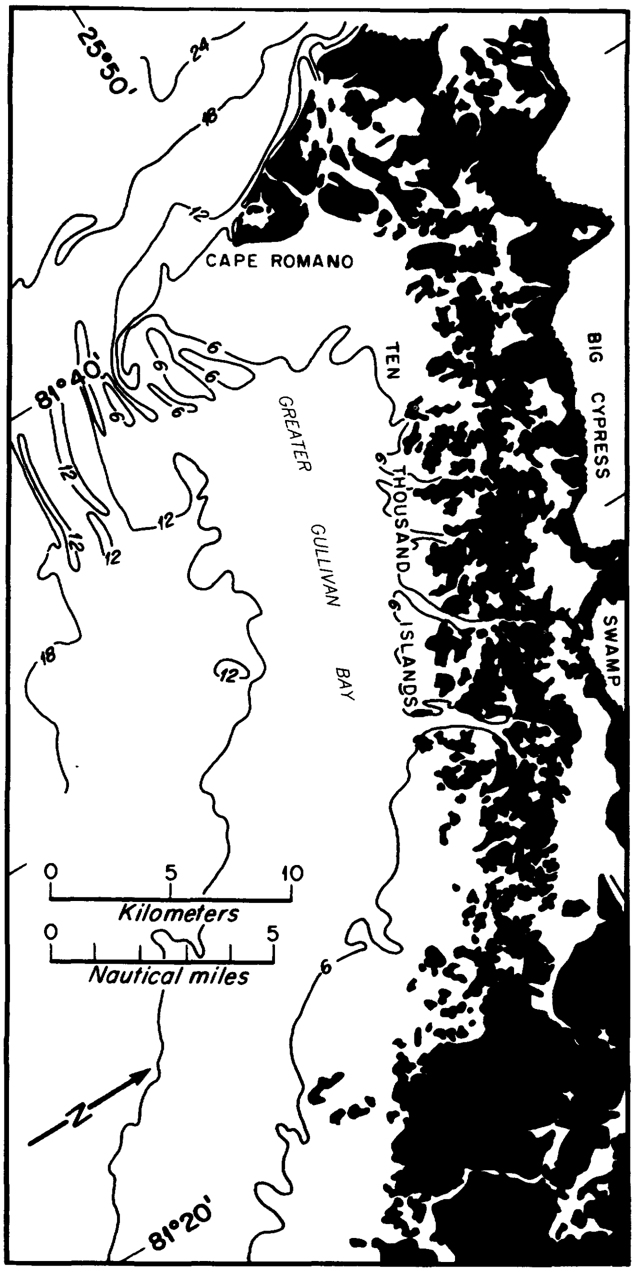

FIGURE 57.—Bathymetry (in feet) of Gullivan Bay, Fla. (from Holmes and Evans, 1963).

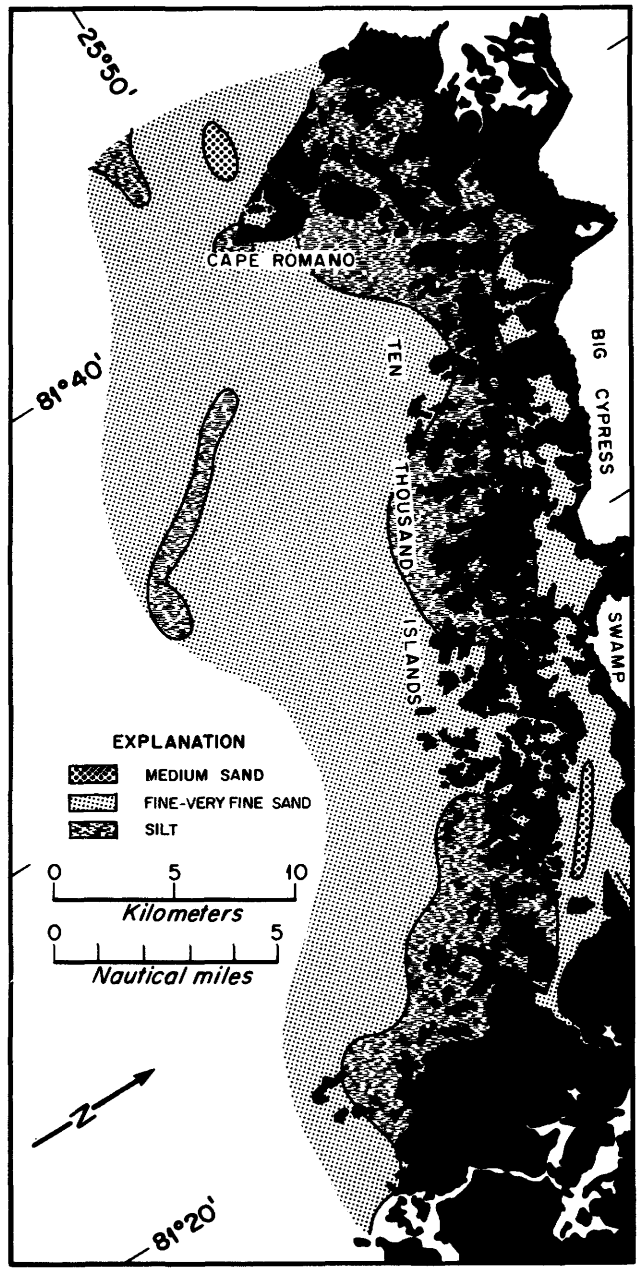

FIGURE 58.—Texture of bottom sediments (carbonate-free) in Gullivan Bay, Fla. Modified from Holmes and Evans (1963).

8 percent, and near the islands where plant detritus is most abundant values are as high as 24 percent.

Mineralogy.—Quartz is abundant in the sand fraction. Heavy minerals, which generally constitute less than 0.4 percent of the sediment, are mostly sillimanite and zircon, followed in abundance by staurolite, kyanite, rutile, tourmaline, and phosphate. Illite and minor amounts of montmorillonite and kaolinite are the most abundant clay minerals in the bay. Illite predominates on the shelf and on shoals; kaolinite, associated with some montmorillonite and illite, is most abundant in the mangrove swamps. Highest carbonate concentrations (60–80 percent) occur locally along the outer fringes of the islands due to the erosion of cemented carbonate shell debris; similar high concentrations are found on oyster bars. In most of the area, however, carbonate concentration generally ranges from 10 to 40 percent (fig. 59).

REFERENCE

Holmes and Evans (1963).

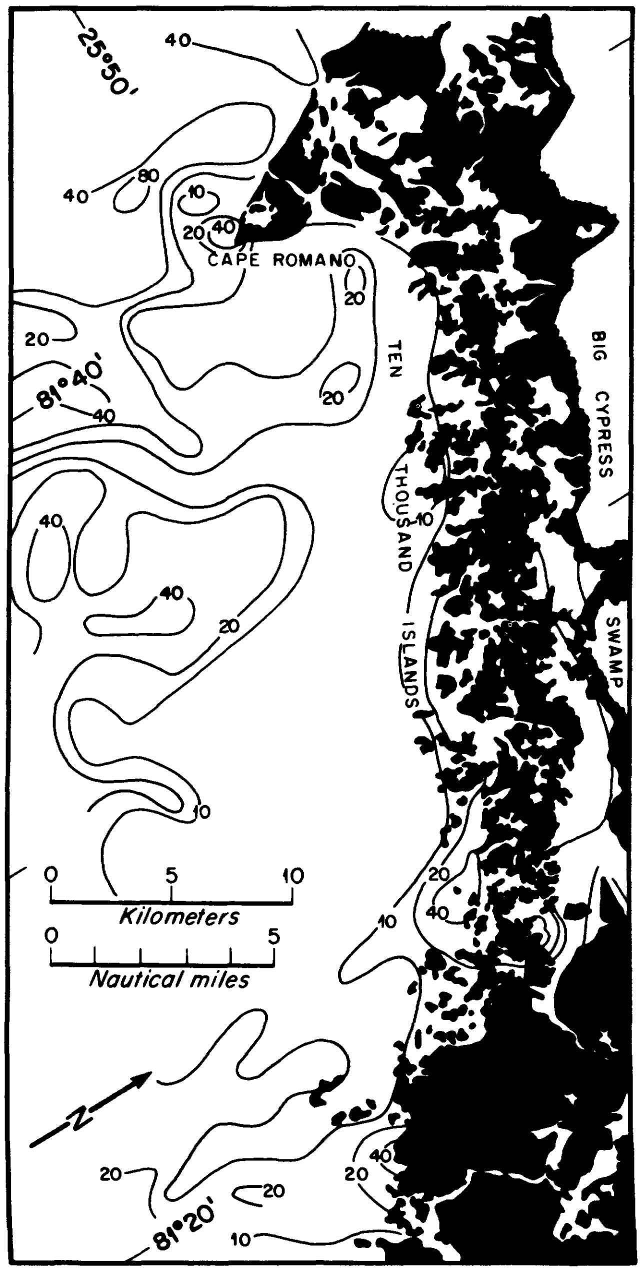

FIGURE 59.—Calcium carbonate content (in percent) of bottom sediments in Gullivan Bay, Fla. (from Holmes and Evans, 1963).

PORT CHARLOTTE HARBOR, FLORIDA

SETTING

Geology.—The area surrounding Port Charlotte Harbor is underlain by post-Eocene limestone and dolomite and minor amounts of clay, quartz sand, and phosphate. A series of barrier islands that are broken by narrow inlets separates the bay from the Gulf of Mexico. The average thickness of Holocene sediments within the bay is about 10 feet (3 m).

Bathymetry.—Most of the harbor is less than 12 feet (3.6 m) deep. Broad, shallow, sandy grass flats less than 6 feet (1.8 m) deep surround the bay margins; depths then increase gradually toward the channels in midbay. The maximum depth (51 feet or 15 m) occurs in Boca Grande Pass (fig. 60).

Hydrology.—Based on limited data the average total fresh-water inflow from the three principal rivers—the Myakka, Peace, and Caloosahatchie—is about 50 m^3/sec. Salinity ranges from 34 to 36 parts per thousand near the inlets to about 13 to 18 parts per thousand at the river mouths. Mean tidal range at the San Carlos Bay entrance is 2.5 feet (0.8 m) and at Boca Grande Pass, 1.7 feet (0.5 m). Maximum tidal current velocities in these two inlets range from 0.9 to 2.2 knots (45–110 cm/sec).

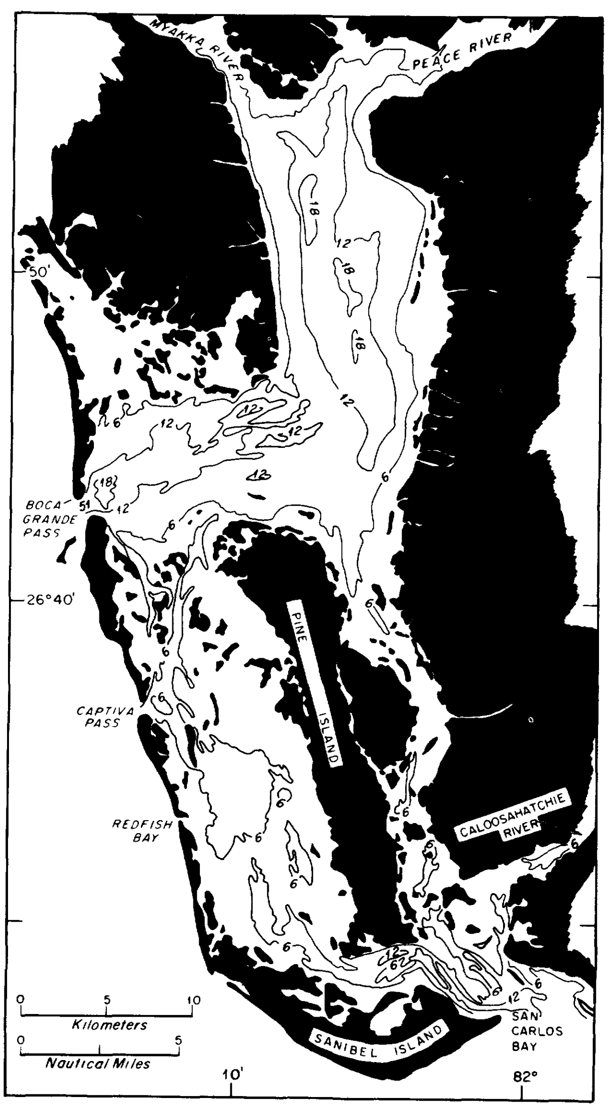

FIGURE 60.—Bathymetry (in feet) of Port Charlotte Harbor, Fla. (from Huang and Goodell, 1967).

SEDIMENT TEXTURE

Bottom.—Based on the mean diameter, most sediment on the bottom of the bay is very fine to fine sand; only a few samples are composed of silt and clay. Medium to coarse sand is abundant north of Pine Island in the channel that extends into the bay from Boca Grande Pass (fig. 61).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Coleman gas analyzer).—Most sediment in the bay contains 0.1 to 1.0 percent organic carbon. The highest value (3.1 percent), among more than 200 measurements, was found in a sample collected between the mouths of the Myakka and Peace Rivers. Most other samples that contained more than 1 percent organic carbon were collected in areas protected from wave and current action (fig. 62).

Mineralogy.—Most sediment in the bay consists of quartz and carbonates. The carbonates include low-magnesium calcite, aragonite, and dolomite. Mollusk shells and shell fragments are the major carbonate source. The carbonate concentration ranges from less than 1 percent in sediments of the river bottoms to 94 percent in those of tidal channels, where shell detritus makes up most of the coarse sediment (fig. 63). Phosphate minerals range in abundance from 0 to 9 percent, but most samples contain less than 2.5 percent.

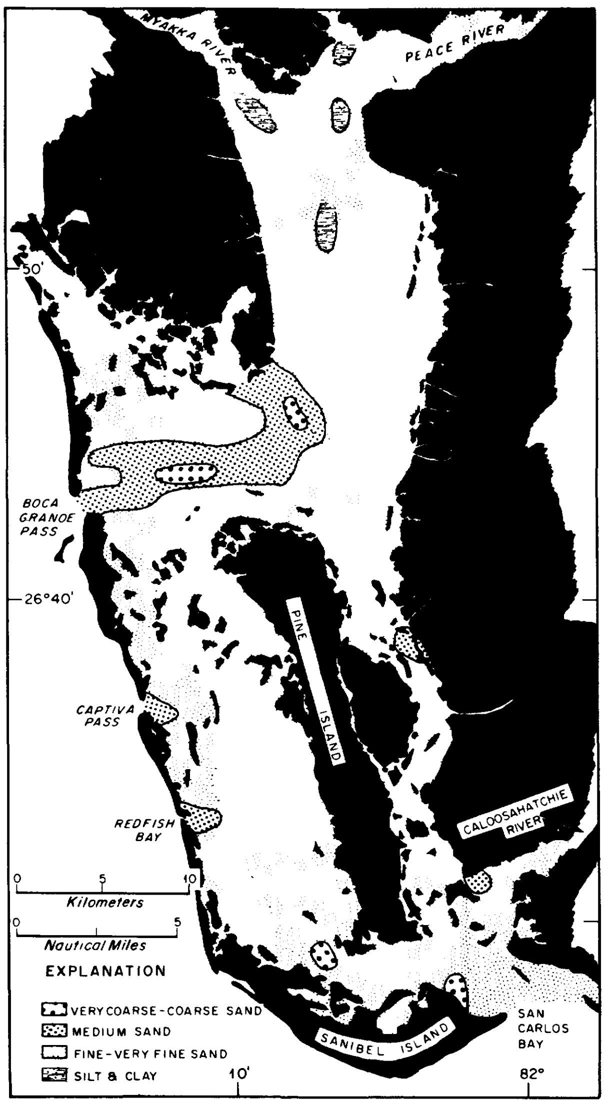

FIGURE 61.—Texture of bottom sediments in Port Charlotte Harbor, Fla. Based on data presented by Huang (1966).

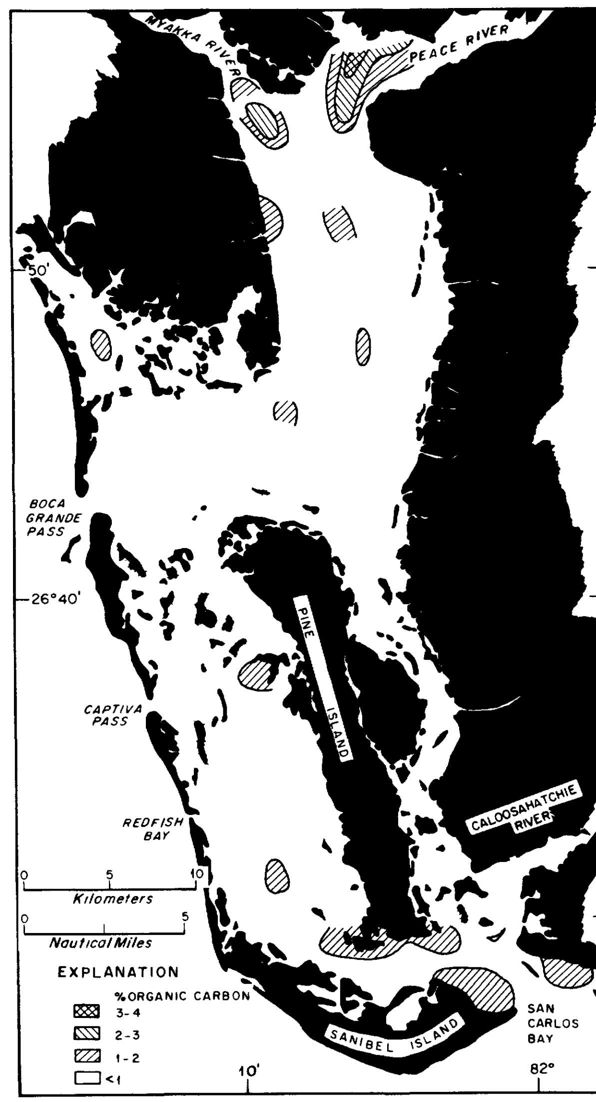

FIGURE 62.—Organic carbon content in bottom sediments of Port Charlotte Harbor, Fla. Based on data presented by Huang (1966).

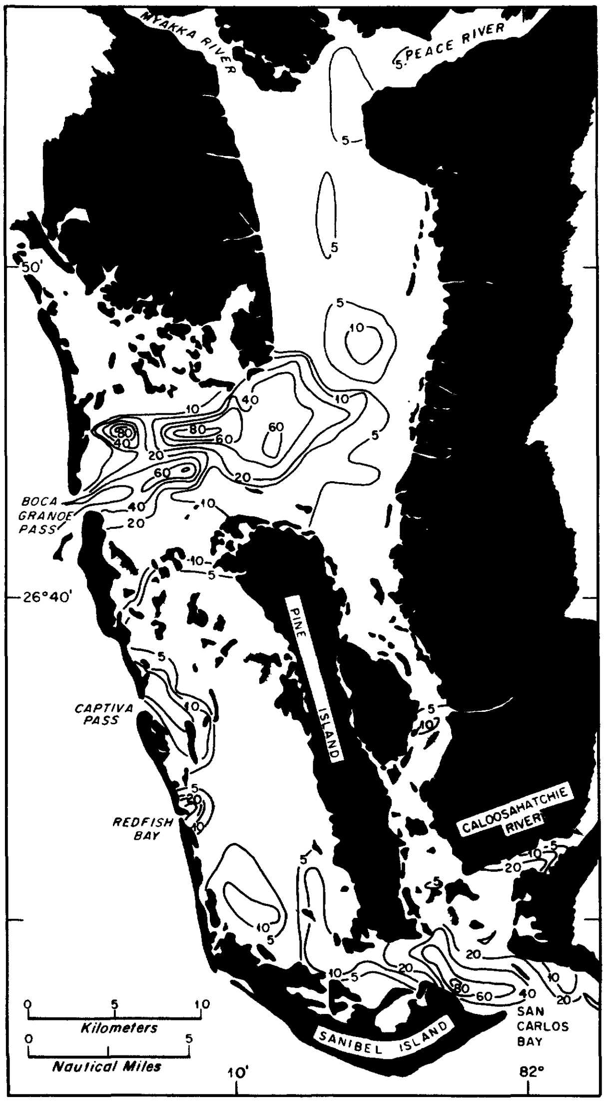

FIGURE 63.—Calcium carbonate content (in percent) of bottom sediments in Port Charlotte Harbor, Fla. Modified from Huang (1966).

Heavy minerals are notably sparse. Layered silicates include montmorillonite, kaolinite, illite, attapulgite, and mixed-layer clays. Kaolinite seems to be concentrated in deep parts of the bay, whereas illite is more abundant near the harbor mouth.

REFERENCES

Huang (1966), Huang and Goodell (1967).

TAMPA BAY, FLORIDA

SETTING

Geology.—Pliocene and Miocene marl, limestone, and sand underlie more recent deposits around the margin of Tampa Bay. Unconsolidated Pleistocene and Holocene sediments in the bay are generally 40 to 50 feet (12–15 m) thick but in channels are as much as 100 feet (30 m) thick.

Bathymetry.—Shallow sand flats around the bay margins are generally less than 6 feet (1.8 m) deep and slope gradually into channels near the axis of the bay; the channels generally are more than 18 feet (5.4 m) deep. The rather smooth topography has been greatly altered in much of the bay by dredging and spoil disposal (fig. 64).

Hydrology.—Discharge from the rivers on the eastern side of the bay is very low. Salinities average 36 parts per thousand at the bay mouth, 26 parts per thousand at the head of Old Tampa Bay, 21 parts per thousand in upper Hillsboro Bay, and 22 to 28 parts per thousand along the eastern shore of Tampa Bay. Tidal range is about 1.5 feet (0.45 m) and tidal currents are generally less than 1 knot (50 cm/sec), except in restricted channels where currents are nearly 2 knots (100 cm/sec). Waters draining the mangrove swamps on the shoreline are acidic.

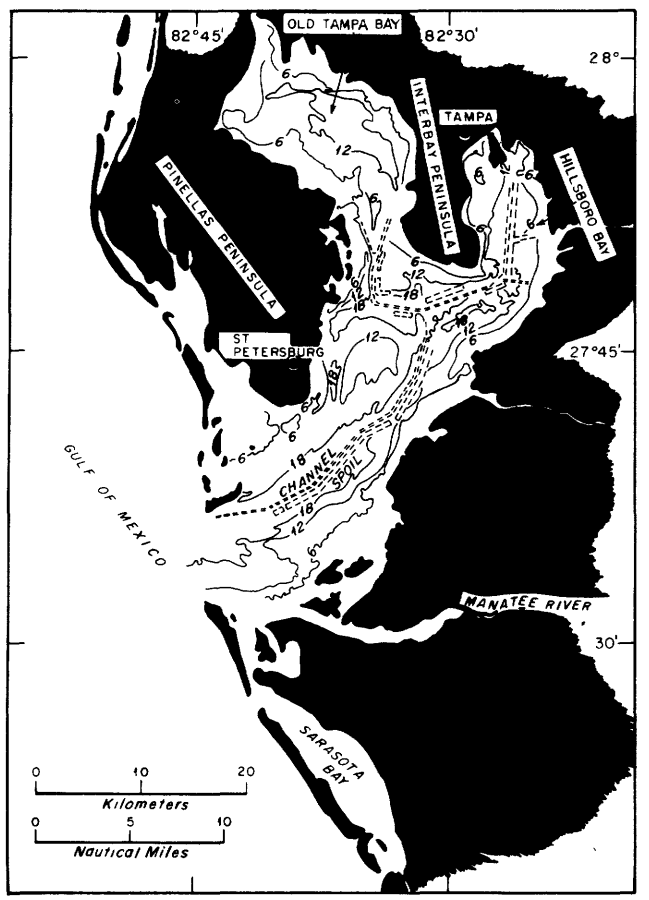

FIGURE 64.—Bathymetry (in feet) of Tampa Bay, Fla. (from U.S.C. & G.S. Chart 587).

SEDIMENT TEXTURE

Bottom.—Sand-sized detritus is widespread throughout the estuary. Silt is abundant only in Hillsboro Bay. Coarsest material occurs in channels where tidal velocities are highest (fig. 65).

Subbottom.—The sediment size distribution is rather homogeneous to a depth of approximately 2 feet (0.6 m), probably due to burrowing by abundant benthic organisms.

SEDIMENT COMPOSITION

Mineralogy.—In the shallow flats around the periphery of the bay the sediment is composed of an almost pure, fine quartz sand. On the slopes and in the channels, abundant fragments of mollusk shells account for most of the calcium carbonate in the sediments (fig. 66) and for the coarse texture. Heavy minerals consist mostly of kyanite, staurolite, and sillimanite. Some fluorapatite and collophane are also present. Clay minerals, including kaolinite and montmorillonite, are present but rare.

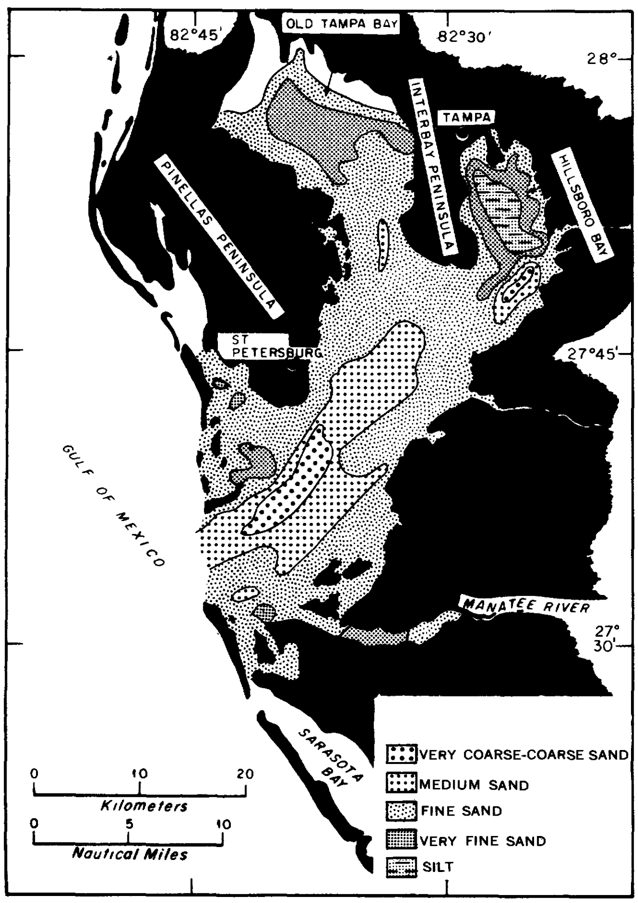

FIGURE 65.—Texture of bottom sediments in Tampa Bay, Fla. Modified from Goodell and Gorsline (1961).

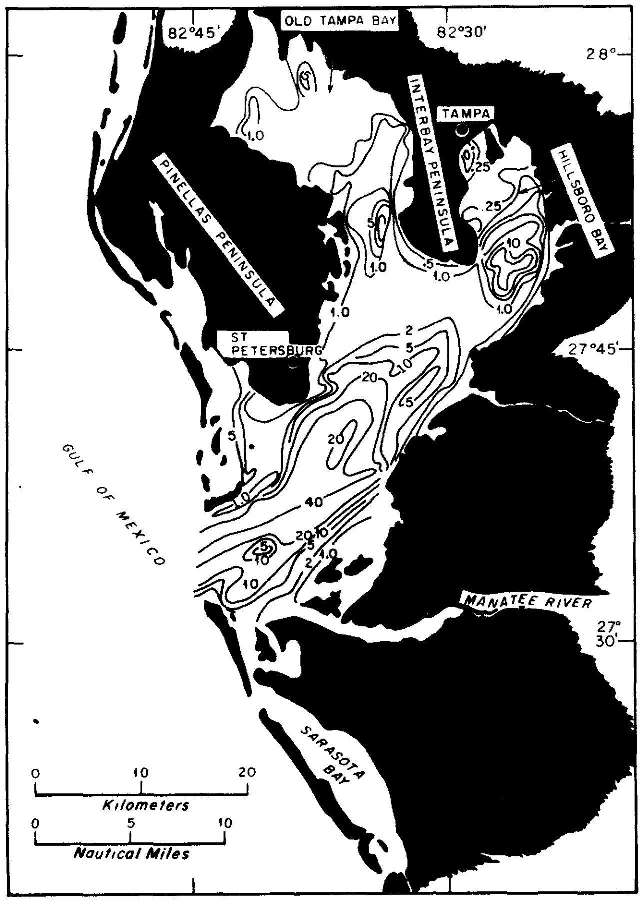

FIGURE 66.—Calcium carbonate content (in percent) of bottom sediments in Tampa Bay, Fla. (from Goodell and Gorsline, 1961).

REFERENCES

Goodell and Gorsline (1961), Walton (1964).

APALACHICOLA BAY, FLORIDA

SETTING

Geology.—The lowlands adjacent to the northern part of the Apalachicola Bay complex are composed of unconsolidated deltaic material deposited on Pleistocene and Pliocene strata by the Apalachicola River. Post-glacial barrier islands form the southeastern margin of the bay complex. Sediment presently accumulating in the bay overlies Tertiary limestone and marl that are exposed in the scoured channels of West Pass and Indian Pass.

Bathymetry.—The bottom dips gently seaward from depths of about 2 feet (0.6 m) at the mouth of the Apalachicola River to 7 feet (2.1 m) before shoaling abruptly at the barrier islands. In the western part of the area (St. Vincent Sound), shallow oyster bars are exposed at low tide. To the east, St. George Bay is partly isolated from Apalachicola Bay by a north-trending bar. The bottom in St. George Bay is hummocky with numerous depressions and shoals. Current scour maintains the depth of West Pass at approximately 54 feet (16 m). Hurricanes have significantly and periodically altered the bottom and the configuration of the barrier islands (fig. 67).

Hydrology.—Fresh-water inflow to the area is derived principally from the Apalachicola River. The mean flow at Chattahootchee, 80 km upriver from the bay, is approximately 600 m^3/sec. Generally, salinity increases from 5 parts per thousand near the river mouth to 30 parts per thousand in the passes. The maximum tidal range is about 3 feet (0.9 m) and averages 1.5–2 feet (0.5–0.6 m). Wind, however, may move the water in the shallow bays sufficiently to mask the normal tidal cycle. Current velocities are a function of river discharge, tides, and wind direction. Velocities in the bay seldom exceed 1 knot (50 cm/sec) but in West and Indian Passes, velocities may reach 5–6 knots (250–300 cm/sec).

SEDIMENT TEXTURE

Bottom.—Much of the fine sediment transported by the Apalachicola River is deposited in Apalachicola Bay and in the eastern half of St. Vincent Sound. Sand accumulating along the bay margins grades into silt and clay in the deep central area (fig. 68). Silt

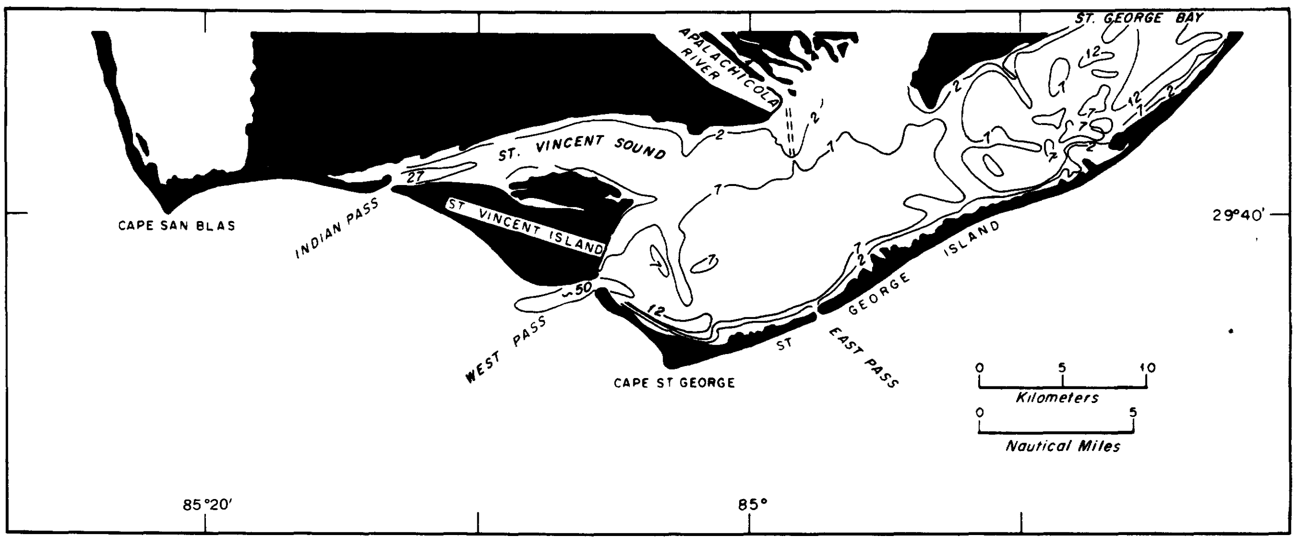

FIGURE 67.—Bathymetry (in feet) in Apalachicola Bay, Fla. (from Kofoed and Gorsline, 1963).

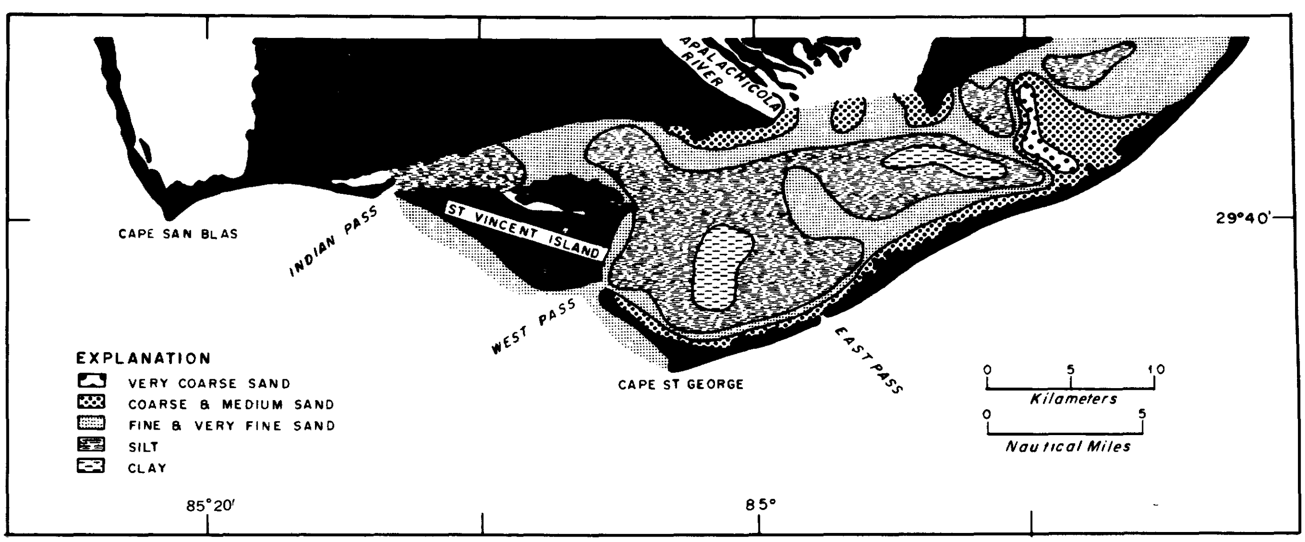

FIGURE 68.—Texture of bottom sediments in Apalachicola Bay, Fla. Modified from Kofoed and Gorsline (1963).

predominates where depths are greater than 6 feet (1.8 m).

SEDIMENT COMPOSITION

Organic carbon.—Values of organic carbon throughout the bay complex generally range from 1 to 2 percent. Around the margins and on topographic highs, however, concentrations are generally less than 0.5 percent. Most of the organic matter is probably derived from indigenous plants and animals. Low values occur in shallow depths where organic matter is apparently oxidized rapidly (fig. 69).

Mineralogy.—Most of the sand consists of quartz mixed with shell debris. Among the layered silicates, kaolinite predominates over much lesser amounts of illite, chlorite, and montmorillonite. Heavy minerals, which are uniformly distributed throughout the area, seldom exceed 1 percent of the sediment. Glauconite is common as small pellets in clay.

Carbonates.—Carbonates, which consist mostly of oyster shells, range from about 10 to 40 percent of the total sediment but only exceed 20 percent in shoal areas and around the bay margins (fig. 70).

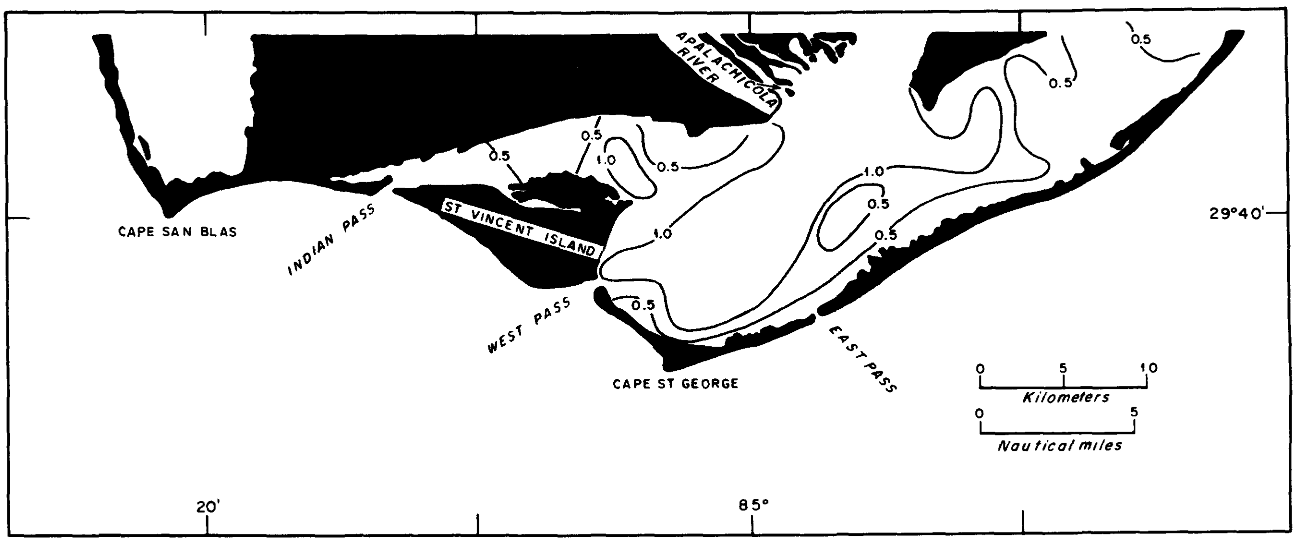

FIGURE 69.—Organic carbon content (in percent) of bottom sediments in Apalachicola Bay, Fla. (from Kofoed and Gorsline, 1963).

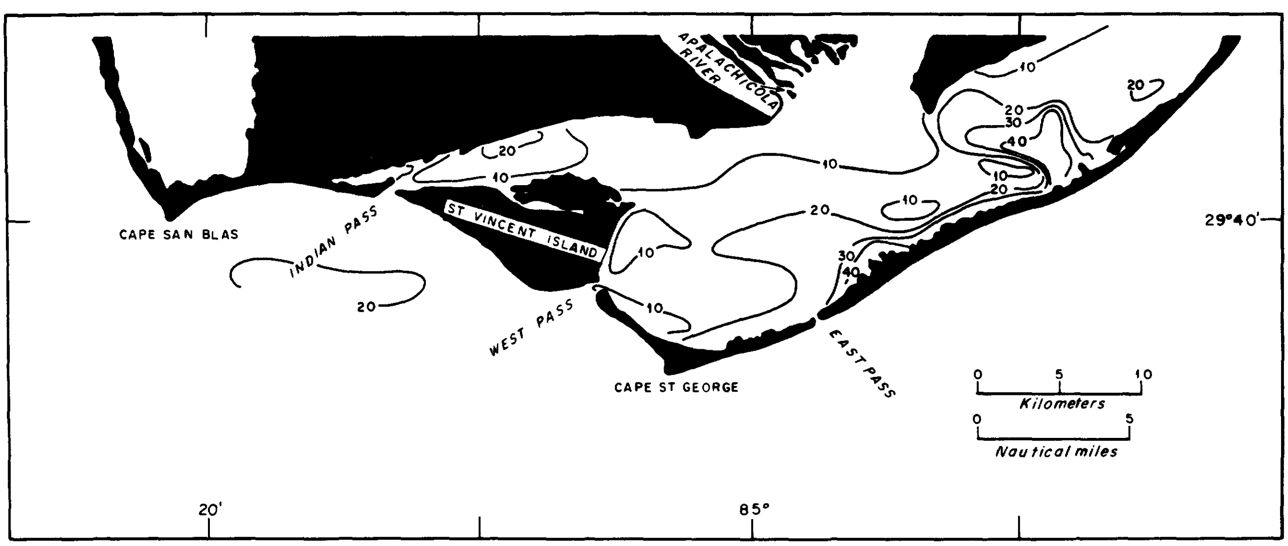

FIGURE 70.—Calcium carbonate content (in percent) of bottom sediments in Apalachicola Bay, Fla. (from Kofoed and Gorsline, 1963).

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REFERENCES

Gorsline (1963), Kofoed and Gorsline (1963).

ST. JOSEPH BAY, FLORIDA

SETTING

Geology.—St. Joseph Bay is underlain by a series of Pleistocene terraces which have been partly covered by Holocene fluvial deposits. No outcrops of consolidated sedimentary rocks have been found in the immediate area of the bay, but to the west, limestone of possible Miocene age is exposed on the bottom in 100 feet (30 m) of water. A postglacial spit isolates the bay from the Gulf of Mexico. Fine to medium sand, which has been swept by longshore currents from the mouth of the Apalachicola River, is presently accumulating in the bay.

Bathymetry.—Gentle bottom slopes on the eastern side of the bay contrast sharply with the steep gradients on the western side. The bottom has an average depth of 21 feet (6.3 m) and a maximum depth of 40 feet (12 m). The physiography of the bottom has changed little since the first bathymetric chart of the area was constructed in 1841 (fig. 71).

Hydrology.—Aside from local runoff, fresh-water inflow is limited to discharge from a papermill into the lagoon through a canal at a rate of 1.3 m^3/sec (fig. 71). Salinity measurements in surface waters range from 16 parts per thousand near the canal en-

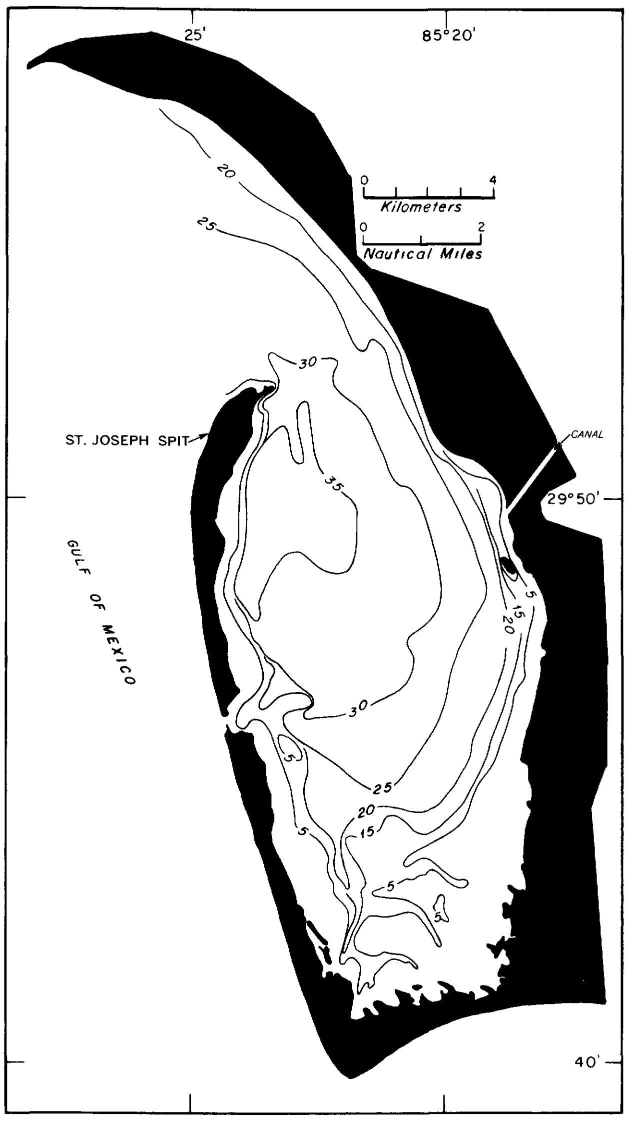


FIGURE 71.—Bathymetry (in feet) of St. Joseph Bay, Fla. (from Stewart and Gorsline, 1962).

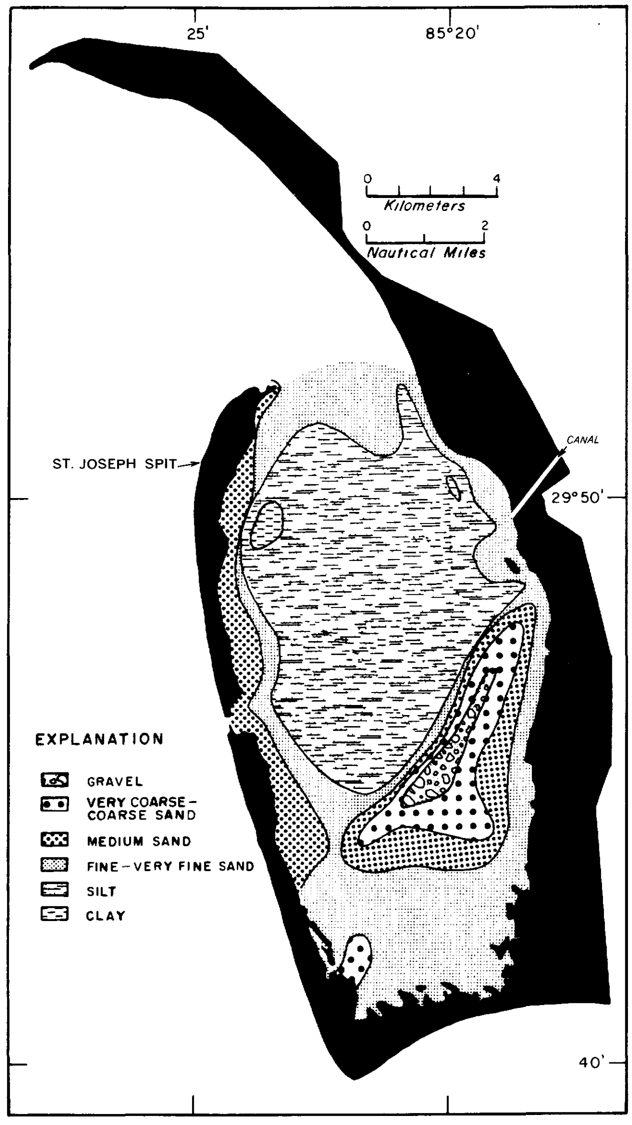


FIGURE 72.—Texture of bottom sediments in St. Joseph Bay, Fla. Modified from Stewart and Gorsline (1962).

trance to 33.5 parts per thousand throughout most of the area. Below a depth of 5 feet (1.5 m) salinity values are similar to those in the open gulf. Tidal current velocities attain a maximum of about 1.5 knots (75 cm/sec) at the tip of St. Joseph spit. Within the bay a counterclockwise gyre has been established. Current movement diminishes rapidly with depth, however, so that reducing conditions exist at the bottom in the deepest areas.

SEDIMENT TEXTURE

Bottom.—Fine sand is presently being deposited at the northern end and around the margin of the bay. Very little clay or silt is being transported into the area. The gradation from sand around the bay margin to clayey silt and clay toward the center reflects two periods of sedimentation rather than textural response to present hydrodynamic or bathymetric conditions. Silty clay under the bay is exposed only in the deepest areas. Coarse material on the southeastern side of the bay consists mostly of shell debris (fig. 72).

Subbottom.—Only a few cores were taken, the longest of which was 46 cm in total length. Silt and clay increase with depth in the core and reach a maximum of 50 percent by weight at 40 cm. The finer sediment is interpreted to be relict from a period preceding the present cycle of sand and silt deposition. The

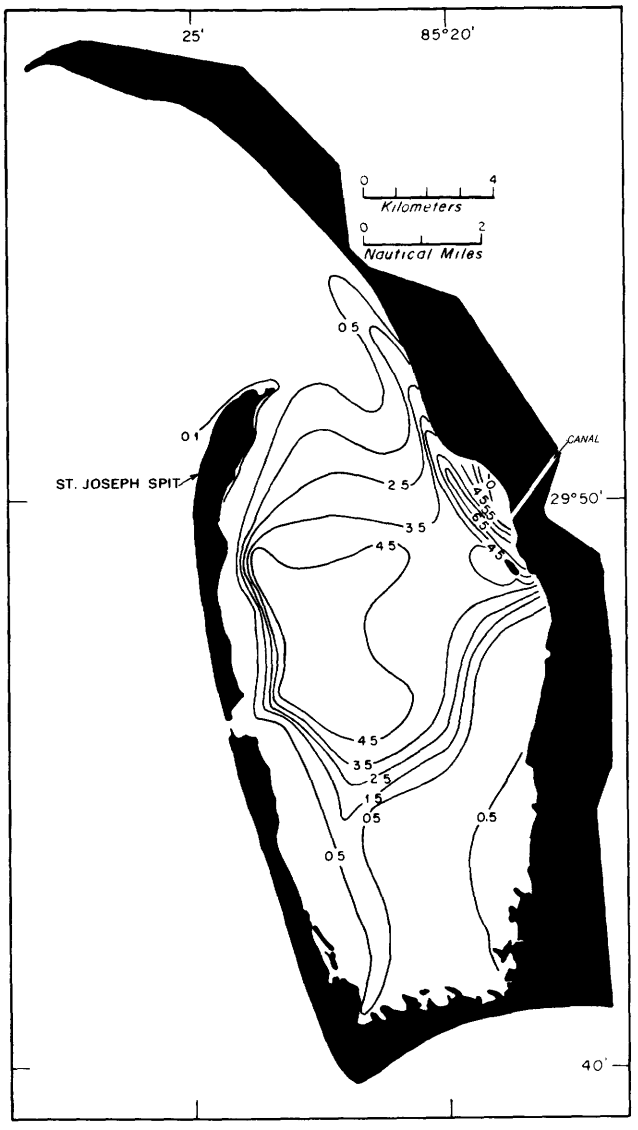


FIGURE 73.—Organic carbon content (in percent) of bottom sediments in St. Joseph Bay, Fla. (from Stewart and Gorsline, 1962).

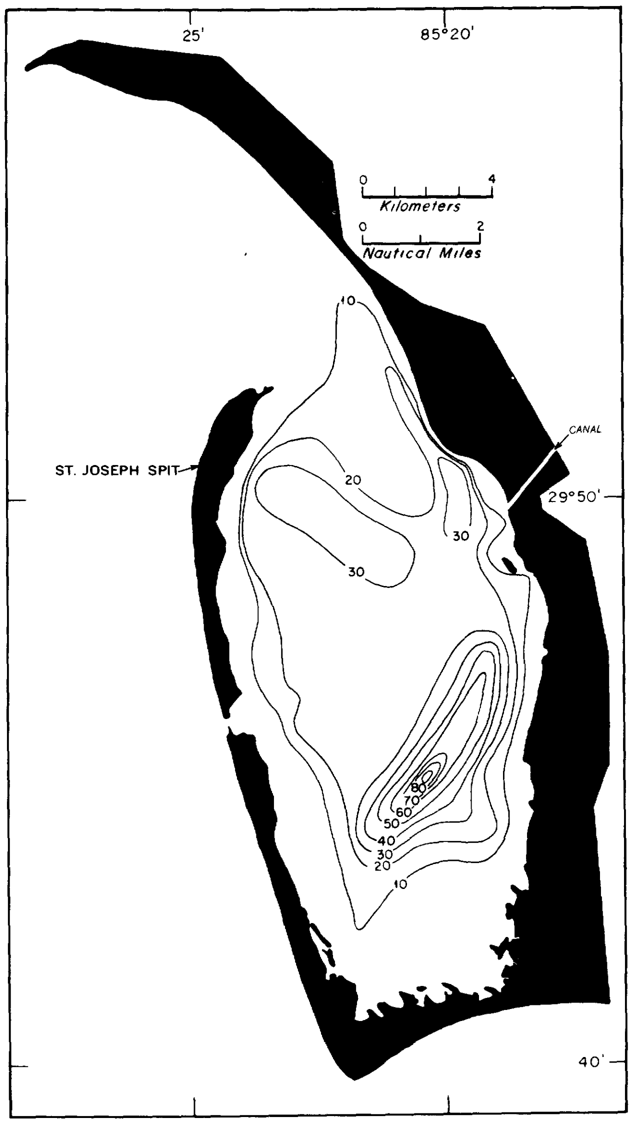


FIGURE 74.—Calcium carbonate content (in percent) of bottom sediments in St. Joseph Bay, Fla. (from Stewart and Gorsline, 1962).

contact between the exposed relict clay and the encroaching sand and silt has been identified by divers where it crops out in the deepest part of the bay at a water depth of 37 feet (11.1 m).

SEDIMENT COMPOSITION

Organic carbon.—Concentrations of organic carbon generally increase from less than 0.5 percent around the bay margin to high values of 4.5 percent in the deep central area. High concentrations (6.5 percent) in rather coarse sediments near the canal mouth are probably due mostly to effluent from the papermill (fig. 73).

Mineralogy.—Layered silicates are most abundant (approximately 50 percent) in bottom sediments of the central part of the bay where fine detritus apparently was deposited by a former distributary of the Apalachicola River; kaolinite is more abundant than either montmorillonite or illite. Most of the fine sand being swept into the bay by longshore currents consists of quartz. Heavy minerals—the most abundant of which are ilmenite, staurolite, and kyanite—make up a maximum of 1 percent of the sediment and average about 0.3 percent.

Calcium carbonate.—Carbonates in the bay are primarily biogenic. In the absence of a significant amount of quartz, the silt fraction consists mostly of foraminifer and ostracode tests and fragments of shell detritus. The highest values of calcium carbonate in the bay are from an extensive bank of shell detritus composed mainly of mollusk shells (fig. 74).

REFERENCE

Stewart and Gorsline (1962).

PENSACOLA BAY, FLORIDA

SETTING

Geology.—The Pensacola Bay system, including Pensacola Bay, East Bay, Blackwater Bay, Escambia Bay, and Santa Rosa Sound, lies on the Gulf Coastal Plain. Holocene sediments are underlain by Tertiary sand, silt, and limestone and by Pleistocene terrace deposits. Only the Citronelle Formation (Pliocene) crops out in the area. Santa Rosa Island isolates the bay complex from the Gulf of Mexico.

Bathymetry.—Most of Escambia, Blackwater, and East Bays are covered by only 6 to 12 feet (1.8–3.6 m) of water (fig. 75). Depths in north-central Pensacola

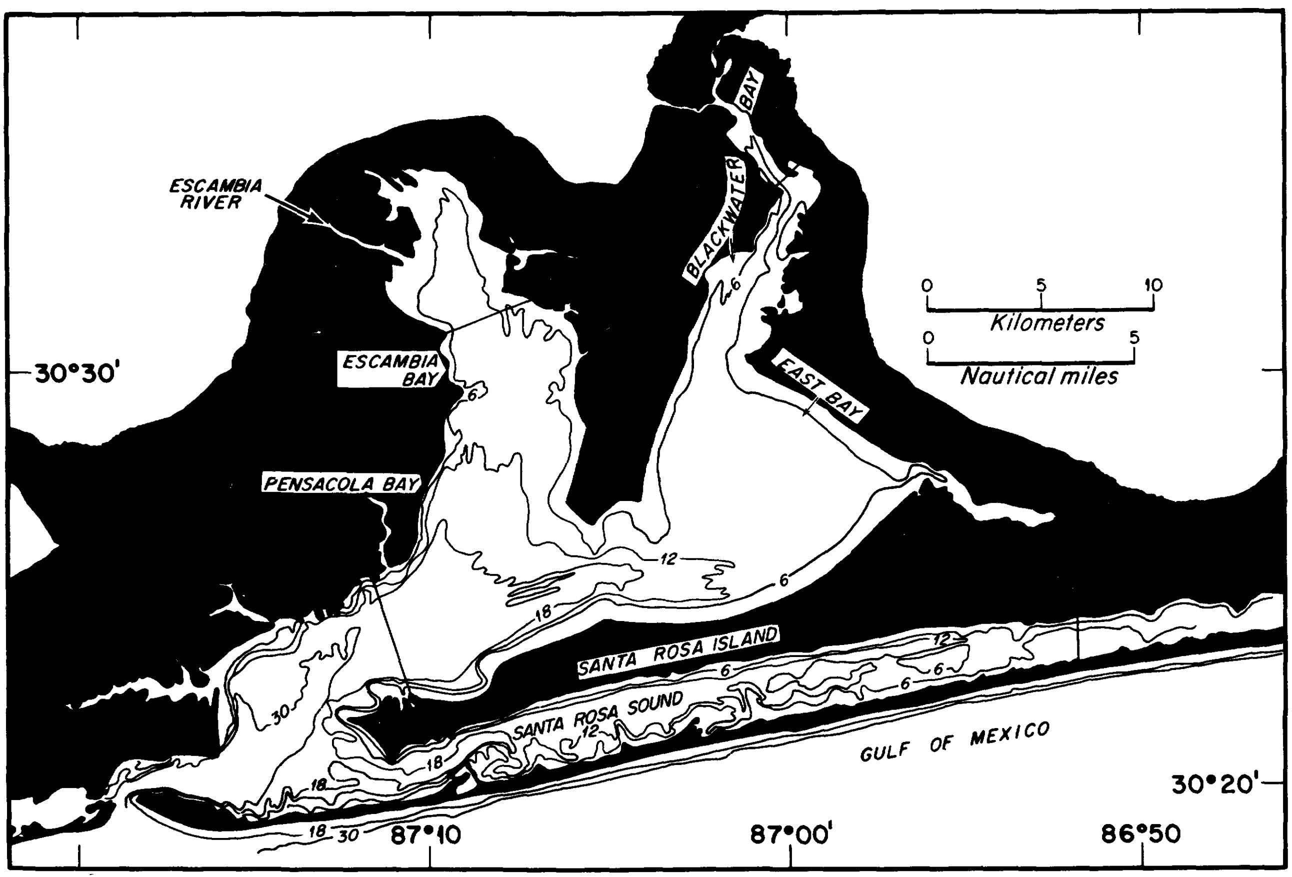


FIGURE 75.—Bathymetry (in feet) of the Pensacola Bay system, Florida (from Horvath, 1968).

Bay are between 18 and 25 feet (5.4–7.5 m) and increase to the south where maximum depths are between 30 and 40 feet (9–12 m). Santa Rosa Sound is over 18 feet (5.4 m) deep at the western end and shallows to the east to about 6 feet (2 m).

Hydrology.—Fresh-water inflow to the bay averages about 250 m^3/sec, 75 percent of which is carried by the Escambia River. Available measurements of salinity taken at Santa Rosa Island ranged from 5.5 to 35.0 parts per thousand. The mean tidal range in Pensacola Bay is 1.3 feet (0.4 m) and at the bay entrance 1.1 feet (0.3 m). Northerly winds often lower the water level by approximately 1.5 feet (0.5 m), and hurricanes have raised the level as much as 9 feet (2.7 m). Tidal current velocities are greatest at the bay entrance and reach 2 to 2.5 knots (100–125 cm/sec) during ebb tide and 1.7 knots (85 cm/sec) at flood tide.

SEDIMENT TEXTURE

Bottom.—The mean grain size of sediments in the bay complex ranges from coarse sand to clay. Sediment becomes finer with distance north of the barrier island. Most sand is therefore located in Santa Rosa Sound and in the lower part of Pensacola Bay. Sand predominates around most of the bay margin and grades into silt and clay in deeper water (fig. 76).

Subbottom.—Borings for the four bridges which cross different parts of the bay system have penetrated to a depth of about 140 feet (42 m). Gray fine to black silty sand is most abundant to a depth at 50 to 60 feet (15–18 m) below which the sediment ranges from silty clay to silty sand.

SEDIMENT COMPOSITION

Mineralogy.—Sand on Santa Rosa Island consists of quartz (99 percent) and such heavy minerals as staurolite, rutile, ilmenite, and kyanite. In the bay sediments, minerals such as quartz, muscovite, albite, and amphiboles have been identified by X-ray diffraction methods. The clay minerals consist of montmorillonite, kaolinite, illite, chlorite, and mixed-layer clays. Calcium carbonate makes up about 3 percent of the sediment; average concentrations are lowest in Santa Rosa Sound (1.3 percent) and increase to the west to almost 5 percent in Escambia and Pensacola Bays.

REFERENCE

Horvath (1968).

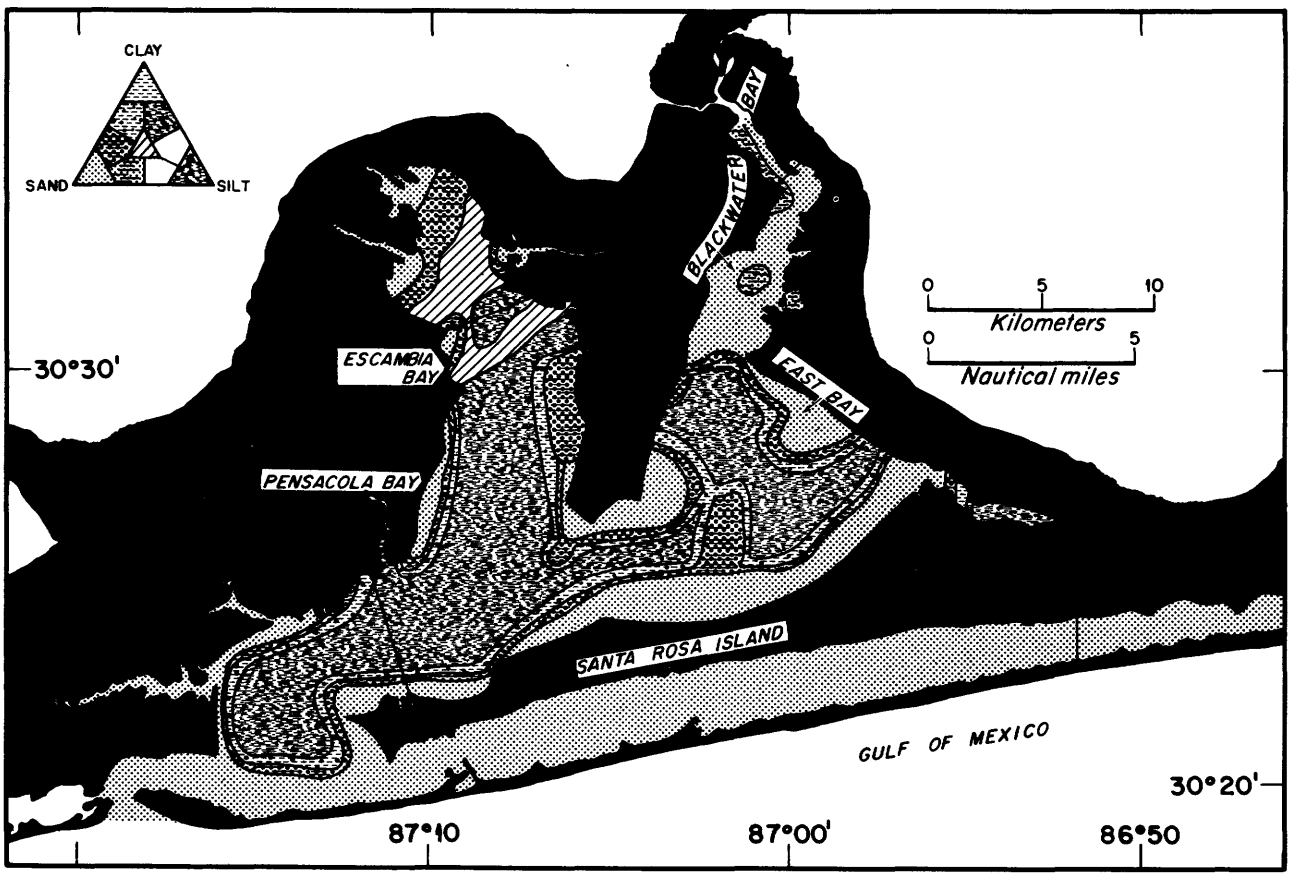


FIGURE 76.—Texture of bottom sediments in the Pensacola Bay system, Florida (from Horvath, 1968).

MOBILE BAY, ALABAMA

SETTING

Geology.—The drainage basins of rivers flowing into Mobile Bay are underlain by sedimentary, igneous, and metamorphic rocks of Precambrian to Holocene age. Locally, Pleistocene and Holocene alluvium overlies Tertiary clay (Miocene?). Sand, gravel, and clay of the Citronelle Formation (Pliocene) crop out on the adjacent Coastal Plain. The shape of the bay is apparently controlled in part by a graben.

Bathymetry.—Most of the flat-floored bay is 10–12 feet (3.0–3.6 m) deep. Shelves 2–6 feet (0.6–1.8 m) deep and about 1 mile (1–2 km) wide surround most of the bay and drop off abruptly to the deeper bottom (fig. 77). Ship channels are maintained at a width of about 400 feet (120 m) and a depth of 40 feet (12 m). The pass between Mobile Point and Dauphin Island is approximately 50 feet (15 m) deep. The bay has shoaled an average of almost 2 feet (0.6 m) in the last 100 years.

Hydrology.—Mean fresh-water inflow (1,700 m³/sec) to the bay from the Mobile River system is about equally contributed by the Alabama and Tombigbee Rivers. (The Tensaw River is a distributary of the Alabama River.) Flow is lowest between September and November and greatest between January and May. The maximum discharge, measured during a flood, was 14,000 m³/sec. Suspended sediment transported to the

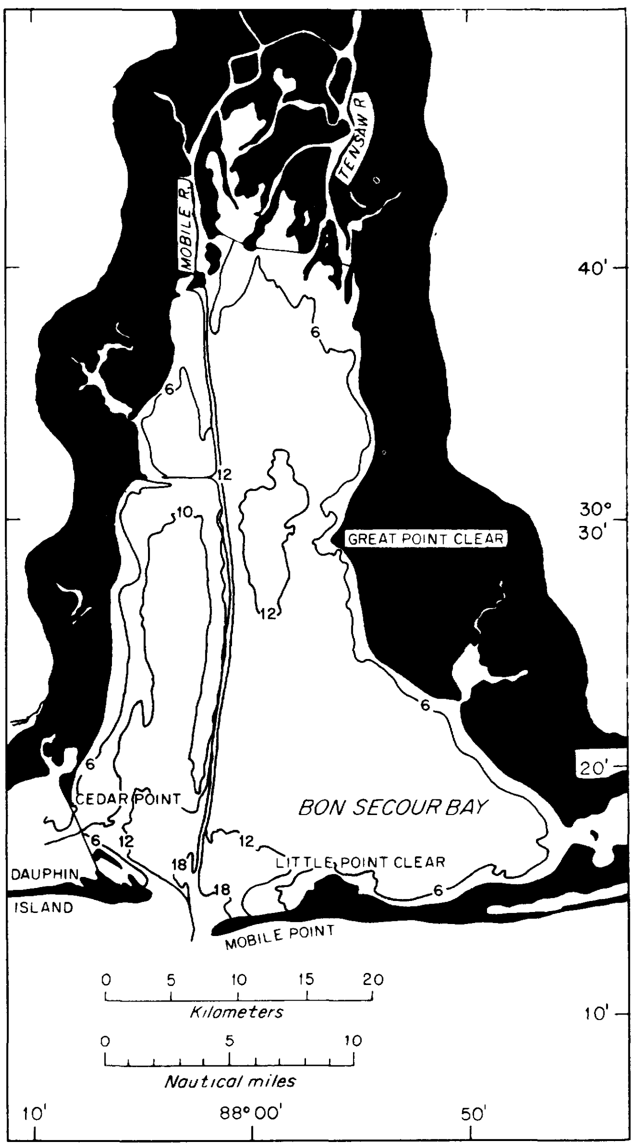


FIGURE 77.—Bathymetry (in feet) of Mobile Bay, Ala. (from Ryan, 1969).

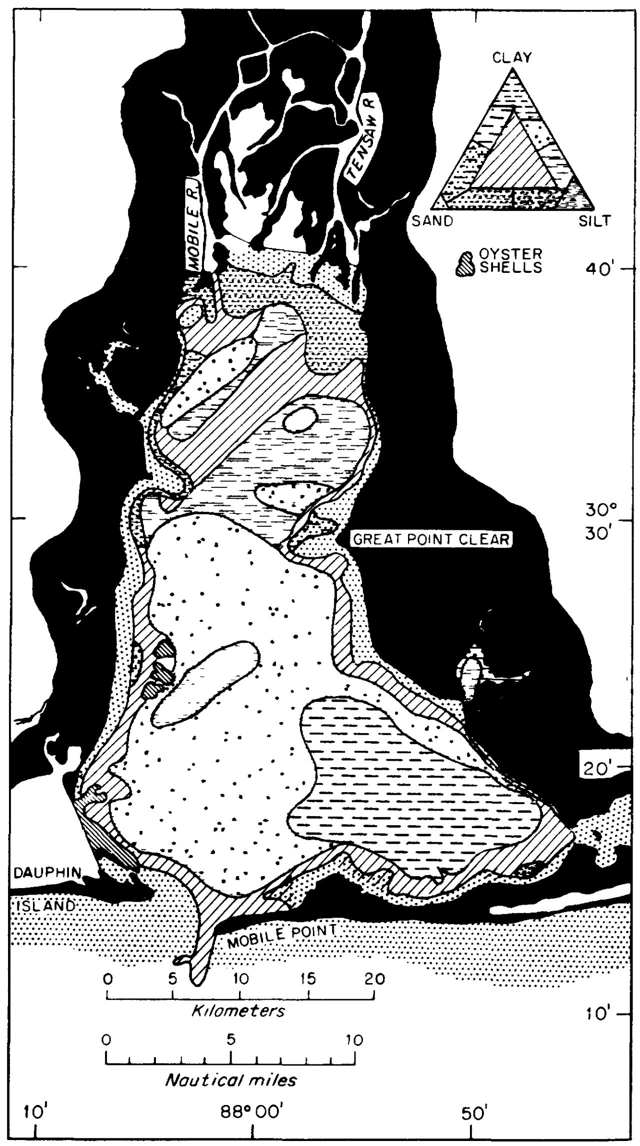


FIGURE 78.—Texture of bottom sediments in Mobile Bay, Ala. (from Ryan, 1969).

bay has averaged about 4.7×10^6 tons per year. Mean tidal range is 1.0 foot (0.3 m) at the lower end of the bay and 1.5 feet (0.4 m) at the upper end. Winds, however, are responsible for greater variations. Hurricanes, for example, have caused the water level to rise about 10 feet (3 m) above and fall about 10 feet (3 m) below mean sea level. Tidal currents average 1.4 knots (70 cm/sec), but maxima of 3 knots (150 cm/sec) have been measured at the bay entrance. During periods of high discharge the salinity may drop to less than 5 parts per thousand throughout most of the bay; during periods of low discharge values of 30 parts per thousand at the bottom may extend almost to the head of the bay. The ship channel has allowed the salt wedge to penetrate the whole length of the bay.

SEDIMENT TEXTURE

Bottom.—Most of the bottom of the lower bay, which is generally deeper than 6 feet (2 m), is covered with clay or silty clay (fig. 78). These sediments grade northward into sandy silt and sand. The finest sediments, concentrated on the eastern side of the estuary, are probably deposited mostly from bottom currents during flood tide. Sand covers almost all the shallow shelf around the bay margin.

SEDIMENT COMPOSITION

Mineralogy.—Kaolinite and montmorillonite dominate the fine sediments. Kaolinite is more abundant at the bottom, but montmorillonite content increases with depth below the bottom. Illite and chlorite are minor and variable constituents. Most sediment contains less than 4 percent carbonate except on or near oyster reefs. Carbonate detritus consists mostly of gravel-sized fragments of pelecypod shells.

REFERENCE

Ryan (1969).

MISSISSIPPI SOUND, MISSISSIPPI AND ALABAMA

Geology.—Quaternary deltaic sands and clays border Mississippi Sound to the north. Five barrier islands and the broad inlets between them form the southern margin. The islands are made up mostly of medium sand, commonly in dunes that are 40 to 50 feet (12–15 m) thick and overlie 10 feet (3 m) of gray clay.

Bathymetry.—Most of the northern half of the sound is less than 10 feet (3 m) deep; in the southern part, depths average 15 to 20 feet (4.5–6 m). Inlet channels near and between barrier islands range from 25 to 50 feet (7.5–15 m) in depth. Shoals consist of sand bars or oyster reefs (fig. 79).

Hydrology.—Among the many streams and rivers contributing fresh water to the sound the most important are the Pearl, Pascagoula, and Biloxi. The Pearl and Biloxi which flow into the sound at its western and eastern ends are not within the area shown by the figures. Total average fresh-water inflow from the three rivers is 1,600 m^3/sec. Salinities range from zero near river mouths to 30 parts per thousand in the

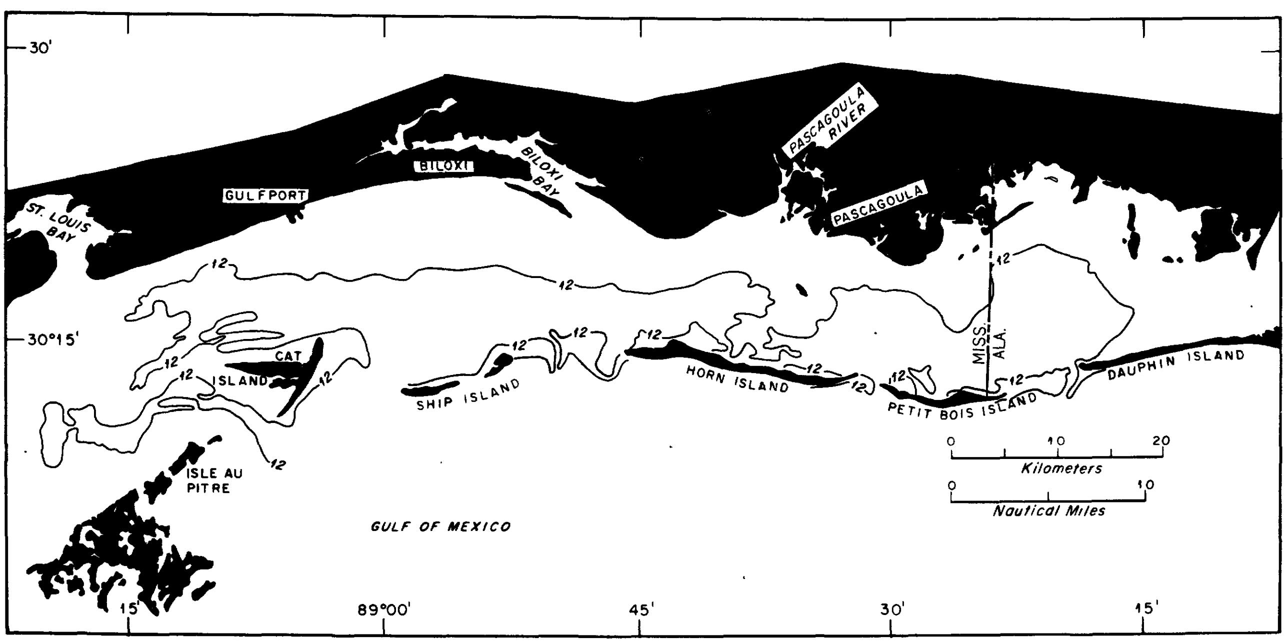


FIGURE 79.—Bathymetry (in feet) of Mississippi Sound, Miss. and Ala. (from Upshaw and others, 1966).

open sound. Normal tidal ranges are less than 2 feet (0.6 m), and currents are most often less than 1 knot (50 cm/sec).

SEDIMENT TEXTURE

Bottom.—Silt and clay (carbonate-free), which are most abundant in the deep central part of tbe sound, grade into very fine to fine sand toward the margins. Near the barrier islands and along the northern margin west of Pascagoula, sands are medium to coarse. East of Pascagoula fine sand, silt, and clay are being deposited along the mainland shore (fig. 80).

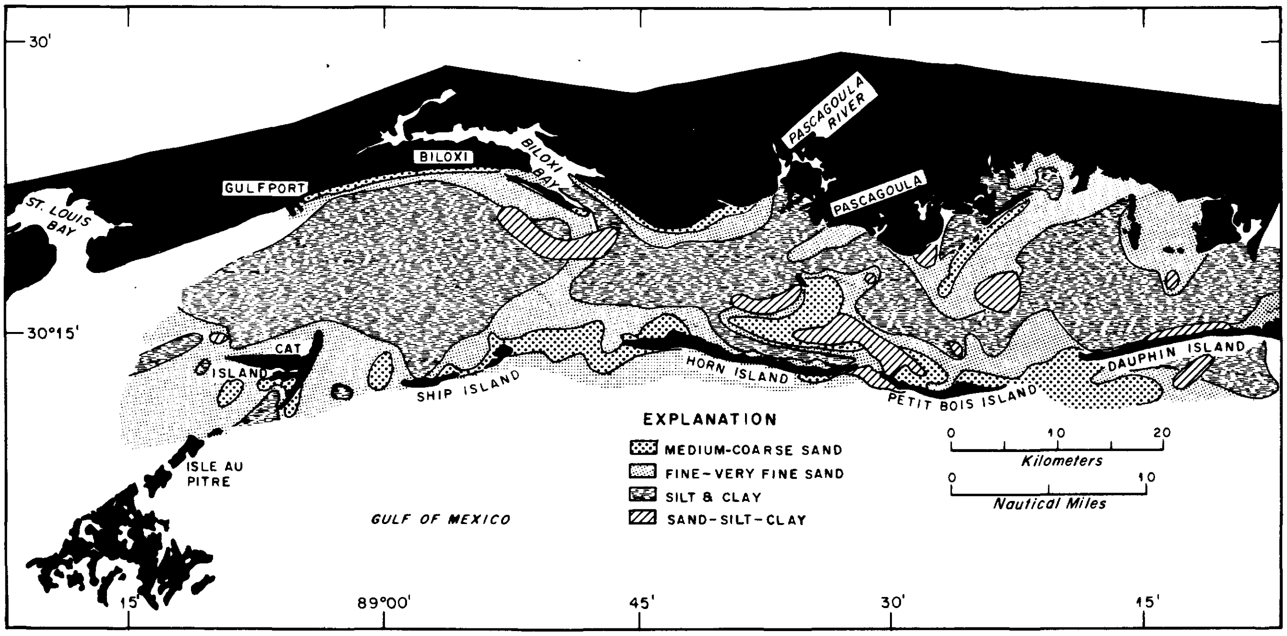


FIGURE 80.—Texture of bottom sediments in Mississippi Sound, Miss. and Ala. Modified from Upshaw, Creath, and Brooks (1966).

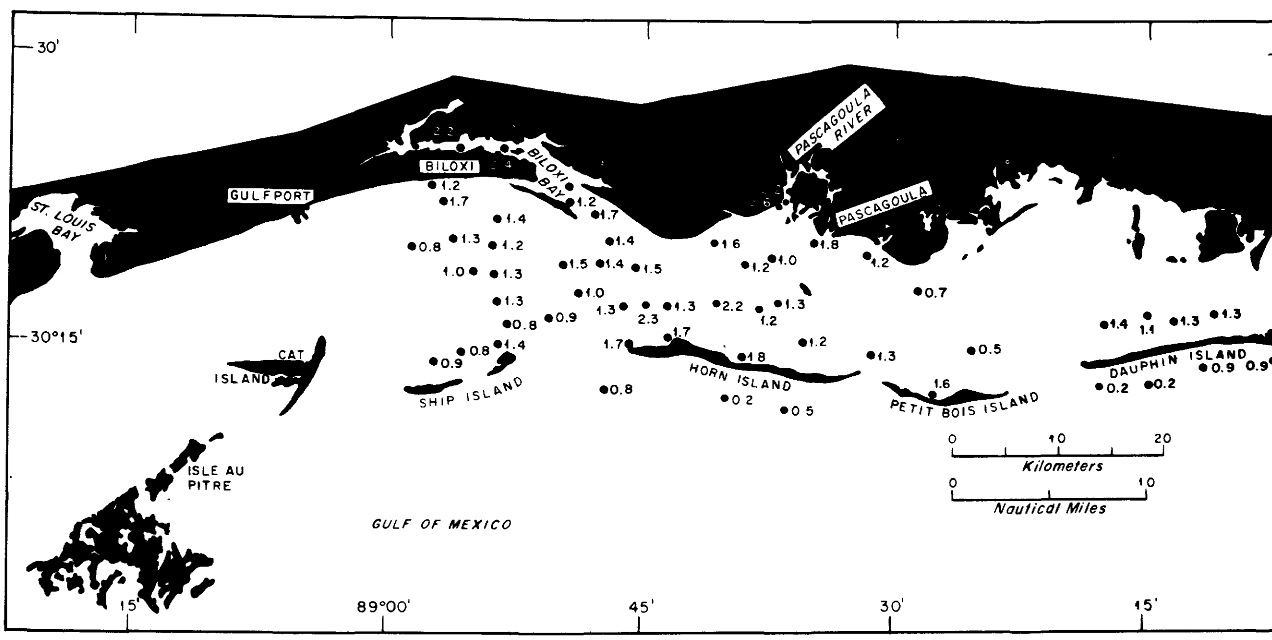


FIGURE 81.—Organic carbon content (in percent) of bottom sediments in Mississippi Sound, Miss. and Ala. Data from W M.. Sackett and R. R. Thompson (in Upshaw and others, 1966).

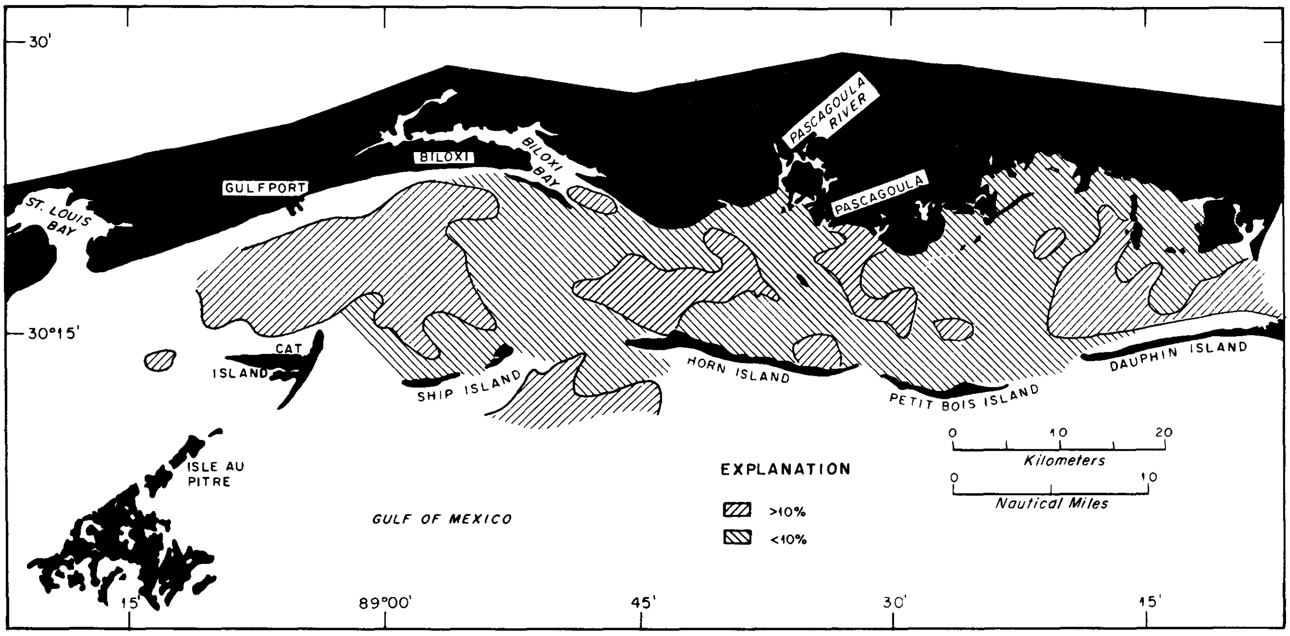


FIGURE 82.—Calcium carbonate content in bottom sediments of Mississippi Sound, Miss. and Ala. (from Upshaw and others, 1966).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed spectrographically).—In the open sound, silts and clays generally contain less than 1.5 percent organic carbon and sands, less than 1 percent. Highest concentrations of between 2 and 4 percent were measured in samples collected near shore in the small bays at Biloxi and Pascagoula (fig. 81).

Mineralogy.—Carbonates in the sound, consisting mostly of shell debris, generally constitute 10 to 15 percent of the fine sediments and less than 10 percent of sands (fig. 82). In average coastal beach or dune sands, heavy-mineral concentrations range from 2 to 6 percent; in order of abundance these include staurolite, kyanite, tourmaline, ilmenite, magnetite, limonite-hematite, leucoxene, zircon, rutile, sillimanite, and andalusite. Light minerals accumulating in the sound consist mostly of quartz and potassium feldspar. The most abundant clay minerals are kaolinite, illite, and montmorillonite; chlorite is rare.

REFERENCES

Foxworth and others (1962), Ludwick (1964), and Upshaw, Creath, and Brooks (1966).

BRETON AND CHANDELEUR SOUNDS, LOUISIANA

SETTING

Geology.—Most of the submerged area of both Breton and Chandeleur Sounds is an abandoned distributary of the Mississippi River Delta which, because of erosion by the sea, compaction of Holocene unconsolidated sediments and regional subsidence is now being covered by marine sediments. The sounds are flanked on the west by brackish and salt marshes of the Mississippi Delta and on the east by a series of barrier islands that consist of well-sorted medium sand deposits as much as 35 feet (11 m) thick. In the sounds, Holocene marine sediments range in thickness from a few inches to several feet and overlie marsh and fluviatile deposits of the abandoned delta.

Bathymetry.—The bottom slopes gently from west to east and reaches depths of between 12 and 18 feet (4–5 m) near the barrier islands (fig. 83).

Hydrology.—Fresh-water inflow to the sound is derived mostly from the swamps and bayous of the delta and from the Mississippi River. Salinities vary roughly between 15–30 parts per thousand depending on season, wind direction, and runoff. Tidal ranges are less than 2 feet (0.6 m). The velocity of the current which flows northward between Breton Island and the delta at about 0.5 and 1.0 knot (25–50 cm/sec) is in part controlled by the wind.

SEDIMENT TEXTURE

Bottom.—The bottom of both sounds is covered mostly with very fine sand. Coarser average textures are primarily due to the presence of shells and shell debris. Silt and clay derived from erosion of deltaic material is being deposited along the western margin of the bay and in a tongue along the western margin

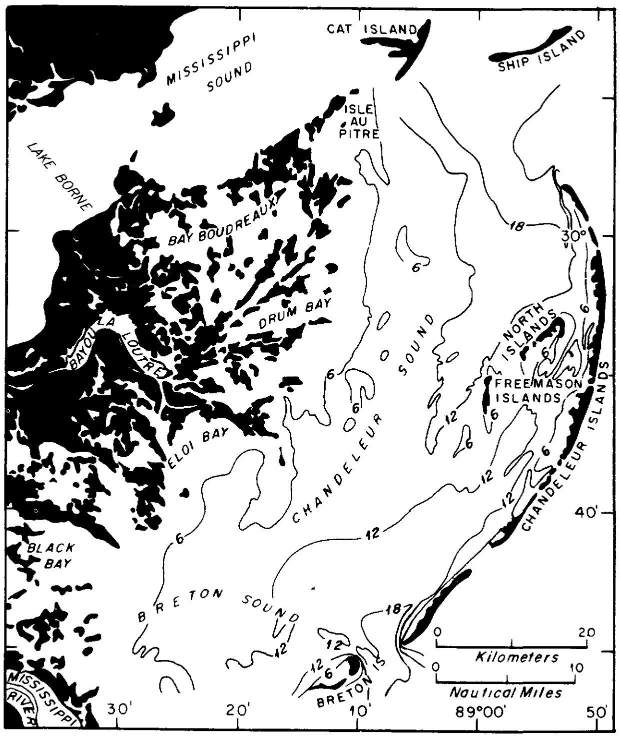


Figure 83.—Bathymetry (in feet) of Breton and Chandeleur Sounds, La. (from Treadwell, 1955).

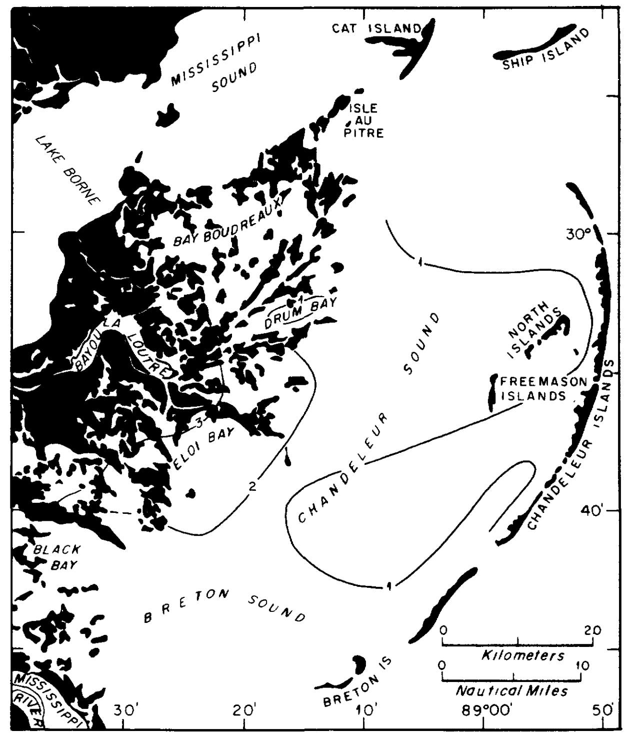


Figure 85.—Total organic matter (in percent) in bottom sediments in Breton and Chandeleur Sounds, La. (from Treadwell, 1955).

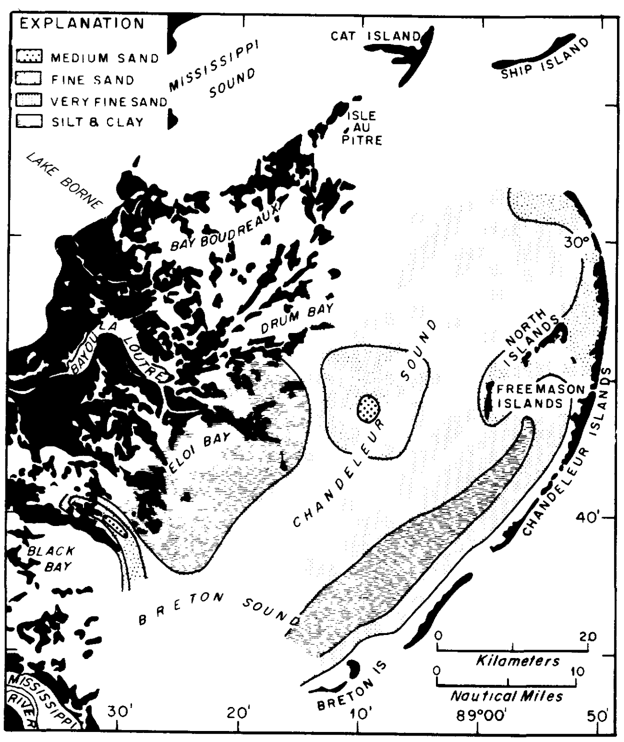


Figure 84.—Texture of bottom sediments in Breton and Chandeleur Sounds, La. Modified from Treadwell (1955).

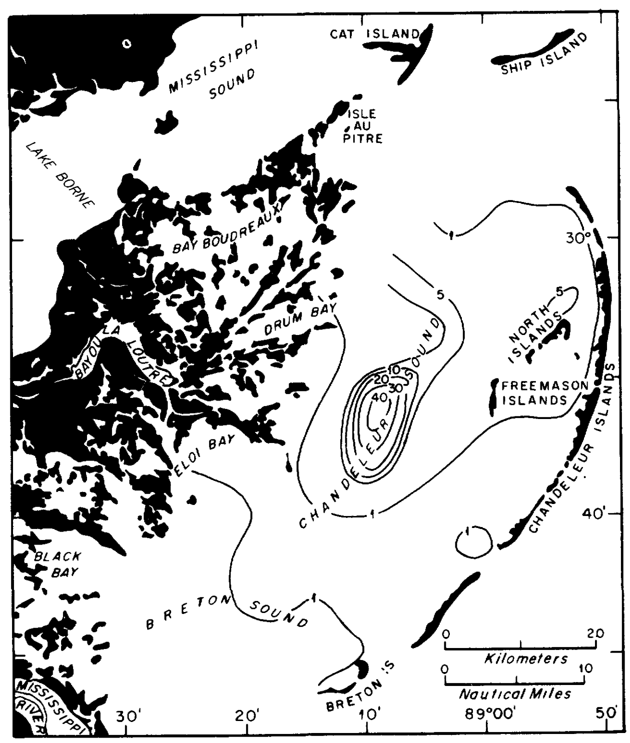


Figure 86.—Shell content (in percent) of bottom sediments in Breton and Chandeleur Sounds, La. Modified from Treadwell (1955).

of the barrier islands, where fine suspended detritus carried by the Mississippi River is evidently being deposited. The texture of much of the bottom sediments results from the mixing of old subdelta deposits and contemporary marine sediments (fig. 84).

Subbottom.—Cores taken in Chandeleur Sound contain an upper 7-foot (2.1 m) section of silty clay and silty sand which overlies approximately 33 feet (10 m) of clay and silty clay.

SEDIMENT COMPOSITION

Organic matter (dry weight loss after boiling sample in 10 percent H_2O_2).—Concentrations of organic matter on the bottom are very low; they range from less than 1 percent in the central area to 2 or 3 percent near marshland borders (fig. 85).

Mineralogy.—Sand along the northwest margin of the sound consists mostly of quartz and feldspar and contains some rock fragments, amphiboles, pyroxenes, epidote, ilmenite, and biotite. Principal clay minerals are montmorillonite and illite, plus lesser amounts of kaolinite and chlorite. Heavy minerals constitute less than 0.5 percent of the sediment in the sounds and consist of an assemblage of mostly hornblende and pyroxene and small amounts of epidote and garnet. Carbonates are generally sparse (less than 2 percent), except in the south-central part of Chandeleur Sound where shells and shell fragments make up roughly 50 percent of the sediment (fig. 86).

REFERENCES

Scruton (1956, 1960), Shepard (1960), Treadwell (1955), Van Andel and Poole (1960).

BARATARIA BAY, LOUISIANA

SETTING

Geology.—Barataria Bay is on the southwest side of the postglacial delta built by the Mississippi River. Several barrier islands isolate the bay from the Gulf of Mexico.

Bathymetry.—Most depths in the shallow bay are less than 6 feet (2 m). A channel which is about 18 feet (5.4 m) deep extends into the central bay from Barataria Pass which is 165 feet (50 m) deep (fig. 87).

Hydrology.—Fresh-water inflow from an ungaged canal, which joins the Mississippi River near New Orleans, is probably very small. The tidal range in the bay is less than 2 feet (0.6 m).

SEDIMENT TEXTURE

Bottom.—Most of the bottom is covered by very fine sand. Only near Pass Justin and Pass Abel is fine sand predominant. Silt is most abundant in shallow protected areas around islands (fig. 88).

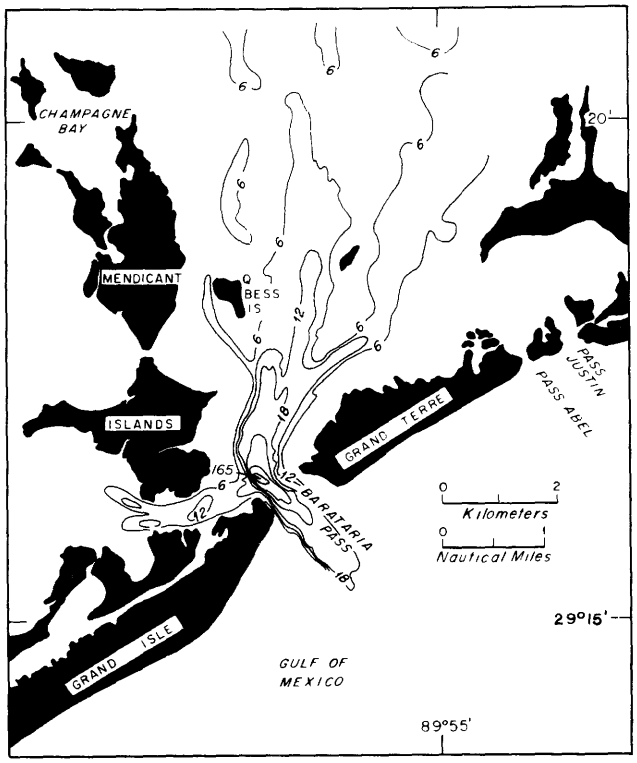


FIGURE 87.—Bathymetry (in feet) of Barataria Bay, La. (from Krumbein and Caldwell, 1939).

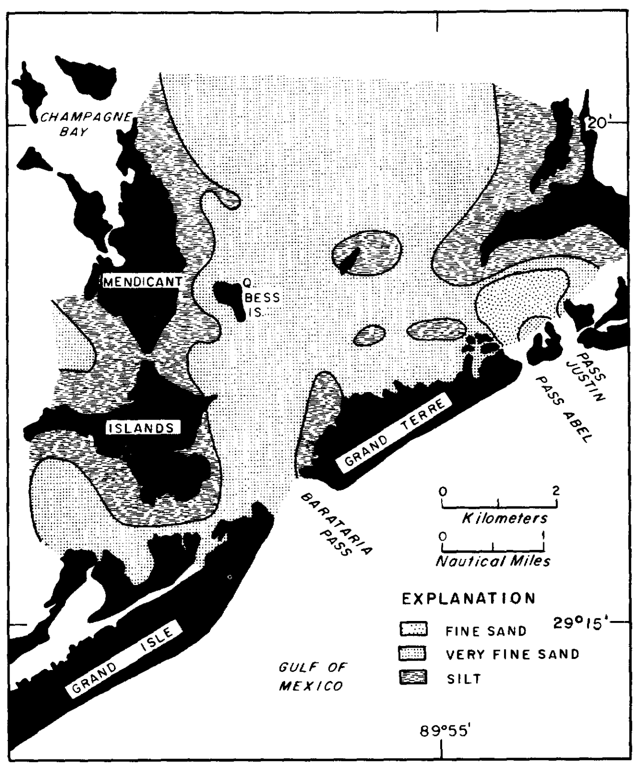


FIGURE 88.—Texture of bottom sediments in Barataria Bay, La. Modified from Krumbein and Aberdeen (1937)

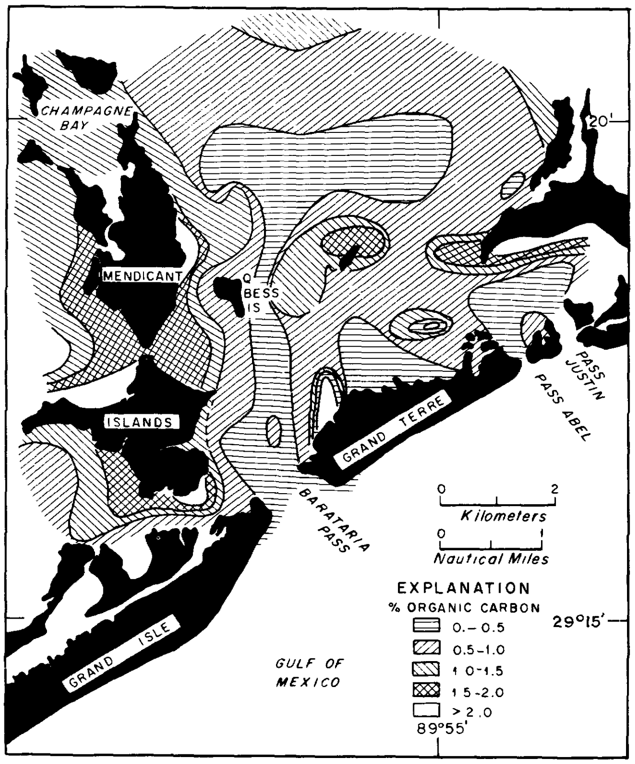


FIGURE 89.—Organic carbon content of bottom sediments in Barataria Bay, La. (from Krumbein and Caldwell, 1939).

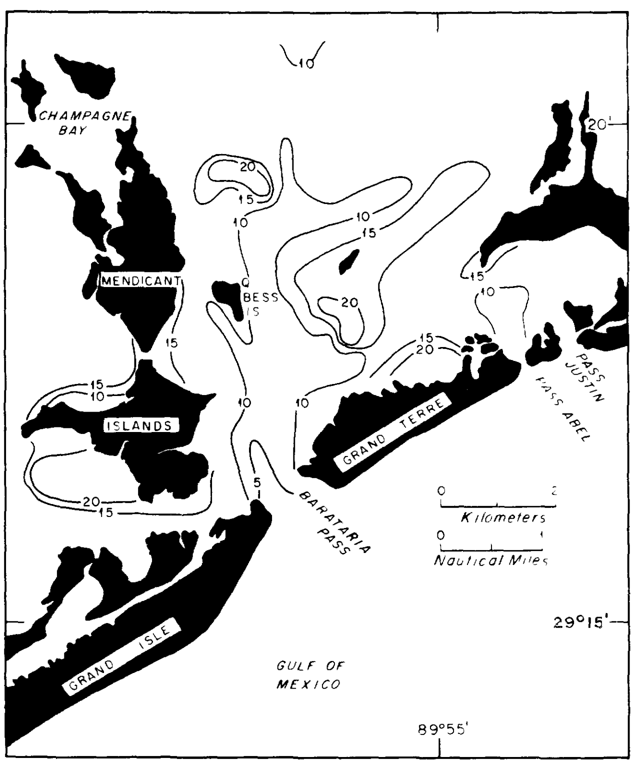


FIGURE 90.—Calcium carbonate content (in percent) of bottom sediments in Barataria Bay, La. (from Caldwell, 1940).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Popoff (1927) method).—Most sediment in the bay contains less than 2.5 percent organic carbon. Highest values occur in silt deposits (fig. 89).

Mineralogy.—Calcium carbonate concentrations generally range from 5 to 20 percent. Rare higher values are confined to areas surrounding small islands and to areas near oyster reefs. Most of the carbonate is concentrated in the finest sediments (fig. 90).

Heavy minerals throughout most of the bay make up 0.8 to 1.6 percent of the sand fraction. A few higher values occur in channels or passes.

REFERENCES

Caldwell (1940), Klovan (1966), Krumbein and Aberdeen (1937), Krumbein and Caldwell (1939), Scruton (1960).

SABINE LAKE, TEXAS AND LOUISIANA

SETTING

Geology.—Sabine Lake is entirely within the Gulf Coastal Plain and is isolated from the Gulf of Mexico by a broad expanse of sand made up mostly of beach ridges (cheniers).

Bathymetry.—The bottom dips gently from the northwest margin of the lake and more steeply on the southeast margin to a maximum depth of approximately 8 feet (2.4 m). Spoil due to dredging has formed a narrow island along the western margin of the lake (fig. 91).

Hydrology.—The Sabine and Neches Rivers account for most of the fresh-water inflow to the lake. At gaging stations, approximately 25 nautical miles (46 km) north of the lake, average flow rate of the two rivers totals 430 m^3/sec.

SEDIMENT TEXTURE

Bottom.—Most sediment on the lake bottom consists of fine sandy or clayey silt and very fine sand; however, near the mouths of the Neches and Sabine Rivers, fine sand is abundant (fig. 92). Sorting is generally poor in the finest material and improves in the sand. The silty muds, which contain abundant plant material, especially in the marshy areas around the eastern margin, are light to dark gray. The sands are mostly light gray.

Subbottom.—Cores as much as 8 feet (2.4 m) long were recovered from the lake bottom; these consisted of a mixture of silt and clay. Gray to greenish-gray Pleistocene clay was penetrated by one core (depth was not given). Plant detritus is abundant below the bottom.

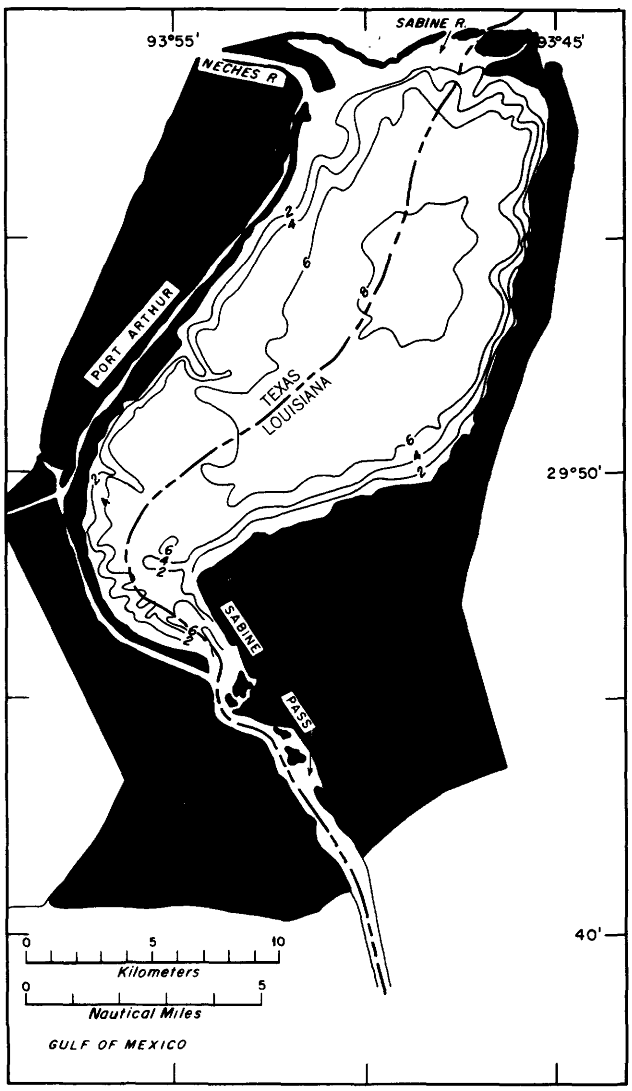


FIGURE 91.—Bathymetry (in feet) of Sabine Lake, Tex. and La. (from Kane, 1966).

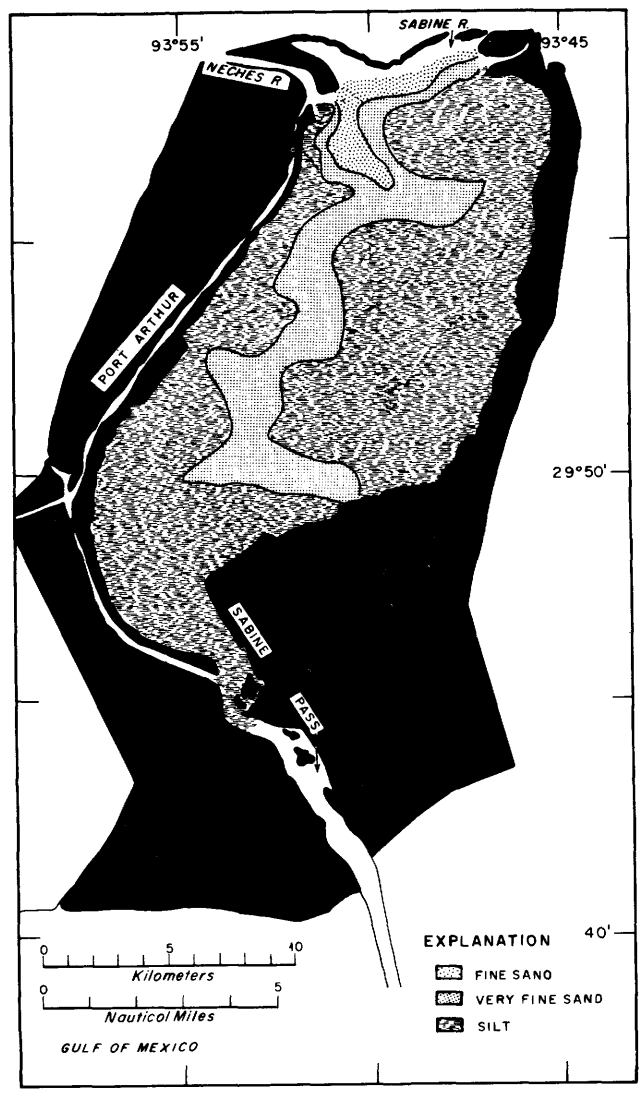


FIGURE 92.—Texture of bottom sediments in Sabine Lake, Tex. and La. (from Kane, 1966).

SEDIMENT COMPOSITION

Mineralogy.—Quartz constitutes approximately 70 percent and potassium feldspar 20 percent of the sand fraction. Plagioclase feldspar and chert make up most of the remainder. Opaque minerals account for 39–56 percent of the heavy-mineral fraction, which makes up about 2–6 percent of the sediments, and zircon, tourmaline, monazite, hornblende, and apatite make up most of the remainder. Carbonates, consisting mostly of oyster and clam shells, make up as much as 20 percent of the total sediment.

REFERENCES

Kane (1963, 1964, 1966).

TRINITY RIVER DELTA AND UPPER TRINITY BAY, TEXAS

SETTING

Geology.—The Trinity River Delta has grown outward from the eastern side of the Trinity River alluvial valley, isolating part of Trinity Bay and forming Lake Anahuac. Upper Pleistocene deltaic sediments deposited by the Trinity and Brazos Rivers form bluffs around the upper bay.

Bathymetry.—The upper bay has a flat floor and gentle slopes dip southwest toward the central area where the maximum depth is approximately 10 feet (3 m) (fig. 93).

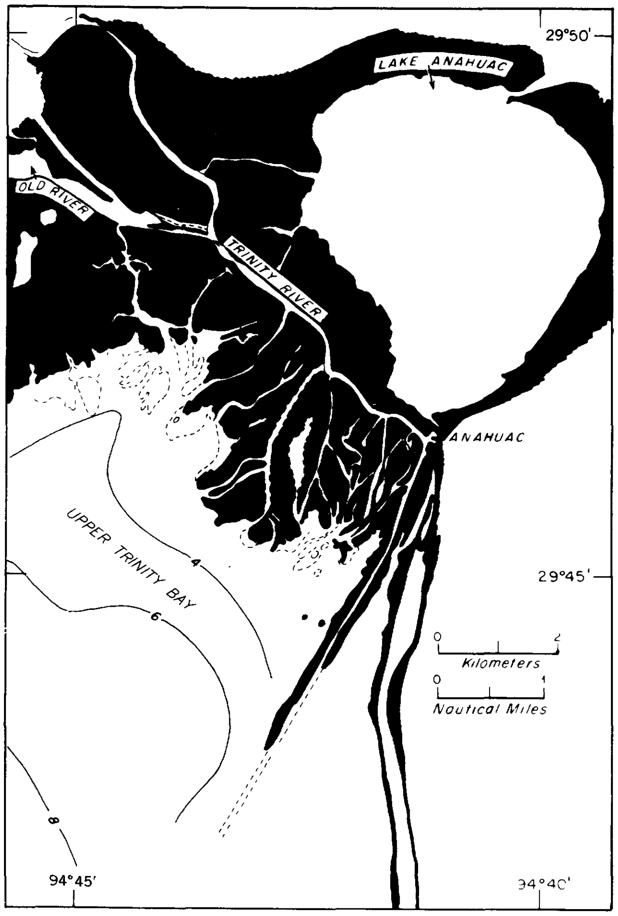


FIGURE 93.—Bathymetry (in feet) of Trinity River Delta and Upper Trinity Bay, Tex. (from McEwen, 1963). Dashed contours enclose areas exposed at mean low water.

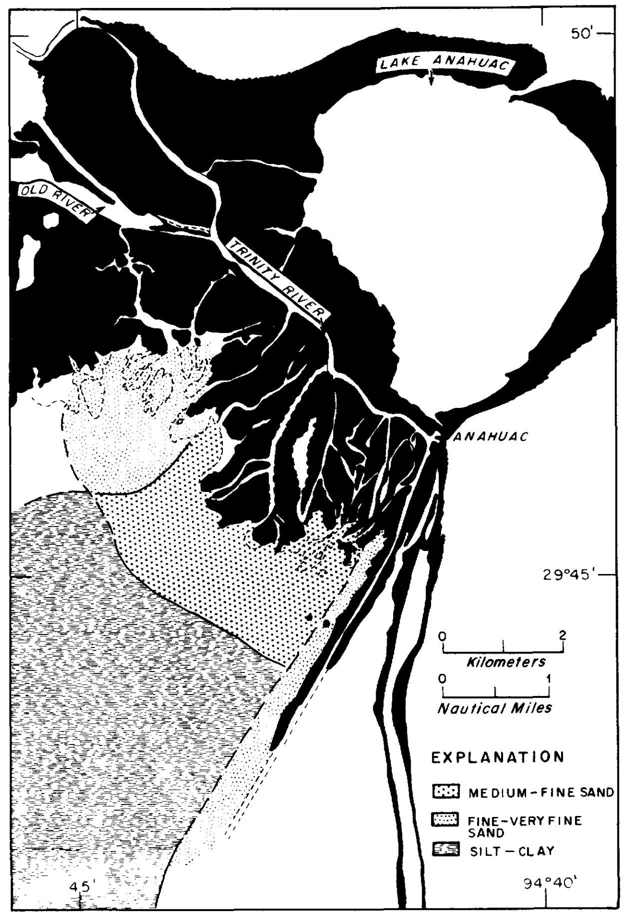


FIGURE 94.—Texture of bottom sediments in Upper Trinity Bay, Tex. Modified from McEwen (1963).

Hydrology.—Fresh-water discharge by the Trinity River averages approximately 240 m^3/sec at a gage about 40 nautical miles (74 km) upstream from the delta. Salinity of the bay is mostly a function of discharge of the Trinity River. Values range from 0 to 15 parts per thousand during periods of normal runoff. Bottom salinities commonly are 2 to 5 parts per thousand greater than those at the surface. Dredging has resulted in salt-water encroachment into the Trinity River above Anahuac. Mean tidal range in the bay is about 1 foot (0.3 m), but water-level fluctuation caused by wind is common, and hurricanes have resulted in tidal ranges of 14 feet (4.2 m). The average silt load of the river is about 0.7 part per thousand (5.5 million tons per year).

SEDIMENT TEXTURE

Bottom.—Silty clay covers most of the bottom in the central-upper part of Trinity Bay except around the margins where sand derived from the Pleistocene bluffs predominates. The submerged delta front consists mostly of fine to medium sand which grades bayward into clay. Channels are filled with sediments ranging from cross-laminated sands to silty clays. On the surface of the subaerial delta, natural levees and marsh deposits consist mostly of sand and silty clays (fig. 94).

Subbottom.—Silty and sandy clays exposed at the surface of the subaerial delta and levees are underlain by delta-front deposits consisting mostly of fine to very fine sands which become finer in texture with increasing depth. Shells are abundant near the base of these sections and decrease upward. Wood is locally abundant. Underlying prodelta sediments consist of Pleistocene fine to medium sand and overlying dark-gray shelly sand, silt, and clay. Some of the sediment under Lake Anahuac is composed of black clay and peat (fig. 95).

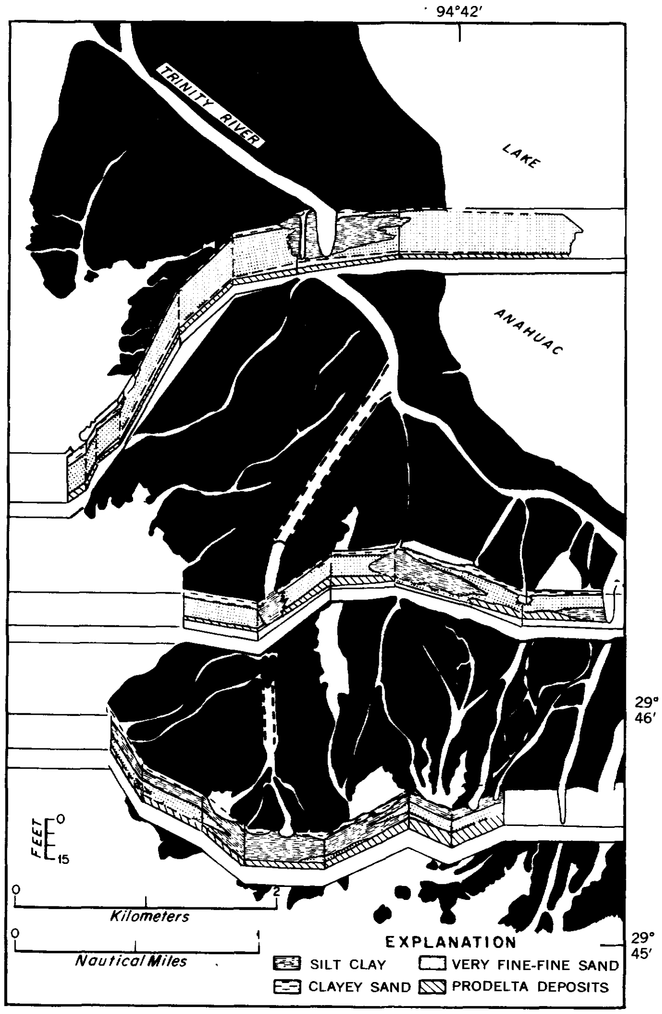


FIGURE 95.—Map and cross sections showing sediment texture of the Trinity River Delta, Tex. Modified from McEwen (1963).

SEDIMENT COMPOSITION

Mineralogy.—Predominant clay minerals in the bay area are kaolinite and montmorillonite, plus lesser amounts of illite. Clay carried by the Trinity River consists mostly of montmorillonite. For example, clay minerals in the sample taken from a Trinity River point bar consisted of 61 percent montmorillonite, 23 percent kaolinite, and 16 percent illite. Some Pleistocene deposits that contribute detritus to the margins of the bay consist of 39 percent montmorillonite, 48 percent kaolinite, and 13 percent illite.

Bay sediments contain as much as 25 percent calcium carbonate, mostly as shell debris.

REFERENCE

McEwen (1963).

BRAZOS RIVER DELTA, TEXAS

SETTING

Geology.—The Brazos drainage basin cuts rocks ranging in age from Paleozoic to Holocene. The delta lies on Quaternary deltaic sands and clays of the Gulf Coastal Plain. After the river was diverted in 1929 to its present channel, it built a delta which by 1952 extended nearly 2 nautical miles (3.6 km) into the gulf from the former shoreline. By 1964 the delta had been cut back and spread westward apparently by storms and prevailing longshore currents (figs. 96, 97).

Hydrology.—At Richmond, 100 miles (185 km) upstream from its mouth, the average flow rate of the Brazos is approximately 200 m^3/sec. During the flood of 1930, the maximum flow rate measured at the mouth was about 2,000 m^3/sec. The river carries a suspended load averaging 4.5 parts per thousand which is the highest of any Texas river flowing into the gulf. The bedload consists of medium to fine sand 35–40 miles (65–74 km) upstream from the gulf and grades into silt near the river mouth.

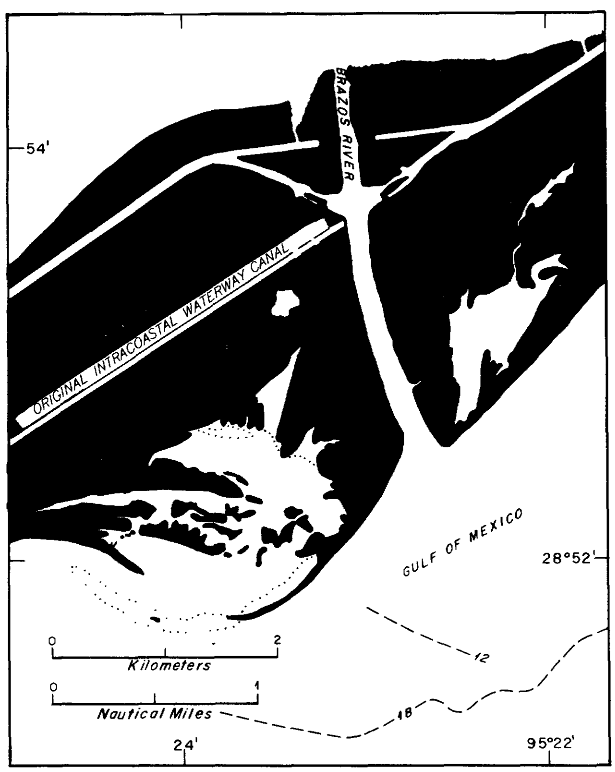


FIGURE 96.—Brazos River Delta, Tex., in 1964. Based on U.S.C. & G.S. Chart 887. Dotted line shows limit of marsh at mean low water. Dashed line shows approximate isobath, in feet.

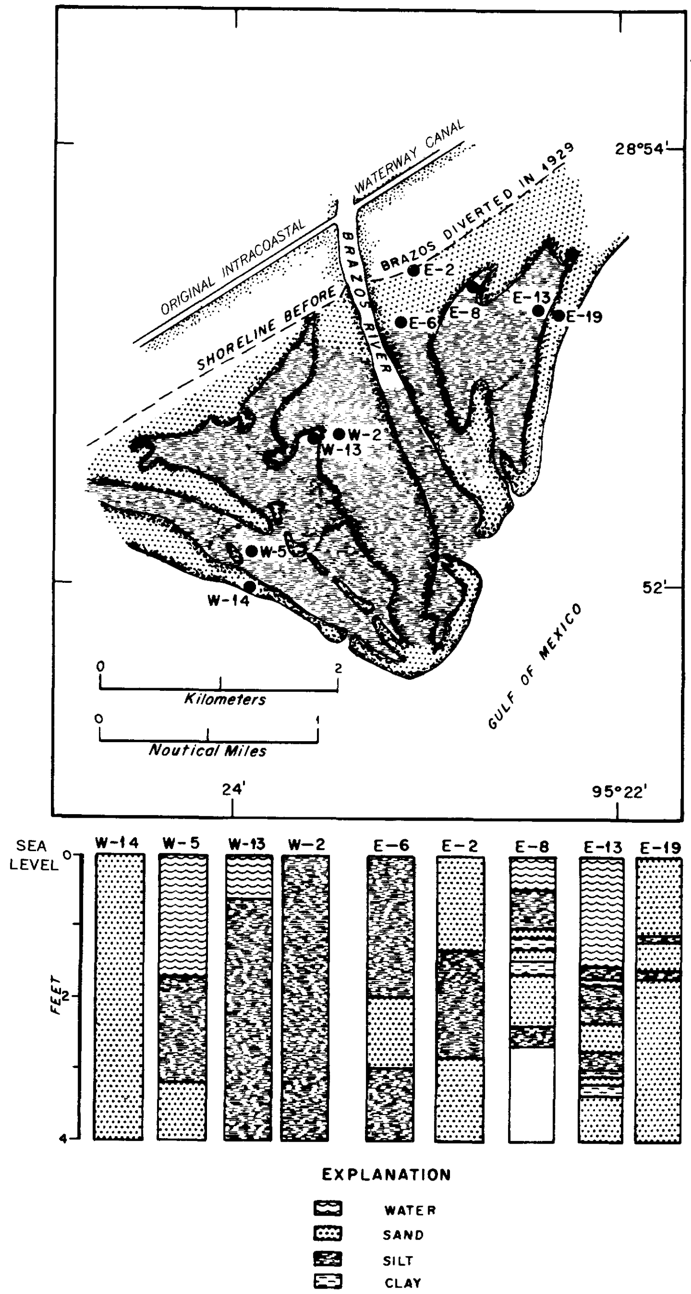


FIGURE 97.—Texture of delta, bottom, and subbottom sediments of the Brazos River Delta, Tex., in 1952. Modified from Odem (1953). •E–2, indicates location and number of core.

SEDIMENT TEXTURE

Bottom.—The distribution of various sediment sizes observed in 1952 is doubtless significantly different from that present today, for the delta has since changed both in size and shape (figs. 96 ,97). The sediment distribution shown in figure 96 has been inferred from only a few samples. Fine sand is most abundant along the original shoreline and along the beaches at the seaward margin of the delta and on the bottom of most inlets. Silt covers most of the lagoon bottoms and the surfaces of the normally exposed marshy areas between the river channel and the lagoons (fig. 96).

Subbottom.—Data from sediment cores 2–4 feet (0.6–1.2 m) long are shown for each major physiographic province of the delta (fig. 96). Interlayered silt and sand reflect changes in the position of the delta margin and channels with time.

SEDIMENT COMPOSITION

Mineralogy.—Heavy minerals on the beaches include ilmenite, magnetite, zircon, garnet, and tourmaline and lesser amounts of epidote, staurolite, monazite, rutile, green hornblende, and spinel. The light fraction consists mostly of quartz and muscovite.

REFERENCE

Odem (1953).

MATAGORDA BAY, TEXAS

SETTING

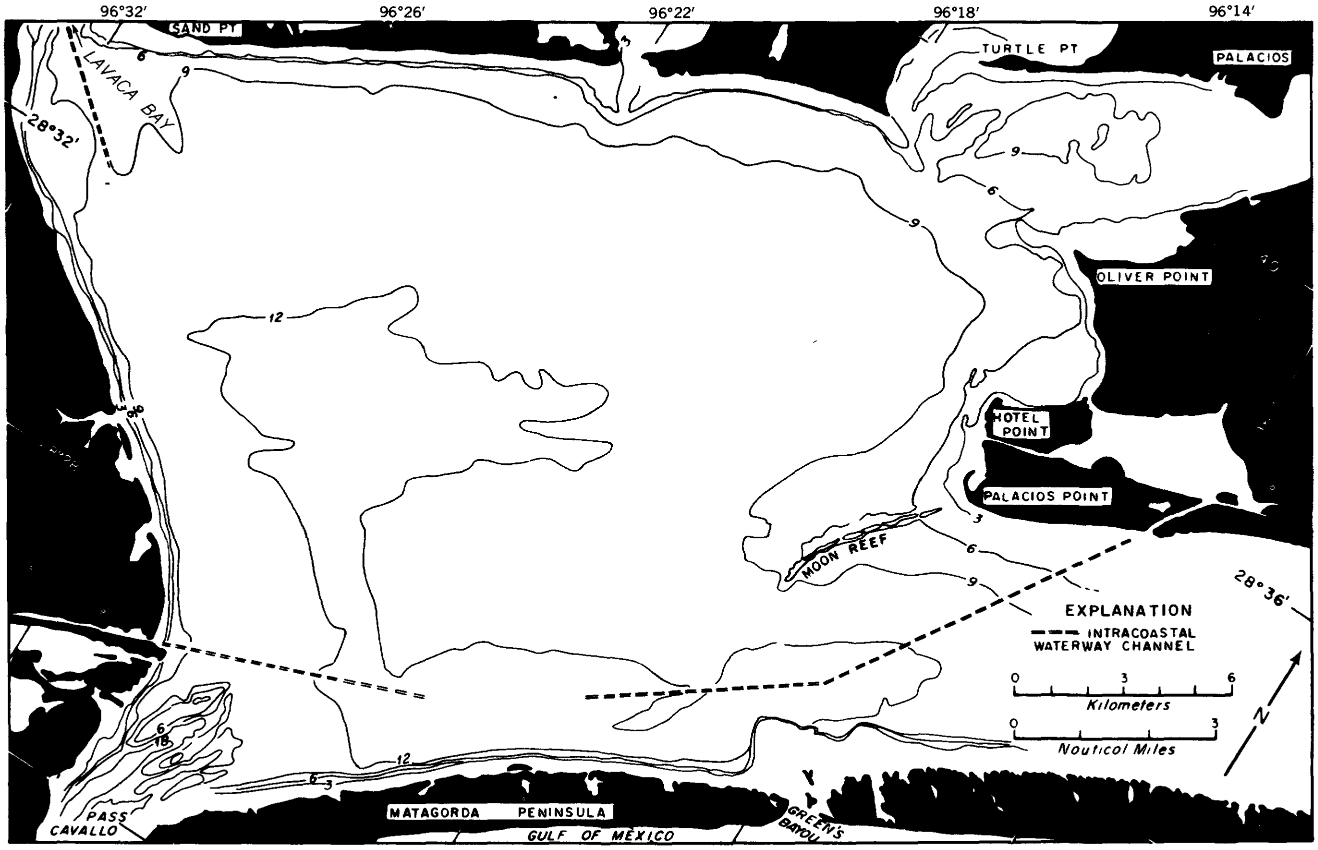
Geology.—Flat-lying Quaternary sand and clay deposits crop out, commonly in bluffs 5 to 8 feet (1.5–2.4 m) high, around the landward margin of Matagorda Bay. A postglacial barrier spit and island, the Matagorda Peninsula, separates the bay from the Gulf of Mexico. Holocene sediments at least as thick as 80 feet (24 m) overlie a channeled Pleistocene surface in the bay.

Bathymetry.—The rather smooth bottom of the bay averages approximately 11 to 12 feet (3.3–3.6 m) in depth and reaches a maximum depth of about 15 feet (4.5 m). The main inlet into the bay from the gulf, Pass Cavallo, is 42 feet (12.6 m) deep. The only other inlet, Green's Bayou, is less than 6 feet (1.8 m) deep. Shell reefs are common and extend bayward from several promontories (fig. 98).

Hydrology.—Most fresh-water inflow comes from the Lavaca River which enters Matagorda Bay at its western end via Lavaca Bay. The river's average flow rate is approximately 20 m^3/sec; its maximum is about 70 m^3/sec, and its minimum is about 1 m^3/sec. Flow from the many small streams draining into the bay has been estimated at 18 m^3/sec. During summer and fall, evaporation generally exceeds runoff and precipitation; this results in salinities of approximately 36 to

FIGURE 98 (right, top).—Bathymetry (in feet) of Matagorda Bay, Tex. (from Fagg, 1957).

FIGURE 99 (right, bottom).—Texture of bottom sediments in Matagorda Bay, Tex. (from Shenton, 1957).


96°32′
96°26′
96°22′
96°18′
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SAND PT
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PALACIOS
LAVACA BAY
28°32′
OLIVER POINT
HOTEL POINT
PALACIOS POINT
MOON REEF
28°36′
EXPLANATION
INTRACOASTAL WATERWAY CHANNEL
Kilometers
Nautical Miles
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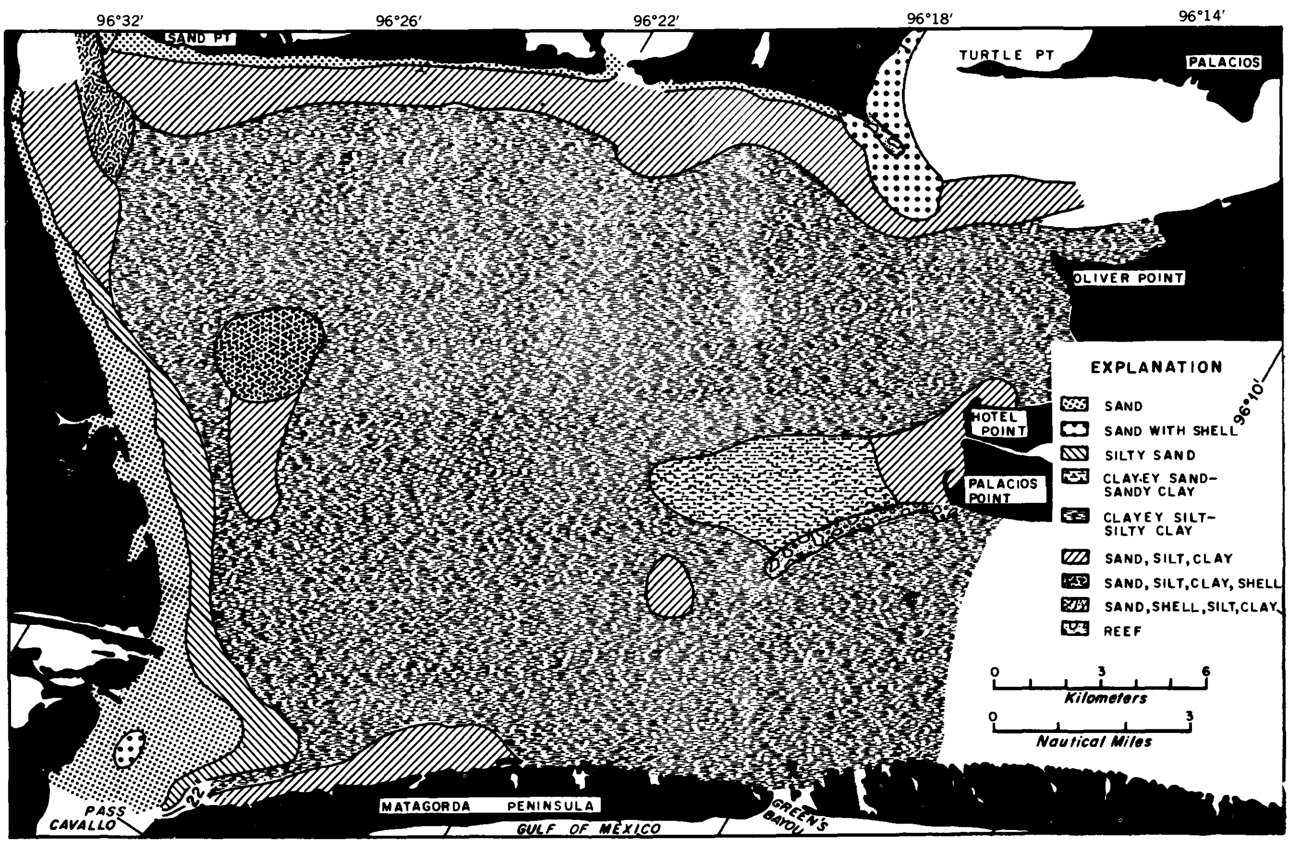
PASS CAVALLO
MATAGORDA PENINSULA
GULF OF MEXICO
GREEN'S BAYOU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TURTLE PT
PALACIOS
OLIVER POINT
HOTEL POINT
PALACIOS POINT
96°10′
EXPLANATION
SAND
SAND WITH SHELL
SILTY SAND
CLAYEY SAND-SANDY CLAY
CLAYEY SILT-SILTY CLAY
SAND, SILT, CLAY
SAND, SILT, CLAY, SHELL
SAND, SHELL, SILT, CLAY
REEF
Kilometers
Nautical Miles
PASS CAVALLO
MATAGORDA PENINSULA
GULF OF MEXICO
GREEN'S BAYOU

37 parts per thousand in the bay. During winter and spring, however, values are generally less than 30 parts per thousand. The tidal range is less than 2 feet (0.6 m), but storms may cause extreme changes in water level. At maximum flood tide, current velocities of 2 knots (100 cm/sec) through Pass Cavallo have been observed. Within the bay, however, current velocities due to tides are very small.

SEDIMENT TEXTURE

Bottom.—In water depths exceeding 9 feet (2.7 m) most of the bottom is covered by silt and clay. Sand, which is present around the southwestern and northwestern shores, grades bayward into a mixture of sand, silt, and clay. Sand also is abundant in Pass Cavallo. Shell debris, which occurs in patches, is most abundant near promontories. The sand is usually well sorted except where shells and shell debris are abundant; but finer sediments, silt and clay, are poorly to very poorly sorted. Reefs are associated with a mixture of sediment types (fig. 99).

Subbottom.—Cores have been recovered along a traverse bisecting the long axis of the bay. The texture of the Holocene subbottom varies slightly with depth from silty clay to sandy, clayey silt (Fagg, 1957, figs. 3–8).

SEDIMENT COMPOSITION

Mineralogy.—Quartz predominates in the coarse fraction of the sediments, but mica, magnetite, glauconite, and pyrite are also common. Carbonates composed mostly of foraminifer tests and mollusk shells and shell fragments are locally abundant.

REFERENCES

Fagg (1957), Shenton (1957), Weiser and Armstrong (undated).

SAN ANTONIO BAY, TEXAS

SETTING

Geology.—San Antonio Bay is flanked on the northwest and west by a Pleistocene barrier island and to the north by Quaternary delta and flood-plain alluvium. Matagorda Island, a postglacial barrier island, separates the bay from the Gulf of Mexico.

Bathymetry.—The delta of the Guadalupe River divides the head of the bay (fig. 100) into two parts which are mostly less than 4 feet (1.2 m) deep. Water depth increases southward to approximately 6 feet (1.8 m), except where oyster beds form shoals. Mesquite Bay, to the west, is mostly less than 5 feet (1.5 m) deep.

Hydrology.—Fresh-water inflow is derived mostly from the Guadalupe-San Antonio River system which

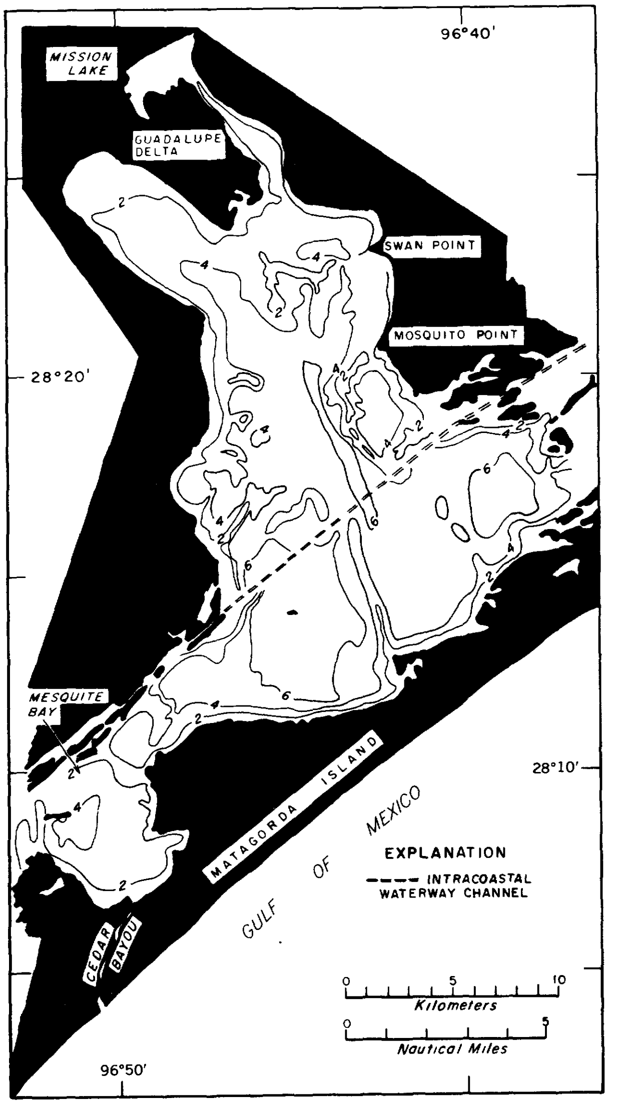

FIGURE 100.—Bathymetry (in feet) of San Antonio Bay, Tex. (from Shepard and Moore, 1955).

enters the bay through Mission Lake. The average rate of flow in this system, measured approximately 30 nautical miles (55 km) north of the bayhead, is about 60 m^3/sec. During spring floods, salinities in waters throughout most of the bay may be only a few parts per thousand. During dry periods in late summer, values may range from 14 parts per thousand at the bay head to 40 parts per thousand in the shallow restricted waters of Mesquite Bay. The tidal range is only about 1 to 2 feet (0.3–0.6 m) and winds are responsible for most fluctuations of water level. Currents are generally less than 1 knot (50 cm/sec).

SEDIMENT TEXTURE

Bottom.—Silty clay covers most of the bottom of the central bay. A north-south trending oyster reef di-

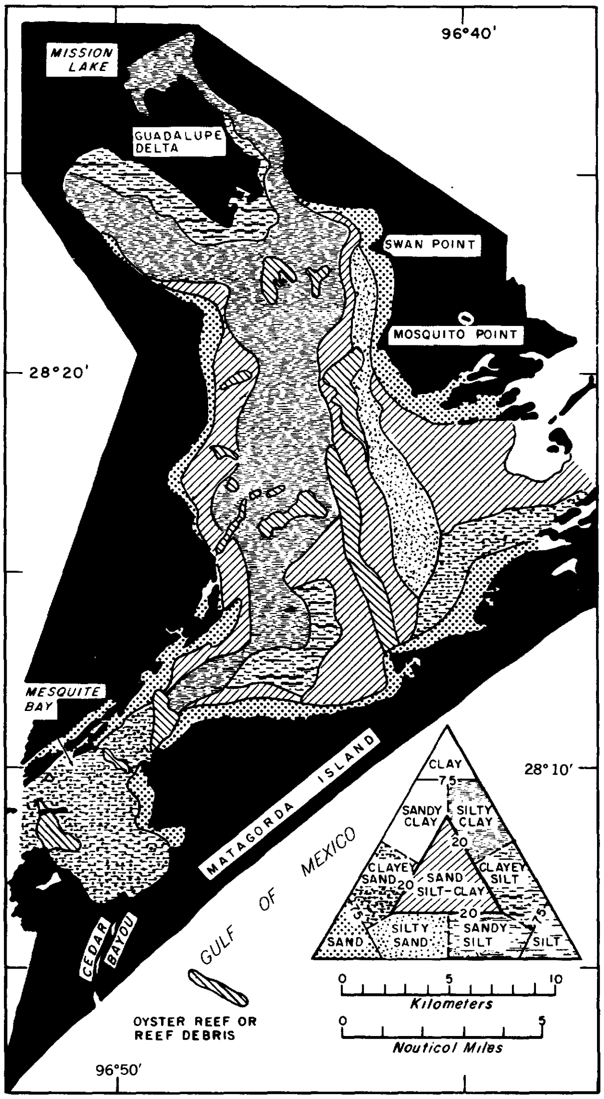

FIGURE 101.—Texture of bottom sediments in San Antonio Bay, Tex. (from Shepard and Moore, 1955).

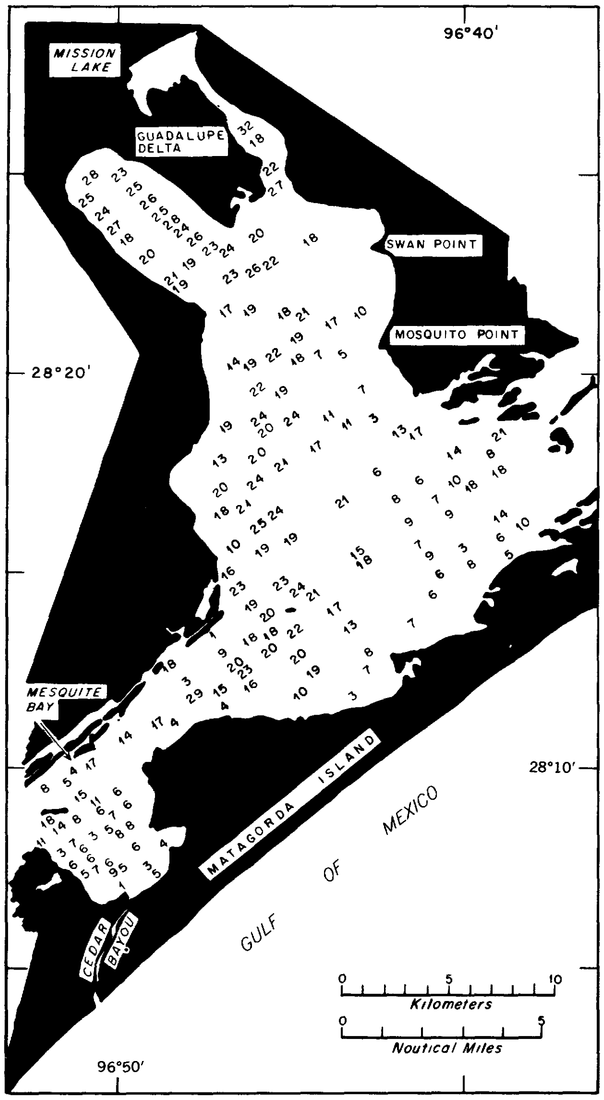

FIGURE 102.—Calcium carbonate content (in percent) of bottom sediments in San Antonio Bay, Tex. (from Shepard and Moore, 1955).

vides the lower bay into two areas of different texture. West of the reef, silty clay is most abundant; east of it, silty sand and a mixture of sand-silt-clay predominate. Sand, silty sand, and clayey sand are most common along the margins of the lower bay (fig. 101).

Subbottom.—Sediments recovered from holes drilled along the axis of the bay consist mostly of silty clay and oyster shells. Only near the barrier island is sand abundant in the upper 20 feet (6 m) of the section (Shepard and Moore, 1960, fig. 18).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Krogh and Keys (1934) technique).—Concentrations of organic carbon are 2–3 precent in the silts and clays of the upper bay and are less than 1 percent in sands of the lower bay.

Mineralogy.—The coarse fraction of the sediments consists mostly of quartz, plagioclase feldspar, and potassium feldspar. Heavy minerals make up less than 1 percent of the sediment and include such stable minerals as tourmaline, garnet, zircon, and rutile. Most staurolite occurs in sediments near the Guadalupe delta; hornblende is most concentrated near Matagorda Island.

In the fine fraction, montmorillonite, chlorite, and illite are equally abundant in the lower bay. In the upper bay, however, montmorillonite predominates. Calcium carbonate ranges from almost 40 percent in oyster reefs to about 5 percent around sandy margins (fig. 102).

REFERENCES

Shepard and Moore (1955, 1960).

ARANSAS BAY, TEXAS

SETTING

Geology.—Aransas Bay is flanked to the northwest by a Pleistocene barrier island and is isolated on the southeast from the Gulf of Mexico by a postglacial barrier island consisting of dunes and washover fans as much as 50 feet (15 m) thick.

Bathymetry.—Depths increase rapidly from the bay margin toward the rather flat floor of the bay (fig. 103). A northwest-trending reef divides the bay into two parts. Maximum depth in the southwestern part is approximately 13 feet (4 m); maximum depth in the northeastern part is only about 7 feet (2.1 m).

Hydrology.—Fresh-water inflow directly into the bay is negligible. Most fresh water is derived from adjacent connecting bays and causes a mean salinity in the bay waters of about 12 parts per thousand. The tidal range is only 1 to 2 feet (0.3–0.6 m), but storm winds cause water-level variations of 4 to 5 feet (1.2–1.5 m). At Aransas Pass, current velocities may exceed 1 knot (50 cm/sec) depending on wind direction and velocity.

SEDIMENT TEXTURE

Bottom.—Clayey or silty sand is abundant around the margin of the southwestern part of the bay, but silty clay predominates over most of the bottom. Sand along the southeastern shore is derived mostly from the barrier island. In the northeastern section of the bay, silty sand is most abundant (fig. 104).

Subbottom.—Size analyses of sediment samples taken from one core recovered in the bay indicate that

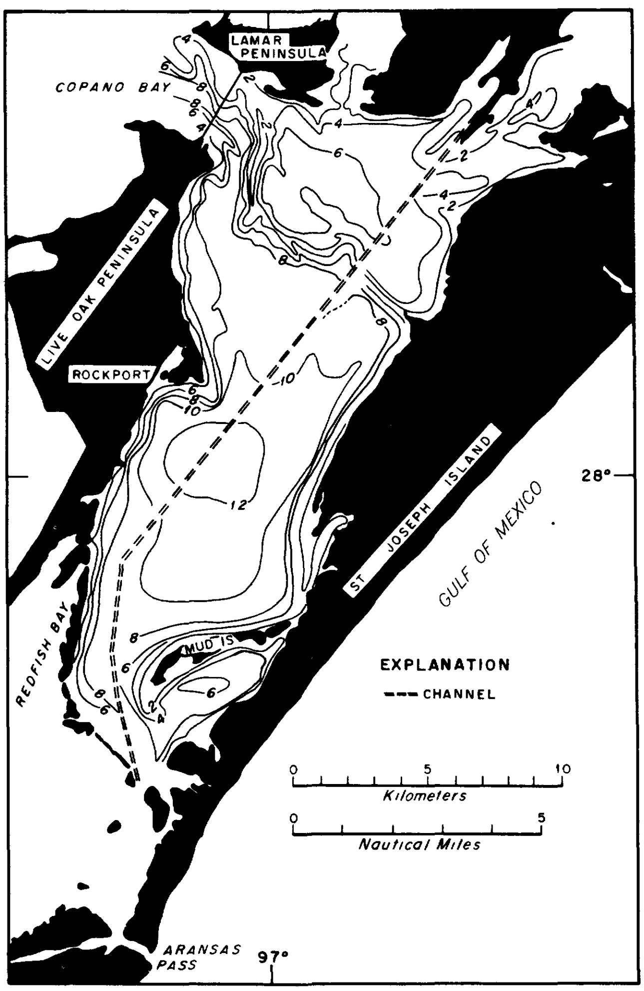

FIGURE 103.—Bathymetry (in feet) of Aransas Bay, Tex. (from Shepard and Moore, 1955).

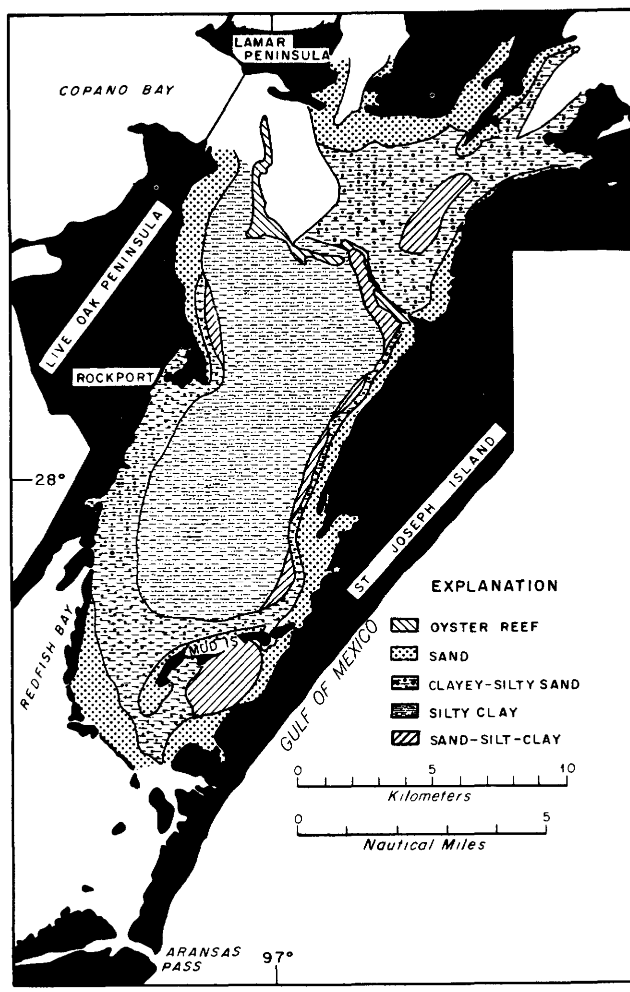

FIGURE 104.—Texture of bottom sediments in Aransas Bay, Tex. Modified from Shepard and Moore (1955).

the coarser fraction increases at approximately 60 cm below the bottom.

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Krogh and Keys (1934) technique).—Concentrations of organic carbon are generally slightly in excess of 1 percent in the fine sediments at the center of the bay and are less than 1 percent elsewhere.

Mineralogy.—In the coarse fraction (>62 microns), light minerals are present in the following proportions: quartz, 65 percent; plagioclase feldspar, 22 percent; and potassium feldspar, 12 percent. Heavy minerals amount to less than 1 percent of the total sediment.

In the fine fraction, montmorillonite, chlorite, and illite are present in roughly equal proportions. Carbonates, which generally make up less than 20 percent of the total sediment, consist mostly of shells of foraminifers and lesser amounts of ostracode, echinoid, and mollusk shells (fig. 105).

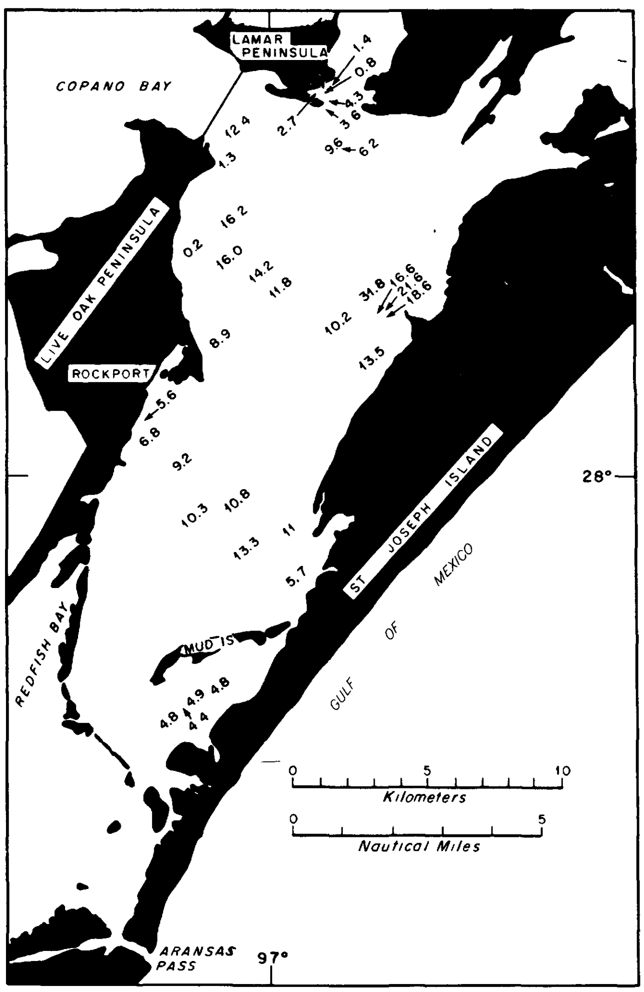

FIGURE 105.—Calcium carbonate content (in percent) of bottom sediments in Aransas Bay, Tex. (from Shepard and Moore, 1955).

REFERENCES

LeBlanc and Hodgson (1961), Shepard and Moore (1955, 1960).

LAGUNA MADRE, TEXAS

SETTING

Geology.—Upper Quaternary sediments on the mainland adjacent to Laguna Madre consist mostly of clayey sands. A barrier island (Padre Island), built during the postglacial rise in sea level, forms the eastern margin. The island has periodically been cut by narrow inlets, and in the lagoon, deltas and washover fans are common. Sand flats (Saltillo flats), built up by landward movement of sediment from the barrier island, divide the bay into northern and southern parts.

Bathymetry.—The bottom of the shallow lagoon slopes evenly from exposed sand flats on the eastern side to a few deep (8 feet or 2.4 m) elongate basins close to the western margin (fig. 106). The Intracoastal Waterway channel is maintained along the western side at an approximate depth of 9 to 12 feet (2.7–3.6 m).

Hydrology.—No major streams drain into the lagoon, and evaporation generally exceeds precipitation and local runoff. In the northern bay, salinities are directly related to abundance of rainfall and generally range from 30 to 80 parts per thousand. Waters in the southern area, which is nearer the Brazos Santiago Pass, have salinities more typical of the open gulf. Celestial tides may vary by 12 to 18 inches (0.3–0.5 m) in spring and fall, but diurnal tides are absent in the lagoon. Extreme winds, however, cause variations in water level of 3 to 4 feet (0.9–1.2 m). Most water circulation is controlled by wind. Velocities at Brazos Santiago Pass are generally less than 1 knot (50 cm/sec). Water is often turbid because strong winds, which blow from the southeast at 9 to 14 miles per hour (14–23 km/hr) during seven months of the year, generate waves that stir up the bottom sediments in the shallow bay.

SEDIMENT TEXTURE

Bottom.—On the eastern side of the lagoon most sediment consists of very fine well-coated quartz sand derived from the barrier island by normal wind-generated wave action and by storm-wave washover. Clayey and silty sand increases in abundance in the narrow deeper areas close to the western shore (fig. 108).

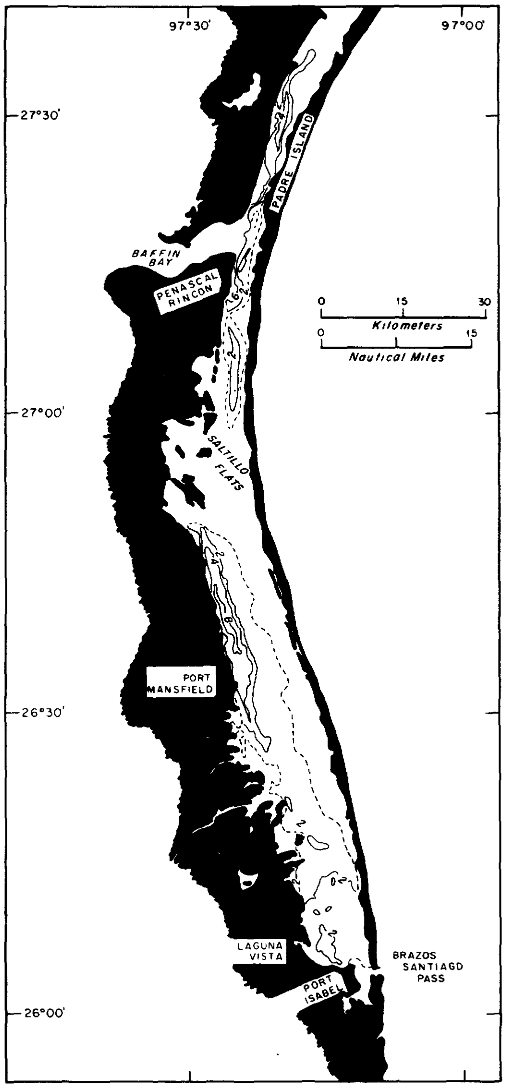

FIGURE 106.—Bathymetry (in feet) of Laguna Madre, Tex. (from Rusnak, 1960). Dashed contour indicates area exposed at mean low tide.

Subbottom.—The general distribution of sediment to a depth of approximately 20 feet (6 m) at mean low water (M.L.W.) along points A, B, and C of figure 108 is shown in figure 107.

SEDIMENT COMPOSITION

Organic matter (data based on dry weight loss after digestion with H_2O_2).—The highest concentrations of organic matter (6 to 7 percent) occur in algal mat deposits which occur in shoal areas; but throughout most of the sandy bay, values are less than 1 percent.

Mineralogy.—Quartz constitutes 90 percent, feldspar less than 10 percent, and chert 1 to 5 percent, of the terrigenous fraction. The northern area contains a

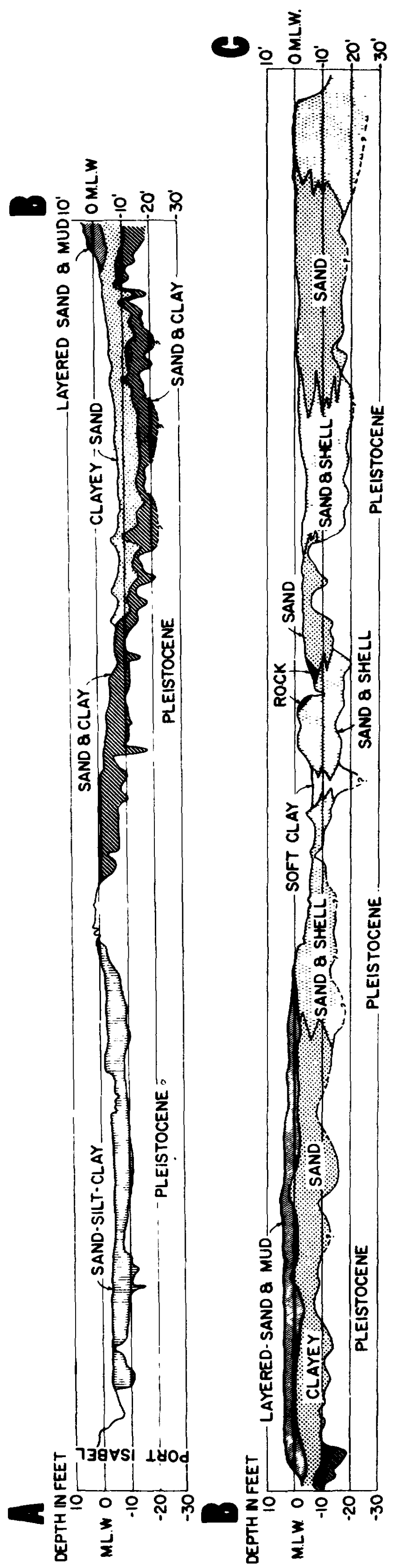

FIGURE 107.—Geologic cross sections of Laguna Madre, Tex., through points A, B, and C shown in figure 108 (from Rusnak, 1960).

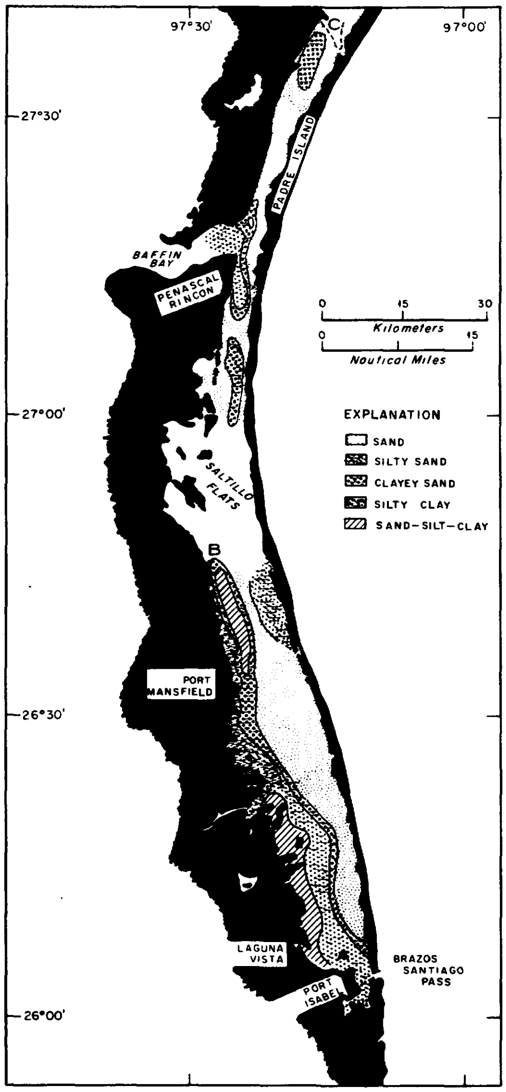

FIGURE 108.—Texture of bottom sediments in Laguna Madre, Tex. Modified from Rusnak (1960). Points A, B, and C lie along the sections shown in figure 107.

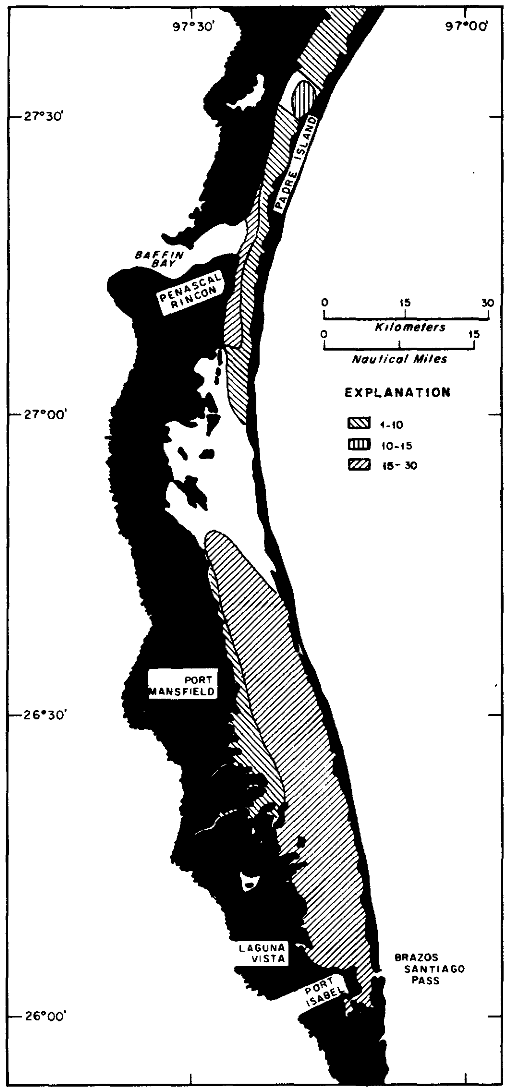

FIGURE 109.—Calcium carbonate content (in percent) of the fine fraction (<62 microns) of bottom sediments in Laguna Madre, Tex. (from Rusnak, 1960).

suite of heavy minerals including tourmaline, zircon, kyanite, and staurolite derived mostly from local outcrops of Pleistocene sediment. South of the barrier flats the heavy-mineral suite consists mainly of green hornblende, pyroxene (augite), epidote, and basaltic hornblende and is apparently derived from erosion and shoreward drift of Pleistocene Rio Grande delta material that is exposed along the shore and occurs near shore on the gulf bottom. The distribution of carbonate in the fine sediment fraction (< 62 microns) is shown in figure 109. Fine-grained well-sorted oolites are most abundant on the wave-exposed shores of the northern lagoon and decline rapidly in abundance with distance from the shoreline.

REFERENCES

Breuer (1957), Rusnak (1960), Simmons (1957).

BAFFIN BAY, TEXAS

SETTING

Geology.—Upper Pleistocene to Holocene dune sand is widespread south of Baffin Bay. The Beaumont clay (Pleistocene), part of the Nueces River deltaic plain, forms bluffs along the northern margin. The bay opens into Laguna Madre which is isolated from the Gulf of Mexico by Padre Island.

Bathymetry.—Numerous shoals border the bay and restrict the water circulation, particularly where the shoals extend bayward from promontories (fig. 110).

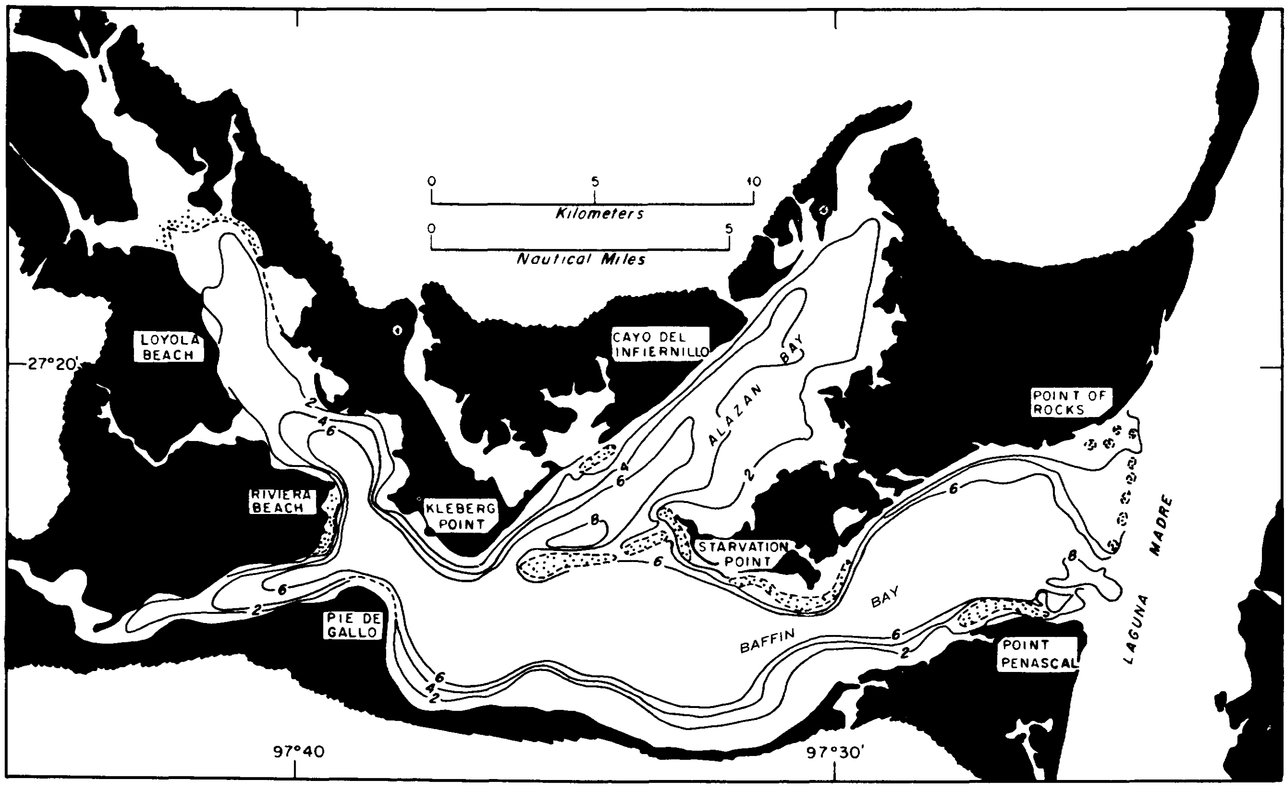

FIGURE 110.—Bathymetry (in feet) of Baffin Bay, Tex. (from Rusnak, 1960). Stippled areas are shoals.

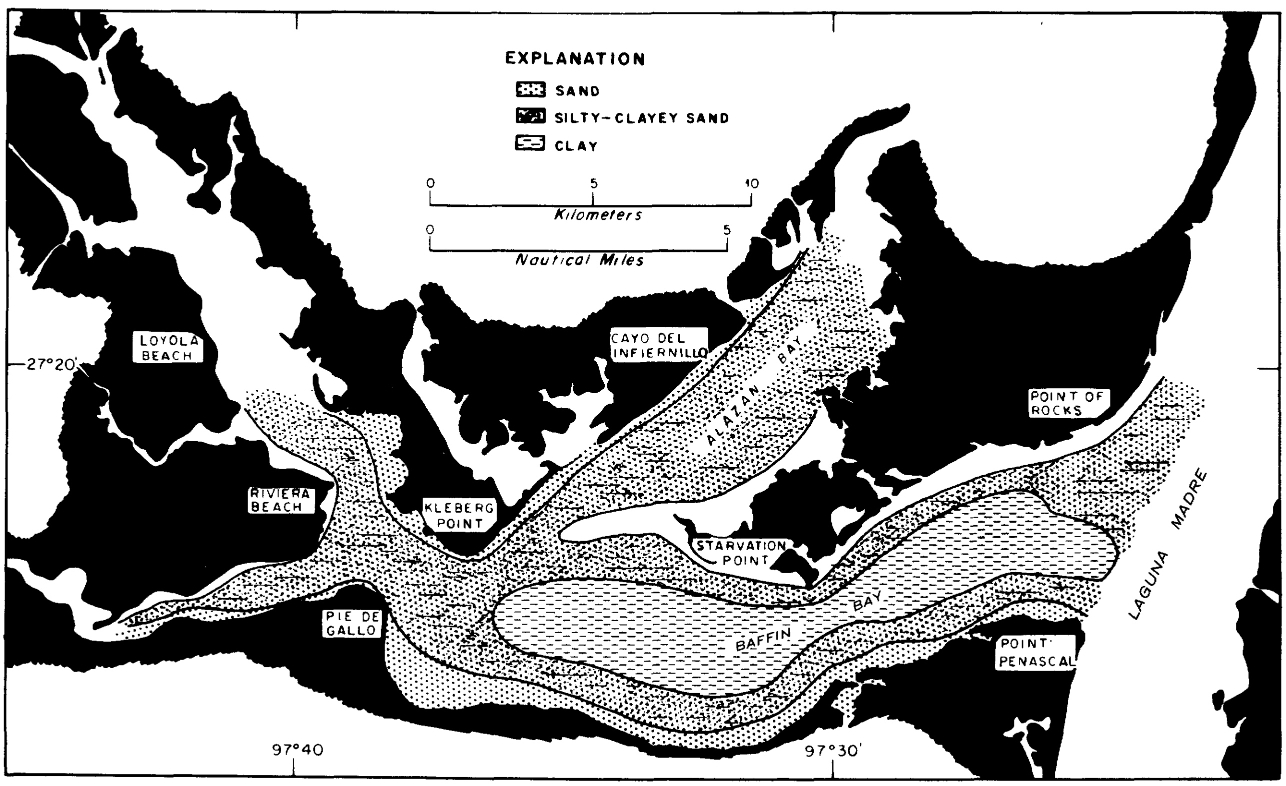

FIGURE 111.—Texture of bottom sediments in Baffin Bay, Tex. Modified from Rusnak (1960).

From the shoals, water deepens rapidly to the basin floor where depths exceed 6 feet (1.8 m).

Hydrology.—Runoff into the bay from a few streams is intermittent and salinity generally varies inversely with rainfall. Salinity from 1951 to 1953 ranged from a low of 1.4 parts per thousand to a high of 75 parts per thousand with a mean of approximately 52 parts per thousand. Lunar tides are negligible and have a range of only 12 to 18 inches (0.3–0.5 m) in spring and fall. Strong winds, however, result in considerable exchange of water between Baffin Bay and Laguna Madre and cause significant changes in water level. Wind-generated waves and currents are sufficiently strong over shoal areas at the entrances to Baffin and Alazan Bays to cause scour.

SEDIMENT TEXTURE

Bottom.—The margins of the bay are covered mostly with fine sand (fig. 111). Most coarser components comprise pelecypod shells and shell fragments. Very fine sand, silt, and clay predominate in the central area of the bay where water depths are in excess of 5 feet (1.5 m).

SEDIMENT COMPOSITION

Organic carbon.—Measurements of organic carbon in the bay average approximately 1.5 percent. An H_2S odor is common in the sediments.

Mineralogy.—Noncarbonates consist mostly of quartz plus minor feldspar and chert. Quartz sands are most widespread in Alazan Bay but are common around the entire bay margin. Based on limited data, the black silty clay accumulating in the deep central part of the bay consists mostly of quartz and illite plus minor amounts of montmorillonite, kaolinite, or chlorite. Carbonates, including shells and shell debris, and oolites which are abundant along wave-washed basins and as coatings on silicate grains constitute a mean of 35 percent of the sediment.

REFERENCES

Breuer (1957), Dalrymple (1964), Rusnak (1960).

SAN FRANCISCO BAY, CALIFORNIA

SETTING

Geology.—The San Francisco Bay complex, which includes Suisun Bay, San Pablo Bay, and central and south San Francisco Bay, lies in a structural valley between the Santa Cruz Mountains on the west and the Diablo Mountains on the east. The faulted synclinal depression which probably began to form in late Pliocene time is surrounded by rocks ranging in age from Late Jurassic to Holocene. Sediments adjacent to the bay and those overlying bedrock (Franciscan Formation of Late Jurassic to Late Cretaceous age) in the bay consist mostly of Pleistocene sand, silt, and clay as much as 300 feet (90 m) thick. Estimates of the sedimentation rate of unconsolidated bay sediments are between 1 and 7 feet (0.3–2.3 m) per thousand years.

Bathymetry.—Approximately 70 percent of the bottom of the bay complex is less than 18 feet (5.4 m) deep and 80 percent is less than 30 feet (9 m) deep. Tidal flats surround most of the bay complex (fig. 112). Maximum depths in channels in the middle of the northern part of San Francisco Bay are about 80 feet (24 m). South of Dumbarton Bridge maximum depths are approximately 50 feet (15 m), but at mean lower low water average depths are less than 6 feet (2 m). At the Golden Gate Bridge the water depth is about 380 feet (114 m).

Hydrology.—The San Joaquin and Sacramento Rivers carry over 70 percent of the average freshwater inflow (800 m^3/sec) to the bay. Runoff is greatest during the winter and spring. The Sacramento River transports most (70 percent) of the suspended sediment entering the bay; the San Joaquin accounts for 13 percent, and smaller rivers and creeks account for the remainder. The mean tidal range varies from about 4 feet (1.2 m) at Antioch to 8.5 feet (2.6 m) at Calaveras Point. The average salinity of the whole bay complex is about 27 parts per thousand. Values in Suisun Bay range from zero at the east end to 27 parts

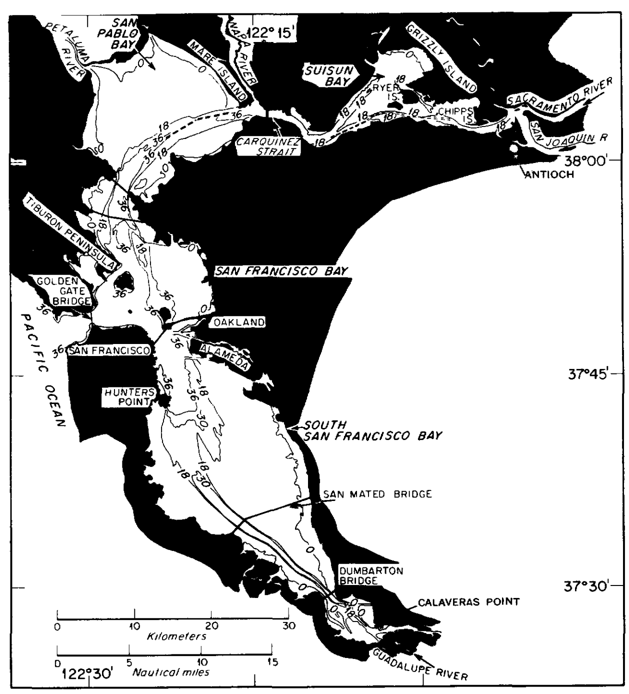

FIGURE 112.—Bathymetry of the San Francisco Bay system, California (from U.S.C. & G.S. Charts 5531–5534).

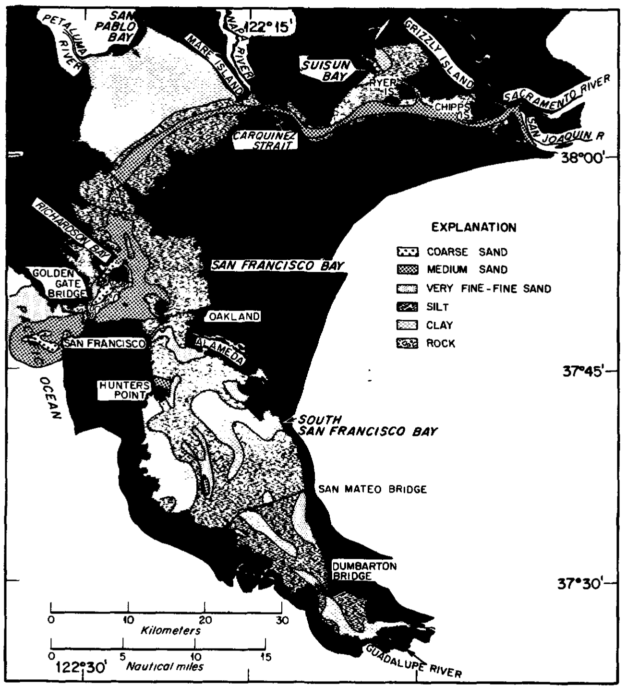

FIGURE 113.—Texture of bottom sediments in the San Francisco Bay system, California. Data in Suisun Bay are generalized from Reese (1965) and Slater (1965); in San Pablo Bay, from Trask (1953) and Storrs and others (1963); in Richardson Bay, from Means (1965); in central San Francisco Bay, from Trask (1953) and Gram (1966); in south San Francisco Bay, from Conomos (1963); and west of the Golden Gate Bridge, from Schatz (1963).

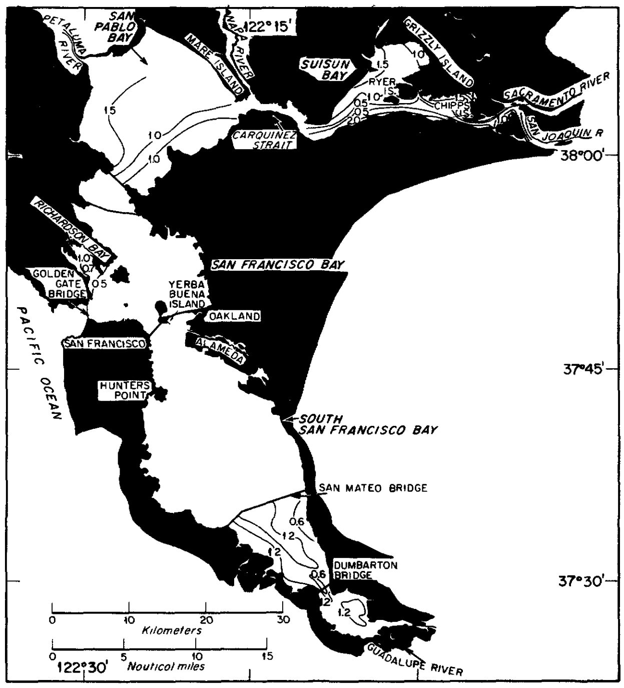

FIGURE 114.—Organic carbon content (in percent) of bottom sediments in the San Francisco Bay system, California. Data in Suisun Bay generalized from Reese (1965) and Slater (1965); in Richardson Bay, from Means (1965); and in south San Francisco Bay, from Conomos (1963).

per thousand at the west end. Average salinity at Dumbarton Bridge is 28 parts per thousand. Maximum currents at ebb and flood tide in central San Francisco Bay are about 2 knots (100 cm/sec). Ebb currents in Carquinez Strait are significantly stronger and reach 4 knots (200 cm/sec).

SEDIMENT TEXTURE

Bottom.—Sediment carried into the bay (mostly by the Sacramento River) is composed of approximately 60 percent clay, 30 percent silt, and 10 percent fine sand. Sediment texture on the bottom of San Pablo Bay varies with seasonal changes in suspended load. Silt and clay, for example, cover the bottom in winter and spring as a result of high runoff. In summer much of the fine material is stirred into suspension by wind-generated waves and transported to shallow protected areas where wave and current energy is not sufficient to keep the material in suspension.

Detailed maps of bottom sediment texture are available for Suisun Bay, Richardson Bay, and south San Francisco Bay. For central San Francisco and San Pablo Bays, sediment texture has been inferred from descriptive data compiled by Trask (1953) and from analyses of samples collected repeatedly at only a few locations (Storrs and others, 1963).

In the northern parts of the bay complex, fine to medium sand generally covers channel bottoms; silt and clay is widespread in the shallow areas and tidal flats. Bedrock surrounded by gravel and coarse sand is exposed over a considerable area of the bottom in central San Francisco Bay. Throughout south San Francisco Bay, silt and clay predominate (fig. 113).

SEDIMENT COMPOSITION

Organic carbon.—Analyses were carried out by the Carbon Determinator No. 30003 (commercial unit manufactured by the H. W. Diedrich Company) and by the Allisson (1935) technique.

Measurements of organic carbon in Suisun, San Pablo, Richardson, and south San Francisco Bays are shown in figure 114. Most values are less than 2 percent organic carbon in silts and clays and less than 1 percent in sands. At a few localities in Suisun Bay, concentrations in peat are as high as 17 percent (not shown). Although industrial contaminants are abundant throughout the bay they do not seem to be reflected by the available measurements of organic carbon in the sediments. Concentrations in south San Francisco Bay and San Pablo Bay vary little with season. Some measurements taken in Suisun Bay, however, range from 3.4 percent in September to 1.2 percent in March.

Mineralogy.—In Suisun Bay, light minerals that make up as much as 90 percent of the sand fraction consist of 51 percent quartz, 31 percent plagioclase feldspar, 5 percent potassium feldspar, and 13 percent rock fragments. Heavy minerals make up 0 to 19 percent of the sand fraction (highest values occur in main channels, lowest values near shore) and consist mainly of biotite, magnetite, hornblende, and garnet. The average clay-mineral composition in Suisun Bay sediment according to Slater (1965) is 47 percent montmorillonite, 35 percent chlorite, and 18 percent vermiculite; according to Reese (1965), however, the clay minerals consist of 34 percent kaolinite, 39 percent illite, 14 percent montmorillonite, and 13 percent vermiculite.

In central San Francisco Bay, pebbles and cobbles are composed mostly of chert, serpentine, and graywacke. In the sand fraction, quartz and plagioclase predominate over potassium feldspar which generally constitutes less than 10 percent of the assemblage. Heavy minerals (13 percent of the sand fraction) consist mostly of serpentine, glauconitic material, chlorite, and various amphiboles and pyroxenes. Montmorillonite and kaolinite are the most abundant clay minerals.

In south San Francisco Bay, quartz, feldspar, and rock fragments are present in a ratio of 2:1:1 and quartz, plagioclase feldspar, and potassium feldspar are present in a ratio of 6.5:2.5:1. Heavy minerals, which roughly range in concentration from 3 to 30 percent, consist mostly of magnetite, ilmenite, serpentine, and tremolite-actinolite. Clay minerals are present as montmorillonite-chlorite-illite in the ratio of 3:1:1.

Carbonates are sparse throughout most of the bay and seldom exceed 4 percent of the total sediment except in a few areas where shell banks are present.

REFERENCES

Conomos (1963), Goldman (1967), Gram (1966), Harris, Feuerstein, and Pearson (1961), Krone (1966), McCarty and others (1962), Means (1965), Mitchell (1963), Porterfield, Hawley, and Dunnam (1961), Reese (1965), Schatz (1963), Slater, (1965), Smith (1965), Storrs, Selleck, and Pearson (1963), Trask (1953), Treasher (1963).

YAQUINA BAY, OREGON

SETTING

Geology.—Yaquina Bay is located on the western flank of the central Oregon Coast Range. The drainage system is superimposed on a Tertiary volcanic complex of lava flows, tuffs, and breccias. Along the southern margin of the bay close to the shoreline, migrating dunes cover parts of Pleistocene marine terraces.

Bathymetry.—The central channel of the bay from the mouth to Oneatta Point is 20 to 30 feet (6–9 m) deep. It is flanked on both sides by shallow broad tidal flats. The bottom topography has been altered significantly by the construction of jetties at the bay mouth and by dredging (fig. 115).

Hydrology.—Average rate of fresh-water inflow from the Yaquina River was measured in February 1965 at 17 m^3/sec and in August 1965 at 1 m^3/sec. Normal marine salinities at the mouth grade into fresh water at the head of the estuary. The water is partly mixed in winter and spring and well mixed in summer and fall. Mixed semidiurnal tides have an average range of 5.5 feet (1.7 m). Maximum tidal current velocities near the entrance are in excess of 2 knots (100 cm/sec). Maximum ebb current velocities slightly exceed those of maximum flood currents.

SEDIMENT TEXTURE

Bottom.—From the mouth of the estuary to Oneatta Point, sediments in the channel are composed of fine to medium sand. Sandy silt covers the bottom in King Slough and on tidal flats at Sally's Bend. Between Coquille Point and Oneatta Point medium to fine sand in the central channel grades into poorly sorted silty sand and sandy silt at the margins (fig. 116).

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Curl (1962) technique).—Highest concentrations of organic carbon (as much as 2.7 percent) occur in sediments that accumulate in sloughs or on tidal flats in quiet shallow water. The two values that were measured in well-sorted channel sediments are less than 0.2 percent (fig. 117).

Mineralogy.—The distribution of minerals in the bay sediments is due to two main sediment-source areas. For approximately 1.5 nautical miles (2.8 km) up the estuary from the mouth, migrating dunes derived from Pleistocene terrace sands, nearby beach deposits, and near-shore marine deposits contribute sediment to the estuary. This source material is of sub-

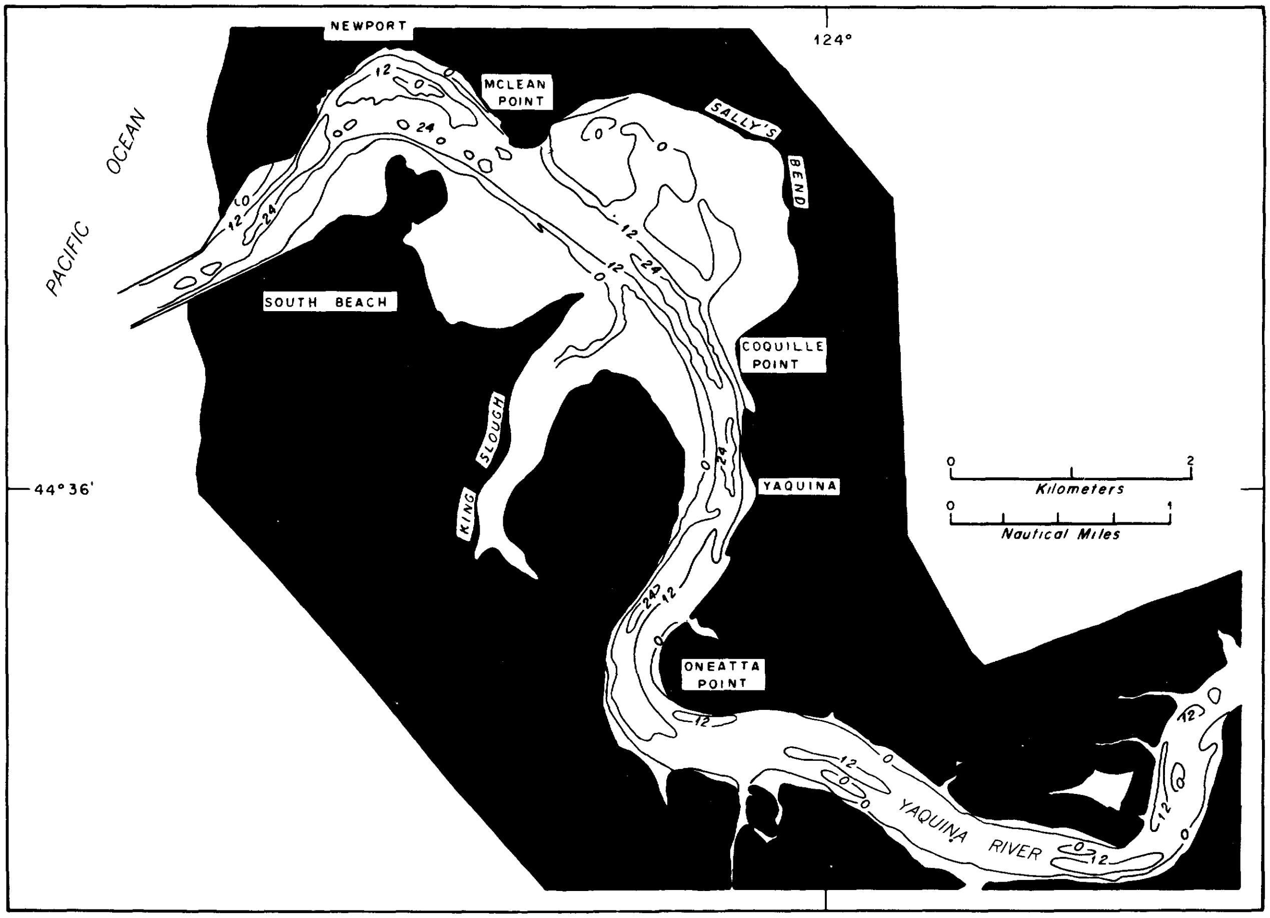

FIGURE 115.—Bathymetry (in feet) of Yaquina Bay, Oreg. (from Kulm and Byrne, 1966).

arkosic composition (quartz-feldspar ratio generally less than 1) and contains heavy minerals such as pyroxene, hypersthene, and diopside in concentrations as high as 15 percent. Upstream above Oneatta Point, sediment composition is due to river-transported detritus, which is more arkosic (quartz-feldspar ratio less than 1) than the source material downstream, and has a heavy-mineral suite consisting mostly of biotite, muscovite, hematite, and limonite. Yellow sand grains composed mostly of weathered feldspars, cherts, and volcanic rock fragments are most abundant (10 percent) in sediments along the Pacific shoreline and in the channel at the mouth of the estuary. In the estuarine sediments the concentration of these grains declines to zero in the area of Oneatta Point. The mineralogy of sands accumulating on tidal flats at Sally's Bend reflects the fluviatile source whereas that of sediments accumulating on the southern margin of the bay is controlled mostly by material contributed by wind from contiguous dunes.

Carbonates.—One to seven percent of the sand fraction consists of molluscan shell fragments and foraminiferal tests. The high carbonate concentrations in river channel depressions and tidal flats decrease toward the bay margins (fig. 118).

REFERENCES

Kulm and Byrne (1966, 1967).

WILLAPA BAY, WASHINGTON

SETTING

Geology.—Willapa Bay is located in an area of folded sedimentary rocks west of the Coast Ranges. Lower Miocene tuff, agglomerate and lava crop out at the northeastern end of the bay. To the south, middle Miocene sandstone overlies Oligocene shale and sandstone exposed in a syncline. Long Beach Peninsula, a Holocene spit, protects much of the bay from the open ocean.

Bathymetry.—Fifty-five percent of the bay is intertidal, and smooth flat topography predominates in water less than 18 feet (5.4 m) deep. Steep-sided channels occupy the midbay. Only the Willapa River channel is dredged. Tidal scour is apparently re-

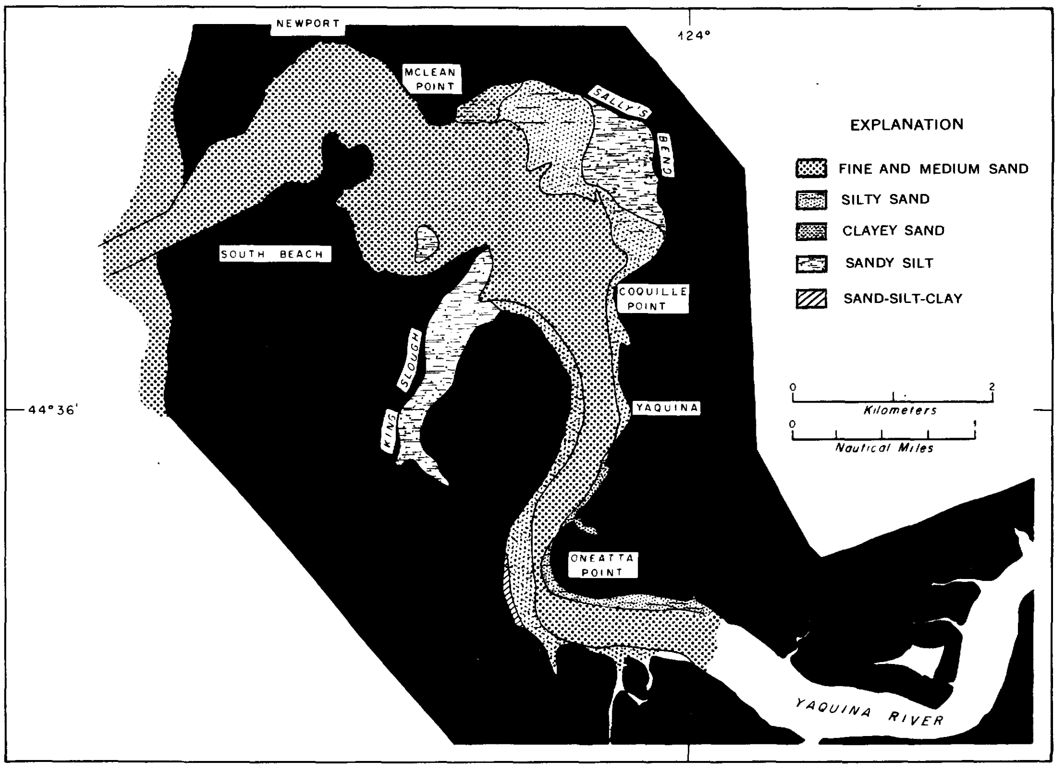

FIGURE 116.—Texture of bottom sediments in Yaquina Bay, Oreg. Modified from Kulm and Byrne (1966).

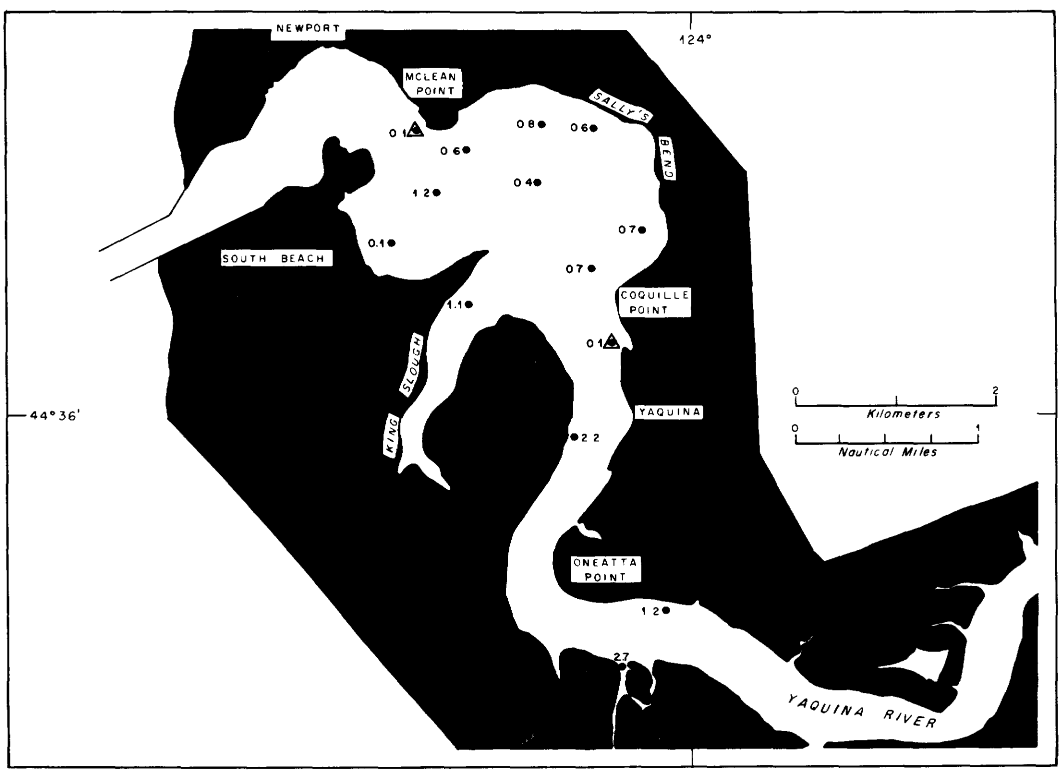

FIGURE 117.—Organic carbon content (in percent) of bottom sediments in Yaquina Bay, Oreg. (from Kulm and Byrne, 1966). Dot in triangle shows measurement of channel sediments; other measurements were in sloughs or on tidal flats.

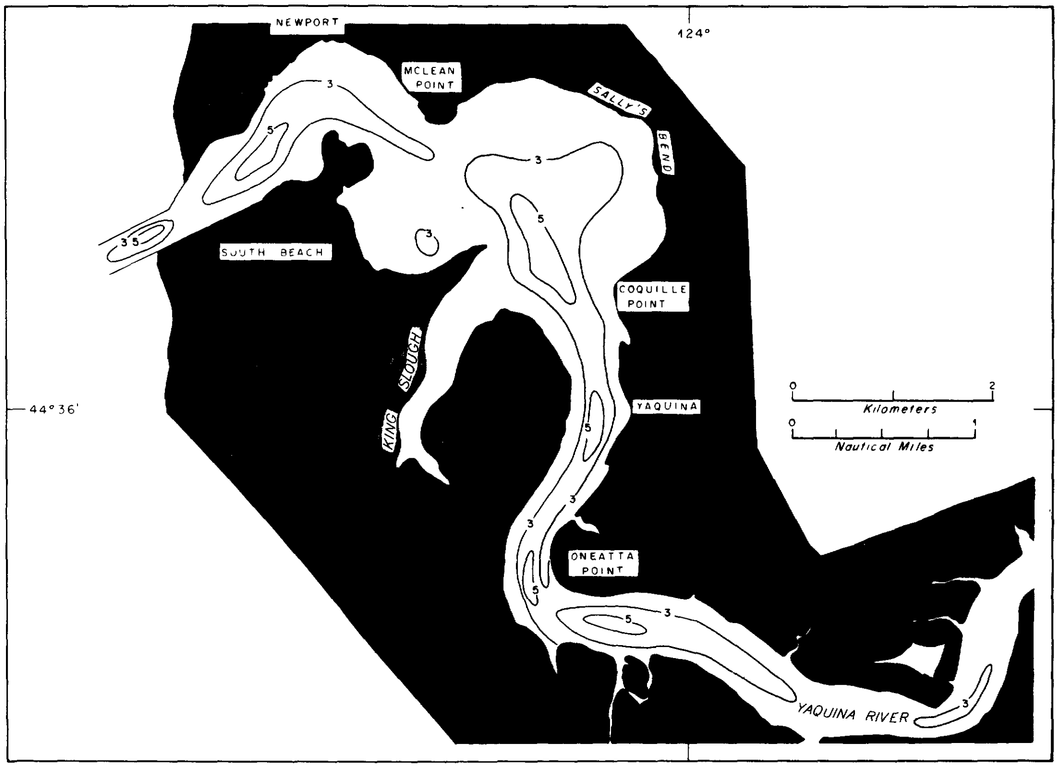

FIGURE 118.—Calcium carbonate content (in percent) of bottom sediments Yaquina Bay, Oreg. (from Kulm and Byrne, 1966).

sponsible for maintaining the depth of 97 feet (30 m) at the bay entrance (fig. 119).

Hydrology.—The average rate of total fresh-water inflow from the Willapa, Nemah, Naselle, and North Rivers is roughly 100–150 m^3/sec. Mixed tidal ranges vary from 8.1 feet (2.5 m) at the bay entrance to 10.2 feet (3.1 m) at Nahcotta. Maximum currents at the bay mouth average approximately 2.5 knots (125 cm/sec) but may attain 4 to 6 knots (200–300 cm/sec) at ebb tide.

SEDIMENT TEXTURE

Bottom.—Fine sand covers most of the bottom. Silt seems to be most abundant near river mouths and on tidal flats. With few exceptions, coarsest material is restricted to narrow channels (fig. 120).

SEDIMENT COMPOSITION

Organic carbon (sample analyses by the Leco gas analyzer).—Measurements were made on samples collected mostly from the margins of the bay. Concentrations are inversely related to grain size (fig. 121). Most organic carbon, therefore, is accumulating with silt and clay near river mouths and on tidal flats (fig. 122).

Mineralogy.—Quartz predominates in the light-mineral fraction, which also contains a small percentage of unaltered plagioclase feldspar. Opaque minerals consist mostly of magnetite, plus small quantities of ilmenite and rutile. Among the heavy minerals, orthopyroxenes and amphiboles are most abundant. Pumice is present in most samples. No data are available on the concentrations of layered silicates.

REFERENCE

Andrews (1965).

GRAYS HARBOR, WASHINGTON

SETTING

Geology.—Grays Harbor lies immediately south of the Olympic Mountains in a hilly region where elevations seldom exceed 600 feet (180 m). The oldest rocks exposed in the area are Tertiary. Unconsolidated to partly consolidated Pliocene sand and gravel crop out in bluffs at Point New and on the eastern side of South Bay. Oligocene and Pliocene marine shaly sandstone and Pleistocene deposits are exposed around the inner harbor. Holocene terraces lie on marine sands on the western margin of the outer harbor.

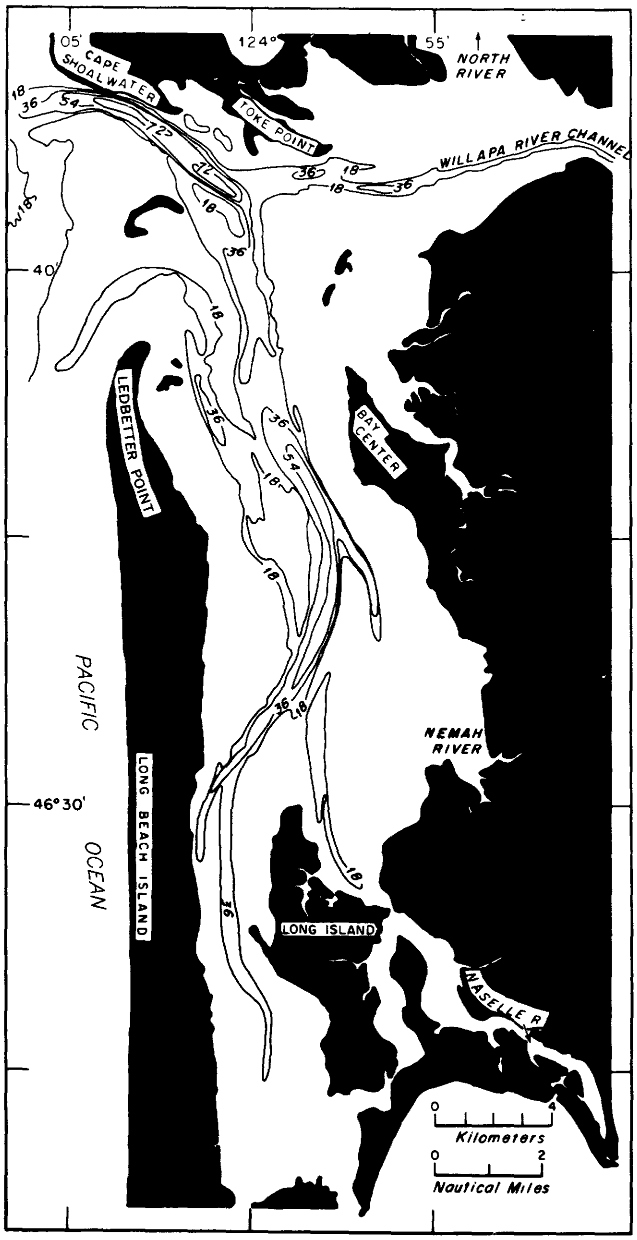

FIGURE 119.—Bathymetry (in feet) of Willapa Bay, Wash. (from Andrews, 1965).

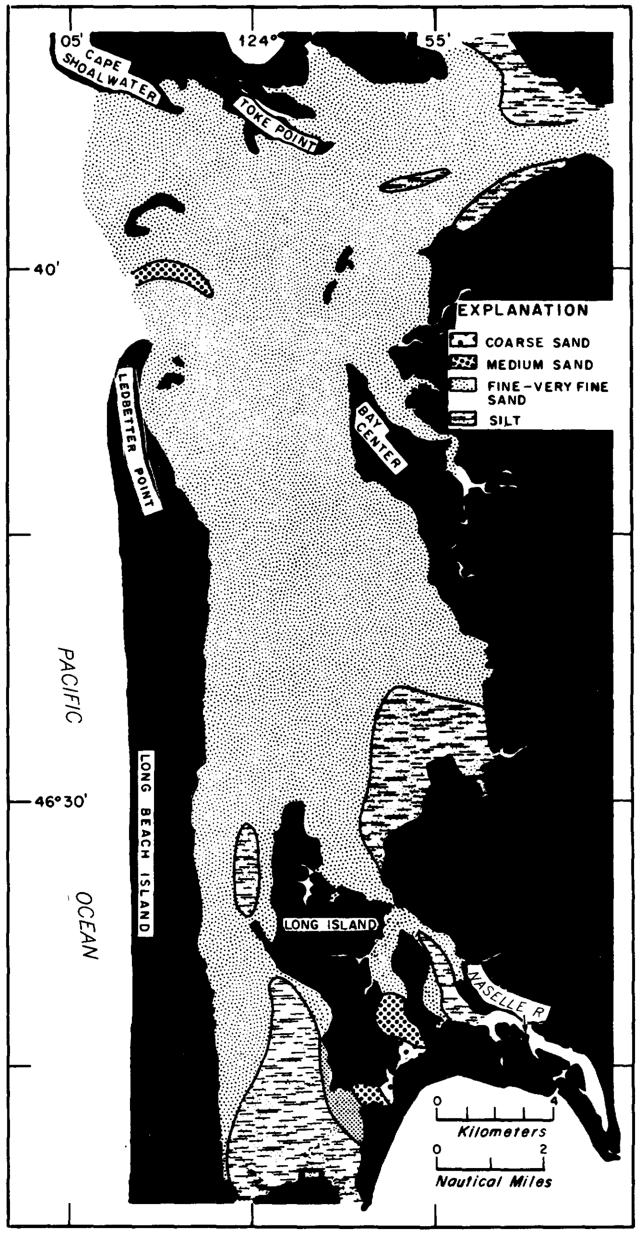

FIGURE 120.—Texture of bottom sediments in Willapa Bay, Wash. Based on data of Andrews (1965).

Bathymetry.—Only 40 percent of the harbor lies below mean lower low water. The remainder consists of tidal flats. Although channels depths reach about 80 feet (24 m), the bottom is generally shallower than 25 feet (7.5 m). Between 1933 and 1961 the harbor became shallower at an average rate of approximately 1 cm/year. Only North Bay and the channel entrance appear to have been eroded during that time. Spoil from the dredging of channels has been dumped in the harbor entrance (fig. 123).

Hydrology.—The Chehalis River system accounts for about 80 percent of the fresh-water drainage into the harbor. The mean flow rate of the river in 1954 was approximately 280 m^3/sec. In winter fresh water at the head of the harbor grades into Pacific Ocean water that has salinities of 30 to 31 parts per thousand at the harbor entrance. In summer when runoff is at a minimum, salinities may reach 16 to 23 parts per thousand near the mouth of the Chehalis River. Tides are of the mixed type. The mean tidal range in-

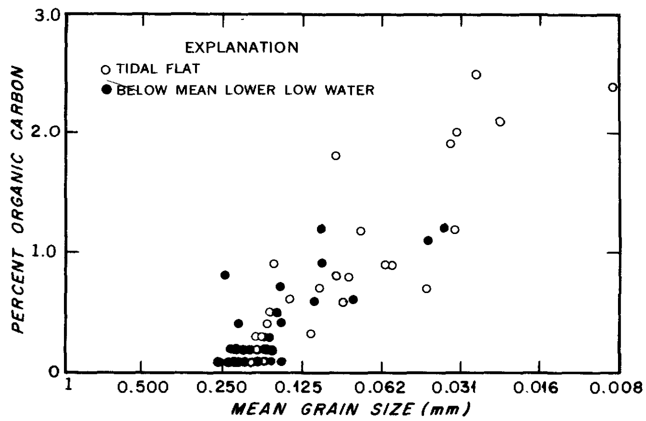

FIGURE 121.—Relation of organic carbon content to mean grain size of bottom sediments in Willapa Bay, Wash. (from Andrews, 1965).

creases from 6.9 feet (2.1 m) at the harbor entrance to 7.8 feet (2.4 m) at the harbor head. Tidal currents are generally about 2.5 knots (125 cm/sec) but maximum velocities of 5 knots (250 cm/sec) occur during spring tides. Current velocities do not change appreicably with depth. Ocean swells in the outer harbor generally do not exceed about 3 feet (0.9 m) in height.

SEDIMENT TEXTURE

Bottom.—Coarse sand is limited to the channel at the harbor entrance. Fine to very fine sand covers most of the bottom in the outer harbor, much of North Bay and northern South Bay, and the western parts of the channels of the inner harbor. Poorly sorted sandy silt is present along the shore of North Bay and on tidal flats nearest the mouth of the Chehalis River (fig. 124); it is also present (not shown in fig. 124) along the shore of South Bay.

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Allisson (1935) technique).—Only a few analyses are available. In North Bay, sand contains 0.01 to 0.9 percent organic carbon, and silt contains approximately 0.9 to 2.0 percent. Insufficient data are available to evaluate the effects of industries located near the head of the harbor on the carbon concentration (fig. 125).

Mineralogy.—The coarse fraction of the sediment consists mostly of rock fragments, minerals, wood, and mud galls. Heavy minerals, constituting less than 1 percent to 16.5 percent of the total sediment, include 50 percent rock fragments, 35 percent hypersthene, 8 percent olivine, 7 percent hornblende, and minor amounts of garnet, chlorite, and corundum (fig. 126). No information is available on the composition of the clay minerals.

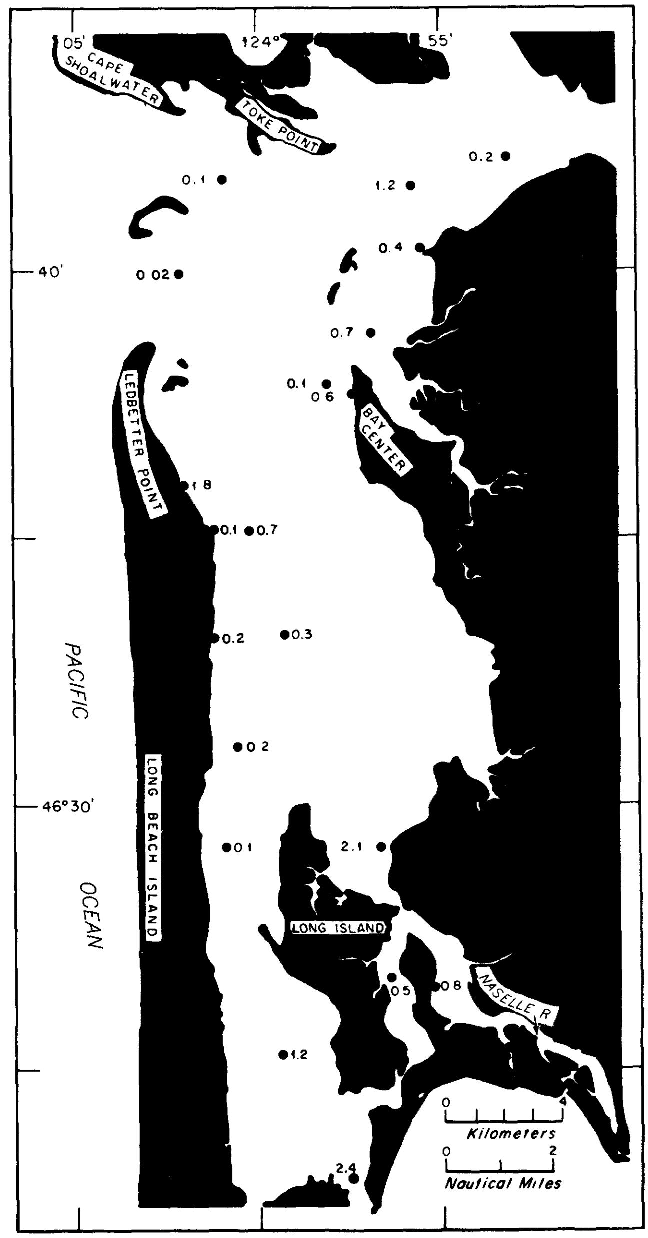

FIGURE 122.—Organic carbon content (in percent) of bottom sediments in Willapa Bay, Wash. (from Andrews, 1965).

REFERENCES

Milliman (1963), Washington [State] University Department of Oceanography (1955).

BELLINGHAM BAY, WASHINGTON

SETTING

Geology.—East of Bellingham Bay glacial debris, Eocene sedimentary rocks, and metamorphic rocks are exposed on steep hillsides. Lowlands at the northern and southern ends are covered by marine silt and clay

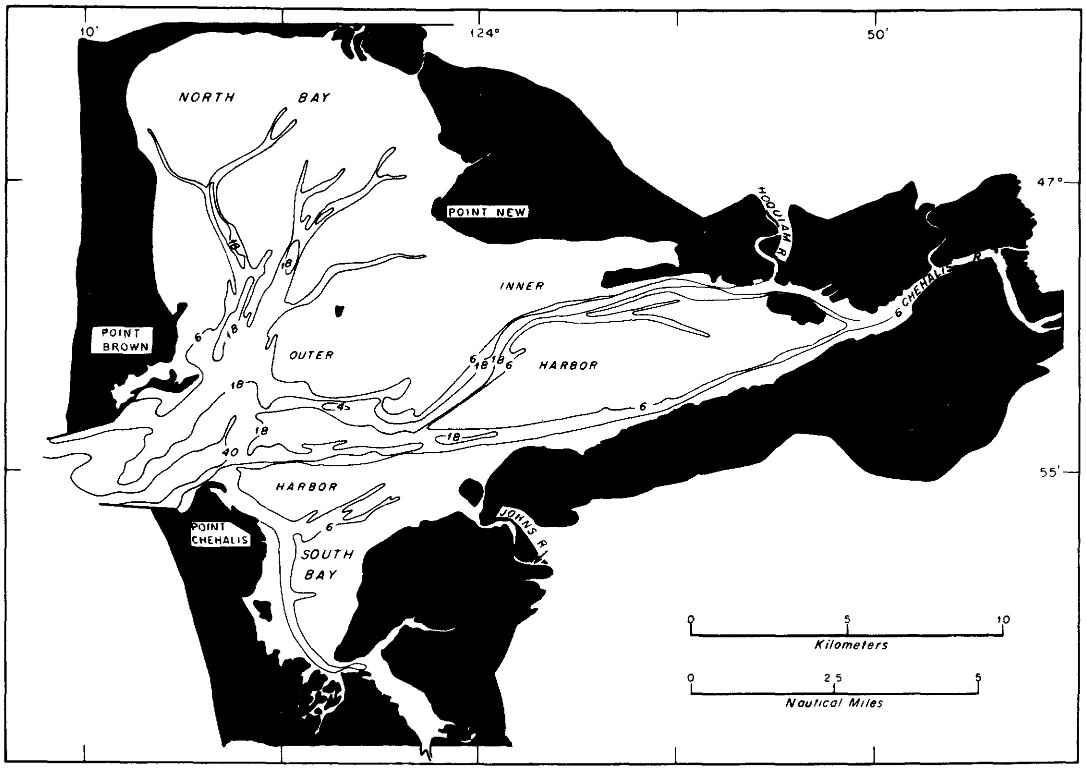

FIGURE 123.—Bathymetry (in feet) of Grays Harbor, Wash. (from Milliman, (1963).

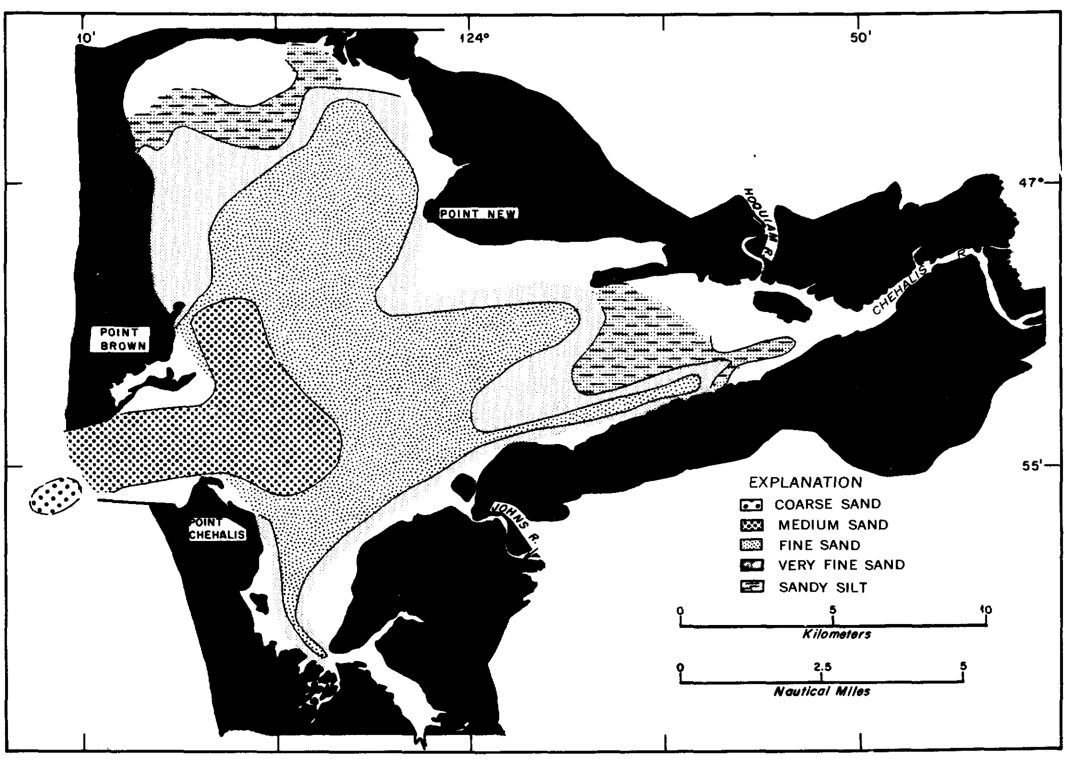

FIGURE 124.—Texture of bottom sediments in Grays Harbor, Wash. Modified from Milliman (1963).

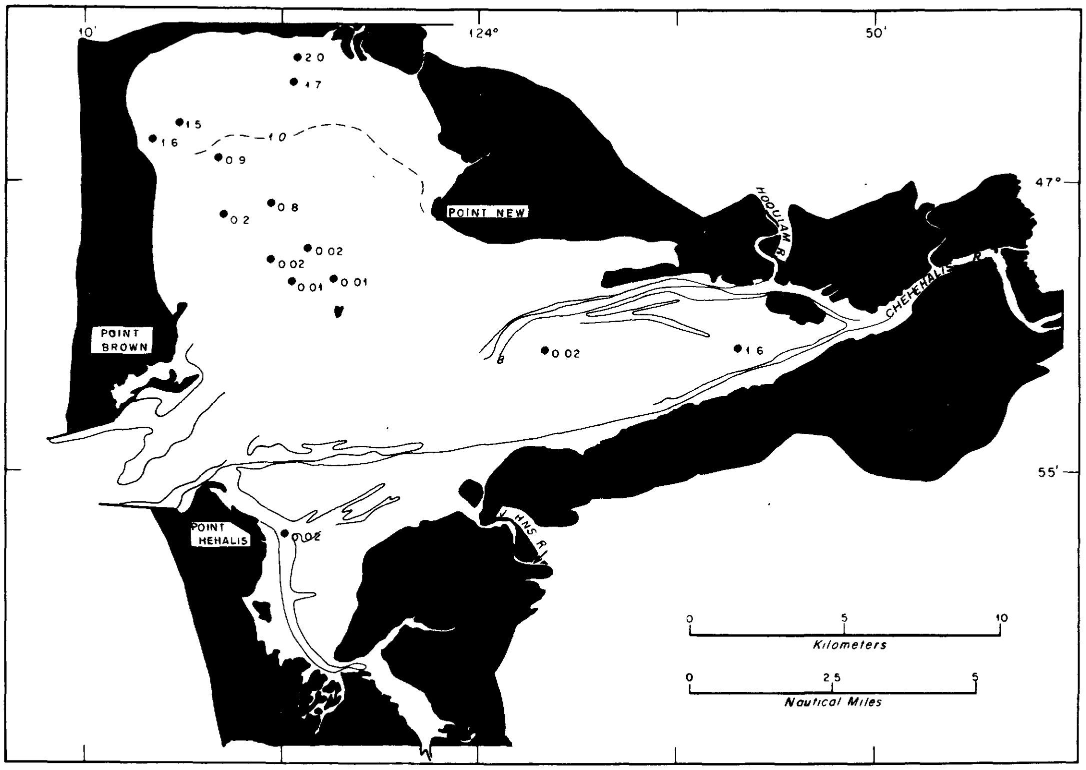

FIGURE 125.—Organic carbon content (in percent) of bottom sediments in Grays Harbor, Wash. (from Milliman, 1963).

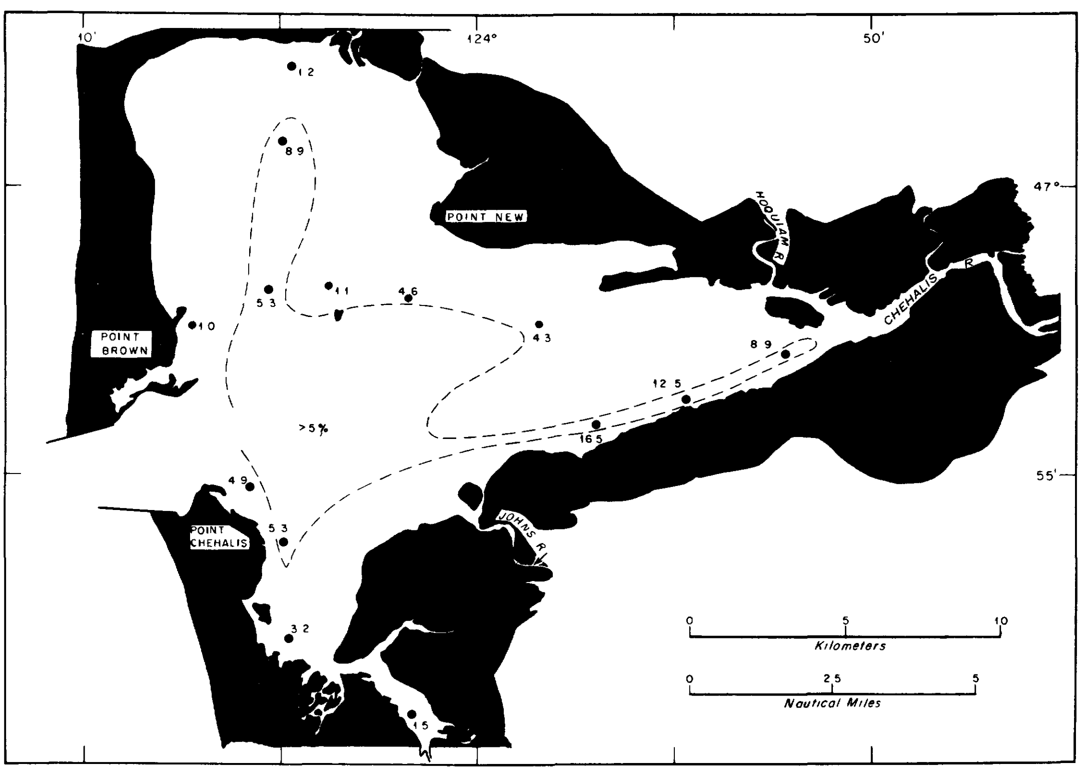

FIGURE 126.—Heavy-mineral content (in percent) of bottom sediments in Grays Harbor, Wash. (from Milliman, 1963).

and glacial detritus. The islands, separating the bay from Puget Sound to the west are composed mostly of metamorphic rocks. Total thickness of unconsolidated sediment in the bay is not known, but bedrock was encountered at 245 feet (75 m) in a water well drilled at Marietta.

Bathymetry.—Most of the bay (fig. 127) is less than 100 feet (30 m) deep. The deepest area, between Eliza and Vendovi Islands, reaches 335 feet (102 m). In the southern part of the bay, depths are less than 60 feet (18 m), except for a depression northwest of Samish Island which is 192 feet (59 m) deep.

Hydrology.—Approximately 75 percent of the fresh water flowing into the Bellingham-Samish Bay drainage basin is derived from the Nooksack River, which flows at a mean rate of approximately 100 m^3/sec, and the Samish River, which flows at roughly 7 m^3/sec. In winter when runoff is greatest, water at the mouth of the Nooksack River is fresh. Normal salinities (29 parts per thousand) are generally present south of a line between Point Francis and Post Point. In late summer when runoff is lowest, salinities near 29 parts per thousand are present throughout the bay. The mean diurnal tidal range in the bay is 8.6 feet (2.6 m). Except in passages between islands, current velocities are generally less than 0.6 knots (30 cm/sec).

SEDIMENT TEXTURE

Bottom.—Sediments in the bay have been divided into three textural provinces: well-sorted medium sand, which makes up the deltas at each end of the bay; clayey silt, which covers most of the central part of the bay; and well-sorted gravel (median diameter about 24 mm), which has accumulated on the sill between Point Francis and Eliza Island (fig. 128).

Subbottom.—Cores collected at each end of the bay within the area covered by silt were megascopically homogeneous to a depth of 36 feet (11 m).

SEDIMENT COMPOSITION

Organic carbon.—No quantitative data are available. Wood fragments derived from a papermill are abundant in the bottom sediments. Within a 4-mile radius

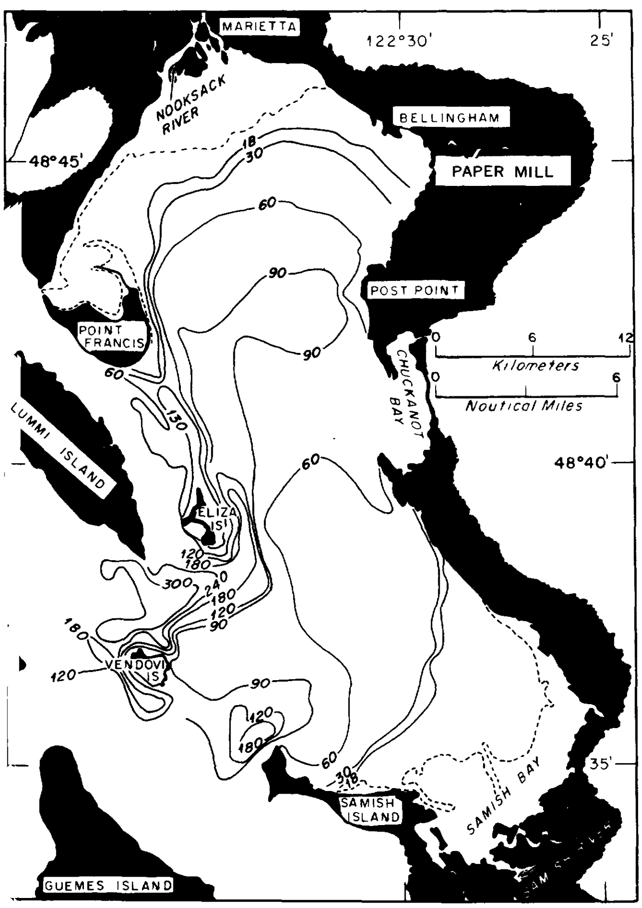

Figure 127.—Bathymetry (in feet) of Bellingham Bay, Wash. (from Sternberg, 1967).

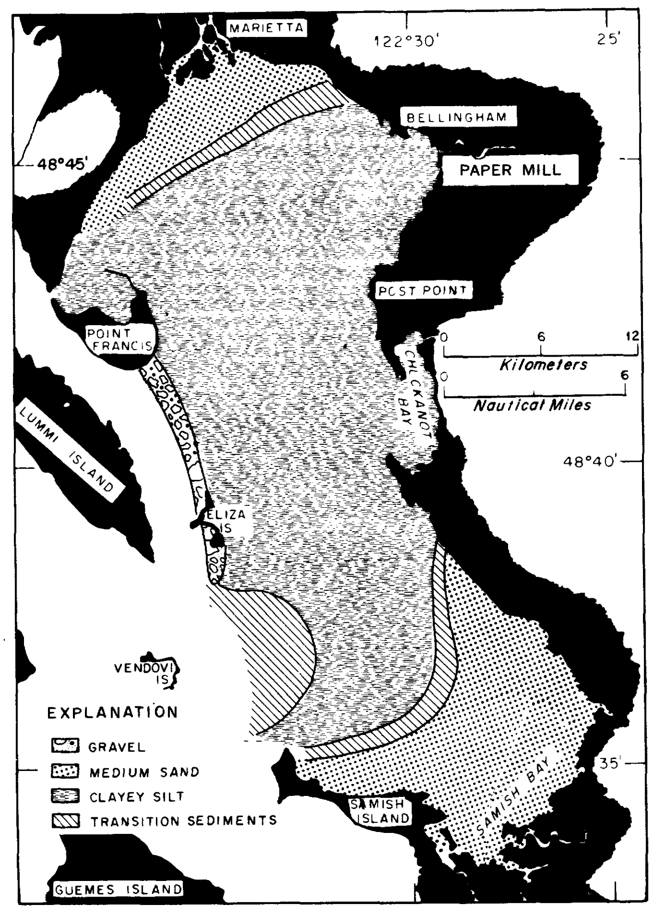

Figure 128.—Texture of bottom sediments in Bellingham Bay, Wash. (from Sternberg, 1967).

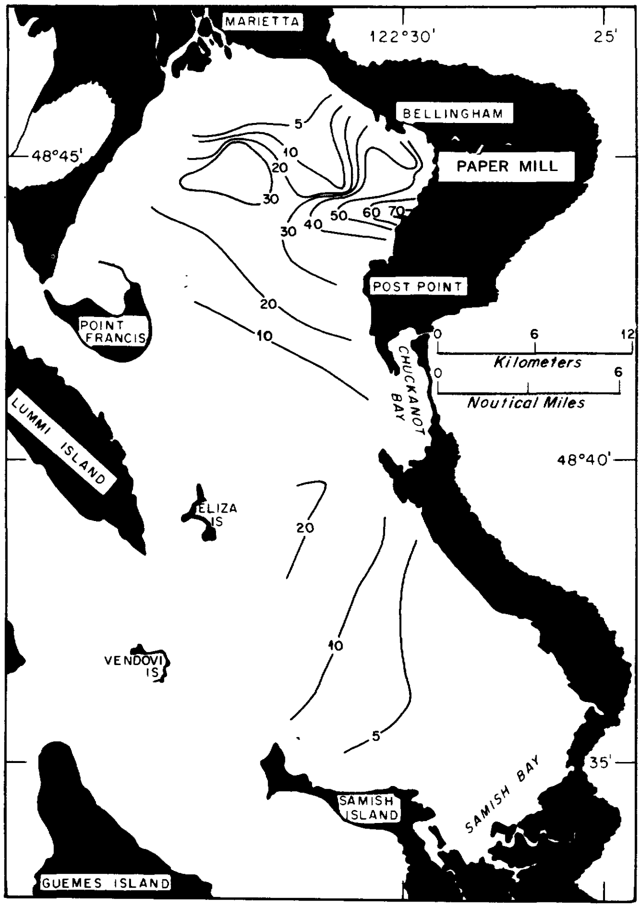

FIGURE 129.—Wood fragment content (in percent) of the coarse fraction (>62 microns) of bottom sediments in Bellingham Bay, Wash. (from Sternberg, 1967). Coarse fraction constitutes about 2 percent of the total sample.

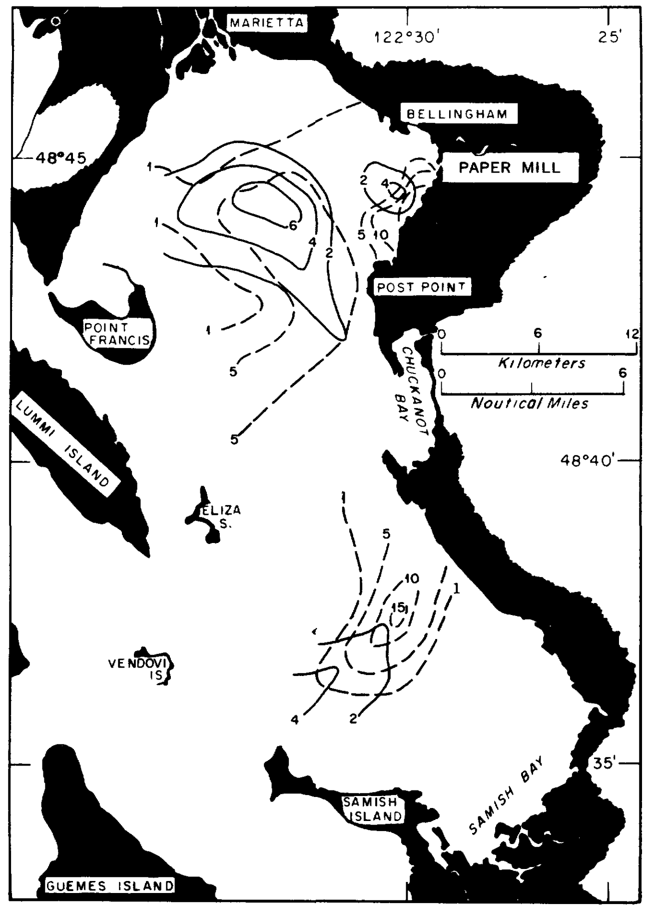

FIGURE 130.—Shell (dashed line) and Foraminifera (solid line) content (in percent) of the coarse fraction (>62 microns) of bottom sediments in Bellingham Bay, Wash. (from Sternberg, 1967). Coarse fraction constitutes about 2 percent of the total sample.

of the pulp mill, wood concentrations in the coarse fraction, which is about 2 percent of the total sample, decline from 70 to about 20 percent (fig. 129). Concentration of wood fragments within the coarse fraction also decreases with depth below the bottom; near the mill, for example, values of 70 percent at the surface decline to 5 percent at a depth of 3 feet (1 m). Hydrogen sulfide in surface sediments was noted only in samples collected near the paper mill and near the sewer outfall of the city of Bellingham. Below the bottom, H_2S odor was noted at various depths in core samples in the north-central part of the bay.

Calcium carbonate.—Pelecypod shell fragments constitute 0–23 percent and foraminifer tests make up 0–6 percent of the coarse fraction of the bottom sediments (fig. 130).

REFERENCES

Collias and others (1966), Sternberg (1967).

PUGET SOUND, WASHINGTON

SETTING

Geology.—Puget Sound lies between the Coast Range and the Cascade Mountain Range and consists of a system of glacially modified drowned channels. Bluffs surrounding much of the bay are composed mostly of glacial deposits and range in height from 50 to 500 feet (15–150 m). The present sedimentation rate in the bay is approximately 0.6 mm/year; more than half the material deposited is detritus derived from shoreline erosion.

Bathymetry.—In the northern part of the sound the bottom has steep sides; midchannel depths are generally about 600 feet (180 m) below sea level and reach a maximum of 900 feet (275 m) near Seattle (fig. 131). To the south, depths are generally about 300 feet (90 m) and maximum depths are roughly 550 feet (170 m).

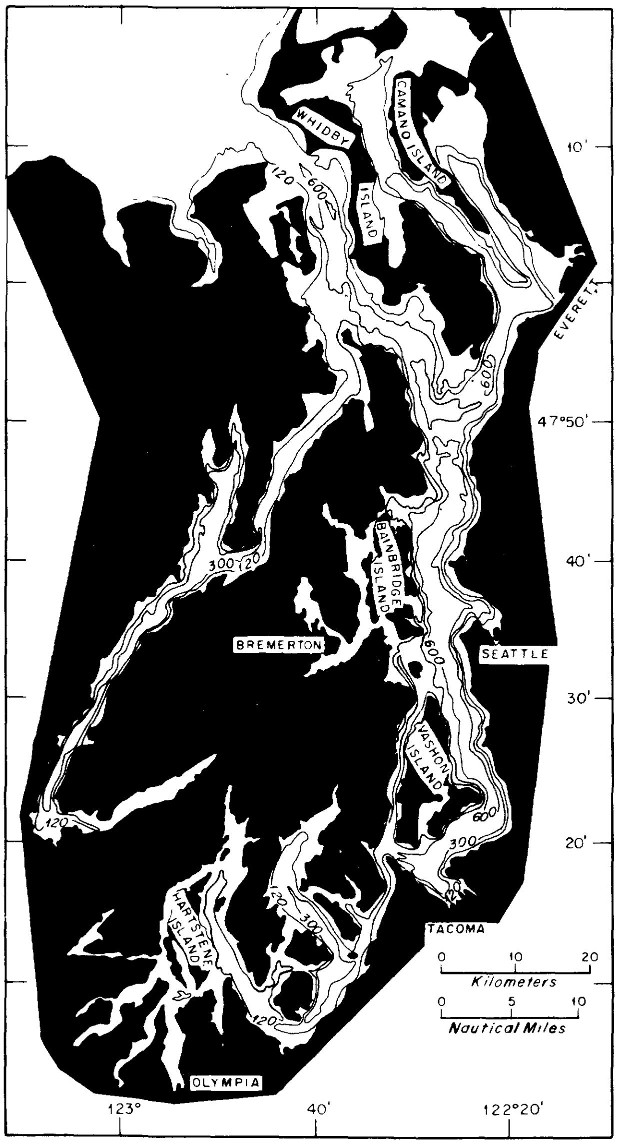

FIGURE 131.—Bathymetry (in feet) of Puget Sound, Wash. (from Wang, 1955).

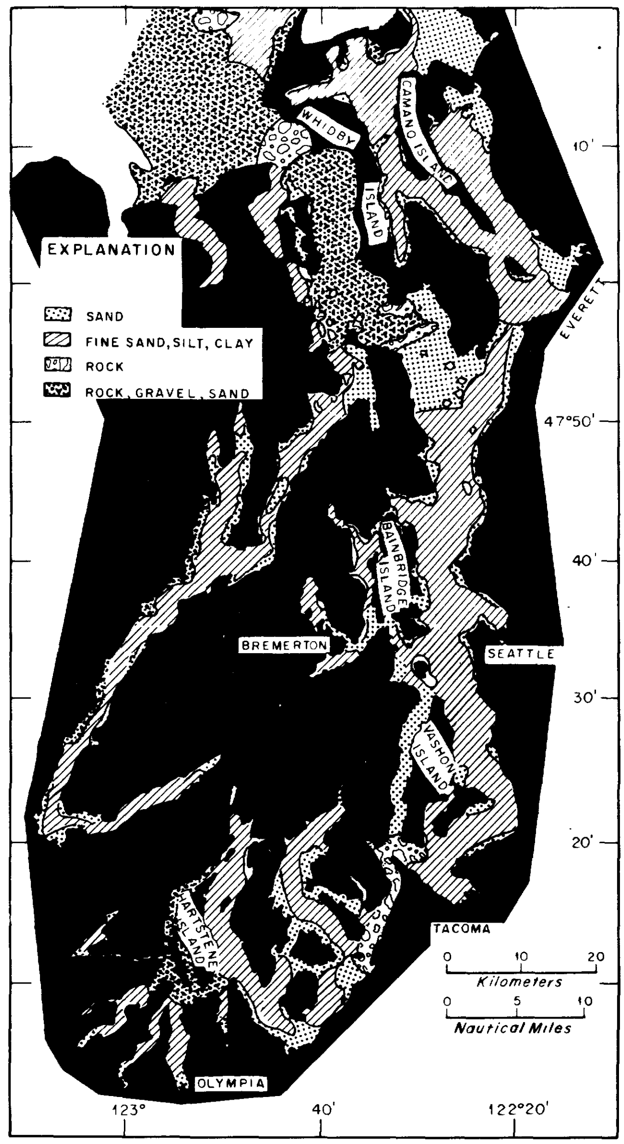

FIGURE 132.—Texture of bottom sediments in Puget Sound, Wash. (from Wang, 1955).

Hydrology.—The mean total fresh-water inflow to the sound has been estimated at 1,100 m^3/sec; monthly extremes range from a minimum of 400 m^3/sec to a maximum of 10,000 m^3/sec. Surface-water salinities vary from less than 27.5 parts per thousand in April and May to 30 parts per thousand in fall. Vigorous vertical mixing results in fairly uniform salinities at all depths in the southern part of the sound. Mixed tides measured at Seattle have mean and diurnal ranges, respectively, of 7.5 feet (2.3 m) and 11.3 feet (3.4 m). The maximum range of spring tides rarely exceeds 16 feet (4.9 m). Current velocities are highest in constricted channels where they may attain velocities of 7.2 knots (360 cm/sec). Elsewhere velocities are generally less than 1 knot (50 cm/sec).

SEDIMENT TEXTURE

Bottom.—Clay, silt, and fine sand cover approximately two-thirds of the bottom of the sound. Sand is most abundant in shallow water near shore, in tidal channels, on deltas, and on slopes; it covers about a sixth of the bottom. In the remaining area exposed rock, gravel, and mixtures of rock, gravel, and sand cover bottoms of tidal channels, banks, and slopes. Sediments are finer grained and more poorly sorted with increasing water depth. Basin mud in deep water is finer grained than estuary and delta mud in shallow water (fig. 132).

SEDIMENT COMPOSITION

Carbonates.—Calcium carbonate occurs mostly as shell fragments and Foraminifera tests; concentrations generally range from 2 to 12 percent. In channels and shelf sands, carbonate concentrations are 0 to 28 percent; in basin muds, 8 to 16 percent.

REFERENCES

Washington [State] University Department of Oceanography (1953, 1954), Wang (1955).

NISQUALLY RIVER DELTA, PUGET SOUND, WASHINGTON

SETTING

Geology.—A broad plain that is composed of glacial detritus and has an irregular kame and kettle topography extends inland from Nisqually River Delta. Approximately 40 nautical miles (74 km) upstream the gradient of the river increases from 14 feet per mile (2.8 m/km) to 99 feet per mile (20.2 m/km), which further increases on the slopes of Mount Rainier to the toe of the Nisqually Glacier. Much of the detritus transported by the Nisqually River is eroded from that volcano.

Bathymetry.—The flat topset surface of the delta extends for approximately 0.5 mile (0.9 km) seaward of the subaerial delta (fig. 133). The foreset slope forms a uniform arc that is about 3.2 miles (5.9 km) long. The gradient of the foreset slope ranges from 20° at the northeast corner to 7° in the center. Seaward of the delta in Nisqually Reach, the maximum depth is approximately 240 feet (73 m).

Hydrology.—The mean flow rate of the Nisqually River is approximately 57 m^3/sec and attains a maximum of approximately 670 m^3/sec. Flooding is common in winter. Salinity measurements near the delta front show highest dilution by river water in the upper 16 to 33 feet (5–10 m) of the water column. Tides in Puget Sound are of a mixed type with large differences between successive heights of low water. The mean tidal range at Nisqually Reach is 9.6 feet (2.9 m). Maximum tidal current velocities at the surface are 2 knots (100 cm/sec) at ebb and 1 knot (50 cm/sec) at flood.

SEDIMENT TEXTURE

Bottom.—Sediment textures range from coarse silt to medium sand over most of the delta. Clay is notably sparse. Moderately sorted, fine to medium sand occurs in the Nisqually River distributary channels. East and west of the channels, most sediment is composed of coarse silt and fine sand. Well-sorted medium sand covers the bottom of Nisqually Reach (figs. 134, 135).

Subbottom.—Cores were collected to a maximum

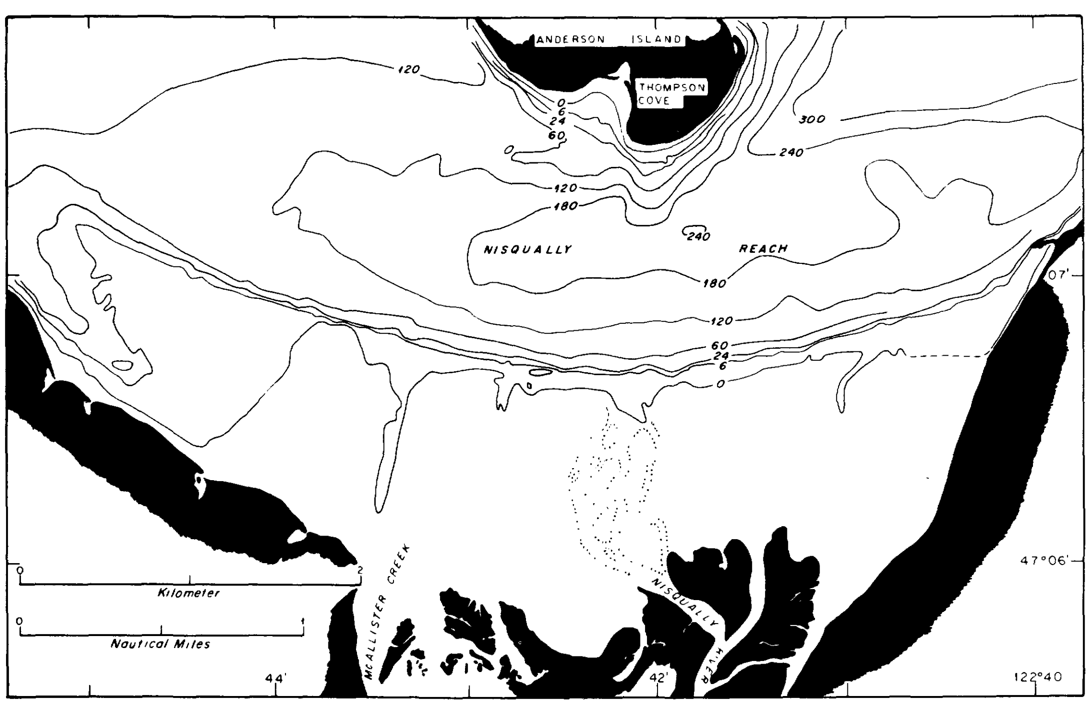

FIGURE 133.—Bathymetry (in feet) of Nisqually Delta and Nisqually Reach, Wash. (from Brundage, 1960).

depth below the bottom of approximately 3 feet (0.9 m). Silt becomes predominant with depth on the subaerial delta front near McAllister Creek, but its abundance at depth decreases toward the delta front. Sand is most abundant at depth in cores from the river channel and seaward of the delta.

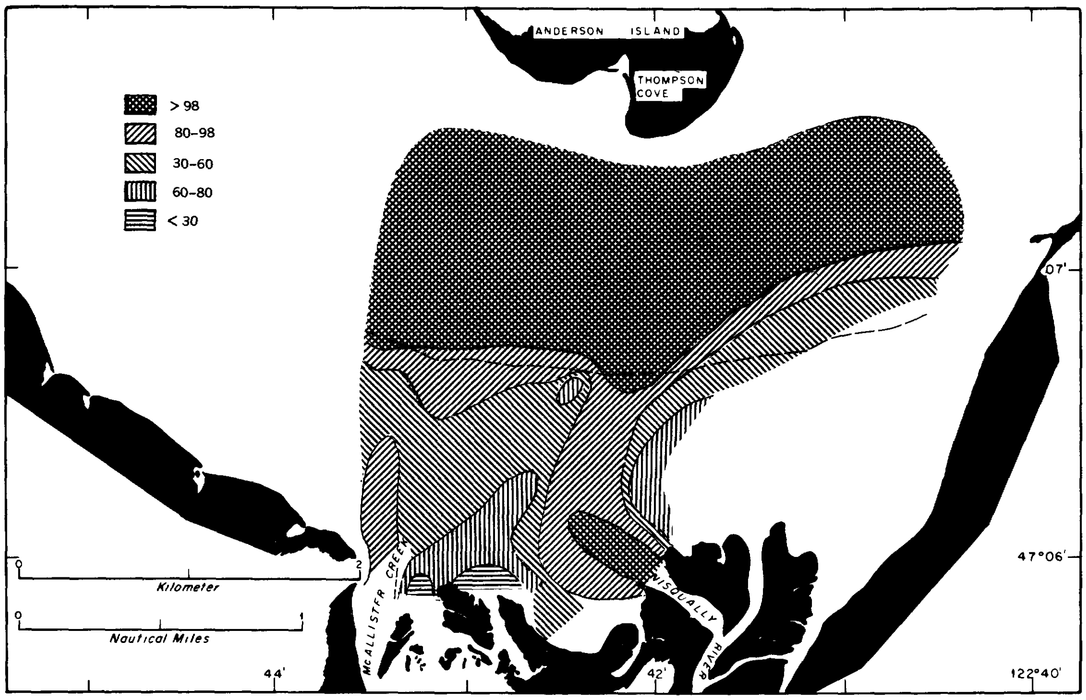

FIGURE 134.—Sand (>62 microns) content (in percent) in bottom sediments of Nisqually Reach, Wash. (from Brundage, 1960). Dashed line shows approximate location of delta front.

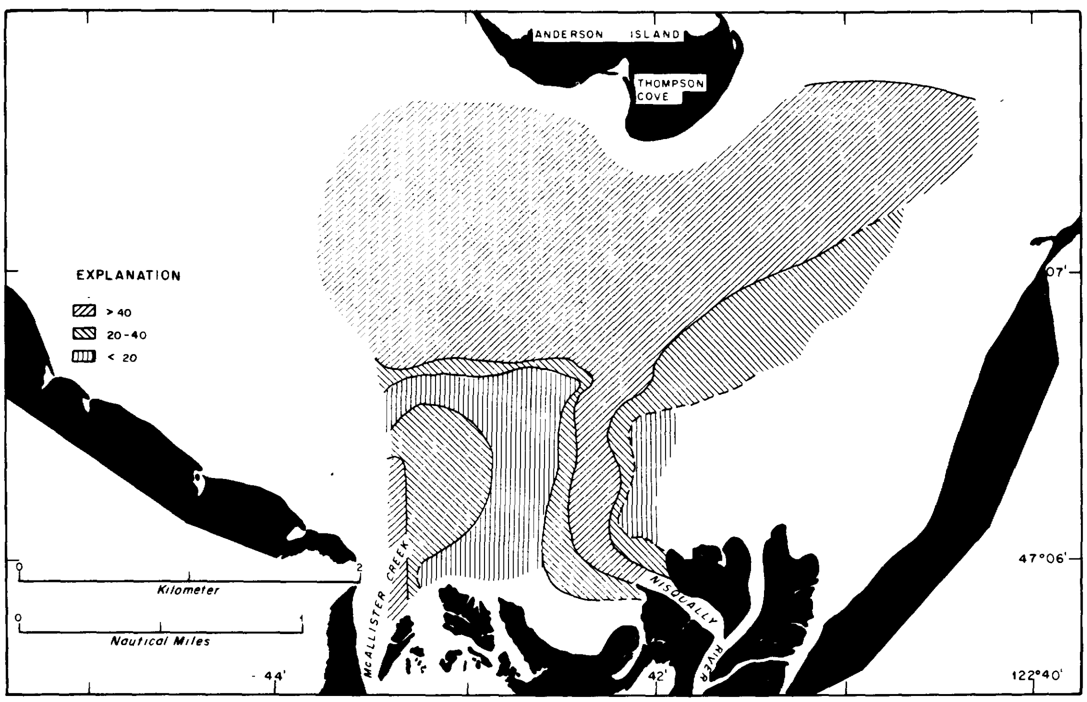

FIGURE 135.—Medium sand (0.25–0.5 mm) content (in percent) of bottom sediments in Nisqually Reach, Wash. (from Brundage, 1960).

SEDIMENT COMPOSITION

Mineralogy.—In the coarse fraction, porphyritic rock fragments and gray to white pumice are common. Abundant minerals include quartz, magnetite, and pyroxene. Wood and plant tissue make up less than 2 percent of the coarse fraction of the sediment.

REFERENCE

Brundage (1960).

DEEP INLET, ALASKA

SETTING

Geology.—The long U-shaped bay, 5 nautical miles (9 km) southeast of Sitka, Alaska, on Baranof Island, is a classic example of a fjord formed primarily by glacial action during the Pleistocene Epoch. Bedrock underlying Deep Inlet is probably composed mostly of graywacke, volcanic rocks, and dark-gray slate of Cretaceous and probable Jurassic age.

Bathymetry.—The precipitous slopes of the valley on each side of the inlet extend beneath the water to a maximum depth of 330 feet (100 m). At the head of the fjord, slopes are more gentle. At the mouth, a sill rises to within 84 feet (26 m) of the surface (fig. 136).

Hydrology.—The volume of fresh-water runoff into the bay is unknown. Salinity values range from 16 to 32 parts per thousand. Tidal ranges at nearby Sitka are approximately 8 feet (2.4 m). No direct measurements of tidal current velocities are available. Dissolved oxygen ranges from 7.1 milligram-atoms per liter at the surface to 0.01 milligram-atoms per liter near the bottom in the deepest areas.

SEDIMENT TEXTURE

Bottom.—Poorly sorted gravel and sand covers most near-shore areas and the sill at the mouth of the bay. Silt, clay, and minor amounts of plant debris and shell and rock fragments cover the bottom of the central bay. Fine sand mixed with abundant plant debris and rock fragments has accumulated near the head of the inlet (fig. 137).

Subbottom.—Texture, determined in nine short gravity cores (1.5 feet or 0.5 m long), coarsens with depth only along the margins of the fjord. Cores from midbay showed little change in grain size downward to the limit of core penetration.

SEDIMENT COMPOSITION

Organic carbon (samples analyzed by the Allisson (1935) technique).—Concentrations of organic carbon range from less than 1 percent to almost 12 percent. Values generally increase toward the basin center but are higher on the moderately gentle southwest slope. H_2S was noted in samples that have high organic carbon concentrations. As no industries or towns contribute effluents to the inlet, most of the carbon is

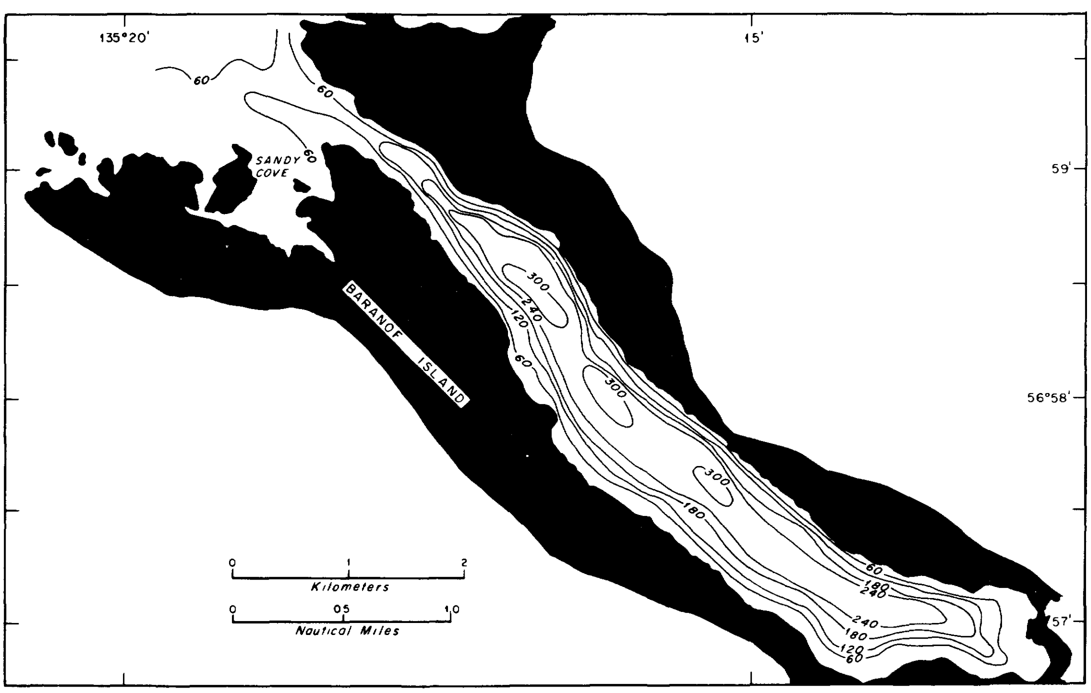

FIGURE 136.—Bathymetry (in feet) of Deep Inlet, Alaska (from Andersen, 1962).

derived from indigenous organisms and allochthonous material carried into the estuary by runoff. Plant debris composed mostly of tree bark is most abundant near the head of the estuary. Reducing conditions in the water below the depth of the sill probably account for the high values in the basin center (fig. 138).

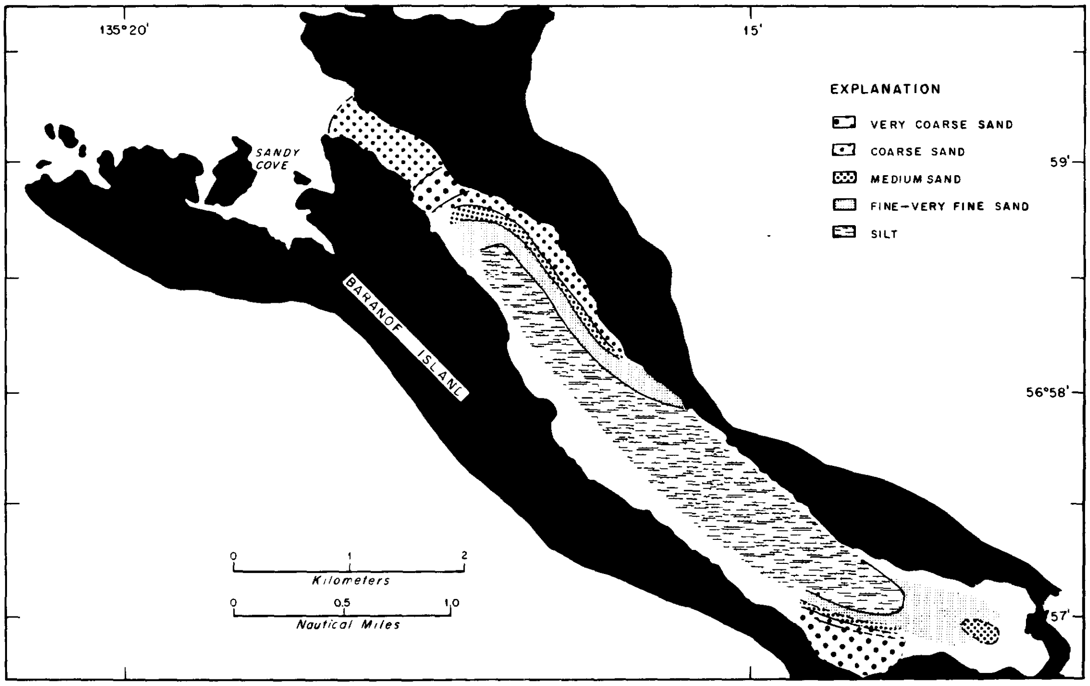

FIGURE 137.—Texture of bottom sediments in Deep Inlet, Alaska. Modified from Andersen (1962).

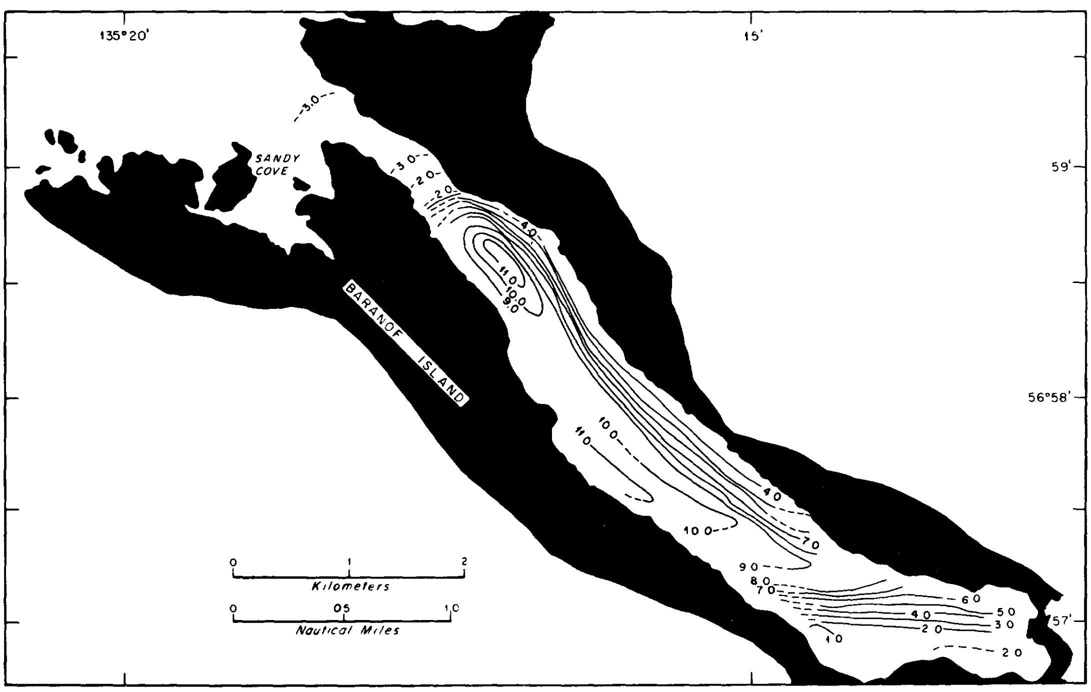

FIGURE 138.—Organic carbon content (in percent) in bottom sediments of Deep Inlet, Alaska (from Andersen, 1962).

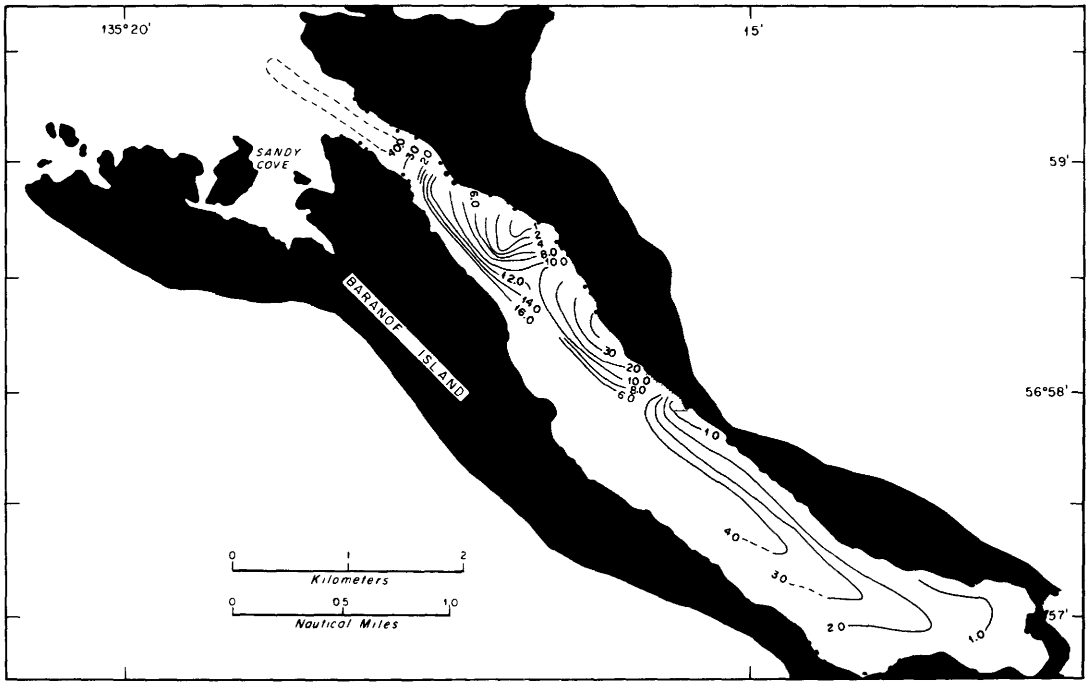

FIGURE 139.—Calcium carbonate content (in percent) of bottom sediments in Deep Inlet, Alaska (from Andersen, 1962).

Mineralogy.—Medium sand and gravel deposits are mostly of graywacke composition; these sediments contain quartz, feldspar, biotite, and rock fragments in a dark aphanitic matrix. Fine material is composed of quartz and low concentrations of feldspar and biotite. Volcanic ash (medium sand) is abundant in sediments at the head of the estuary and on the bay slope of the sill at the mouth.

Carbonates.—High carbonate values (as much as 40 percent) shown in figure 139 are due mostly to concentrations of pelecypod shell debris. Highest concentrations occur in local near-shore areas and on the sill at the mouth of the inlet. A few gastropod shells and echinoid spines are also present. Foraminifera tests account for less than 1 percent of the sediments.

REFERENCE

Andersen (1962).

SUMMARY OF THE CHARACTERISTICS OF SEDIMENTS IN ESTUARIES AND ESTUARINE ZONES OF THE UNITED STATES

The distribution and composition of contemporary sediments in estuaries and estuarine zones result from the complex relations between the geology and hydrology of the coastal region. The rate and amount of sediment erosion and deposition determine the evolution of the shape and character of the shoreline. Summaries of the processes involved, in areas both inside and outside the United States, have been presented by Emery and Stevenson (1957), Shepard and Moore (1960), Emery (1967), Postma (1967), Gorsline (1967), Pritchard (1967), and Reineck (1967).

SETTING

GEOLOGY AND BATHYMETRY

The approximate shape and maximum depth of most estuaries, lagoons, and embayments on the coast of the United States were initially established during the period of lowered sea level associated with the last Pleistocene glaciation. Differences in width and depth of river valleys at that time were related to the type of sediment or bedrock over which the rivers flowed and to the volume and rate of river runoff. During and after the subsequent rise in sea level (11,000–3,000 years ago), marine processes became dominant in the drowned embayments. The degree to which estuaries and embayments have currently evolved toward extinction—that is, complete infilling by sediments—has been determined mostly by the volume of detritus transported into these areas by rivers and by the consequent development of offshore bars, spits, and islands across bay mouths. The most notable changes have taken place where unconsolidated sediments exposed on wide, gently dipping coastal plains have been eroded rather rapidly and deposited in the estuarine zones or on broad continental shelves (Emery, 1967). Least notable changes have occurred where coastal plains and continental shelves are narrow or consist mostly of resistant rock.

The glaciated coast of the Northeastern United States is characterized by low relief and exposures of crystalline or sedimentary rocks covered by thin patchy deposits of glacial detritus. Erosion of these resistant rocks is slow, and little suspended sediment has been carried by rivers to the coast. The roughly triangular shape that was acquired at the end of the postglacial rise in sea level by many of the estuaries in the region has therefore been preserved. These estuaries are generally narrow and deep. Narragansett Bay, for example, which fills a drowned valley cut into Paleozoic consolidated sedimentary rocks, is more than 150 feet (45 m) deep. Glacial scour is probably in part responsible for the more than 500-foot (150 m) depth of Penobscot Bay, which is underlain and bordered by metamorphic and igneous rocks. In some areas where glacial detritus is most abundant, the general shape of large deep embayments, such as Buzzards Bay (140 feet or 42 m deep) and Cape Cod Bay (220 feet or 66 m deep), has been modified only slightly by postglacial processes; however, many small bays, such as Nantucket Bay (30 feet or 9 m deep) and Moriches Bay (8 feet or 2.4 m deep), that have shorelines composed of glacial detritus have almost been isolated from the open sea by the postglacial formation of spits or barrier islands.

South of New York the character of the coastline changes. Offshore bars, spits, and barrier islands are common, whereas to the north they are present mainly where glacial detritus is most abundant (Cape Cod, Nantucket, Long Island). The change is due mostly to the transition from the New England shore, where resistant igneous and metamorphic rocks are exposed, to the shore of the Middle Atlantic States, where the broad Atlantic Coastal Plain is covered by relatively unconsolidated sediments. Coastal Plain deposits—mainly Quaternary and Tertiary sand, silt, and clay—have been rather rapidly eroded by rivers, and the detritus has been carried to and deposited in the estuaries and bays or on the continental shelf. Where marine currents and waves have concentrated the sediments on the continental shelf into spits, bars, and barrier islands that parallel the coast, many drowned river valleys have been partly isolated from the open sea. The original triangular shape of many bays in this area has also been modified by building of deltas at the head, by erosion of the banks by waves, and by transport of sediments from the shelf into the estuaries. Only the largest estuaries south of New York, Chesapeake Bay and Delaware Bay, are still deep and have not been partly cut off from the sea by barrier islånds. Albemarle Sound, which has maintained its triangular shape, no longer has any direct connection with the open sea, and its neighbor to the south, Pamlico Sound, has been reshaped by postglacial formation of the extensive barrier island chain, the Outer Banks.

On the shores of the Southeastern States many estuaries have been completely filled with sediment and rivers such as the Altamaha in Georgia meander through extensive salt marshes to the sea.

The southern part of the Florida Peninsula, however, is far from the source of terrigenous sediment which has filled many estuaries to the north. Erosion of the low-lying terrain, consisting mostly of limestone, is slight and provides scant terrigenous detritus to the many bays and estuaries. Therefore, most infilling has been derived from local material and biogenic detritus formed in situ in the bays or on the continental shelf. Most bays have been partly isolated from the open sea by carbonate banks (Biscayne Bay), reefs (Florida Bay), or mangrove swamps (Whitewater Bay). On the Florida west coast, terrigenous detritus which enters the northern Gulf of Mexico from rivers becomes sufficiently abundant between Port Charlotte Harbor and Tampa Bay to significantly influence the composition of bay sediments.

Along the shores of the gulf coast an extensive series of barrier spits and islands extends from Apalachicola Bay to the Laguna Madre. Rivers flowing to the coast not only drain the broad Gulf Coastal Plain but much of the interior of the United States. The chain of barrier islands, formed mostly because of the abundance of available sedimentary material, is broken only where deltas have filled estuaries and have overridden the continental shelf (Mississippi River Delta, Brazos River Delta). In estuaries where the triangular drowned river valleys have been filled with sediment, the long axis now parallels the coastline (Apalachicola Bay, Mississippi Sound, Matagorda Bay, Laguna Madre). Others, such as San Antonio Bay or Baffin Bay, which still have a rough triangular outline, have not evolved as far.

Few large estuaries indent the rugged California Coast Ranges. The San Francisco Bay complex, which owes its origin partly to mountain-building processes, is deep only at the mouth (380 feet or 114 m), but abundant sediment derived from the Coast Ranges and the Sierra Nevada has reduced depths generally to less than 20 feet (6 m) and formed widespread tidal flats. To the north along the coasts of Oregon and southern Washington, an abundant supply of sediment has nearly filled several estuaries, and wide tidal flats are common (Yaquina Bay, Willapa Bay, and Grays Harbor). In northern Washington and Alaska, however, sediment supply has been inadequate to fill many glacially scoured estuaries such as Puget Sound, Bellingham Bay, or Deep Inlet, Alaska, and great depths (about 1,000 feet or 330 m) are still present.

In summary, estuaries are common on the Atlantic and gulf coasts, are sparse along the California coast, and are more abundant in the Northwestern States and Alaska. The estuaries and embayments are deepest on the extreme northwestern and northeastern coasts. Most of the bays and estuaries located on the broad Atlantic and Gulf Coastal Plains have for the most part been filled with sediment and are generally less than 50 feet (15 m) deep.

HYDROLOGY

Within the geologic framework of the coastal region, the hydrologic regime determines the extent and rate that erosion and deposition will modify the shoreline. The size of the coastal river valleys during the time of lowered sea level was, therefore, determined in part by the character of rivers flowing into the ocean. Subsequent erosion during the rise in sea level was related as well to the vigor of the waves, currents and tides. After the sea reached its present level, sediment deposition in the bays was limited by the fresh-water inflow at the head, by tidal exchange of sea water through the bay mouth, and by wave erosion of the contiguous shorelines. The amount of mixing of salt and fresh water has influenced the amount and kind of biotic activity in the bay and hence the sediment texture and composition.

In the Northeastern and Middle Atlantic States, fresh-water inflow to the major estuaries is fairly large. For example, Penobscot Bay receives an average of 470 m^3/sec; New York Harbor, 740^3/sec; and Chesapeake Bay, 2,000 m^3/sec. The suspended load of these rivers is low, however, due mainly to the erosional resistance of the terrain over which they flow.

On the southeastern coast north of Florida, the only estuary included in this report, Charleston Harbor, receives about 400 m^3/sec from the Santee-Cooper River system. The flow is regulated by the Pinopolis Dam. Although little suspended sediment is carried from the reservoir, the high flow rate (due to the diverted flow of the Santee River) has caused severe erosion of the river and estuary banks and has resulted in extensive shoaling in the channels. In southern Florida, flow rates into most of the shallow bays are difficult to estimate because of the swampy terrain.

Along the gulf coast, average fresh-water inflow to the areas included in this study varies widely. In the eastern gulf, average values range from less than 1.3 m^3/sec in St. Joseph Bay to about 1,700 m^3/sec in Mobile Bay. (Mississippi River flow to its delta averages 18,000 m^3/sec.) There are a few rather high values west of the Mississippi Delta (Brazos River Delta, Sabine Lake, and Trinity River Delta), but most receive less than 100 m^3/sec of fresh water. All the rivers, however, often carry large suspended loads which account in part for the shallow depths of most bays in the region and for the formation of large deltas (Brazos River Delta and Mississippi Delta).

On the Pacific coast north of San Francisco, average fresh-water inflow is generally high—as much as 1,100 m^3/sec in Puget Sound.

The salinity distribution in most embayments is a function of the amount of fresh-water inflow and the salt-water circulation. During periods of greatest runoff average salinities of a few parts per thousand may extend throughout an entire bay (Albemarle Sound). In dry periods, however, water of almost normal oceanic salinity may extend well up the rivers at bay heads (Trinity Bay). In arid regions or in lagoons receiving little runoff, evaporation may result in supersaline conditions. In Baffin Bay, Texas, for example, salinities are as high as 75 parts per thousand. The salinity distribution is largely responsible for variations in the distrbuton of shellfish that have produced significant banks of shells and shell detritus in such estuaries as San Antonio, Matagorda, and St. Joseph Bays.

The water circulation in the estuarine zone is an important control on the distribution, composition, and texture of the bottom sediments. Tides are not only important as the driving mechanism for most horizontal water motion, but the magnitude of their vertical range has an important effect on sediment distribution as well. Diurnal tides of large vertical range are limited to the northern Atlantic coast (mostly north of Cape Cod) and to the Pacific coast. In Penobscot Bay, Boston Harbor, and Cape Cod Bay the tidal range is about 9 feet (2.7 m); in San Francisco Bay, about 6 to 8 feet (1.8 to 2.4 m); and in Puget Sound, about 7 to 11 feet (2.1 to 3.3 m). In the Middle Atlantic States, values are generally 1 to 3 feet (0.3 to 0.9 m), and on the gulf coast they are mostly less than 1.5 feet (0.4 m).

The effects of large tidal ranges are manifold. Currents in restricted channels may scour the bottom and allow little sediment to accumulate. Where the sediment supply to the estuary is rather large, as in San Francisco Bay, the large tidal range results in the transportation of silt and clay, during flood tide, from the channels into the shallow marginal areas where tidal flats are then formed. This process has been summarized by Postma (1967) for estuaries in the Dutch Wadden Sea.

On the gulf coast the tidal range of only 1 to 2 feet results in strong currents only in the narrow passes between barrier islands and spits. Inlet deltas on the bay bottoms indicate, however, that considerable sediment exchange takes place between the estuary and the continental shelf.

Exceptional tides caused by storms often have more influence on sediment distribution than normal diurnal tides or tidal currents. Hurricane-generated tides that exceed 10 feet on the gulf coast have periodically transported great quantities of sand into the estuaries from the continental shelf and from the barrier islands. In areas subject to many storms, such as Cape Hatteras (east of Pamlico Sound), waves often cross the barrier island and carry sand into estuaries to form washover fans.

In summary, the hydrologic regime not only was important in shaping the initial form of the present coastline through erosion, but it continues to modify the shape of the bays and the sediment texture and composition. The most rapid changes occur where rivers and marine currents supply large quantities of sediment from the continent and continental shelf to the estuaries.

SEDIMENT TEXTURE

Regional differences in the processes that affect sediment distribution in estuaries have been discussed. The sediment texture on the bottom indicates the response of the component particles to these processes.

In simplest terms, coarsest sediment accumulates in bays and estuaries where energy levels are high, and finer sediments, such as silt and clay, accumulate where energy levels are low. The mean or median grain diameter of most bottom sediments accumulating in areas cited in this study ranges from that of clay to that of gravel; rarely, however, is material coarser than sand (>2 mm) volumetrically significant.

Deep estuaries in the Northeastern States, such as Penobscot Bay, receive little suspended sediment from rivers. Tidal ranges are large and wave energy at the shoreline is commonly great. Clay, therefore, is most abundant in deep areas in the upper estuary and grades seaward into silt and sand near the bay mouth.

In deep embayments such as Cape Cod Bay and Buzzards Bay, sand and gravel at the margins give way with depth to silt and clay despite the predominance of sand in the glacial debris that is the source of most of the sediments. Even in the bar-built estuaries and lagoons such as Moriches and Nantucket Bays, which also derive most of their sediment from glacial detritus, silt and clay are accumulating in the deepest areas.

The differences in the distribution of sediment texture under various physical conditions is apparent in three estuaries of the Middle Atlantic States—Chesapeake Bay, Pamlico Sound, and Bogue Sound. In Chesapeake Bay, a large deep estuary that has abundant fresh-water inflow, silt and clay are widespread in the deep central area, and fine to medium sand predominates around the margin. Pamlico Sound, a large but rather shallow bar-built estuary south of Chesapeake Bay, contains a preponderance of sand; silt is concentrated only in the bay center and in drowned river channels. The widespread distribution of sand in Pamlico Sound is due mostly to washover fans, inlet deltas, and the winnowing action of waves on the rather shallow bottom. Bogue Sound, south of Pamlico Sound, receives very little fresh-water inflow and most of the shallow bottom is subject to wave action. As very little fine suspended matter is transported to Bogue Sound by rivers, the bottom is almost entirely covered by sand.

Of the estuaries on the southeastern Atlantic coast, Charleston Harbor is significant mainly because the present sediment distribution is due to the diversion of the Santee River into the Charleston estuary. Two important changes occurred when the estuary started recieving the greatly increased inflow of fresh water: first, the banks of both river and estuary were eroded rapidly and much fine sediment was contributed at the head of the harbor; and second, the stronger flow apparently set up a two-layer circulation system that resulted in transport of sand into the harbor from the continental shelf. Much spoil derived from extensive dredging has flowed back into the system. Silt and clay, therefore, cover most of the bottom in the upper harbor, and fine to medium sand is abundant near the mouth.

In bays along the coast of Florida, fine sediment is most abundant in swampy areas (Whitewater Bay) or where carbonates are precipitating directly from sea water (Florida Bay). Little silt and clay is carried from the peninsula or from the continental shelf into such shallow estuaries as Biscayne Bay and Port Charlotte Harbor, and fine to medium sand is therefore predominant.

The depositional environments of the northern gulf coast are sufficiently uniform to produce a broadly similar distribution of sediment textures in most bays. Virtually all the estuaries are partly barred from the open gulf by spits or barrier islands. Abundant suspended sediment is transported to most bays in the area, which therefore have an average depth of less than 10 feet (3 m). In this low-energy marine environment, tidal ranges are less than 1.5 feet and winds and waves, except during hurricanes, are usually moderate. Due to the abundant sediment supply from the rivers and to the absence of strong currents, silt and clay cover most of the central areas of bay bottoms. Sand is abundant only near the bay margins where waves and currents are most vigorous. From Apalachicola Bay to Mississippi Sound, this pattern of sediment distribution is uniform.

Around the Mississippi Delta, however, the sediment pattern changes. The inactive parts of the delta are presently subsiding and the fine delta deposits around the perimeter are being covered by marine sediments. In Chandeleur and Breton Sounds, sand is abundant over much of the deepest area and grades shoreward into silt and clay, which are characteristic of recent delta sediments. A similar pattern in Barataria Bay has been attributed to scouring by strong tidal currents.

West of the Mississippi Delta—Matagorda, Aransas, and San Antonio Bays all have silt and clay concentrated in the central region. Sand is most common around the margins and oyster reefs are also abundant. Recent dredging has been extensive in all these bays and the textural pattern has doubtless been altered since the studies used in this report were made. Baffin Bay and Laguna Madre are unique in that arid conditions prevail most of the year. Sand blown from the barrier island by the prevailing winds has separated Laguna Madre into two parts; windblown material therefore is a very important component of the sediments filling this lagoon.

The contrast between the low-energy environment of the gulf coast and the high-energy environment of the Pacific coast has been described by Gorsline (1967). This difference is reflected in the pattern of sediment distribution in the estuaries. In San Francisco Bay, for example, fine sand is most common in the channels; silt and clay are distributed around the margins in shallow water and on tidal flats. Similar patterns are present in Yaquina and Willapa Bays. These patterns apparently are in part due to the large diurnal tidal range which permits fine material to be carried during flood tide over the tidal flats where it is deposited in shallow water where wave motion is restricted. Most fine material deposited on the tidal flats in the west coast estuaries is probably derived from river detritus rather than from offshore deposits, as is the case in the Dutch Wadden Sea (Postma, 1967).

In estuaries on the Washington coast the textural distribution is similar to that in Penobscot Bay, Maine. In Grays Harbor, for example, silt and clay at the head of the estuary grade seaward into sand. In Puget Sound, bedrock is commonly exposed at the bottom.

In summary, the distribution of sediment texture at the bottoms of estuaries, bays, and lagoons along the United States Coast is determined by the complex relations between geology, hydrology, and bathymetry. In estuaries of the northeast and northwest that receive a small influx of suspended sediment, clay near the bay heads grades seaward into sand. Where suspended load is greater and tidal range large, as on the California and Oregon coasts, sand is most abundant in the channels and fine materials accumulates in the shallow marginal areas and on tidal flats. On the gulf coast where sediment supply is large and energy low, the finest sediments are most abundant in the central areas of the bays and grade shoreward into fine and medium sands. Sands in the barred estuaries are mostly derived from shore erosion, from the offshore barrier bar, and from the continental shelf.

SEDIMENT COMPOSITION

The bottom sediments in the coastal region consist of a mixture of mineral particles eroded from the continents, biogenic debris derived from indigenous organisms, and various human and industrial waste products. Inorganic terrigenous detritus, except in a few areas, account for most of the sediment which has accumulated. Biogenic debris, particularly pelecypod shells (mainly clam and oyster), are locally abundant in many areas. The shells only become dominant constituents of the sediments, however, where terrigenous components are almost entirely lacking as in southern Florida. Many of man's influences on sedimentation in estuaries have been described in reports by Meade (1969a, 1969b, 1972). Organic carbon is the only component discussed in this report which may give an indication of the volume of pollutants retained by estuarine sediments.

ORGANIC CARBON

The concentration of organic carbon in the sediments represents about half the total organic matter present and consists of natural plant and animal remains and of pollutants. Silt and clay generally contain the highest concentrations of finely divided organic matter. The inverse relationship between sediment grain size and organic matter concentration was recognized by Trask (1932). Areas where organic matter will accumulate can therefore be predicted, with some degree of accuracy, by knowing the distribution of sediment texture on the bottom.

In most areas where pollutants are sparse the organic carbon concentration seldom exceeds 5 percent and is most commonly less than 3 percent. Concentrations, for example, in clays of Penobscot Bay, Pamlico Sound, Mississippi Sound, Baffin Bay, and Willapa Bay are less than 4 percent. Concentrations in sands of these same bays are generally less than 1 percent. In some unpolluted areas, however, high values exist because of special conditions. The clays of Deep Inlet, Alaska, for example, contain concentrations as high as 11 percent. This deep fjord has a sill at the mouth which inhibits circulation of deep water and results in anaerobic bottom conditions. In estuaries that have swampy or peaty bottoms, such as Whitewater Bay, Fla., values as high as 20 percent are due mostly to plant detritus. Some local values of as much as 20 or 30 percent are occasionally recorded from bottom samples recovered from restricted peat deposits (Albemarle Sound).

Systematic measurements of organic carbon in sediments of estuaries near major population centers are sparse. In New York Harbor, for example, few measurements are available. And in the San Francisco Bay complex, measurements are only available in Suisun Bay and in part of south San Francisco Bay. Comprehensive studies have been carried out, however, in Boston and Charleston Harbors where pollutants mostly composed of sewage are abundant. Concentrations of organic carbon in these areas are as high as 15 percent. In Chesapeake Bay, the few available organic carbon values increase toward the head of the estuary and reach 7 percent where finely divided coal is known to be abundant in the sediments. Some thorough studies were made of organic matter in bottom sediments of several small bays. The results give us an indication of the amount of pollutants that can be retained in the sediments under different conditions. In Moriches Bay, Long Island, for example, values of total organic matter are as high as 28 percent and are mostly due to the extensive duck farms operated in the small drowned river valleys on the north side of the bay. In St. Joseph Bay, Fla., which presently is receiving very little sediment influx, organic carbon is abundant in the deepest area and in sand on the bay margin near a small canal that carries effluents to the bay from a paper plant. The supply of pollutants has evidently been sufficiently great to override the effects of normal winnowing action which removes most fine terrigenous detritus.

MINERALOGY

Most bottom sediments in the estuarine zone contain only a few species of minerals. Much of the sediment is derived from the coastal plains and the continental shelf and therefore has undergone a previous cycle of erosion and deposition. Furthermore, many minerals that have poor resistance to weathering are destroyed before reaching the estuarine environment.

In the bottom sediments of most estuaries reviewed in this report, the minerals in the sand fraction (>62 microns) that have a specific gravity of less than 2.8 consist mostly of quartz (50–95 percent) and feldspar (0–30 percent). Highest concentrations of quartz are present in reworked glacial material (Nantucket Bay, 90 percent) and in shallow estuaries such as Bogue Sound where abrasive wave action evidently is particularly strong and has worn down and removed less mechanically resistant minerals. Even in Biscayne Bay, which is bordered and underlain by carbonate rocks, the coarse fraction of the sediments contains abundant quartz derived from a thin quartz-bearing stratum. Plagioclase and orthoclase feldspar are abundant and in some places exceed quartz content in sediments of bays along the Pacific coast where the Coast Ranges and the Sierra Nevada contribute igneous rock fragments (Grays Harbor, Yaquina Bay).

The composition of the heavy minerals (specific gravities greater than 2.8) in bottom sediments is related to the source of the sediment and to the amount of abrasion which the particles have undergone prior to deposition. On the Atlantic and gulf coasts, concentrations are generally less than 3 percent. In Nantucket Bay the reworked glacial detritus contains only ilmenite and magnetite. In the Middle Atlantic States (Chesapeake Bay), hornblende, garnet, and hypersthene are abundant. Along the eastern gulf coast, metamorphic minerals that probably were derived mostly from the southern Appalachians predominate. Along the western gulf coast (San Antonio Bay), tourmaline, garnet, and zircon are most common. On the Pacific coast, high heavy-mineral percentages (as much as 18 percent) reflect the proximity of mafic source rocks (Grays Harbor, Yaquina Bay, and San Francisco Bay). In San Francisco Bay, biotite, magnetite, hornblende, and garnet are abundant; to the north in Grays Harbor, rock fragments are followed in abundance by hypersthene, olivine, and hornblende.

Clay minerals commonly constitute over 90 percent of the fine fraction. The relative abundance of the specific clay minerals varies with the source region supplying the estuarine area and with the type of weathering which the source rocks have undergone. From Penobscot Bay to Chesapeake Bay, for example, illite and chlorite are the most abundant clay minerals. These minerals probably are mostly derived from the continental shelf and slope and are being transported into the estuaries by bottom currents (Hathaway, 1972). Kaolinite, derived mostly from the crystalline Piedmont region, is most abundant in east coast bays south of Chesapeake Bay and predominates over illite, montmorillonite, and mixed-layer clays. Kaolinite abundance is greatest (80 percent of the fine fraction) in Albemarle Sound. The Apalachicola River contributes a similar clay-mineral assemblage to fine sediments in several eastern gulf coast bays. The Mississippi River and other rivers in the western gulf transport a preponderance of montmorillonite, which is reflected in the composition of the fine sediments in most bays between the Mississippi Delta and Laguna Madre. On the Pacific coast where volcanic rocks are abundant, montmorillonite is also more abundant than illite, kaolinite, or chlorite.

Calcium carbonate concentrations in bay sediments reach a maximum of about 90 percent. In most areas, highest concentrations are principally due to abundant molluscan shells and shell fragments. On the Atlantic coast some local high values (40 percent) are due to mussel and oyster banks (New York Harbor). In the gulf coast estuaries, such as San Antonio Bay, Matagorda Bay, and St. Joseph Bay, values are as high as 40 to 80 percent in reefs and shell banks but are generally less than 20 percent. In the estuaries of the Northwestern States, such as Puget Sound and Bellingham Bay, maximum carbonate concentrations are 20 to 30 percent. Only the bays along the coast of southern Florida contain widespread concentrations exceeding 50 percent. In Biscayne Bay, carbonate contents as high as 80 percent consist of fragments of calcareous algae; in Florida Bay, carbonates make up as much as 90 percent of the sediment and generally consist of 50–70 percent aragonite, 20–30 percent high-magnesium calcite, and 10–20 percent low-magnesium calcite.

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