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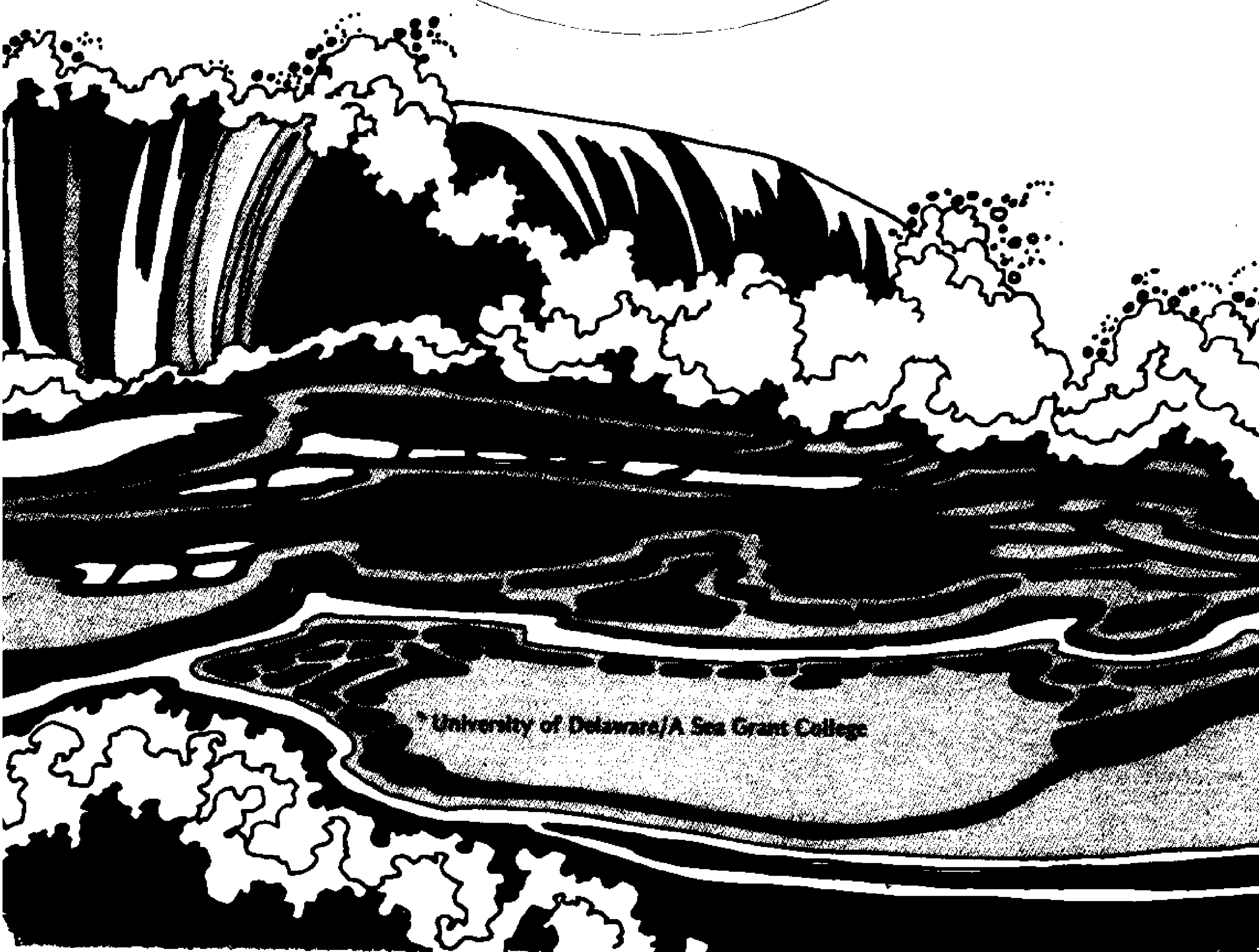

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SEDIMENTS, STRUCTURAL FRAMEWORK, AND EVOLUTION OF DELAWARE BAY, A TRANSGRESSIVE ESTUARINE DELTA

by

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ABSTRACT

Grain-size analyses of 411 bottom surface sediments from Delaware Bay show a distinctive pattern of progressive sorting, with grain size decreasing in the upbay direction and toward shore. The texture pattern is produced by tidal currents and is related to bathymetry. In general, the sediments become coarser-grained as water depth increases. Coarse-to-medium sands occur in the tidal channel bottoms, fine to very fine sands make up the linear sand shoals adjacent to the channels, and muds form the tidal marshes at the margins of the bay. Interlaminated muds and fine sands characterize the shallow subtidal flats, except in near-shore areas where waves and tidal currents have eroded the fine-grain marsh or estuarine sediment, exposing the underlying coarse Pleistocene sediments.

The relationships of transgressive Holocene estuarine deltaic environments in the subsurface are complex because different parts of the sedimentary record may be present or absent depending upon the extent of erosion at the shoreline, deposition and sediment reworking on the subtidal flats, and deposition of linear sand shoals associated with tidal channel development. The subsurface environments represented in piston cores can be related to bottom surface environments by texture characteristics, sedimentary structures, and by an ideal vertical sequence developed from Walther's Law for the Correlation of Facies.

As sea level rose during the early Holocene, the locus of fine-grain estuarine deposition migrated upward and landward along the transverse shelf valley (or estuary retreat path) from the Continental Shelf to the present site of Delaware Bay. The ancestral Delaware River channel and valley behind Capes May and Henlopen began to fill with fine-grain estuarine sediments derived from the Coastal Plain and the Piedmont. With the continued rise of sea level, the active estuarine depocenter migrated north out of the bay into the tidal river, and tidal currents replaced river discharge as the dominant influence on estuarine circulation in the bay. In response to changing dynamic and physical conditions, Delaware Bay began to change from a constructive to a

destructive estuarine delta, characterized by low sediment input, high tidal current energy, extensive sediment reworking, and the development of flood tidal channels. As tidal influence increased at the bay mouth, (1) bottom sediments throughout the bay became increasingly subject to reworking by tidal currents; (2) flood tidal currents eroding channels headward into the muddy substrate of the lower bay removed mud in suspension, left the coarser sands in the channel bottom as a lag deposit, and deposited fine sands along the channel margins like levees as current velocity and competence decreased at the channel margin; and (3) coarse sediments derived from the Continental Shelf were deposited in the southeastern part of the lower bay by the net landward transport of bottom tidal currents.

The major sedimentary environments of the tide-dominated transgressive Delaware delta include: (1) the subaerial tidal marshes and washover barrier beaches in the lower bay; (2) the fine-grained deposits of the subtidal flats; (3) the linear sand shoals; and (4) the estuary mouth shoal complex with mutually evasive tidal channels and flood tidal delta. The Delaware Estuary, characterized by a low supply of coarse sediment, rising relative sea level, and intensive sediment reworking by tidal currents, is a depositional model for the transgressive estuarine delta.

CONTENTS

CONTENTS (cont.)

LIST OF TABLES

ACKNOWLEDGMENTS

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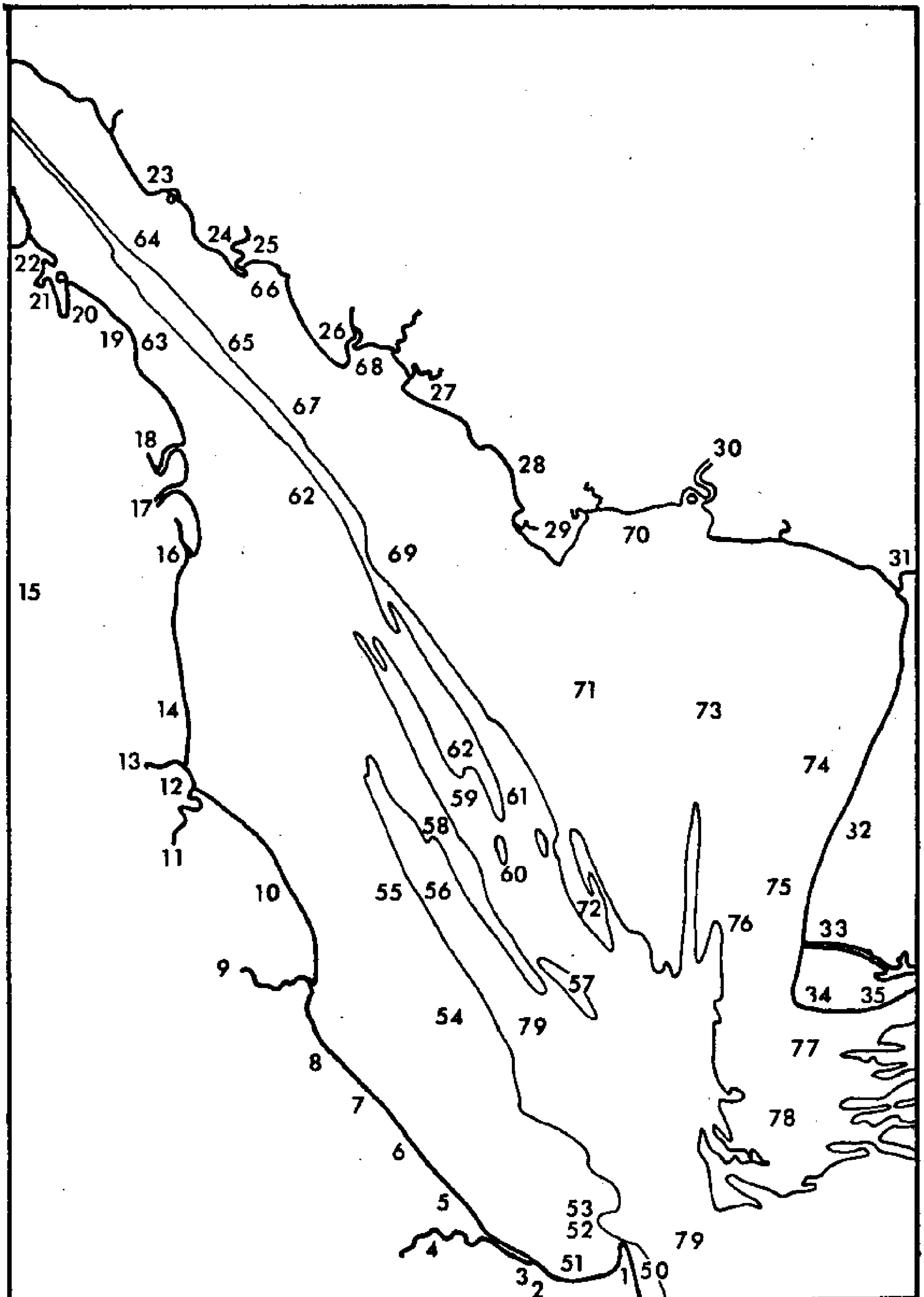


Figure 1. Index map of Delaware Bay and vicinity.

INTRODUCTION

The Delaware River Estuary, like other estuaries of the Atlantic Coastal Plain, follows a deeply incised river valley which was drowned as the latest Wisconsin glaciers melted and sea level began to rise across the Continental Shelf producing a marine transgression. Along the coast of Delaware, the transgression has caused the lateral and vertical migration of successive Holocene depositional environments over a Pleistocene unconformity (Kraft, 1971a). Similar changes occurred offshore as the Delaware shelf valley was drowned, serving as an estuary retreat path along which estuarine environments migrated to their present position (Swift, 1973). The long-term paleogeographic and morphologic changes have continued in Delaware Bay as the drowned estuary system is subjected to changing conditions of dynamic equilibrium (Kraft and others, 1973b).

Recent studies have characterized different aspects of the Delaware River Estuary so that in many ways, it is one of the best described coastal-plain-type estuaries. However, most of the detailed sediment studies have been concerned with the area from the head of tide at Trenton, New Jersey to the head of Delaware Bay (U. S. Army Corps of Engineers, 1973a, 1973b; Neiheisel, 1973); the suspended sediments and nearshore environments of Delaware Bay (Oostdam, 1971; Kraft, 1971b; Strom, 1972; Elliott, 1973; Meyerson, 1972); and the drowned river valley of the Delaware (Swift, 1973; Belknap and others, 1976). There is no detailed study of the character and distribution of bottom sediments in Delaware Bay, nor is there a clear understanding of the relationship of sedimentary processes in the bay to the Delaware River, the Atlantic Coastal Plain or the Continental Shelf.

The purpose of this study is to present detailed sediment and facies maps for the surface and subsurface of Delaware Bay. The study also presents a conceptual model to describe the long-term changes in estuarine sedimentation and morphology caused by the Holocene marine transgression, the configuration of the transgressed Pleistocene surface, and changing estuarine circulation patterns.

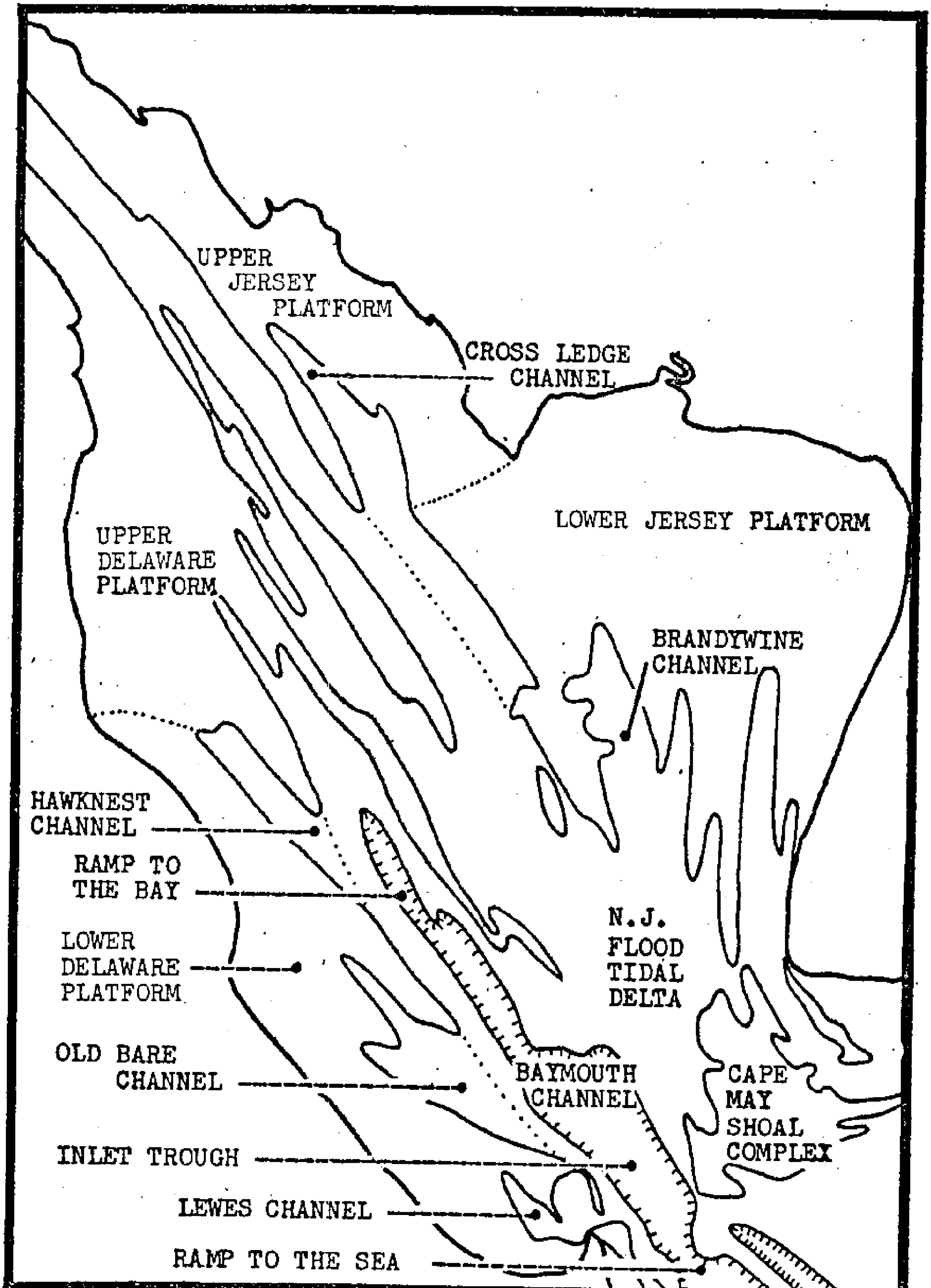


Figure 2. Index map for unnamed geomorphic features in Delaware Bay.

THE STUDY AREA

The limits of the study area are the present shorelines of Delaware Bay on the east and west, a line between Cape Henlopen, Delaware and Cape May Point, New Jersey on the south, and a line from Bombay Hook and Arnold Point on the north (Figure 1). This map of Delaware Bay also shows the coded locations of prominent geomorphic and geographic features referred to in this study. The key for the coded place names is presented in Table 1.

To increase the convenience and precision of place name references, new place names have been adopted and used in both Table 1 and Figure 1. These new names permit reference to important features which do not have formal names. All new place names in Table 1 are identified with an asterisk and their areal extent is shown in Figure 2.

In this study, the Delaware Estuary has been divided into three segments: (1) the upper tidal river (the fresh water segment of the Delaware between Trenton and the upstream limit of saline intrusion); (2) the lower tidal river (the brackish water segment between the upstream limit of salt intrusion and the Smyrna River; and (3) Delaware Bay (the wider embayed segment of the estuary between the Smyrna River and the Capes. The exact location of the upstream limit of saline intrusion varies with fresh-water discharge and stage of tide, but is normally found between Wilmington, Delaware and Philadelphia, (Keighton, 1965).

PHYSICAL SETTING OF THE DELAWARE ESTUARY

Geology

The Delaware Estuary lies at the seaward end of the Delaware River, which drains a 32,060-square-kilometer area of the northeastern United States (Figure 3). The estuary extends 214 kilometers from the head of tide at the Fall Line near Trenton, New Jersey to the Atlantic Ocean at Cape May, New Jersey and Cape Henlopen, Delaware. Between Trenton and New Castle, Delaware, the estuary parallels the Fall Line with early

TABLE 1

Index to Place Names

1. Cape Henlopen, Del.
2. Lewes, Del.
3. Roosevelt Inlet
4. Broadkill River
5. Broadkill Beach
6. Primehook Beach
7. Fowler Beach
8. Slaughter Beach
9. Mispillion River
10. Big Stone Beach
11. Murderkill River
12. Bowers, Del.
13. St. Jones River
14. Kitts Hummock
15. Dover, Del.
16. Port Mahon
17. Simons River
18. Leipsic River
19. Bombay Hook Point
20. Woodland Beach
21. Broadway Meadows
22. Smyrna River
23. Arnold Point
24. Dunks Point
25. Cohansey River
26. Ben Davis Point
27. Nantuxent Point
28. Fortesque, N. J.
29. Egg Island Point
30. Maurice River
31. Dennis Creek
32. Villas, N. J.
33. Cape May Canal
34. Cape May Point
35. Cape May, N. J.
50. Hen and Chickens Shoal
    Del. Ebb Tidal Delta
    Ramp to the Sea*
    Inlet Trough*
51. Breakwater Harbor
    Lewes Channel*
52. Harbor of Refuge
53. The Shears
    Lower Delaware Platform*
    Old Bare Channel*
54. Old Bare Shoal
    Hawknest Channel*
55. Hawknest Shoal
    Ramp to the Bay*
56. Anchorage Area

TABLE 1 (cont.)

57. Brown Shoal

58. The Lower Middle Shoal

59. Blake Channel

60. Fourteen Foot Bank

61. Navigation Channel

62. Joe Flogger Shoal
    Upper Delaware Platform*

63. Bombay Hook Shoal

64. Arnold Point Shoal
    Upper Jersey Platform*

65. Ship John Shoal

66. Cohansey Cove

67. Ben Davis Point Shoal

68. Nantuxent Cove
    Cross Ledge Channel*

69. Cross Ledge Shoal
    Lower Jersey Platform*

70. Egg Island Flats

72. Brandywine Shoal
    Brandywine Channel*
    N.J. Flood Tidal Delta*

73. Deadman Shoal

74. Fishing Creek Shoal

75. Bay Shore Channel

76. Crow Shoal

77. Cape May Channel
    N.J. Ebb Tidal Delta*
    Cape May Shoal Complex*

78. Baymouth Complex

79. Baymouth Channel*
    Delaware Shelf Valley*
    Inlet Trough*

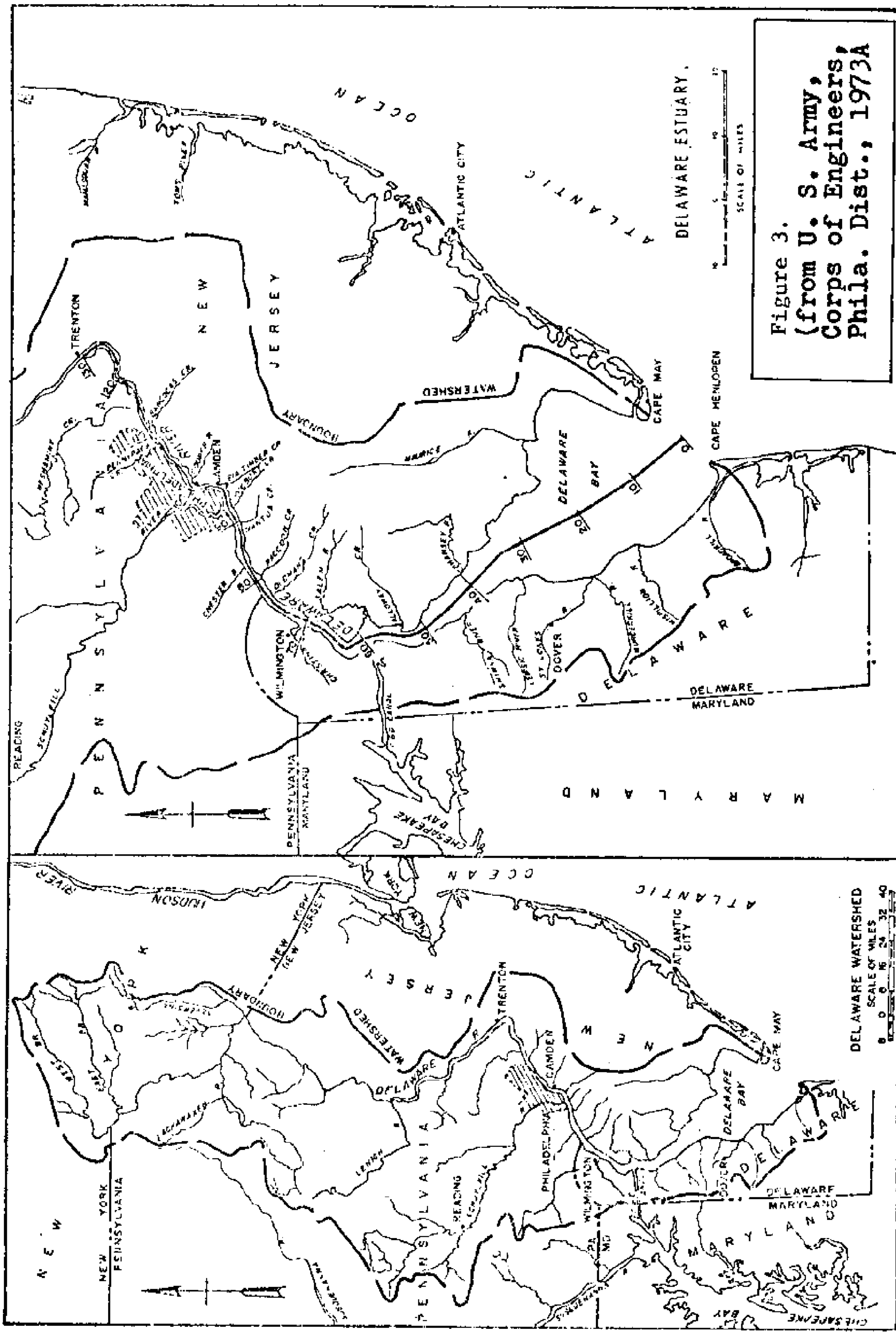
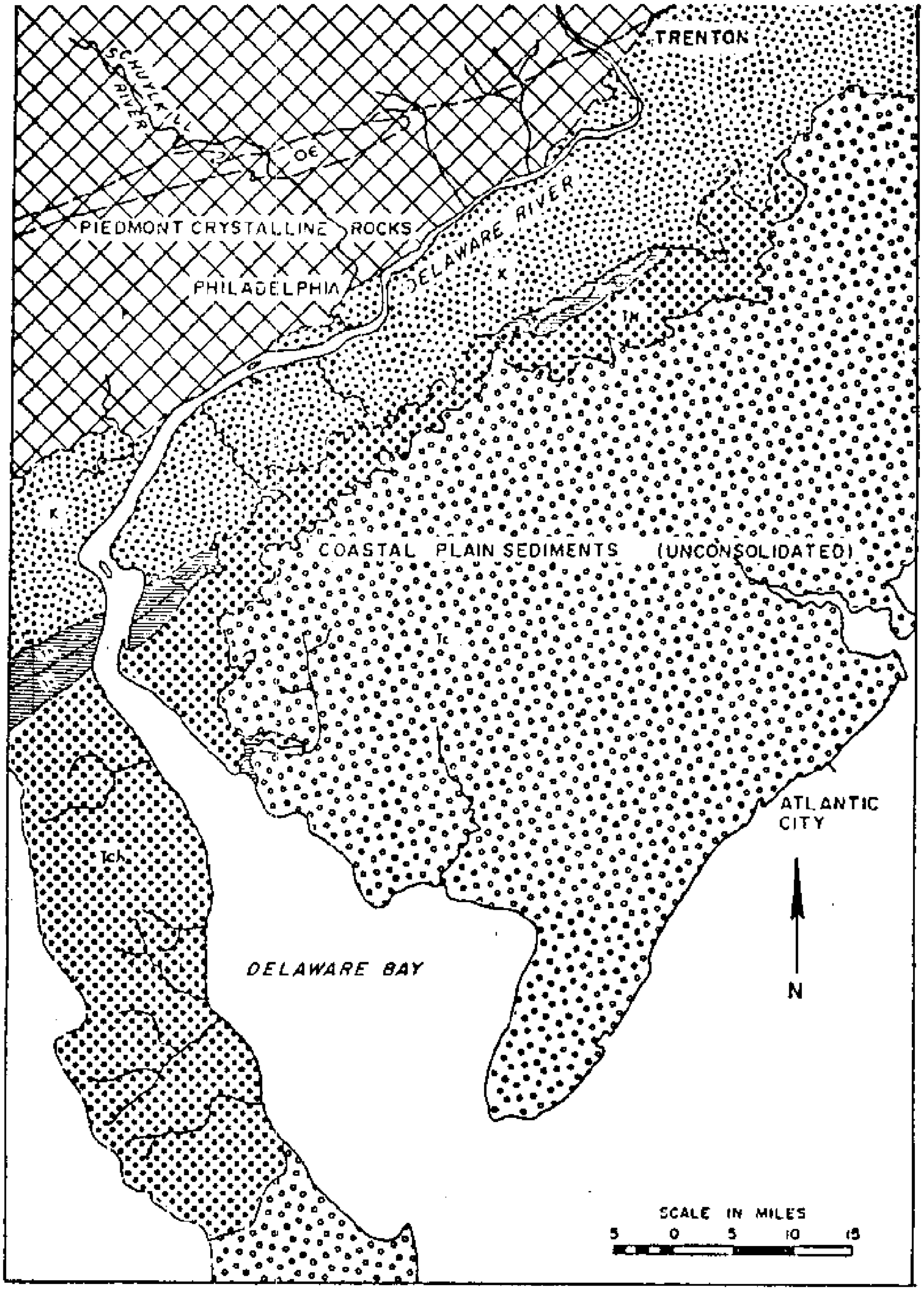


Figure 3.
(from U. S. Army, Corps of Engineers, Phila. Dist., 1973A

Paleozoic metamorphic rocks of the Piedmont on the west and unconsolidated coastal plain sediments on the east. South of New Castle, the lower tidal river and Delaware Bay are underlain by the sediments of the Atlantic Coastal Plain (Figure 4). In the vicinity of the bay, a veneer of fluvial Pleistocene sands and gravels up to 33 meters thick covers the older sediments of the Coastal Plain sediments (Jordan, 1964). These Pleistocene sediments form the Columbia Group in Delaware and the Cape May, Pennsauken, and Bridgton Formations in New Jersey. In most cases, Pleistocene sediments form the basal substrate upon which the sediments of the Holocene marine transgression have been deposited (Richards, 1944; Kraft, 1971a). However, subsurface data suggest that sediments of the Cohansey Formation and upper Chesapeake Group (Miocene) may possibly outcrop in Delaware Bay (Sundstrom and Pickett, 1968, 1969; Miller, 1971). In the following discussions, sediments underlying Holocene estuarine deposits will be referred to as pre-Holocene without further distinction of their age.

From the head of tide to the mouth of the bay, the total average annual fresh water inflow to the estuary is approximately 572 cubic meters per second. About 80 percent of this flow is derived from the Delaware and Schuylkill Rivers and is discharged into the upper tidal river. Extreme variations in fresh water discharge may cause wide excursions of isohaline positions in the estuary (Figure 5). Normally, the upstream limit of saline intrusion is found between Wilmington, Delaware and Philadelphia (Keighton, 1953).

Of the 1.27×10^6 metric tons of sediment supplied to the estuary each year by rivers, the Delaware and Schuylkill Rivers supply 0.77×10^6 and 0.23×10^6 tons respectively. Other natural and anthropogenic related sources contribute approximately 4.0×10^6 tons annually to the estuary (U. S. Army Engineers, 1972). The bulk of the sediment deposition in the estuary (3.4×10^6 metric tons per year) occurs in the dredged navigation channel and anchorage areas between the head of Delaware Bay and Philadelphia (Figure 19E). Organic-rich silty clays and clayey silts characterize sediments deposited in this zone of rapid deposition, which is upstream of the "null point" or "stagnation point" where "the tidal time average velocity near the bottom changes from a landward to a seaward direction"



T	TERTIARY	
	Tc	Cohansey fm.
	Tk	Kirkwood fm. in N.J.
	Tch	Chesapeake gp. in Del.
	Tv	Vincentown fm.
	Th	Hornerstown fm.
K	CRETACEOUS	
P	PALEOZOIC	

Figure 4. Pre-Pleistocene geology of Delaware, New Jersey, and Pennsylvania (after U. S. Army Corps of Engineers, 1973a).

(Harleman and Ippen, 1969, p. 10). There is virtually no sediment deposition along the axis of the bay below the null point, and limited shoaling (7 x 10^5 tons) in the 65 kilometers of dredged channel between Philadelphia and Trenton. At the mouth of the bay, the net seaward transport of suspended sediment exceeds landward transport under most conditions (Oostdam, 1971). Bottom sediments are transported landward on the north side of the bay mouth and seaward on the south side (Neiheisel, 1973). Quantitative data on the magnitude of landward and seaward transport of bottom sediment is not available.

Sea Level Rise

The temporal and spatial character of the various sedimentary environments of the Delaware coast and estuary are the result of the rising sea level during the Holocene Epoch and the resulting marine transgression. The rate at which Holocene sea level rose along the Atlantic coastline of Delaware has been determined (Kraft, 1971a) from numerous radiocarbon dates of basal marsh peats which are closely related to the position of mean sea level (Figure 6). Refined analysis of Kraft's relative sea level curve (Belknap and others, 1976) indicates a rapid rate of sea level rise prior to 7,000 years before present (B.P.). Between 7,000 and 5,000 years B.P., relative sea level rose at 0.3 meters/century, slowed to 0.2 meters/century from 5,000 to 2,000 years B.P., and has risen at 0.12 meters/century during the past 2,000 years. Recent data (Hicks, 1971; Balazs, 1974) indicate that relative sea level is continuing to rise along the Atlantic coastline of Delaware.

Man's Activities

In its natural condition below Philadelphia, channel width of the tidal river varied from 175 to 600 feet wide, and locally, numerous shoals and sand bars limited the draft of sailing vessels to 17 feet at low water. Larger ships sailing up to Philadelphia had to wait for high tide to pass over the shoals, often requiring four days to make the trip. The first navigation improvements to the estuary were authorized by the Rivers and Harbors Act of 1885. This first project,

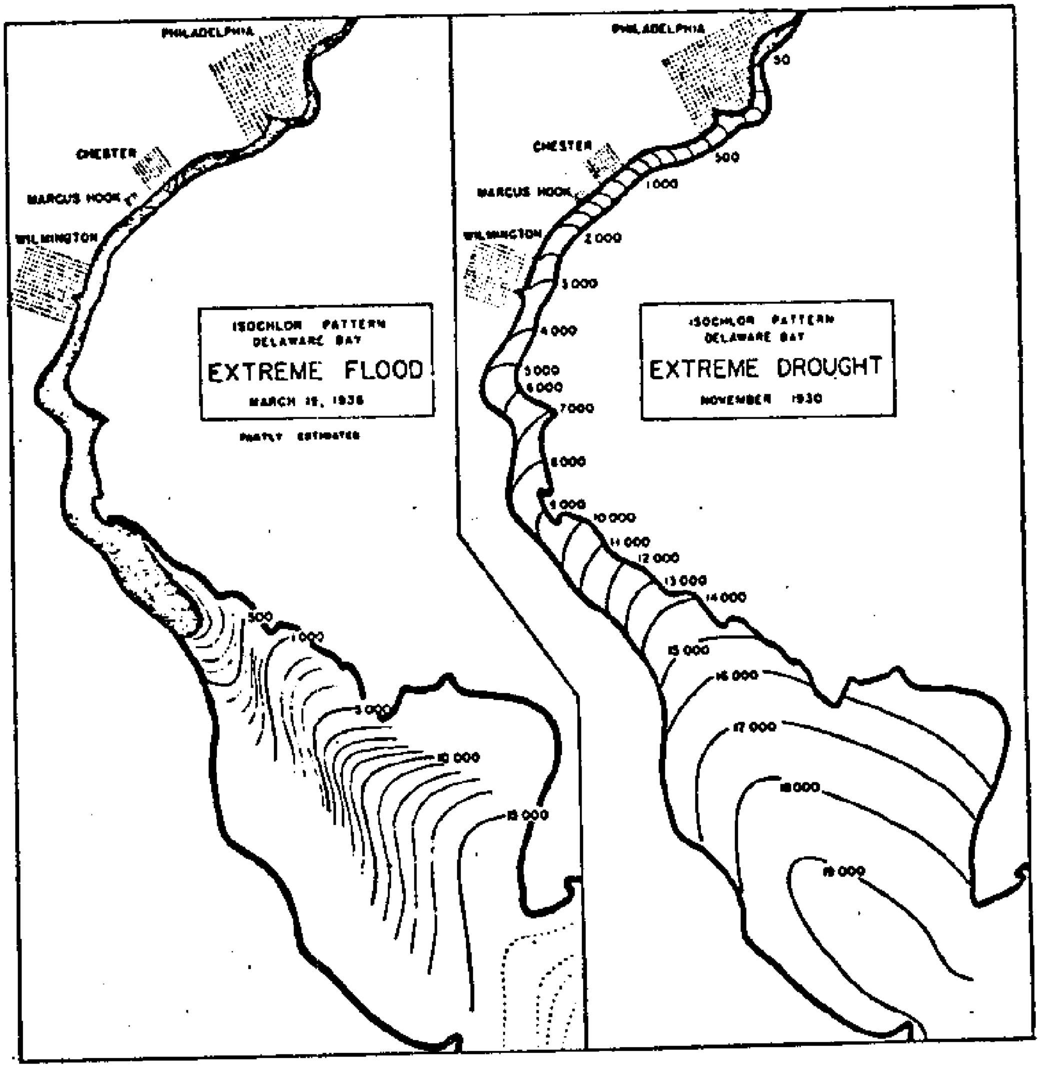


Figure 5. Isochlor patterns in Delaware Bay during extremes of river flow (from Mason and Pietsch, 1940).

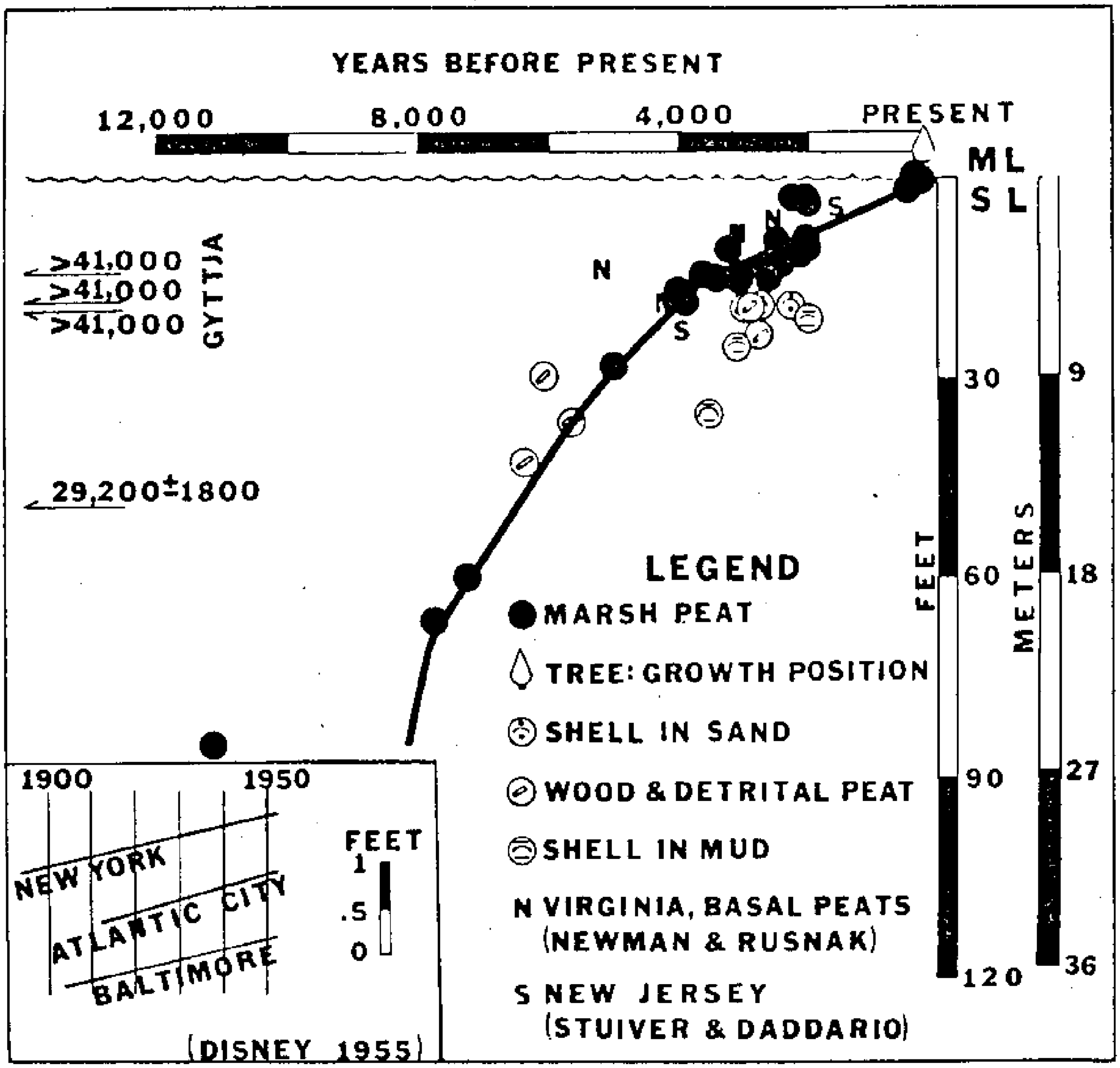


Figure 6. Relative rise of sea level for the Delaware coastal area. Radiocarbon dates are in years before present (B.P.) (from Kraft, Biggs and Halsey, 1963).

and those which followed, provided for widening and deepening the channel to Philadelphia; construction of dikes, jetties, and lighthouses; installation and maintenance of tide gauges; and establishment of the Overfalls Lightship. The Harbor of Refuge breakwater and ice breakers were built adjacent to Cape Henlopen to provide safe harbor for vessels along this section of the Atlantic coast (Emerson, 1950; U. S. Army Engineers, 1938; Boggs, 1926).

Development of the Navigation Channel between Delaware Bay and Philadelphia took place in four stages: (1) authorization of a 26-foot channel in 1885; (2) a 30-foot channel in 1889; (3) a 35-foot channel in 1910; and (4) a 40-foot channel to the Philadelphia Navy Yard in 1938, with a 37-foot channel up to the Philadelphia-Camden Bridge. In 1959, dredging began for an extension of the 40-foot channel upstream to within six miles of Trenton, New Jersey.

Army Corps of Engineers records indicate that the Federal Government dredged approximately 863 million cubic yards from the Delaware Estuary between 1874 and 1968. In recent years, channel dredging in the 40-foot channel amounts to seven to eight million cubic yards, five million of which comes from the Marcus Hook area and one million from the Mifflin range below the Schuylkill River (Hartzel, 1969).

One effect of channel dredging activities has been to alter significantly the range of tides in the estuary above Delaware Bay (Figure 17a). This increase in tidal range has been attributed to decreased frictional dissipation of the tidal wave (Harleman, 1966; Polis and Kupferman, 1973).

Channel dredging has also caused the upper limit of salt water influence to migrate upstream. During the 18th century, sailing vessels used the Delaware at New Castle below Wilmington as a source for potable water (Tyler, 1955). Present chloride levels at New Castle are at least 2600 ppm (Cohen, 1957, p. 34). No reliable records of pre-dredging salinity measurements are available to support this inference. However, recent model studies (FWPCA, 1966) on salinity distribution were conducted to determine the effects expected from proposed channel deepening and widening between Philadelphia and the sea. The proposed modifications were rejected because the chlorine concentrations at Philadelphia's Torresdale Water Treatment facility would have increased from the present 20 ppm (Cohen, 1957) to 50-85 ppm in the late fall with assured flow rates at Trenton.

In 1829, a canal was constructed between Chesapeake and Delaware Bays, reducing the sailing distance between Philadelphia and Baltimore by 295 miles. The Chesapeake and Delaware Canal has since been enlarged to a 35-foot-deep and 450-foot-wide sea level canal. Due to recent widening, the short-term, mean net flow of fresh water from Chesapeake Bay to Delaware Bay may, under extreme conditions, approach the flow of the Delaware River at Trenton (Boyd and others, 1973). This fresh water flow could cause a significant change in the salinity distribution, stratification, and tidal elevation in the tidal river estuary and Delaware Bay.

PHYSICAL DESCRIPTION OF DELAWARE BAY

The bathymetric map (Figure 7) shows the fringing tidal marshes, extensive subtidal flats near the shoreline, incised tidal channels, and linear sand shoals which characterize the morphology and major sedimentary environments of Delaware Bay. Each of these geomorphic features will be described in this section.

The Salt Marshes and Shoreline

Approximately 830 square kilometers of tidal salt marshes along the margins of Delaware Bay form the leading landward edge of the ongoing Holocene marine transgression of the ancestral Delaware River Valley (Kraft, 1971a, 1971b; Elliott, 1972; Meyerson, 1972). The relationship between depth of burial and radiocarbon age of basal marsh peat deposits indicates that the marsh surface has migrated upward and landward in response to sediment deposition and rising sea level (Figure 8). Where rivers, or the littoral drift system, or offshore Pleistocene subcrops supply sands to the bay shoreline, the marshes are overlain by a series of transgressive barrier beaches. Washover barriers characterize the

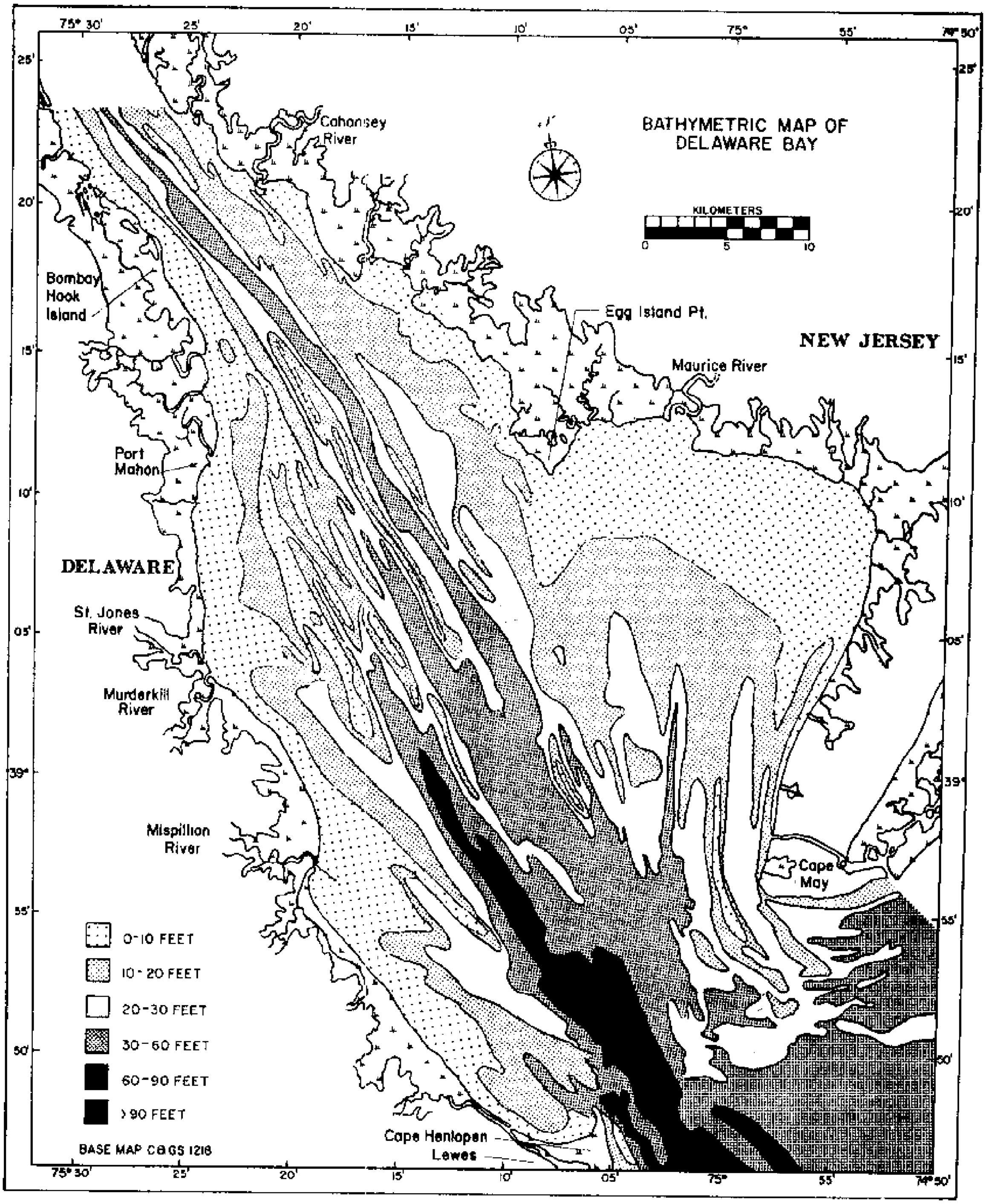
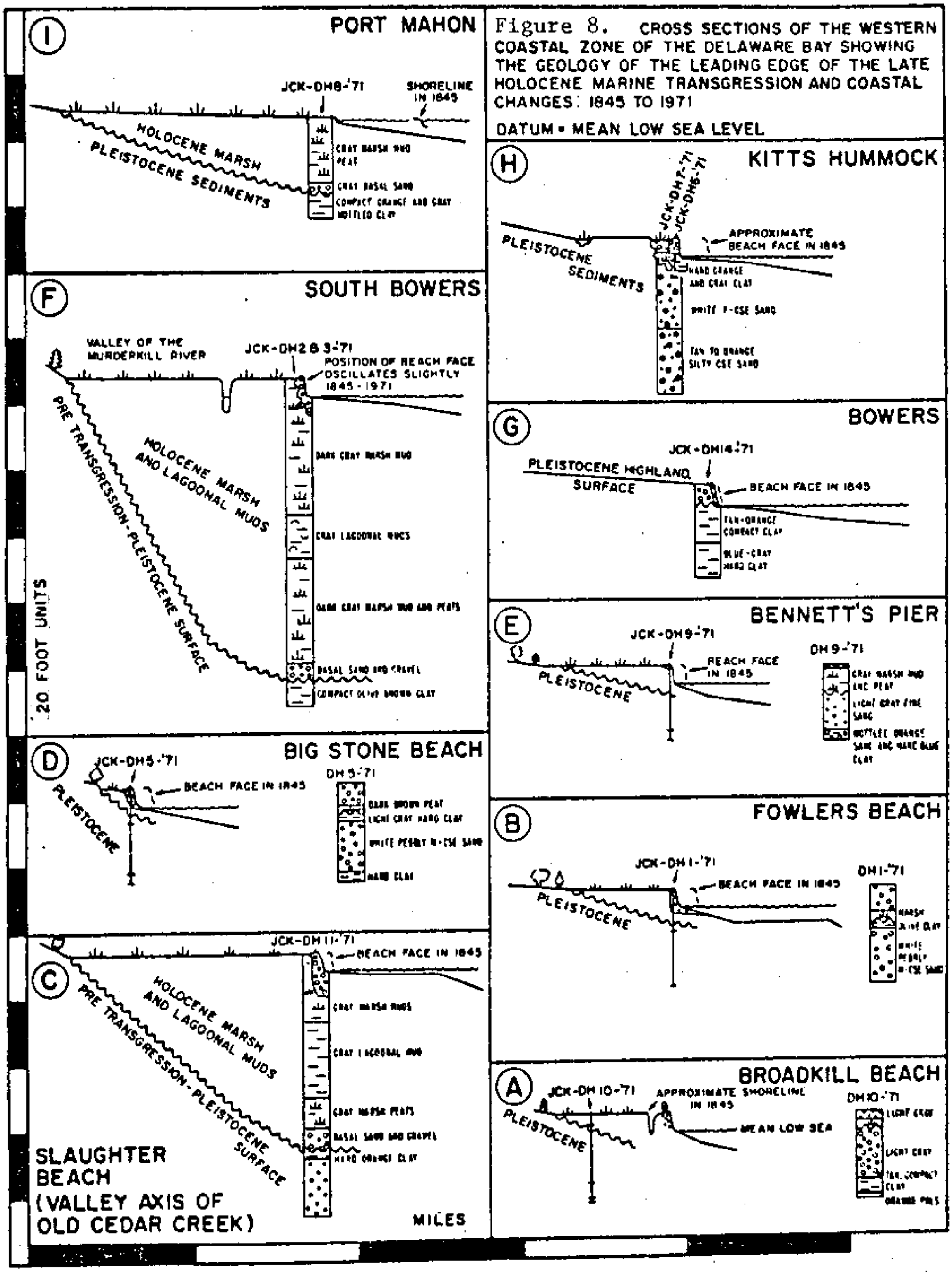


Figure 7. Bathymetric map of Delaware Bay. Contours, in feet, are taken from the navigation chart no. 1218 published by the U. S. Coast and Geodetic Survey (now National Ocean Survey).

Figure 8. CROSS SECTIONS OF THE WESTERN COASTAL ZONE OF THE DELAWARE BAY SHOWING THE GEOLOGY OF THE LEADING EDGE OF THE LATE HOLOCENE MARINE TRANSGRESSION AND COASTAL CHANGES: 1845 TO 1971

DATUM = MEAN LOW SEA LEVEL



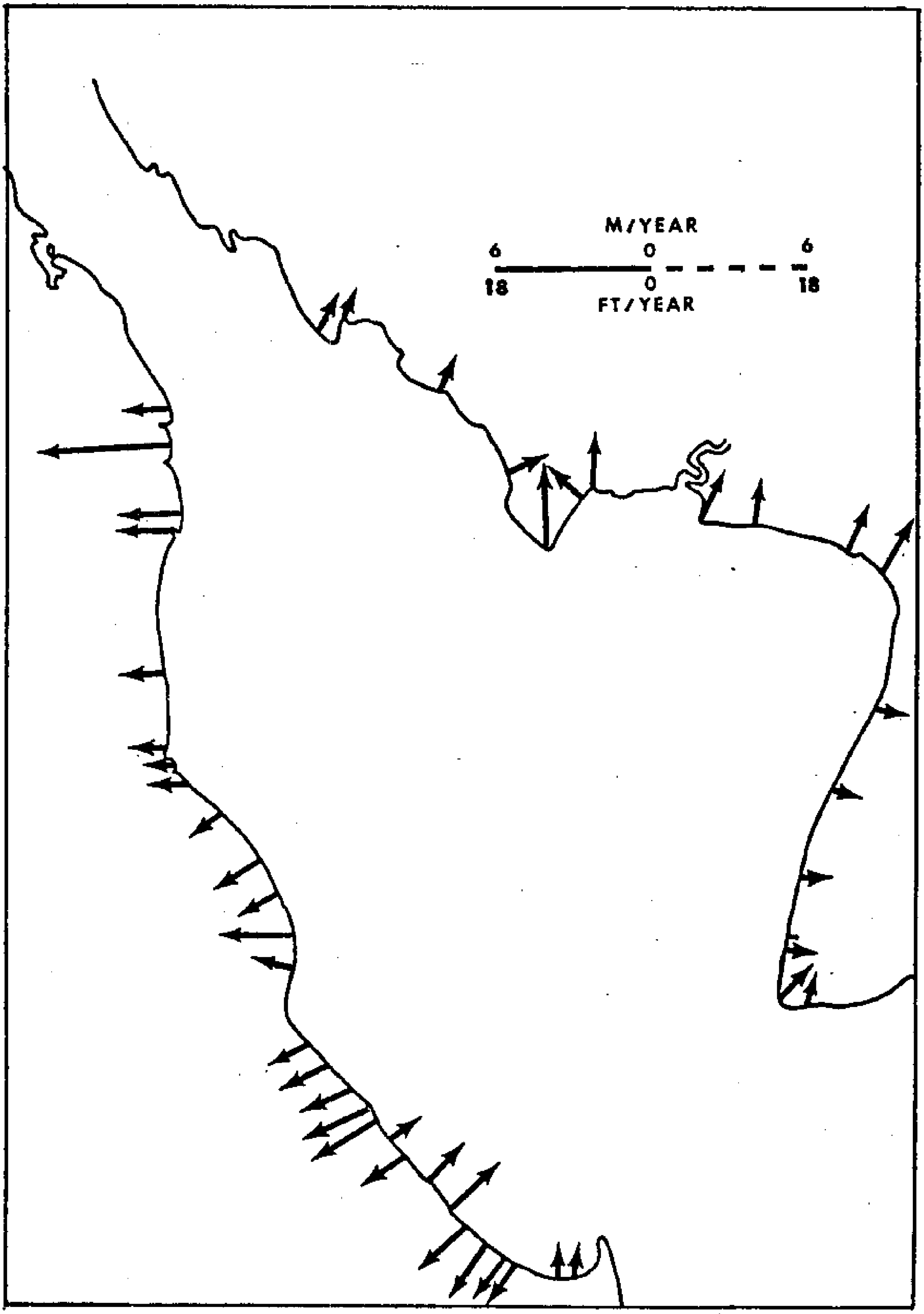


Figure 9. Average annual rate of shoreline erosion in Delaware Bay from 1848 to 1972, compiled from aerial photographs and U. S. Coast and Geodetic Survey maps of the bay.

lower 40 kilometers of the bay's western shoreline, but further north and along the eastern shoreline of the bay, the washover barriers are rare and discontinuous (Kraft 1971b, 1974). In those areas of the bay where there is no source of sands, the bay-facing edge of the marsh is subject to erosion by wave and block slumping. The shorelines of the bay are eroding at an average rate of one meter a year, except in the vicinity of dock and pier facilities behind Cape Henlopen, and the groins and jetties between Broadkill and Primehook beaches (Figure 9). Cape Henlopen, at the mouth of the bay, is the only natural prograding section of the bay shoreline.

The Subtidal Flats

The nearshore areas of Delaware Bay are characterized by extensive subtidal flats which are subject to erosion and sediment reworking by waves and tidal currents. Subtidal flats in less than four meters of water comprise 40 percent of the bay area (Figure 10), and extend as far as 15 kilometers from the shore. Close to shore, the subtidal flat may represent eroded tidal marsh muds which outcrop on the bay bottom (Figure 11) or outcrops of Pleistocene sands and gravel from which the overlying marsh sediments have been eroded (Figure 8). Further from shore, interlaminated muddy sands and sandy muds occur on the flats (Jordan, 1968). The low relief subtidal flats are commonly dissected by finger-like flood tidal channels with linear sand shoals along the margins of the tidal channels.

Channels

There are two distinct types of channels in Delaware Bay: the river channel and finger-like flood tidal channels (Figure 12). The Delaware River channel can be traced from the upper bay to the lower bay. Along this stretch, the river or navigation channel is fairly straight and is bounded by six linear sand shoals. Channel depths ranging from 12 to 17 meters are natural and no dredging is required to maintain the authorized channel depth of 12 meters (Wicker, 1969). South of Brown Shoal, the river channel is no longer confined by sand shoals and becomes indistinct, with no clear expression in the bathymetric contours.

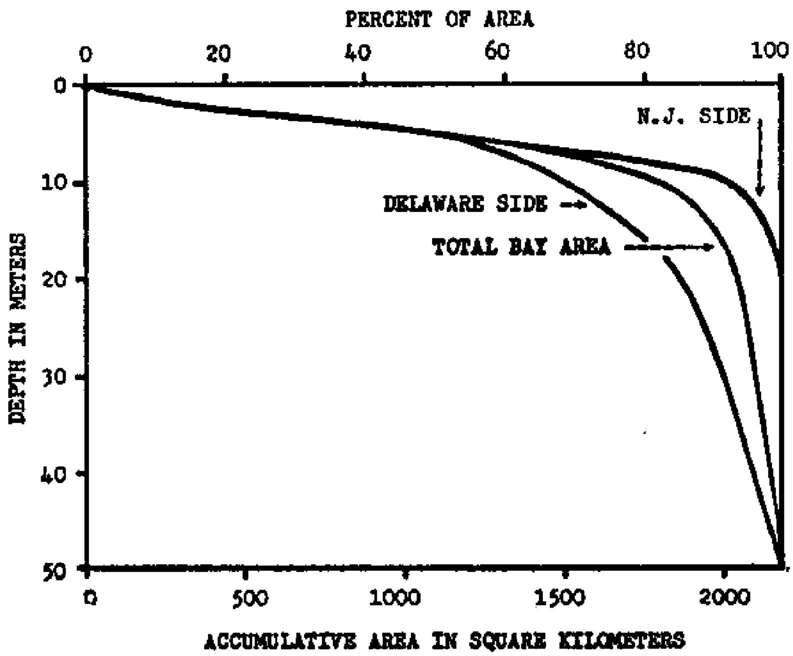


Figure 10. Hypsographic curve of Delaware Bay (after Schuster, 1959).

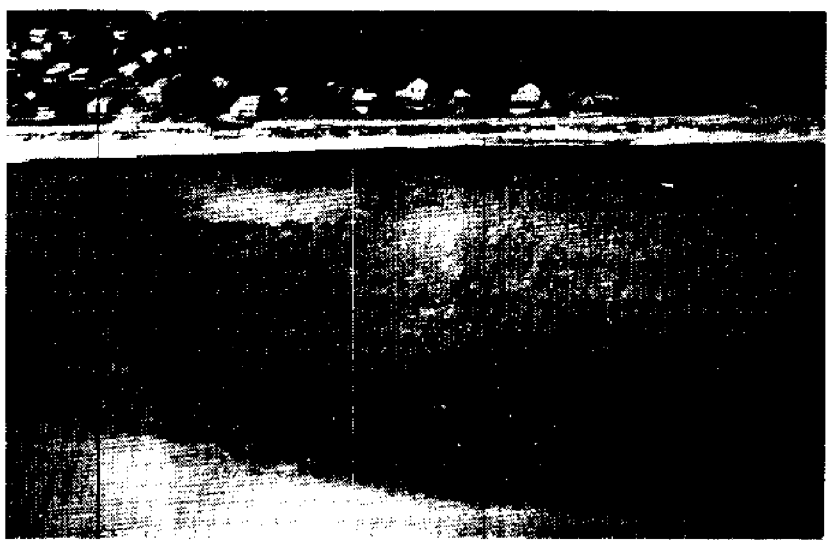


Figure 11. Oblique aerial photograph of an eroded subtidal marsh subcrop near Kitts Hummock, Delaware. A washover barrier beach and tidal marsh are visible in the background (courtesy of Elizabeth Allen).

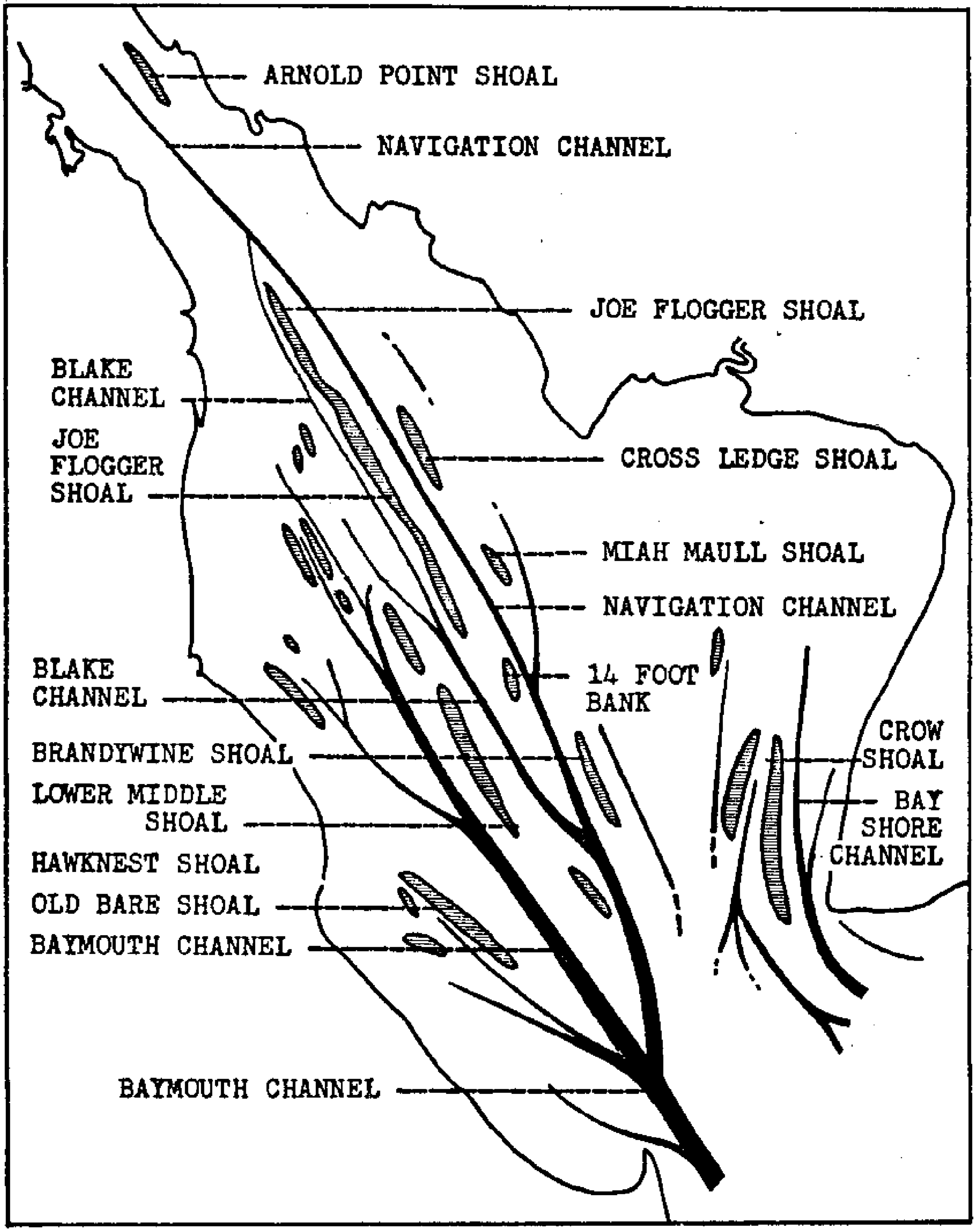


Figure 12. Distribution and relationship of tidal channels and linear sand shoals in Delaware Bay.

Parallel to and west of the Navigation Channel are the Blake and Baymouth Channels. Both these channels are open to the flood current, shoal in the upbay direction, and have been compared to Van Veen's "flood channel" by Oostdam (1971). These and ten smaller flood channels are straight and have a fan-like distribution radiating from the bay mouth, trending north-south on the eastern side and north-northwest on the western side of the bay. Depths within Blake Channel are comparable to those in the Navigation Channel. The deepest parts of the bay occur in the Baymouth Channel, with a maximum depth of 46 meters.

Linear Sand Shoals

Thirteen linear sand shoals adjacent to the tidal channels in Delaware Bay were originally described as "tidal current ridges," shaped by and oriented parallel to the tidal currents (Off, 1963). The linear shoals are asymmetric in cross section, with the long axis of each shoal aligned parallel to the adjacent tidal channel (Figure 12). The heights of the shoals range from 1.5 to 6 meters and their crests rise to within 0.6 to 1.8 meters of mean low water. Morphologically, these linear sand ridges are very similar to those described on the western Atlantic Continental Shelf (Duane and others, 1972), the North Sea (Caston, 1972; Houbolt, 1968) and other areas of the world.

Baymouth Complex

The mouth of the bay is 18 kilometers wide, and water depths range from 1.6 to 50 meters. The Cape May Shoal Complex, a broad shallow sill or estuary-mouth shoal (Swift, 1973), extending south from the shoreline at Cape May to the Baymouth Channel, is characterized by a complex array of linear to arcuate sand shoals separating mutually evasive pairs of tidal channels. The channels are up to 10 meters deep and maximum current velocities reach 1.7 meters/second. Seismic profiles across the shoals show extensive fields of sand waves similar to those described by Ludwick (1972) on a morphologically similar shoal complex at the mouth of Chesapeake Bay.

South of and adjoining the Cape May Shoal Complex is the Baymouth Channel, consisting of three distinct depressions greater than 18 meters in depth. The deepest depression lies on a line between the Capes and will be called the inlet trough. The two depressions upbay from the inlet trough will be called the ramp to the bay, and the seaward extension of the inlet trough depression the ramp to the sea. The axis of the present Delaware Shelf Valley is approximately parallel to that of the Baymouth Channel, but is offset by 4.5 kilometers to the north. The Baymouth Channel extends only 13 kilometers seaward from the inlet trough, while the Delaware Shelf Valley continues almost 100 kilometers across the Continental Shelf seaward from the base of the Cape May Shoal Complex.

Cape Henlopen, a recurved spit complex on the south side of the bay mouth is the only natural prograding shoreline feature in the bay. The long-term growth of the Cape is the result of accumulating littoral drift sediments at the intersection of the bay and Atlantic shorelines. Sediments eroded from and transported north along the Atlantic coast converge with sediments derived from and moving southeastward along the bay shoreline (Figure 13).

ESTUARINE CIRCULATION IN DELAWARE BAY

The energy for sediment erosion and transportation in Delaware Bay is derived from the tide, wind, waves, and estuarine circulation. Man's activities have modified both the natural tidal effects and estuarine circulation in the tidal river, but in the bay it is difficult to determine the extent to which natural processes may have been affected or modified by man's activities.

Because of its large size and variation in depth, Delaware Bay exhibits both a moderately stratified, type B estuarine circulation (Figure 14) and a vertically homogeneous, type C circulation pattern (Pritchard, 1967; Pritchard and Carter, 1971). Waters in the deep channels of the bay are moderately stratified (Cronin and others, 1962), while the shallow areas of the bay are well mixed and vertically homogeneous

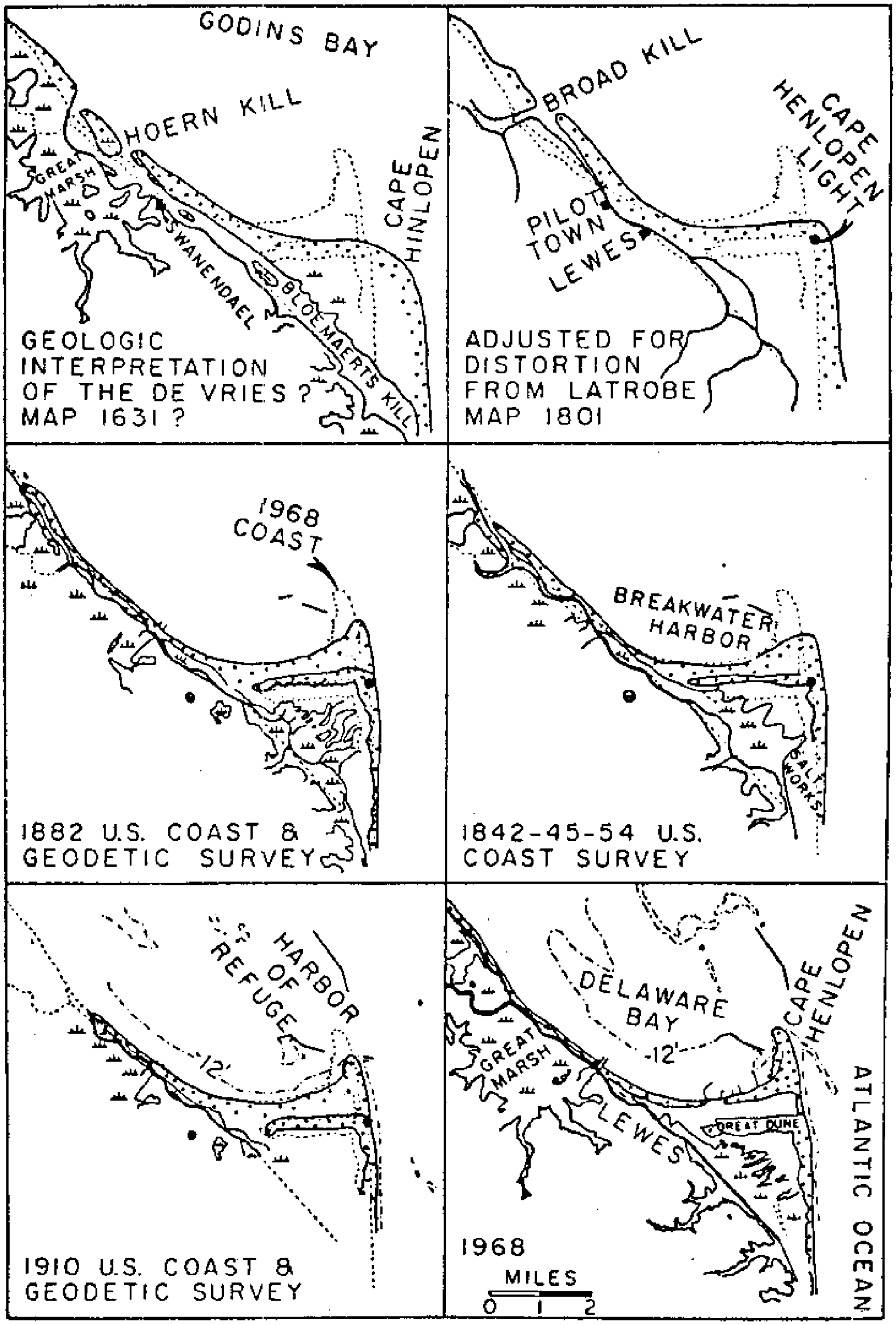


Figure 13. Historical changes and growth of Cape Henlopen, Delaware, 1631 - 1968 (from Kraft, 1971b).

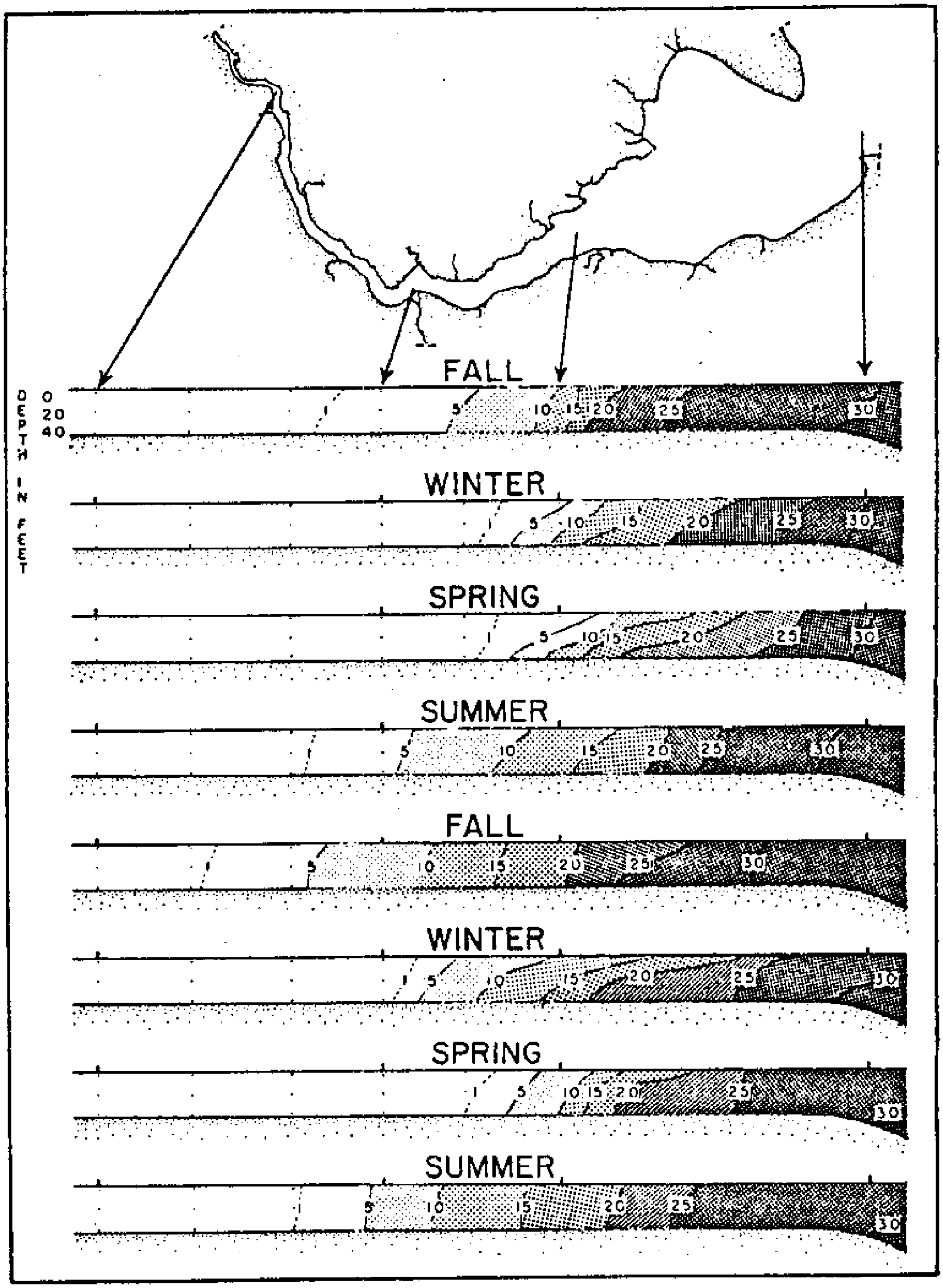


Figure 14. Seasonal variation of isohalines along the axis of Delaware Bay (from Cronin and others, 1962).

(Oostdam, 1971). The general circulation pattern of the bay, while subject to modification caused by changes in fresh water discharge and meteorological effects, is characterized by a strong net landward movement of bottom waters and a net seaward flow at the surface (Figure 15). Measurements of tidal current, river discharge, and wave height (Zeskind and LeLacheur, 1926; Oostdam, 1971; Maurer and Wang, 1973) clearly indicate that the tide is the dominant driving force for the currents and sediment transport in most of the bay.

Along its entire length, the width of the Delaware channel decreases exponentially from the Atlantic to the head of tide (Figure 19a), producing the classic funnel shape characteristic of river courses with a moderate tidal range (Wright and others, 1973). The tidal range increases up the estuary from 1.3 meters at the bay mouth to 2.0 meters at the head of tide (Figure 17a). In general, the currents in the bay are linear reversing, flowing parallel to the axes of the tidal channels (Figure 16). One exception occurs at the inlet trough where there is a pronounced clockwise rotation of flow direction throughout the tidal cycle. The Coriolis force modifies both the tidal and nontidal flows in the bay. Flood currents are deflected toward the New Jersey shoreline while ebb currents are deflected toward the Delaware shore (Zeskind and LeLacheure, 1926). These deflections affect the salinity distribution across the bay (Figure 5) and the distribution of fine sediment in the upper bay (Biggs, 1972), and cause the tidal range to be greater on the eastern side of the bay than on the western side (Figure 17b). A westward flowing, net-nontidal flux of 6.8 cm./sec. has been reported in the upper end of the Baymouth Channel (Dennis Polis, personal communication).

<u>Relationships of Estuarine Circulation and Sedimentation</u>

The tide, as noted above, is the principal driving force for currents and sediment transport in the greatest part of the bay. Within the bay, tidal currents are strongly influenced by the Coriolis force. The effects of wave action are greatest near shore and on the tops of shoals. Analyses of current measurements, suspended sediment data (Oostdam, 1971) and ERTS-1

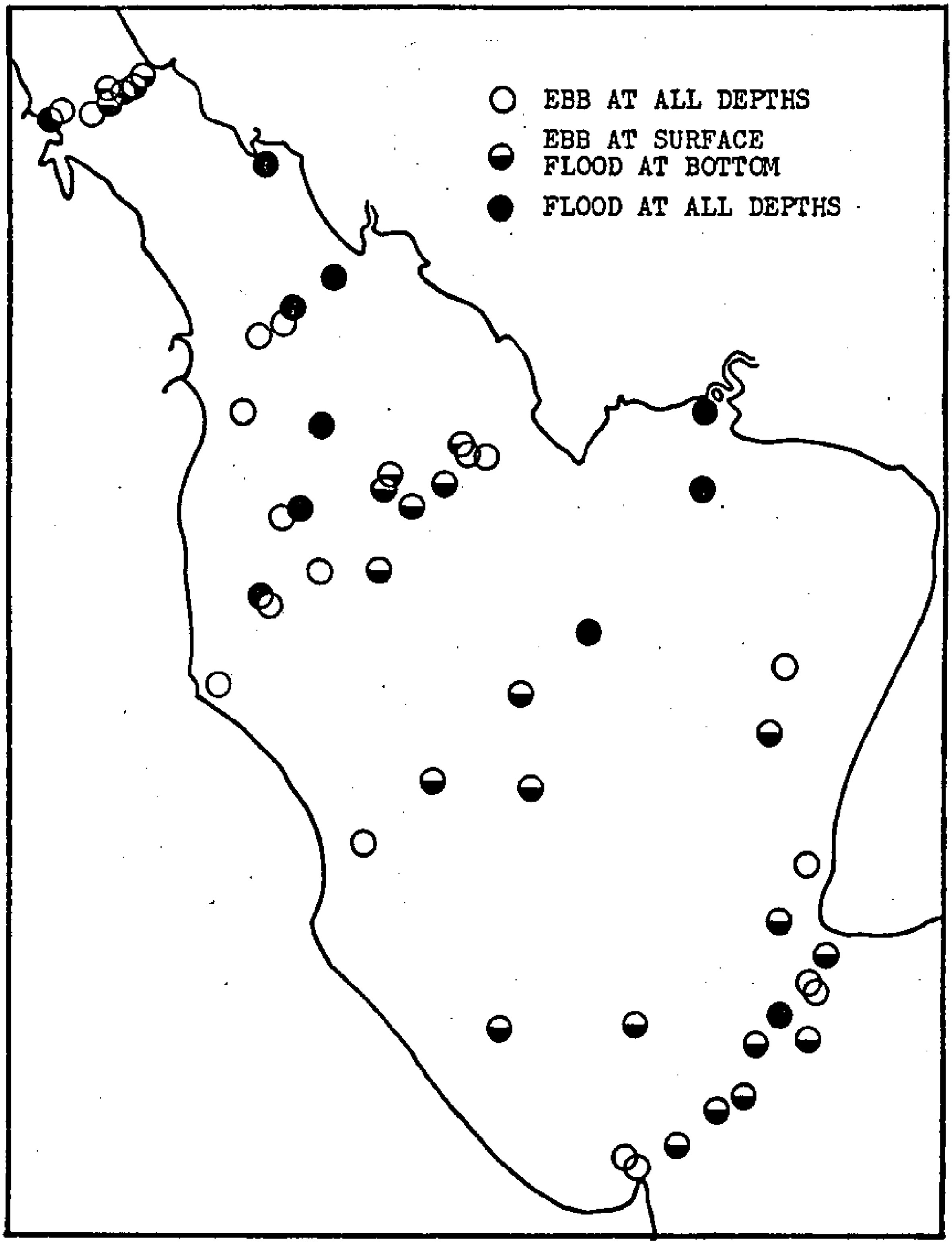


Figure 15. Dominant average tidal transport direction at the surface and bottom of Delaware Bay (based on U. S. Coast and Geodetic Survey data in Polis and Kupferman, 1973).

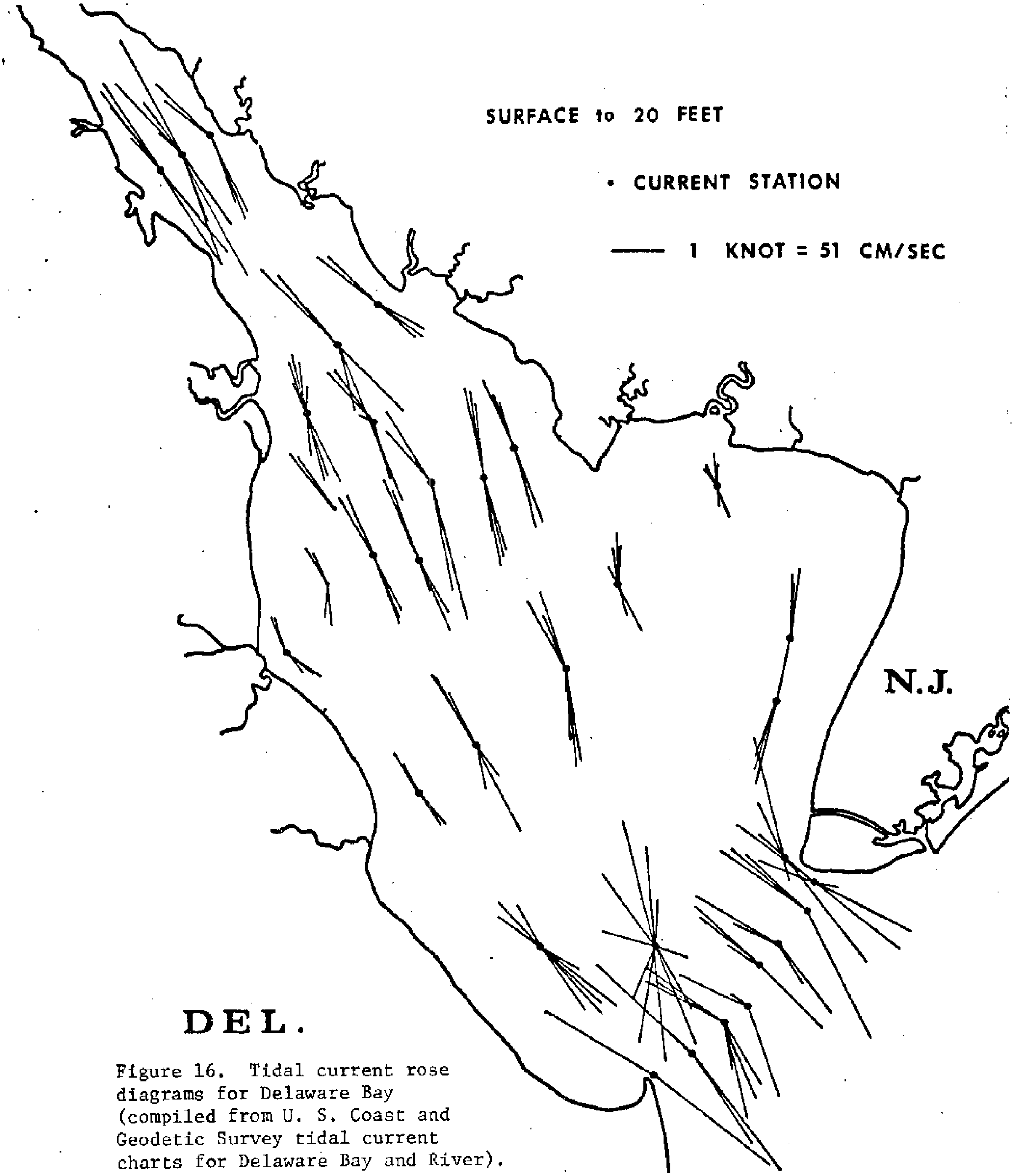


Figure 16. Tidal current rose diagrams for Delaware Bay (compiled from U. S. Coast and Geodetic Survey tidal current charts for Delaware Bay and River).

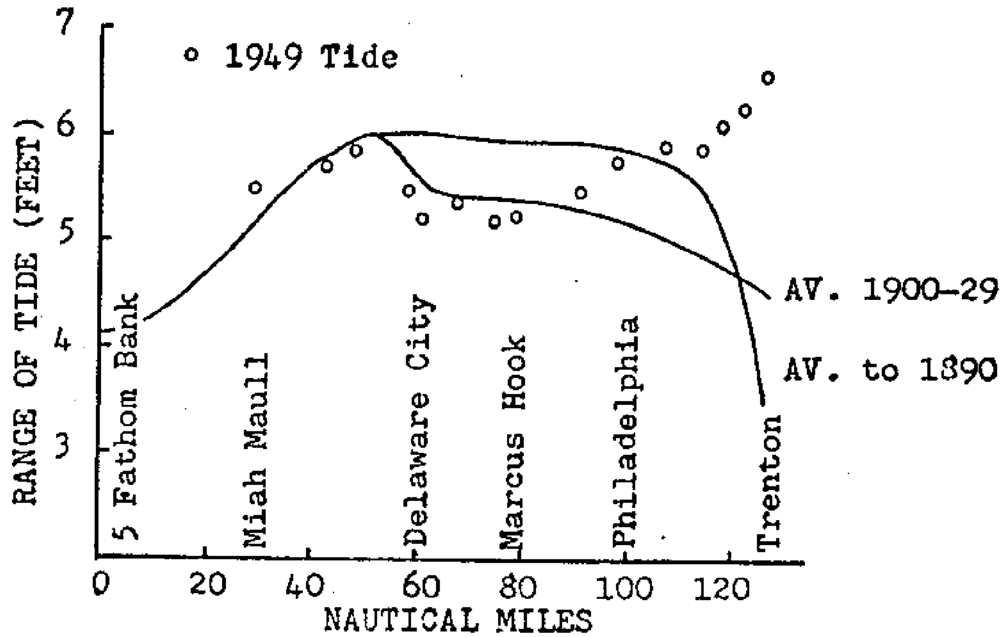


Figure 17a. Variations in tidal range along the axis of the Delaware Estuary (from Zeskind and LeLacheur, 1926).

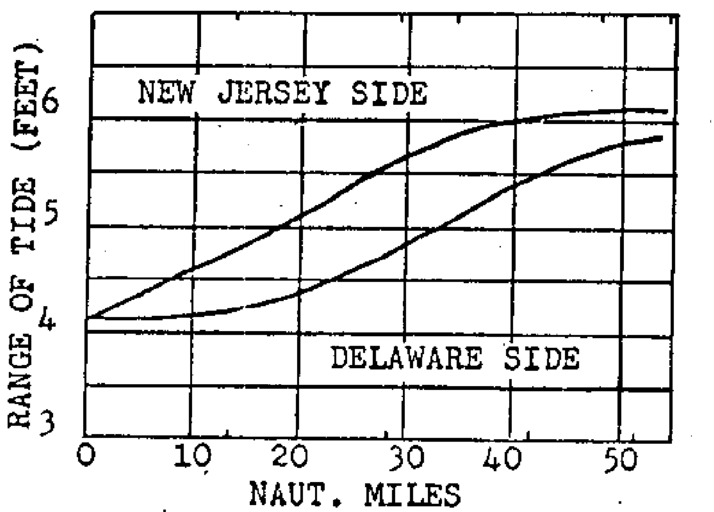


Figure 17b. Variations in tidal range across Delaware Bay due to influence of Coriolis force (from Zeskind and LeLacheur, 1926).

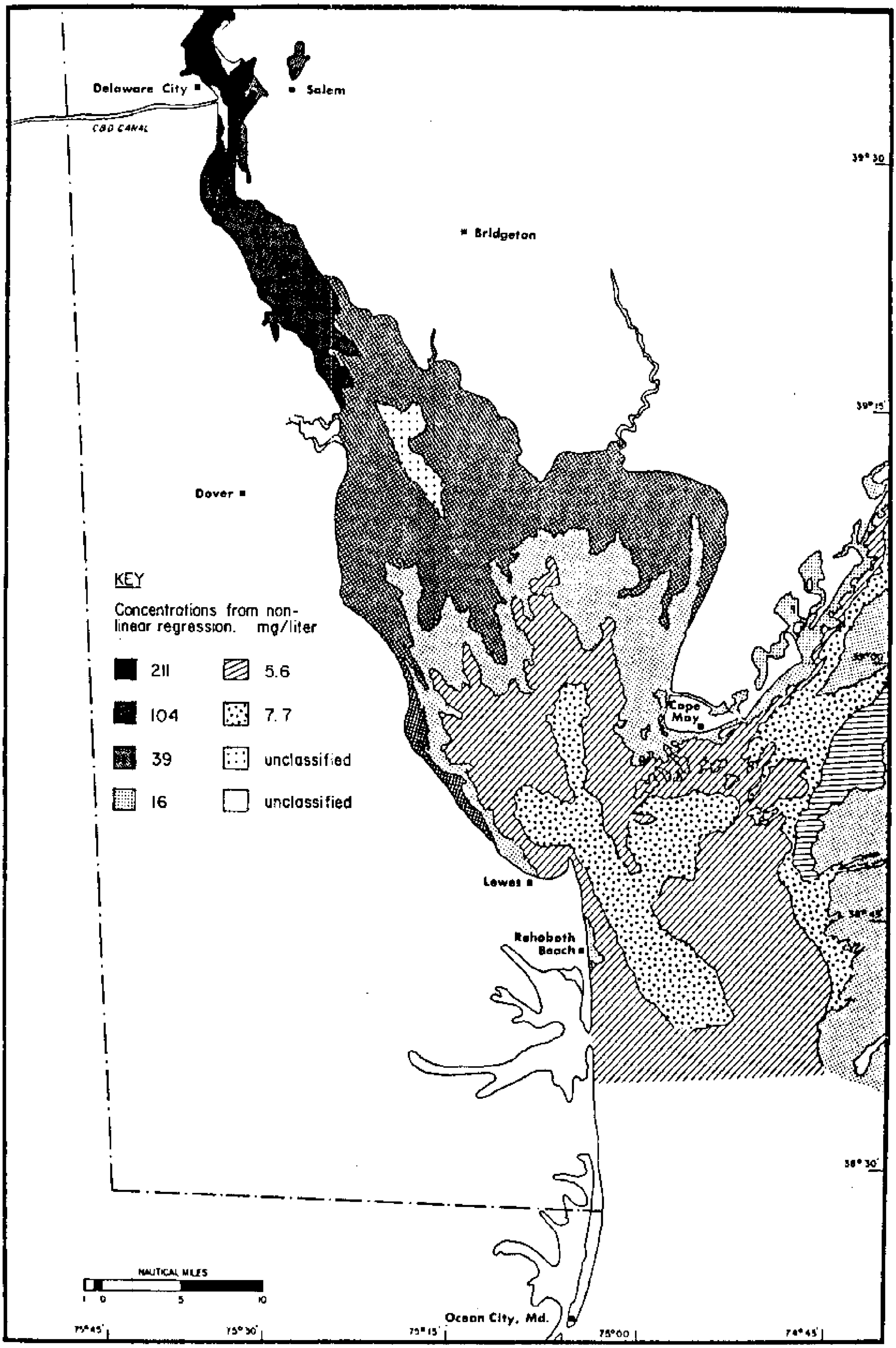


Figure 18. Synoptic distribution of suspended sediment in Delaware Bay, prepared by correlating image brightness of satellite pictures with ground truth water samples collected from boats and helicopters (courtesy Dr. V. Klemas).

satellite imagery (Klemas, 1973) have shown the direct relationship between tidal stage, current velocity, and the amount of sediment in suspension. These data also show that the distribution of suspended sediment concentrations is generally: (1) higher in the shallow nearshore areas than in the deeper waters of the central bay (Figure 18); (2) higher during the flood than the ebb in the nearshore areas; (3) higher during the ebb than the flood in the central bay; and (4) higher near the surface than the bottom in the central channels of the lower bay.

To some degree, each of the physical processes described in this section influences the behavior and distribution of sediments in the Delaware Estuary. The present day relationships between the physical, hydraulic, salinity, and mid-channel sediment deposition in the estuary are summarized in Figure 19. These relationships can change on a short-term daily basis, due to the effects of storms, floods, droughts, and the activities of man. Any of these changes can produce major changes in the estuarine sedimentation pattern. Long-term changes in the sedimentation pattern have resulted from changes in river discharge, changes in the character and volume of sediment load, and the filling and drowning of the Delaware River valley. The second half of this study is an examination of the distribution and character of the sediments in Delaware Bay, and how they and the physical parameters of the estuary have changed during the past 12,000 years.

SURVEY AND ANALYSIS METHODS

For this study, grain-size data from 411 bottom samples and 413 samples from 50 piston cores, 1,600 line kilometers of high resolution seismic reflection profiles, and 50 kilometers of side-scan sonar profiles were analyzed to provide a detailed synthesis of surface and subsurface sediment distribution and structure in Delaware Bay. The locations of all sediment samples, core sites, and geophysical profiles are plotted on Figures 20 and 21 respectively.

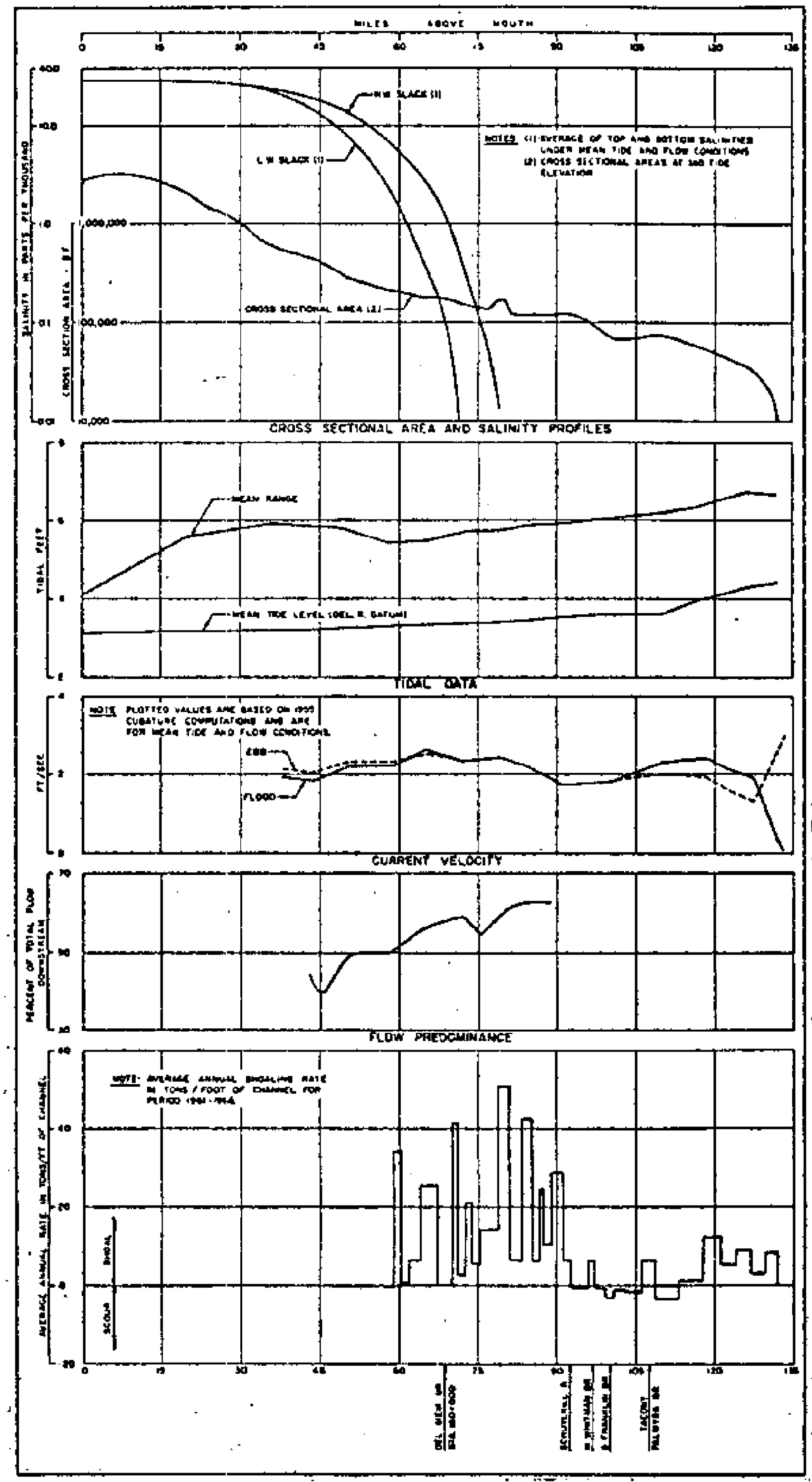


Figure 19. Summary of the geometric, hydraulic, salinity and shoaling characteristics of the Delaware Estuary (from U. S. Army Corps of Engineers, 1973a).

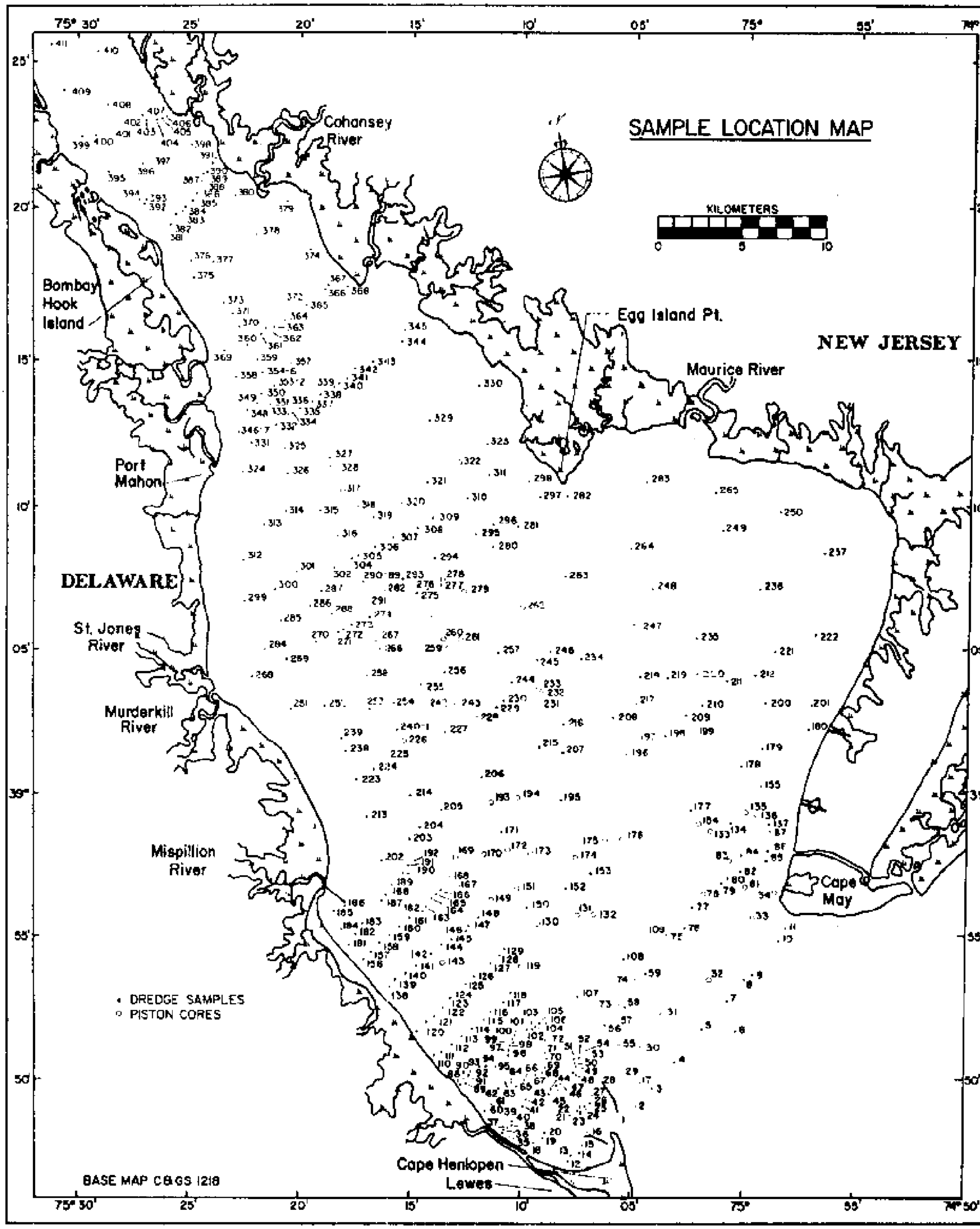


Figure 20. Location of surface sediment samples and piston cores used in Delaware Bay study.

Figure 21. Location of 7 kHz seismic reflection profiles in Delaware Bay.

Bottom samples were collected from the upper 5 to 10 centimeters of the sediment between May 1971 and November 1972 with a modified Foster-Anchor dredge (Kraft, 1971b). In addition, the results of size analyses of 178 bottom samples provided by R. N. Strom and Don Maurer have been incorporated into the study.

Each piston and vibratory core was described visually, photographed, and samples were taken for size analysis. The dredge and core sediment samples were air-dried and split, and those with a high mud content were wet-sieved. The sand-size fraction was sieved on a Ro-Tap at one-half phi intervals. The silt and clay-size fractions were analyzed by pipette. The results of all size analyses, the computer-calculated graphic parameters (Folk and Ward, 1967), and other pertinent information have been tabulated by Weil (1976). Tabulations of these data for all surface samples are presented in Appendix I. The mapped distributions of the sediment characteristics are presented in the following section.

SURVEY RESULTS

Surface Sediment Characteristics

Textural Distribution

The mapped distribtuion of the median diameter of the sand and gravel-size fraction (Figure 22) closely resembles the patterns of the bathymetric map (Figure 7). Coarse-to-medium sands dominate the mouth of the bay and extend upbay in narrow linear bands that coincide with the axes of the major tidal channels. Generally, the coarsest sands occur in the bottoms of the channels. Within any channel, the median grain diameter decreases in the upbay direction and away from the center of the channel. Very fine sands characterize the linear sand shoals, the channel margins, most of the lower Jersey Platform, and all of the Delaware Platform except the area between Mispillion River and Lewes Harbor. Major departures from the upbay and shoreward fining pattern occur on the Upper Jersey Platform and the Cape May Shoal Complex, where sediments become coarser in the shoreward direction.

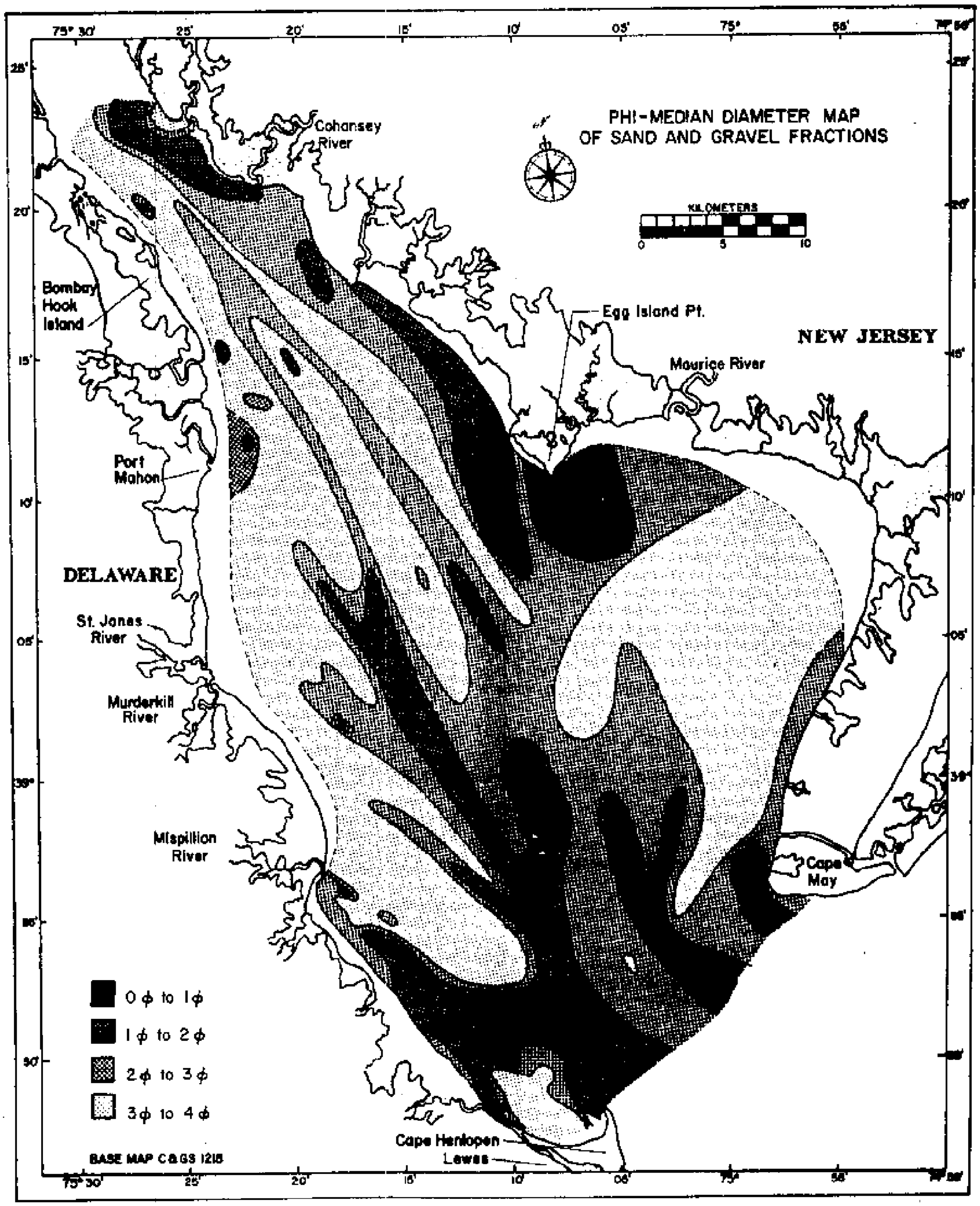


Figure 22. Map of median grain size (in phi units) of sand and gravel-size fractions in Delaware Bay bottom sediments.

The map pattern of the inclusive graphic standard deviation or sorting (Figure 23) also shows a series of linear trends which closely parallel the axes of the tidal channels. Very well sorted sands (0.50ϕ) are limited to the crests of the linear sand shoals, while well sorted sands (0.35 - 0.50ϕ) are much more widespread, occurring on the flanks of the tidal channels and subtidal flats of the middle bay. Bands of moderately well sorted sands (0.5 - 0.7ϕ) radiate upbay from the mouth of the bay and occur as linear bands on the subtidal flats and in the central areas of the upper bay. Poorly sorted sands (0.7 - 1.0ϕ) occur in the lower bay channels, in the Navigation Channel in the central bay, and on subtidal flats in the upper bay. Very poorly sorted sands occur in the lower Baymouth Channel, Bayshore Channel, upper Navigation Channel, and a nearshore zone of the Upper Jersey Platform.

The best sorted sediments are associated with the linear sand shoals and the flanks of the tidal channels. Sorting becomes poorer toward the bay shoreline and in the upbay direction. Sands in the Blake and Navigation Channels are better sorted than those in the Bayshore and Baymouth Channels of the lower bay.

Reflecting the general patterns of the median diameter and standard deviation maps, Delaware Bay sands become more finely skewed in the upbay direction and toward the shoreline (Figure 24). Extensive areas of fine and strongly fine skewed sands (1 - 0.1) cover most of the Upper Jersey Platform, thin as a wedge from the midbay region toward the bay mouth, and extend from the Delaware shoreline out to sea along the western edge of the Baymouth Channel. A band of near symmetrical sands (0.1 to -0.1) along the eastern edge of the Baymouth Channel bifurcates below Brandywine Shoal toward Egg Island Point and extends upbay in the Baymouth and Blake Channels. Linear bands of coarse and very coarse skewed sands (-0.1 to -1.0) occur on both sides of the Baymouth Channel near the Capes, extending up the Bayshore and Old Bare Channels. The deeper waters behind Cape Henlopen are characterized by strongly fine skewed sands.

The weight percent of mud (less than 62 microns) is greater than 10 percent in all nearshore areas of the bay except for portions of the Upper Jersey Platform and the area between Broadkill Beach and the Mispillion

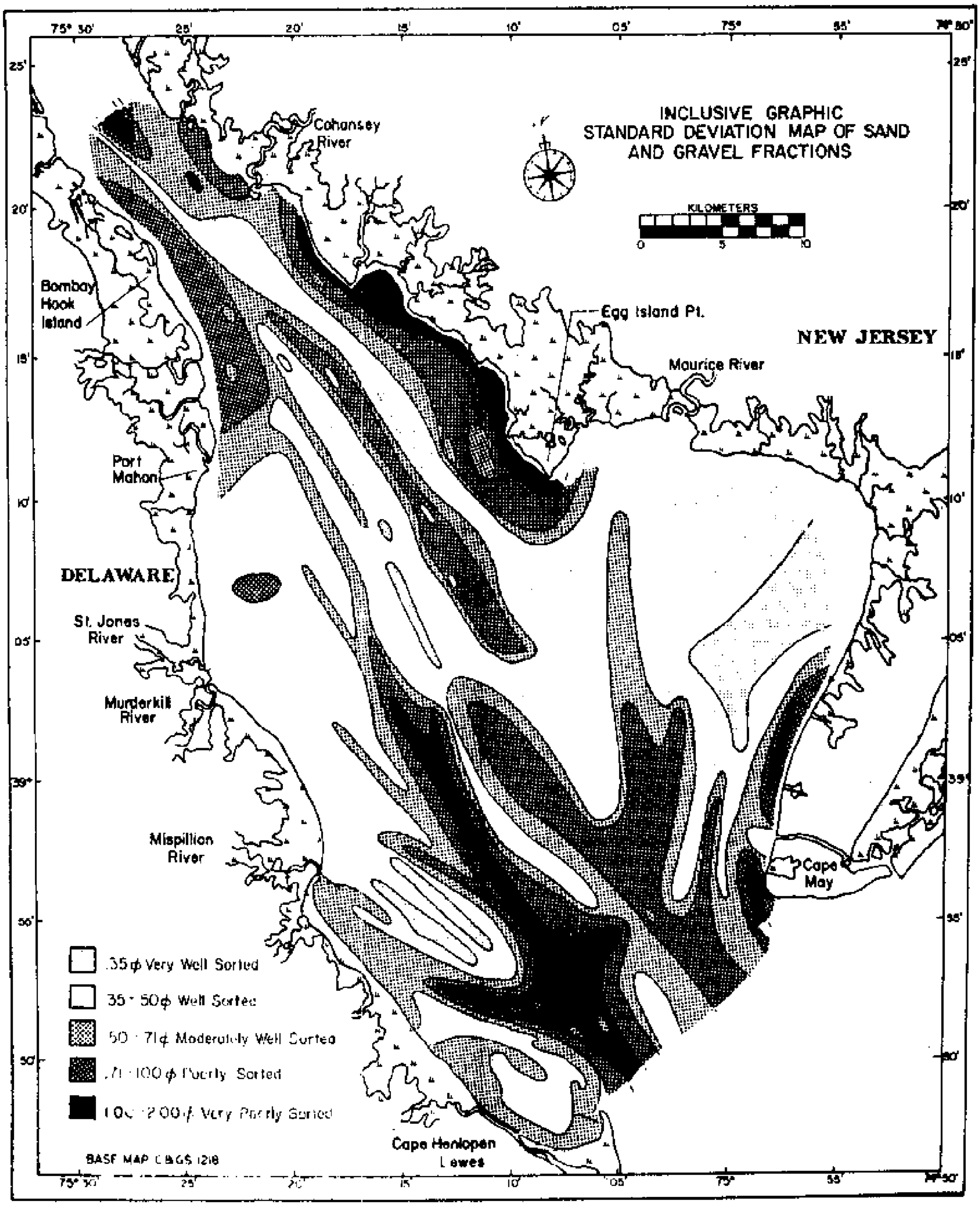


Figure 23. Map of inclusive graphic standard deviation (in phi units) of sand and gravel-size fractions in Delaware Bay bottom sediments.

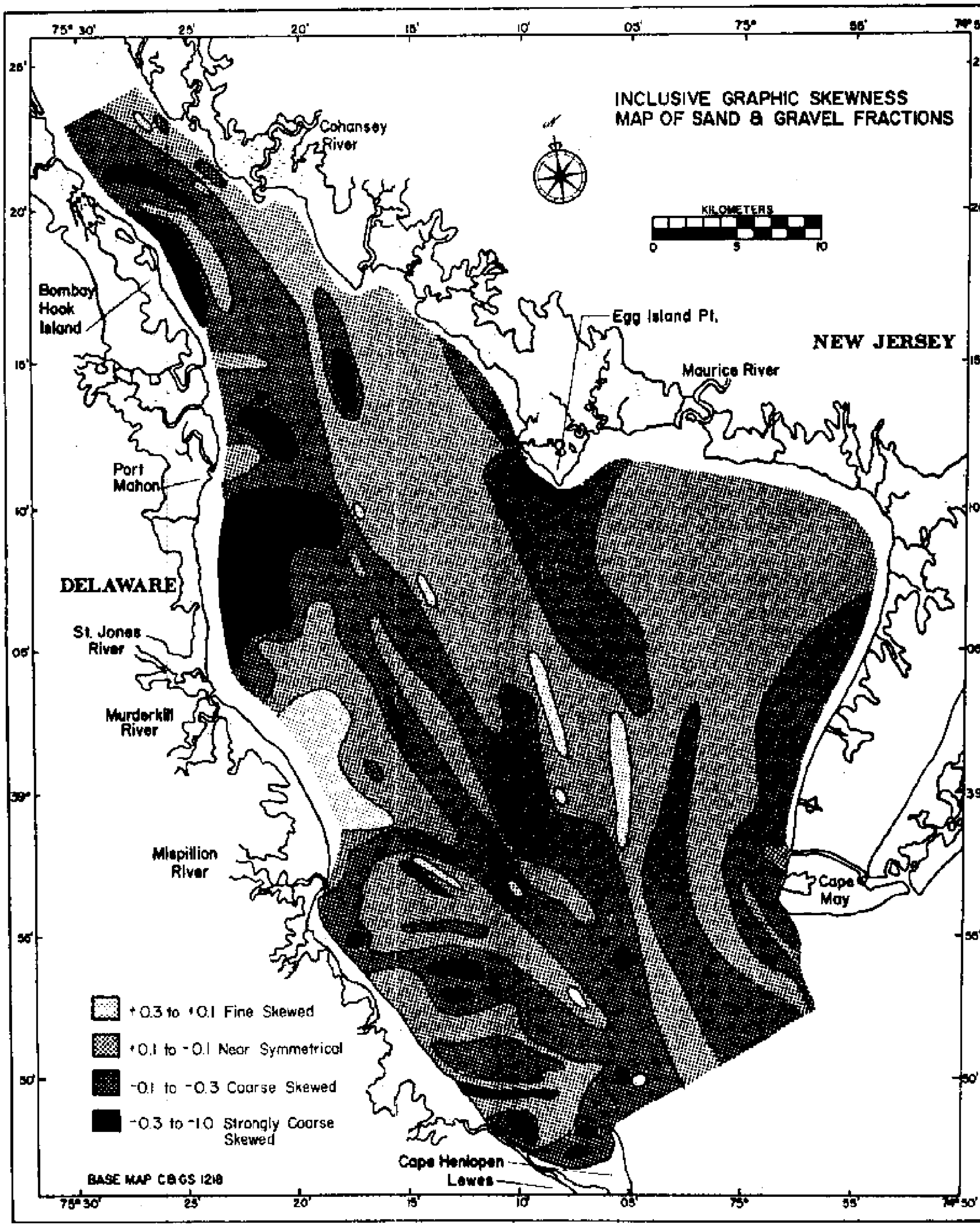


Figure 24. Map of inclusive graphic skewness of sand and gravel-size fractions in Delaware Bay bottom sediments.

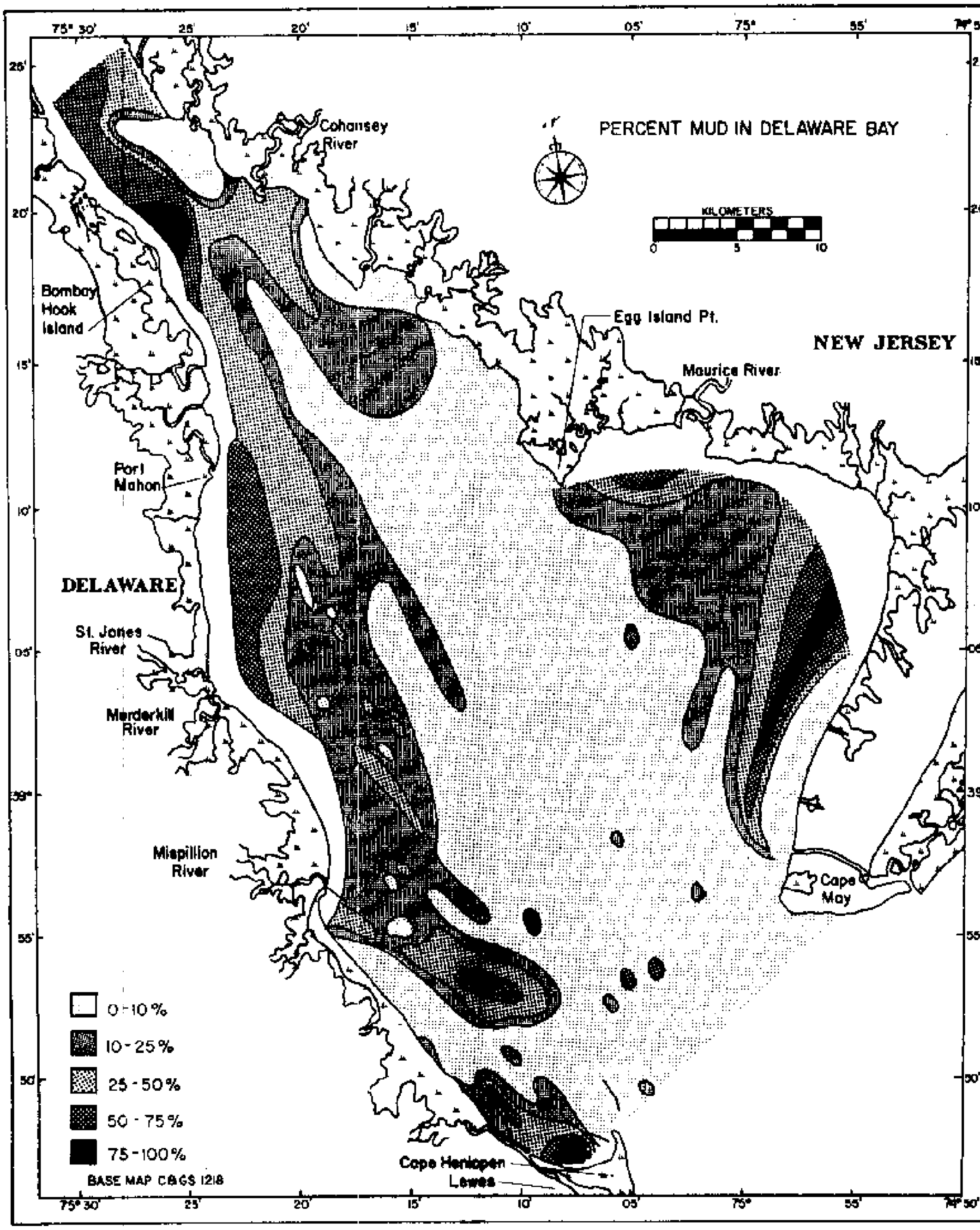


Figure 25. Distribution of weight percent mud (less than 62 micron diameter) in Delaware Bay bottom sediments.

River (Figure 25). Muddy sediments (greater than 10 percent mud) also occur on the Lower Jersey Platform in a "shadow zone" behind Cape May. There is a similar shadow zone of high mud accumulation behind Cape Henlopen. Muddy sediments extend upbay from the Mispillion River to the center of the Navigation Channel opposite Bombay Hook.

Sediments in the central areas of the lower and middle bay are characterized by less than 10 percent mud. Toward the margins of the bay, there is an offset en-echelon or interfingering pattern of the 10 percent mud contour, especially along the western shore. The higher mud values occur at the heads of the tidal channels, with lower mud values occurring adjacent to the channels on the linear sand shoals where winnowing effects of waves and currents are greater.

Folk's (1968) sediment texture classification (Figure 26) was used to grade all bottom sediment samples from the bay. The mapped distribution of the texture classes (Figure 27) shows that sands dominate the central areas of the bay from the mouth to the upper end of Joe Flogger Shoal. Linear bands of gravelly sand with up to 29 percent gravel occur in the lower bay channels and on the Upper Jersey Platform. A band of muddy sands extends along the Delaware Platform north of Old Bare Shoal and on large areas of the Lower Jersey Platform. Large areas of sandy mud occur at the head of the Bayshore Channel and along the Delaware coastline between the Murderkill and Smyrna Rivers. Patches of sandy mud also occur in Lewes Harbor and at the upper ends of Old Bare and Blake Channels. The distribution of mud in Delaware Bay is limited to isolated patches, most of which lie near the shore in water less than 4 meters deep. There are, however, isolated occurrences of mud in the lower Baymouth Channel and in the upper Navigation Channel, which represent outcrops of older deposits.

Recent studies (Folk-Ward, 1957; Visher, 1969, 1972, 1974; Klovan, 1966; Allen, 1971) have shown the relationships between energy of different sedimentary environments, transport mechanism, and the textural attributes of the sands. In this study, a cluster analysis was run on all bottom samples to group sediment samples with similar grain-size distributions. The clustered textural groups were used to define sedimentary environments

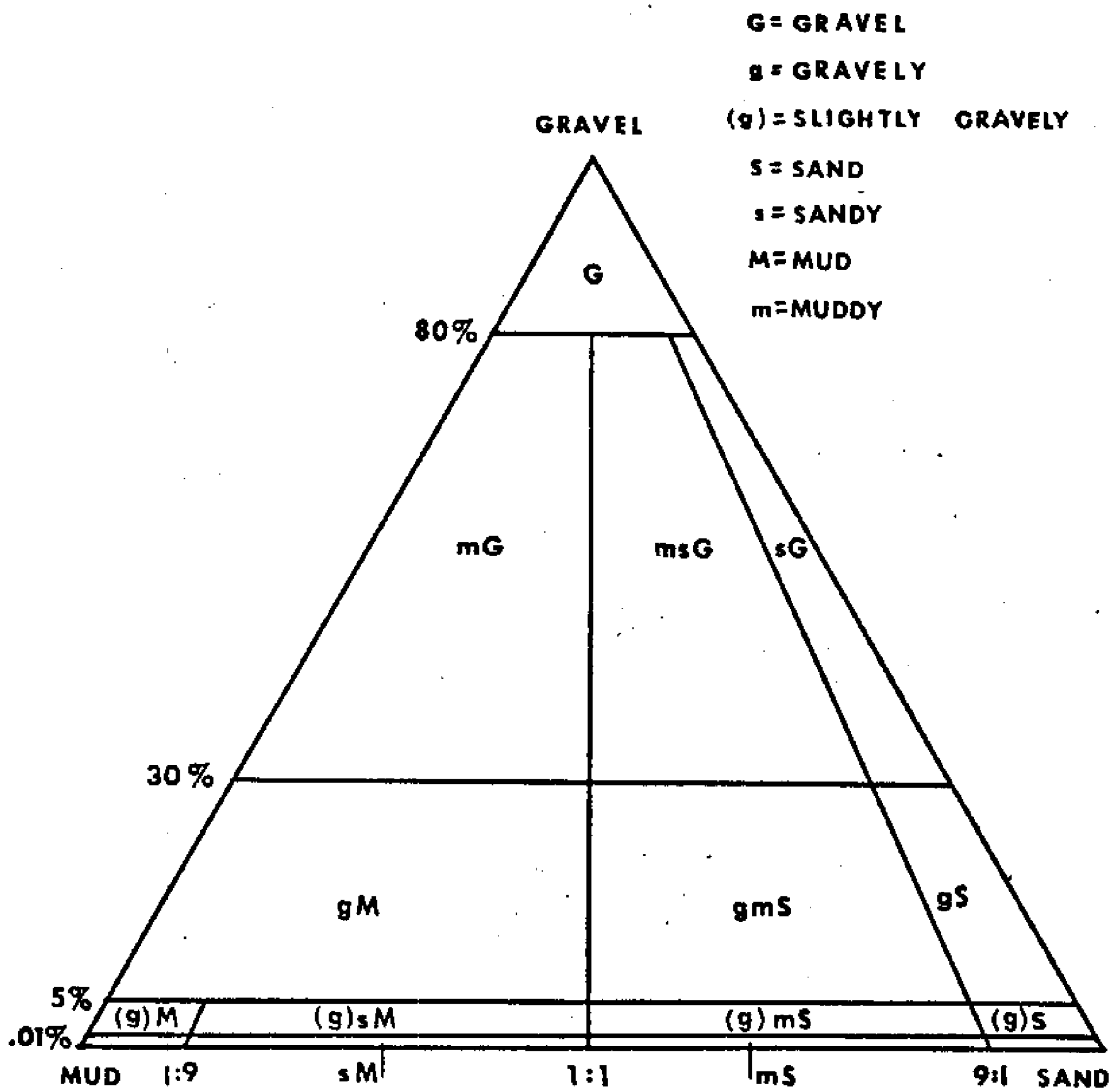


Figure 26. Three component textural classification of Folk (1968) used to classify all bottom sediments from Delaware Bay.

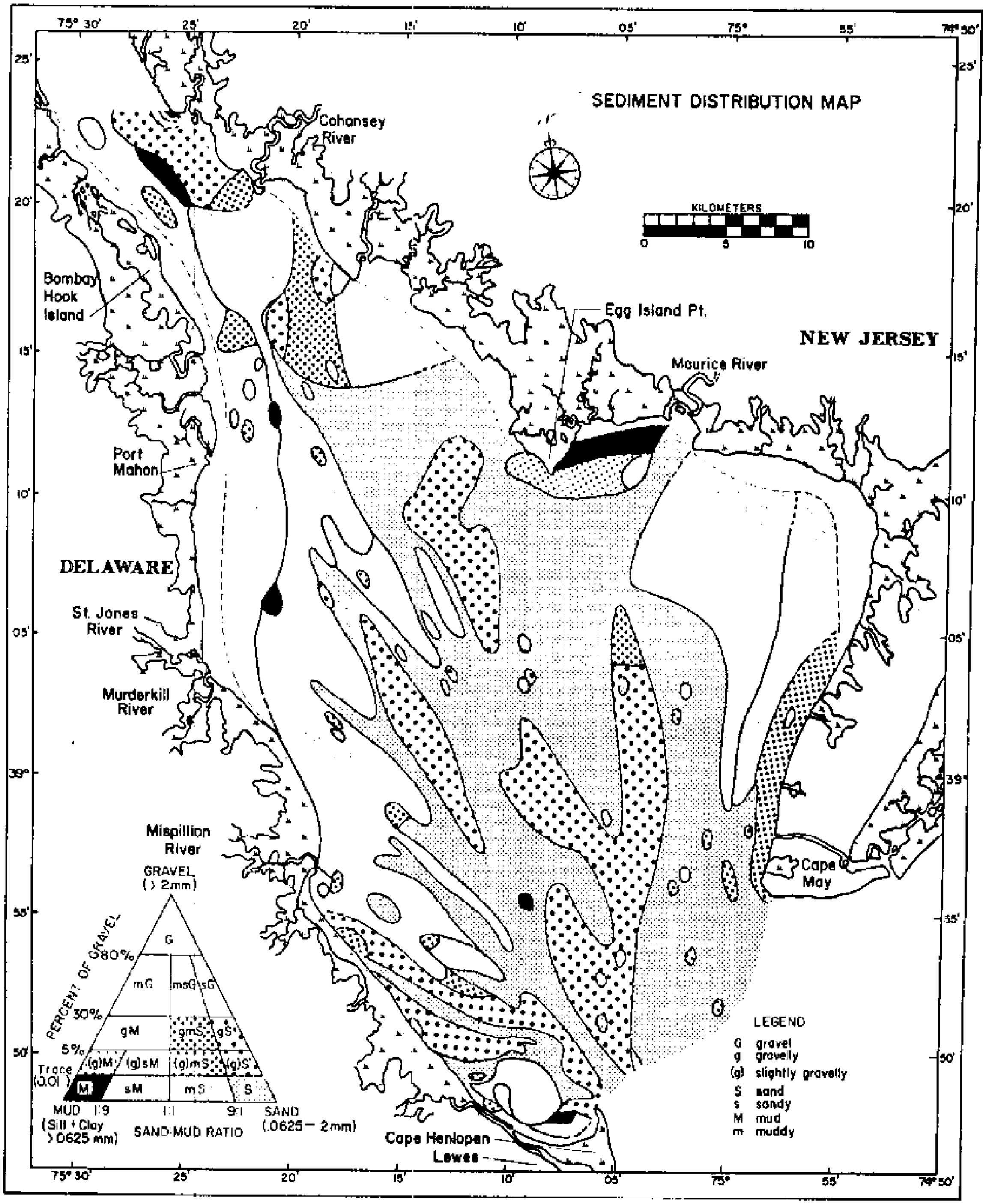


Figure 27. Distribution of Folk texture classes (1968) in Delaware Bay bottom sediments.

TABLE 2

Textural Characteristics of Facies Sediments

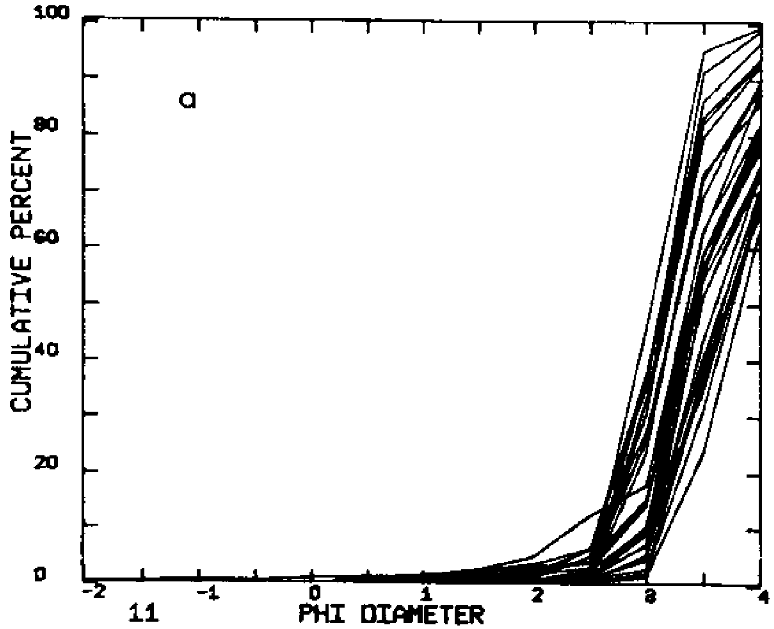
Facies	Textural Characteristics
Facies A (Cluster Groups) 1 - 13	Fine-grain sands (3-4 phi) with variable mud (0-60%), very well sorted to poorly sorted.
Facies B (Cluster Groups) 14 - 17	Muds (50-97%) with fine-grain sands (3-4 phi), poorly sorted to extremely poorly sorted.
Facies C (Cluster Groups) 18 - 34	Medium-to-coarse sands (1-3 phi) with low mud content (0-35%), moderately well sorted to very poorly sorted.

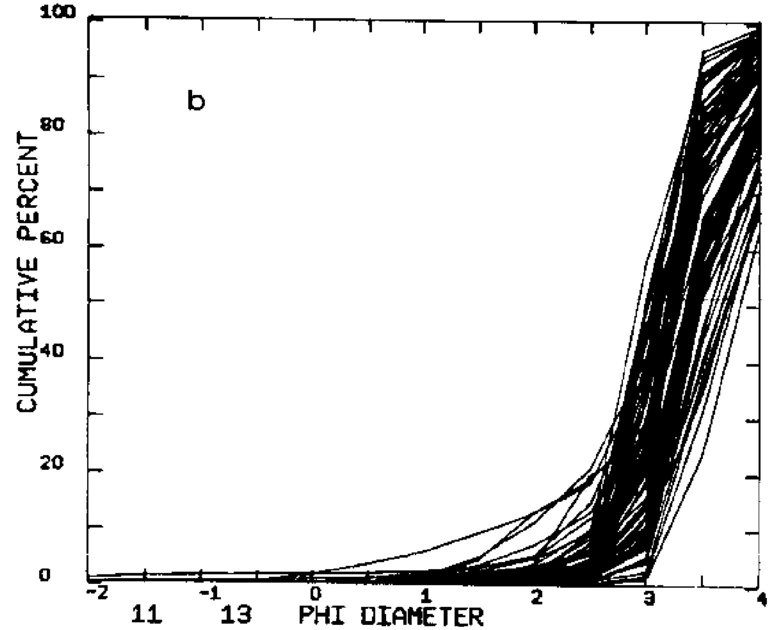
in Delaware Bay and were studied to determine the hydraulic processes which characterize each environment. The purpose and procedures of cluster analysis are described by Parks (1966) and Anderberg (1973). Input for the cluster analysis was the weight percent data for each one-half phi sieve fraction from the grain-size analyses. The silt and clay-size fractions were not used in the analysis. The computer program used for the analysis was written by Parks (1970) and the results presented as a dendrogram (Weil, 1976). On the dendrogram, each sediment sample is grouped with those samples with which its textural characteristics are most similar (Figure 28). The characteristics of these initial cluster groups (28a) are used to form new clusters which describe the successively lower degrees of similarity between the groups as the number of samples in each group increases (28b and c). The resulting clusters of samples may be studied at any convenient level of similarity. In this study, three major cluster groups of the dendrogram have been analyzed and will be referred to as facies, or as textural groups A, B, and C. The textural characteristics of the sediments in each of the three textural groups are summarized in Table 2.

The textural relationships within the three textural groups are shown in Figure 29. Each cumulative curve represents the averaged weight percent of each size class for all samples within each cluster group, and closely approximates the textural characteristics of the individual cumulative curves within the cluster group. The envelope of textural variation within each textural group is also shown.

From the dendrogram, each sediment sample was characterized by its textural group and the distribution of the groups mapped (Figure 30). This map can be interpreted as representing the combined information content of several textural descriptor maps (e.g., Figures 22-25) in one single textural similarity descriptor on a single map.

The mouth of the bay and the lower bay channels are characterized by poorly sorted medium-to-coarse sands with a low mud content (Facies C). Sediments of this type also occur near shore along the Upper Jersey Platform. Finer sands with a highly variable mud content (Facies A) are found in most areas of the upper and middle bay and along the margins





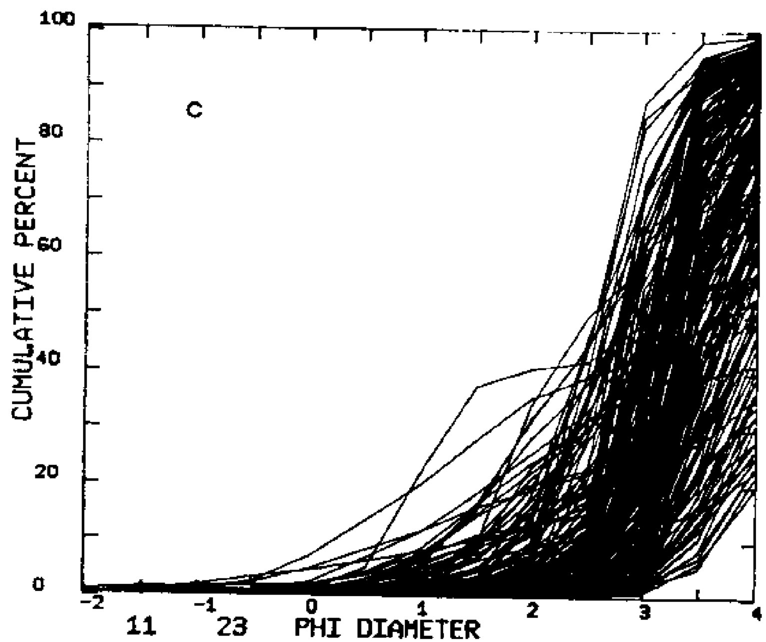
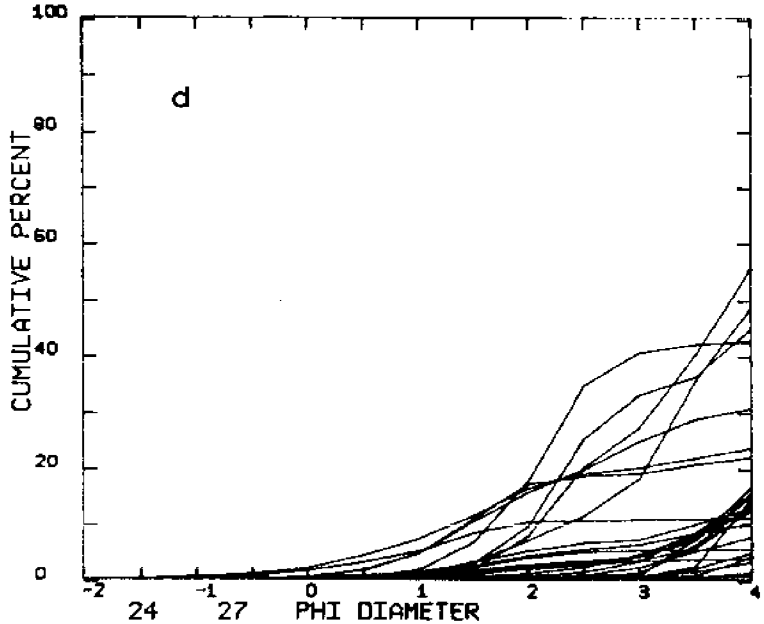
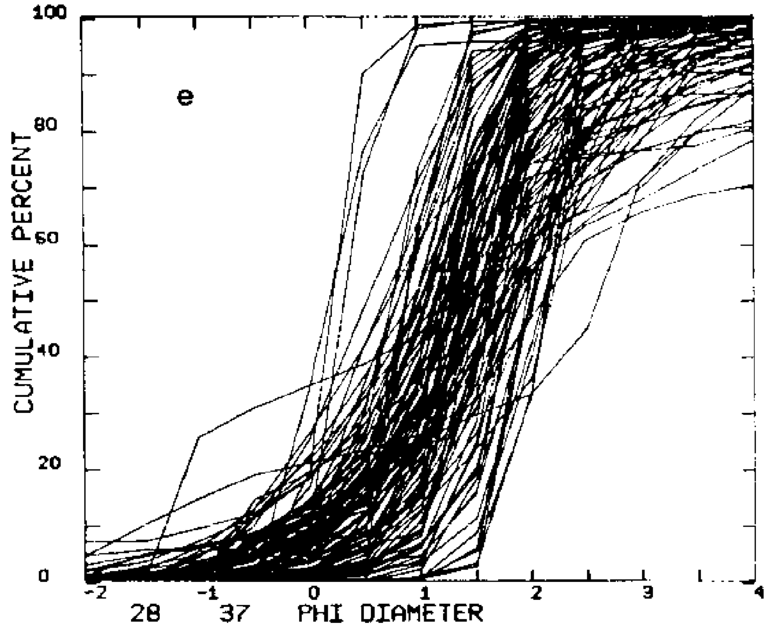


Figure 28a, b, c. Cumulative weight percent curves for clustered groups of Delaware Bay bottom sediments. Most of the sediment samples in group 1 (Figure 28a) occurred on top of linear sand shoals. Samples from groups 1, 2, and 3 (28b) occurred on the tops and lower flanks of the shoals. The sediments from groups 1-13 (28c) define textural Facies A.





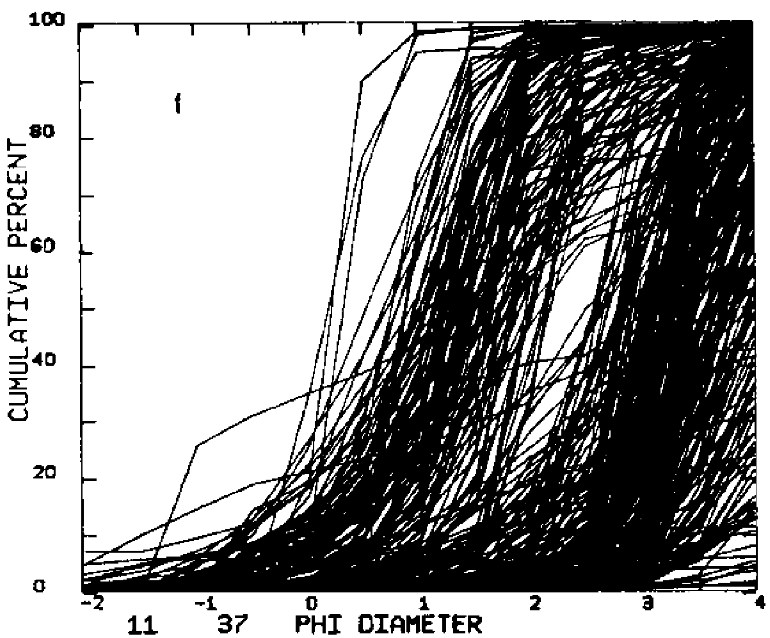


Figure 28d, e, f. Textural Facies B and C are defined by fine-grain and coarse sediments in Figures 28d and 28e respectively. The "natural" separation of sediments in Facies A and C is apparent in Figure 28f.

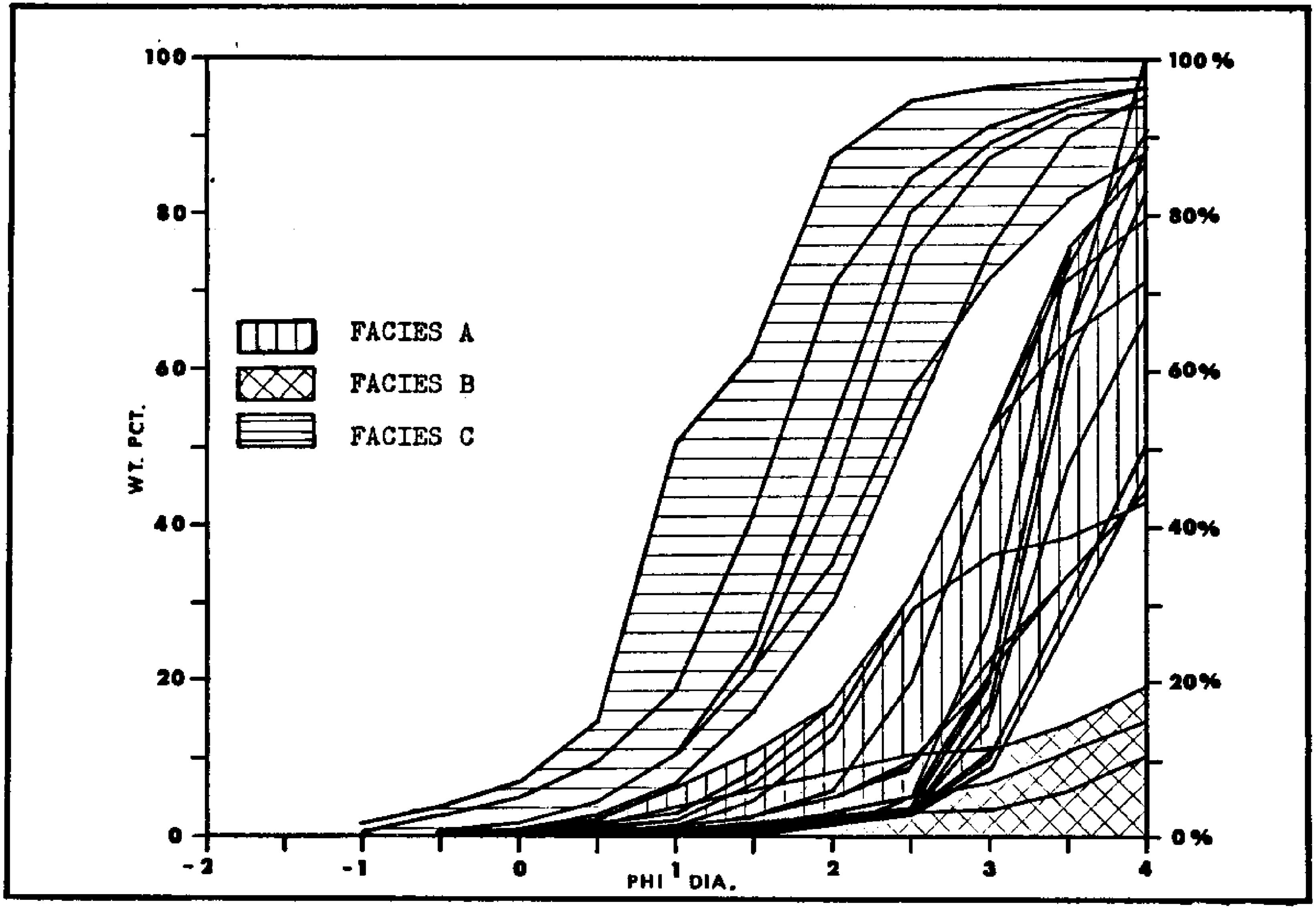


Figure 29. Cumulative curves for averaged weight percent values for each of 34 cluster groups. Textural range of each textural facies is indicated.

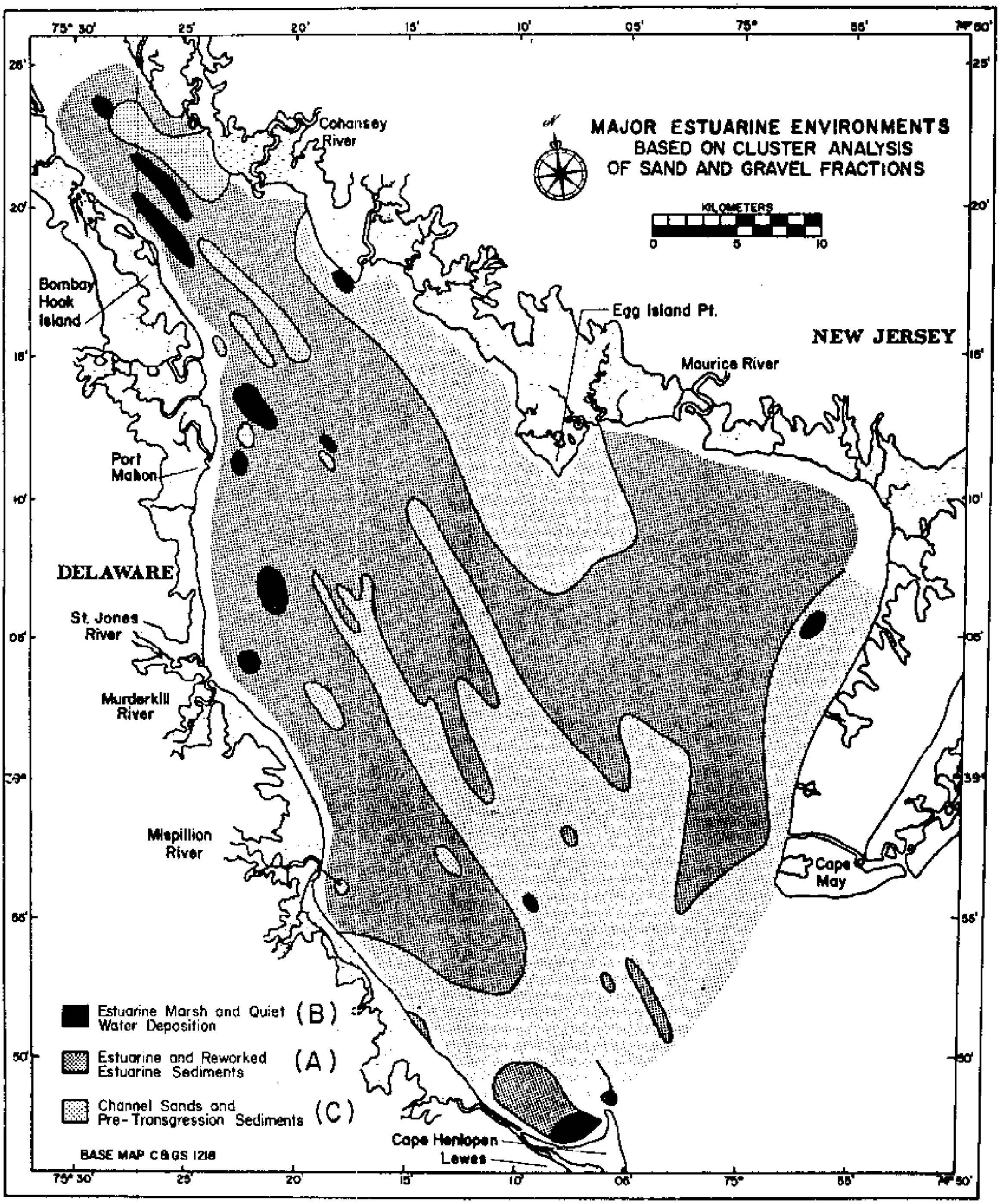


Figure 30. Major sedimentary environments of Delaware Bay based on cluster analysis of bottom sediment textures.

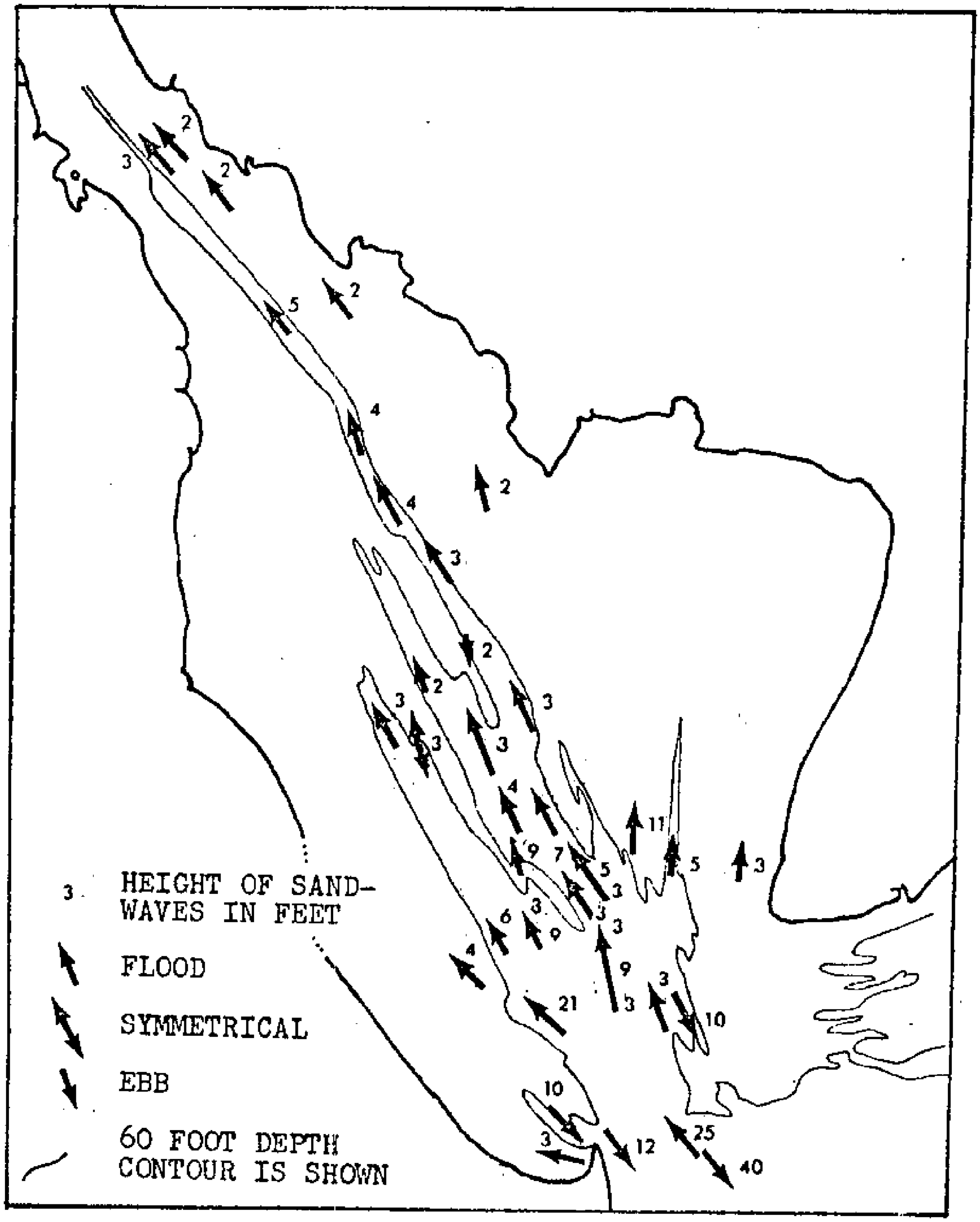


Figure 31. Location, orientation, and maximum height of sand waves in Delaware Bay, based on seismic and side-scan sonar profiles.

of the lower bay. Patches of very poorly sorted fine sands with a very high mud content (Facies B) occur throughout the bay, but occur most commonly along the Delaware shoreline of the middle and upper bay.

Bedforms

Low light television, seismic reflection and side-scan sonar profiles in Delaware Bay show that asymmetric bedforms are common in the tidal channels and on the flanks of the linear sand shoals. These bedforms include ripples, megaripples and sand waves with wave lengths of less than 0.6 meters, 0.6 to 6 meters and greater than 6 meters respectively (Boothroyd, 1969). The amplitude of the ripples was estimated to be 5 centimeters, while sand waves up to 5.5 meters high were recorded on seismic profiles. The direction of bedform transport was inferred to be toward the steeper slip face of the asymmetric bedform. It is not possible to determine or assume the true direction of bedform orientation from a single sounding profile; therefore, the general direction (i.e., ebb or flood), not the true strike direction, has been summarized with their location and height (Figure 31). Almost without exception, the occurrence of sand waves is associated with the coarser and more poorly sorted sediments of cluster textural Facies C (Figure 30). The steeper slip face of the asymmetric bedforms in the tidal channels was, in most cases, oriented in the flood direction. Sets of sand waves with seaward orientations were found in several locations and in the Baymouth Channel just seaward of the study area (G. F. Jordan, 1962).

Visual inspection of the low light television monitor showed that ripples commonly occur on the back of megaripples in the central areas of the bay. Similarly, side scan sonar profiles show megaripples on the back of sand waves in the Navigation Channel (Figure 32). Asymmetric megaripples with amplitudes up to 1.3 meters occur on the flanks of the linear sand shoals. In all cases, the slip face was oriented toward the ridge crest (Figure 33) indicating sediment transport out of the tidal channel toward shallower water, as previously reported by G. F. Jordan (1962) and Moose (1972). The amplitude of the megaripples decreased toward the shoal crest. Shallow water and safety considerations

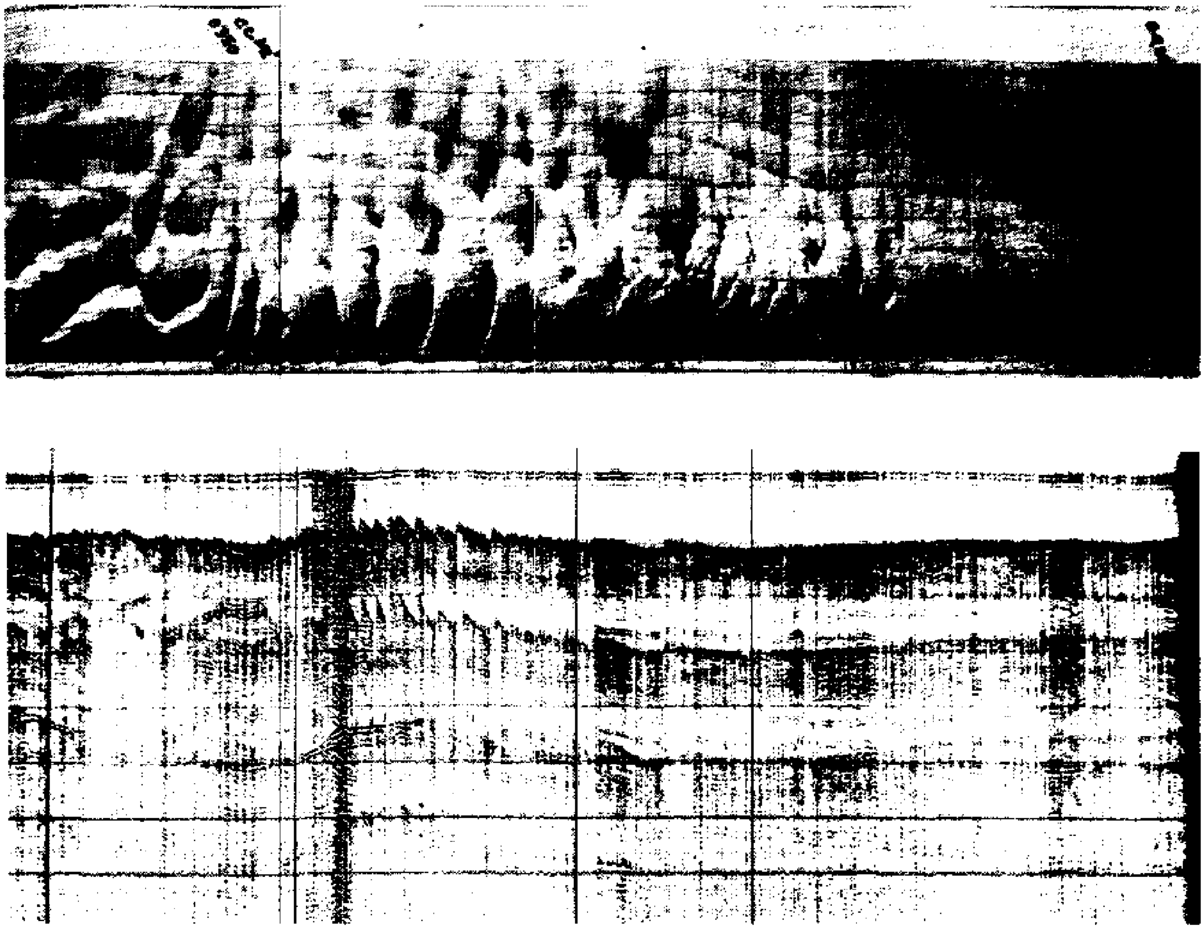


Figure 32. Side scan sonar profile showing well-developed megaripples on and at an angle to linear sand waves. The steep face of the megaripples is oriented toward Brandywine Shoal on the western margin of the Navigation Channel. Note course change.

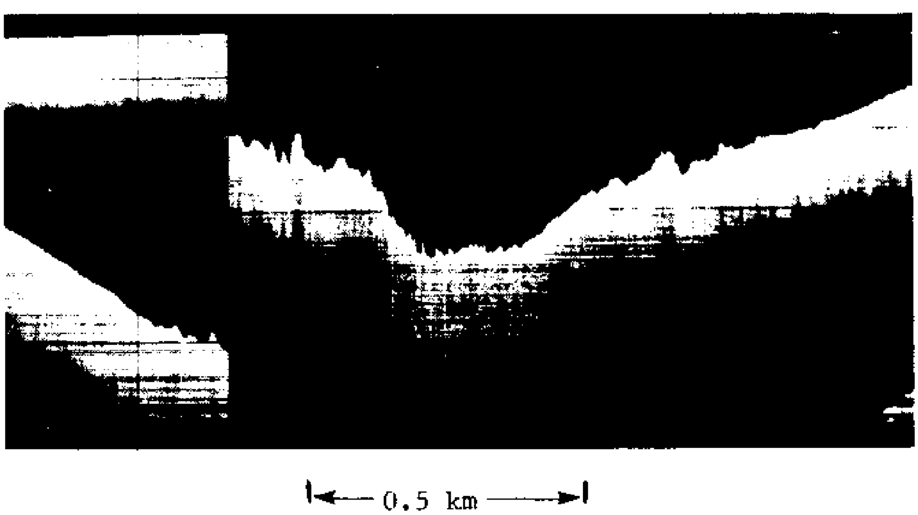


Figure 33. Sand waves migrating out of the Navigation Channel between Bombay Hook Point and the Cohansey River.

forced the cancellation of side scan profiles for the purpose of determining possible changes in bedform orientation toward the crest of the shoal (Caston, 1972), and the orientation of bedforms on the opposite sides of the shoals (Smith, 1969).

Subsurface Data

Sediments

• Recognition Criteria Two approaches, vertical lithologic sequences and physical characteristics of the sediments, have been used as criteria to recognize and distinguish Holocene and pre-Holocene sediments. In other coastal studies (Redfield, 1967; Newman and Munsart, 1968; Jelgersma, 1961), extensive use has been made of a transgressive model which assumes that a marsh with a basal peat unit overlying a sandy substrate was formed during the initial stage of onlap at the site. The same model, used along the Delaware coast by Kraft (1971a, 1973) and Elliott (1972) to interpret vertical sediment sequences of transgressive barrier islands and marshes, was employed in this study to recognize the base of the Holocene section in Delaware Bay cores wherever the nature of the sediments permitted.

In the absence of a marsh and basal peat, other criteria were used to recognize the basal Holocene unconformity. These criteria are more problematic since they do not provide a unique or definite solution to the boundary recognition problem. Pleistocene sediments in Delaware and New Jersey are commonly oxidized sands and gravels, in contrast to the dark grey or grey-green estuarine sands and muds of Delaware Bay. However, the problem is complicated because oxidized and reduced sediments representing fluvial, estuarine, lagoonal, and near-neritic environments have been described in the Pleistocene record of Delaware (R. R. Jordan, 1962). Recognizing the problems and limitations of each, the following criteria were used to recognize Holocene and Pleistocene sediments and the boundary between them: (1) abrupt, non-systematic changes in texture and/or mineralogy; (2) color changes in the sediments from orange, yellow, or white (Pleistocene) to dark grey or grey-green

(Holocene); (3) highly compacted muds; (4) radiocarbon, paleontological, or pollen data; and (5) tracing a known boundary contact from one area to another by continuous seismic reflection profiles. Similar criteria for Holocene-Pleistocene boundary recognition were used by Rehkemper (1969) in Galveston Bay and by Kraft (1971a) along the Delaware coastline.

● Vertical Sediment Sequences From the 50 cores studied and described in Appendix II, five vertical sediment texture sequences were recognized and are described below.

I. A uniform fine-grain mud throughout the core (Samples 1, 109, 261).

II. A uniform coarse-to-medium sand throughout the core (Samples 17, 173, 176, 262).

III. A sequence of alternating sandy mud and clean fine sand (Samples 136, 133, 260, 317, 397, 83, 135, 151).

IV. A sequence of clean fine sands overlying muds, finer muddy sands or sandy muds (Samples 31, 57, 73, 81, 119, 151, 149, 169, 167, 193, 231, 259, 278, 279, 317, 362, 372).

V. Muds, sandy muds or muddy sands overlying coarser sands which sometimes contained gravel and/or mud (Samples 30, 53, 55, 74, 170, 174, 322, 328).

In general, the estuarine sands above the Holocene/pre-Holocene boundary tend to fine-grained (3-4 phi) and the percent mud decreases upward in the core. The median diameter of sands in the cores remains constant (cores 17, 132, 133, 173, 175, 262, 372), or fine upward (cores 136, 143, 174, 243, 247, 322, 328), except in cores near the mouth of the bay or associated with the tidal channels (cores 37, 57, 149, 291, 317).

The estuarine sediments from cores in the middle bay are characterized by alternating layers of mud and clean fine sand greater than one centimeter thick. Laminae less than one centimeter thick of sandy mud and muddy sand are also common. The thickness of individual sedimenation units often varies within a core from less than one millimeter to several centimeters. These units may be continuous or discontinuous across the core.

Core sections of interlaminated muds and sands can be further characterized as mud-dominated or sand-dominated, based on textural analyses and visual inspection of the comparative thickness and relative frequency of the sand and mud layers. Flaser and lenticular bedding occur in the sand-dominated and mud-dominated segments of the core, respectively. Vertical sections dominated by sandy laminae overlie sections dominated by muddy laminae. Similarly, thinly-bedded fine sediments are commonly found below coarser, apparently structureless, sands with few primary structures.

Sediments below the Holocene/pre-Holocene contact tend to be white or iron-stained mixtures of coarse sand and gravel which often contained a high percentage of silt and clay-size material. At the contact, the coarse basal sediments are overlain by a fine dark mud, grey-green sand, or interlaminated mud and sand sequence. Six of the ten core sections interpreted as representing pre-transgression sediments showed well-developed, upward fining sequences.

• Primary Structures Primary structures, a useful means of determining conditions at the time of deposition, are generally absent or not apparent in the coarse subsurface sediments of the bay. Primary structures are abundant and common in the finer-grained estuarine sediments and closely resemble the fine rhythmically laminated sediments described by Hantzschel (1939) and Reineck (1967a, 1967b, 1968). The full range of tidal bedding features is present from simple flaser bedding to lenticular bedding with flat lenses. The nature of the bedding type and primary structure present depends on the water depth and the kind of geomorphic feature from which the core was taken.

Lenticular bedding is best developed in lower energy environments, such as the subtidal flats and in outcrops of subtidal flat deposits which outcrop in the tidal channels. The prevalence of lenticular bedding on the subtidal flats appears related to (1) the higher concentrations of suspended matter in the water column (Oostdam, 1971; Klemas, 1973, 1974) and (2) the greater potential for fine grain deposition because of the lower current velocities and longer duration of slack water period over the subtidal flats (Oostdam, 1971).

Flaser bedding is associated with higher energy environments such as the linear sand shoals. The inclined and truncated cross-bedding and other bedding features in cores from the linear shoals suggest extensive sediment reworking. Within a core, flaser-type bedding generally overlies lenticular bedding.

Seismic Data

● Methods In order to determine the relations between morphology, sediment distribution, and subsurface structure of the bay, more than 1600 kilometers of seismic reflection profiles were collected by Roger Moose and the author under the direction of Professor Robert Sheridan (Figure 21). Most of the seismic data was collected with a 7.0-kHz Raytheon RTT-1100 Survey System. Seismic reflection profiles (3.5-kHz) were also collected on R/V Eastward cruises and 50 kilometers of high resolution Uniboom (250-1000 Hz) seismic reflection profiles and side-scan sonar profiles were collected aboard the R/V Annandale with equipment made available by Dr. Don Swift at NOAA-AOML in Miami.

The seismic data was examined to: (1) identify character and distribution of subbottom structures; (2) recognize and determine the depth to the pre-transgression surface; and (3) determine the thickness of the bay sediments above the pre-transgression surface. This information was used to compile seismic cross sections, an isopach map of the Holocene sediments, and a structural contour map on top of the pre-transgression surface. Criteria used to recognize and trace internal reflectors and the pre-transgression surface included: (1) correlation of reflecting horizons with water jet borings (Biggs, 1972) and sediments in piston cores; (2) tracing identified pre-transgression reflectors along a seismic profile and intersecting profiles; (3) utilizing the signature of identified pre-transgression reflectors from one area of the bay in other areas when other means of correlation and identification were not possible (Moose, 1973). These procedures provided a substantial measure of control for the mapping of subbottom characteristics.

● Subbottom Character and Structures One seismic profile across core site 247 (Figure 34) south of Egg Island Point, permits the correlation

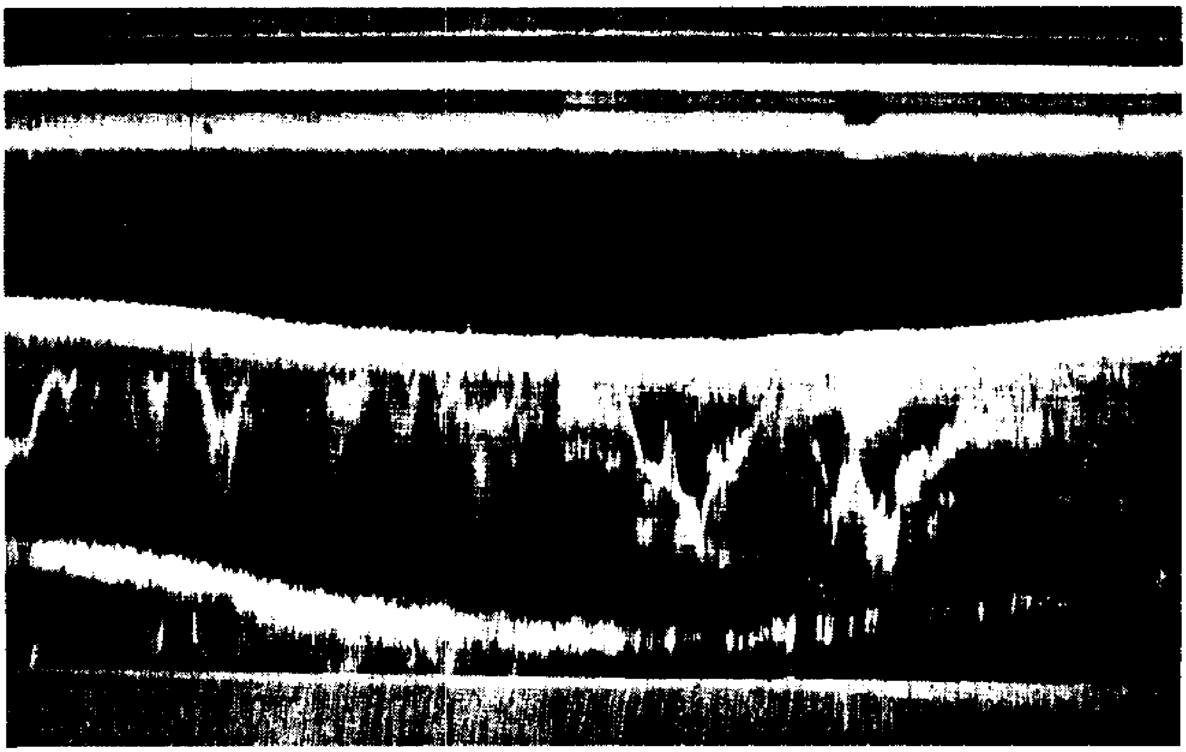


Figure 34. 7 kHz seismic profile across core size 247 on Lower Jersey Platform. The prominent ragged-appearing subbottom reflector is the S-1 reflector (Moose, 1973) and correlates with the pre-transgression surface throughout Delaware Bay.

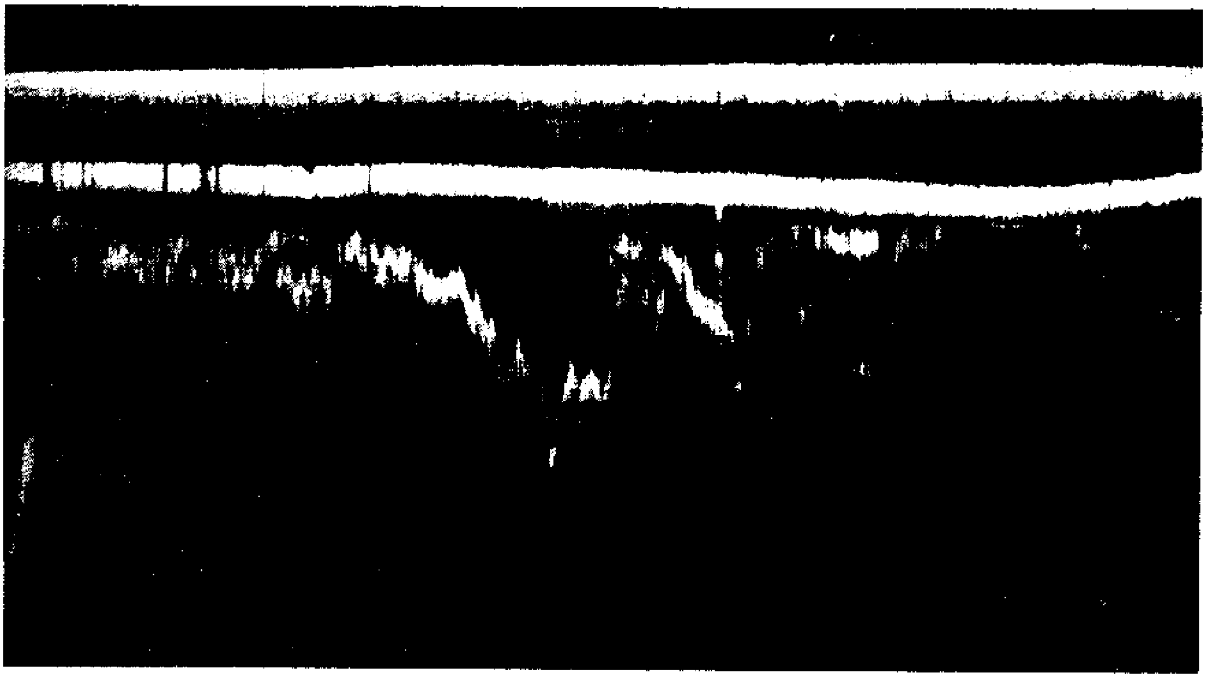


Figure 35. Ragged seismic reflection signature from marsh muds and underlying pre-Holocene sediments off Mispillion River.

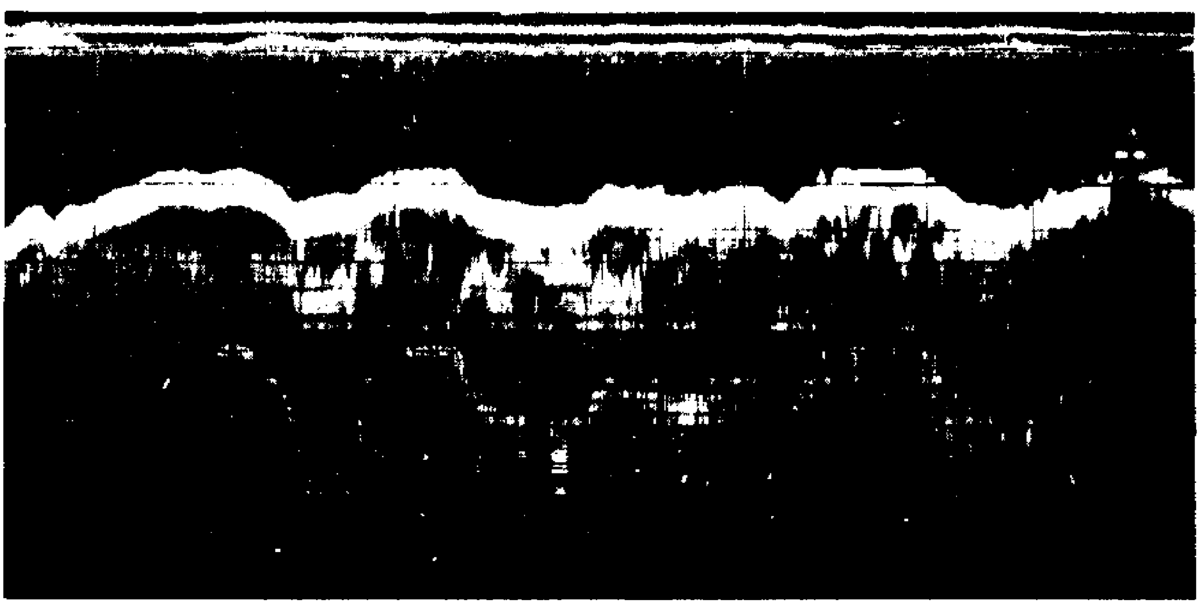


Figure 36. Ragged seismic reflection signature from pre-Holocene sediments off Ben Davis Point, N.J. This reflector appears to outcrop in the bottoms of the topographic depressions.

between subsurface lithology and the signature of seismic subbottom reflectors. The weak horizontal reflector 1 to 2 meters below the surface corresponds to a textural change in the core from muddy fine sands of the subtidal flat to underlying marsh muds. The stronger, ragged-appearing reflector 2 to 5 meters below the surface represents the boundary between marsh muds and pebbly coarse sands. The ragged-appearing reflector occurs commonly throughout the bay (Figures 35 and 36) and can be traced to the shoreline where it is exposed as the subaerial Pleistocene surface. This subbottom seismic signature has been interpreted and mapped as the unconformable contact between Holocene sediments and the underlying pre-transgression sediments.

Seismic subbottom profiles across the eastern flank of Old Bare Shoal show Holocene sediments with well-developed internal bedding inclined toward the east (Figure 37). Similar inclined bedding structures were observed on the western slopes of the Baymouth Channel along profiles off Broadkill Beach (Figure 38), north of the Shears, and the Delaware Shelf Valley outside the bay (Figure 39). The inclined bedding on these Holocene slopes resembles "lateral" sediment accumulation described in salt marsh channels (Van Straaten, 1954).

Profiles across the linear sand shoals indicate the shoals overlie a flat horizontal subbottom reflector (Figures 40 and 41) similar to sand banks of the North Sea (Houbolt, 1968) and the Atlantic inner Continental Shelf (Duane and others, 1972). Examples of combined "lateral" and "vertical" sediment accumulation observed on the flanks of the linear sand shoals will be presented in a later discussion of the shoals.

Poor quality seismic reflections were associated with fine-grain sediments in the upper bay. This was attributed to signal absorption by gas bubbles formed by decaying organic matter in the sediments (Moose, 1973; Moody and Van Reenan, 1967).

Ancestral Drainage Patterns

Within the bay area, the ancestral river system is characterized by a dendritic drainage pattern and an abrupt offset to the south of the north-northwest trending channel in the mid-bay region (Figure 42).

Figure 37. 7 kilohertz seismic reflection profile across the eastern flank of Old Bare Shoal. Foreset bedding indicates that the shoal is building toward the east. Note the course change and reversal of ship's track across the shoal.

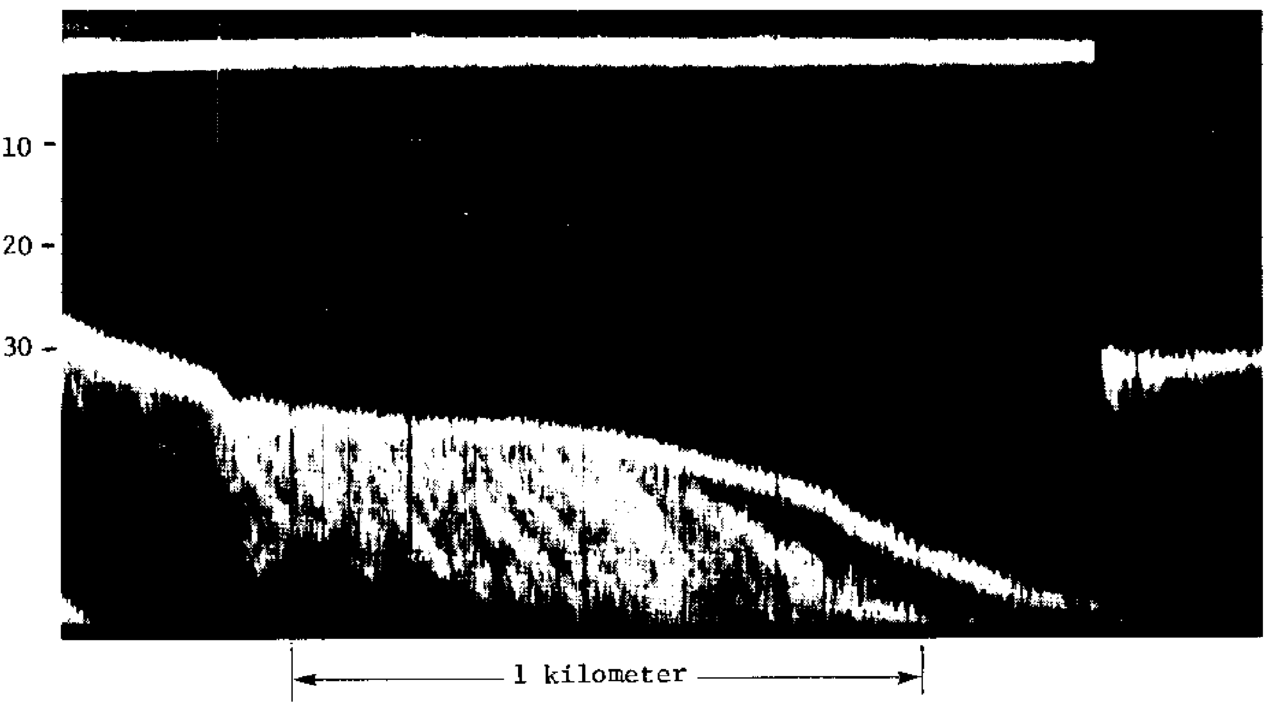
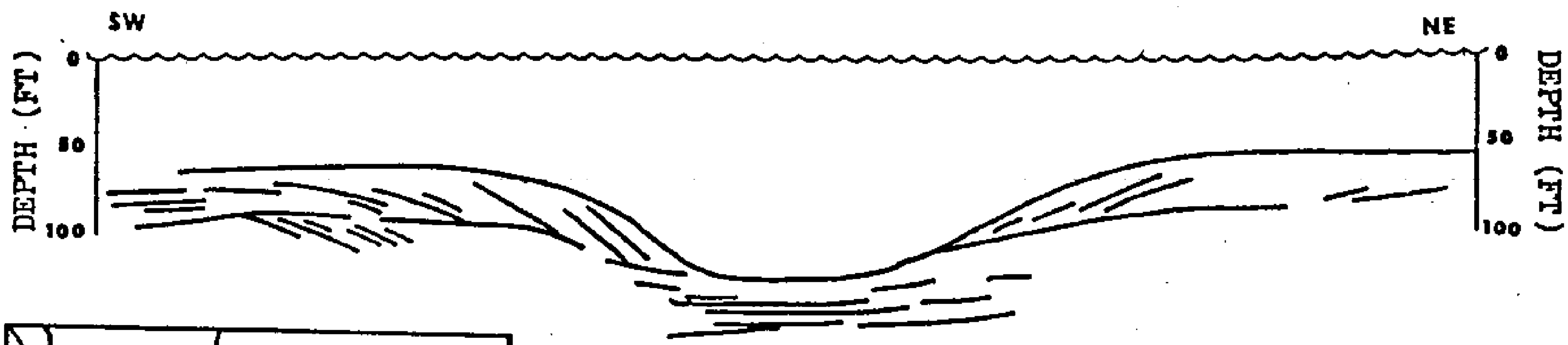


Figure 38. 7 kilohertz seismic profile across the outer portion of the Lower Delaware Platform off Broadkill Beach. Foreset beds dipping eastward into the Baymouth Channel suggest lateral eastward growth of the Platform.



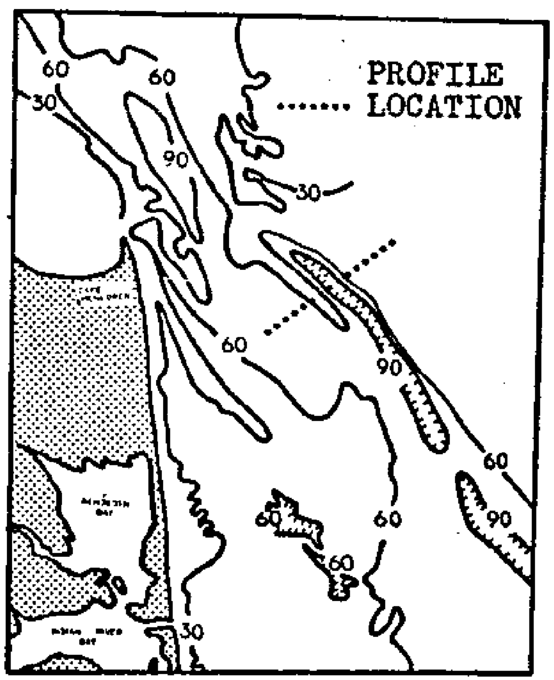


Figure 39. Line tracing of 3.5 kHz seismic profile across the head of the Delaware Shelf Valley. The dip direction of foreset beds on either side of the channel and the net tidal transport direction at the bay mouth suggest that the channel is filling with shelf-derived sediment on the northeast and bay-derived sediment on the southwest. The Valley and Baymouth Channel were probably once connected, but have been separated by the seaward growth of an ebb tidal ridge (from Sheridan and others, 1974).

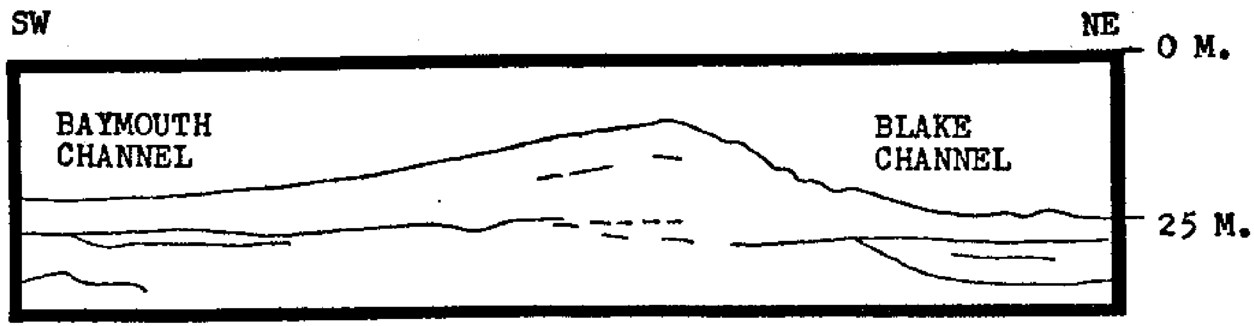


Figure 40. Line tracing of a 3.5 kHz seismic reflection profile shows that the south end of Lower Middle Shoal overlies a nearly featureless horizontal substrate of coarse sand and gravel.

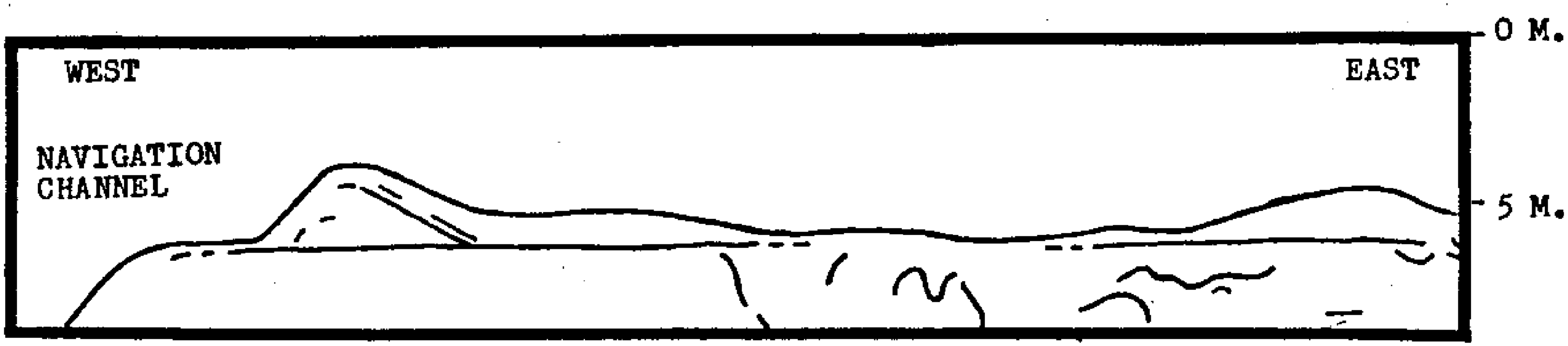


Figure 41. Line tracing of a 7 kHz seismic reflection profile shows that the muddy substrate of the subtidal flat extends westward beneath Cross Ledge Shoal and crops out on the flank of the Navigation Channel.

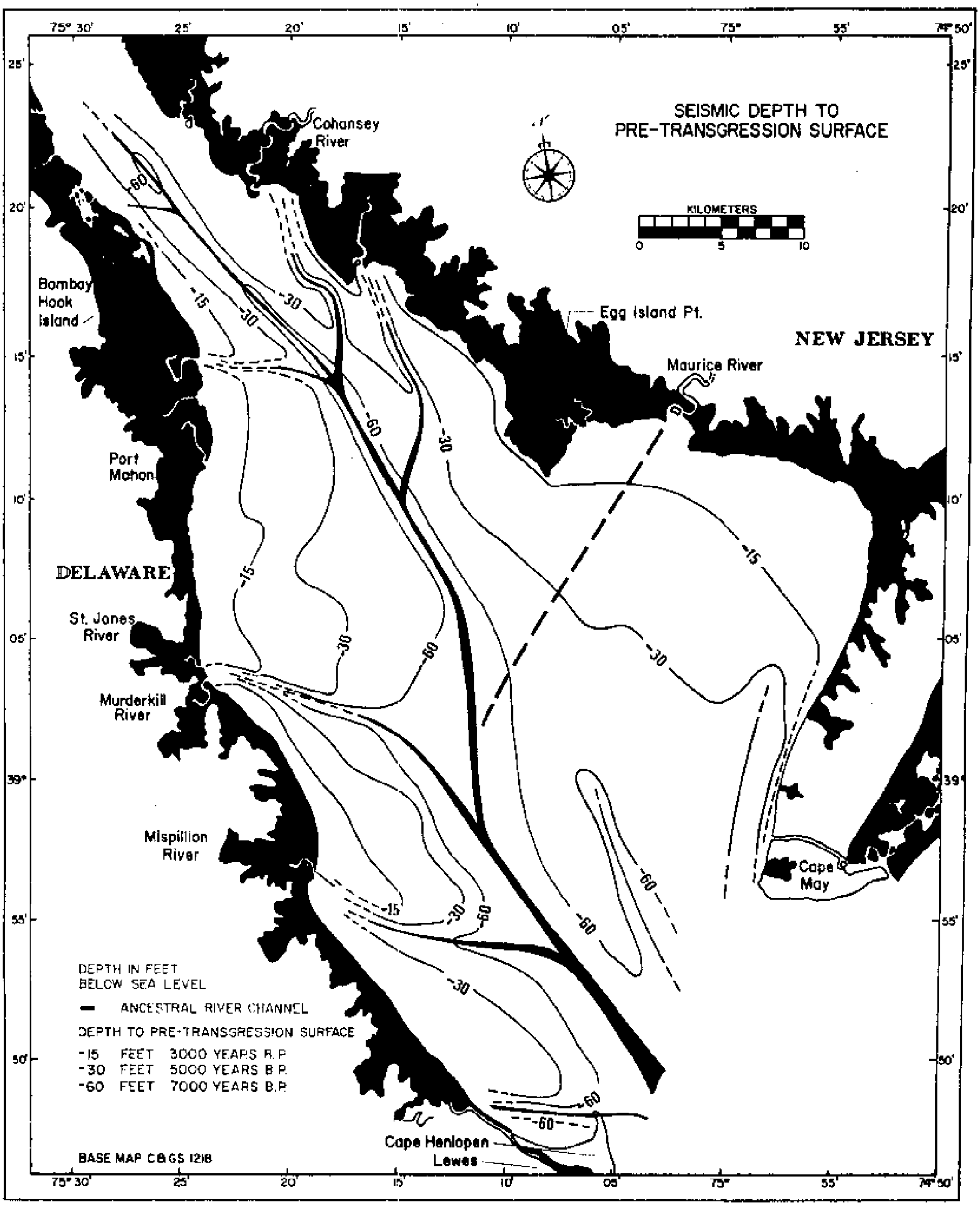


Figure 42. Depth to the pre-transgression surface in Delaware Bay based on seismic reflection data shows the configuration of the ancestral drainage system.

Seaward of the channel offset, the width of the channel, defined by the 20-meter contour, increases from 2 to 5-8 kilometers. The deeply incised tributaries of the Delaware have very narrow valleys which widen in the downstream direction. In the upper and middle bay, the main buried channel of the ancestral Delaware is deeper than 20 meters below present sea level. The presence of multiple buried channels in the lower bay suggests a braided or meandering stream system (Figure 43). The maximum buried channel depth in the bay was 44 meters. Depths of 50 to 55 meters were reported for the buried Delaware channel on the Continental Shelf (Sheridan and others, 1974). The depth and orientation of a buried channel just east of Brandywine Shoal is the same as that for the upper segment of the upper bay channel and the head of the Delaware transverse shelf valley, but no evidence was found to indicate a continuity between the channel segments. Similarly, no seismic evidence was found for an ancestral Maurice River Channel, although topographic relief on shore suggests that a deeply incised channel is present.

A low gradient (1:1,000) buried Pleistocene surface extends from the leading edge of the tidal marshes on both sides of the bay, increasing toward the buried river channel. South of Egg Island Point, the width of the buried Pleistocene surface from the leading edge of the tidal marsh to a depth of 12 meters ranges from 3 to 22 kilometers, and the slope gradient is as low as 1:1800.

Holocene Sediment Thickness

The general pattern of Holocene sediment thickness in Delaware Bay is simple (Figure 44). Sediments 0-3 meters thick characterize the axes of the tidal channels, upper bay, and nearshore areas less than 4 meters deep. Sediment deposits 3-6 meters thick occur at the heads and along the margins of the lower bay tidal channels. The linear sand shoals and underlying sediments adjacent to the tidal channels represent the thickest accumulations of Holocene sediments (6-13 meters) in the bay.

The thickness of sediments in channels tributary to the bay is not shown because of inadequate data. Along the shoreline, drill-hole data indicate the Holocene sediments in the incised valleys of the Murderkill,

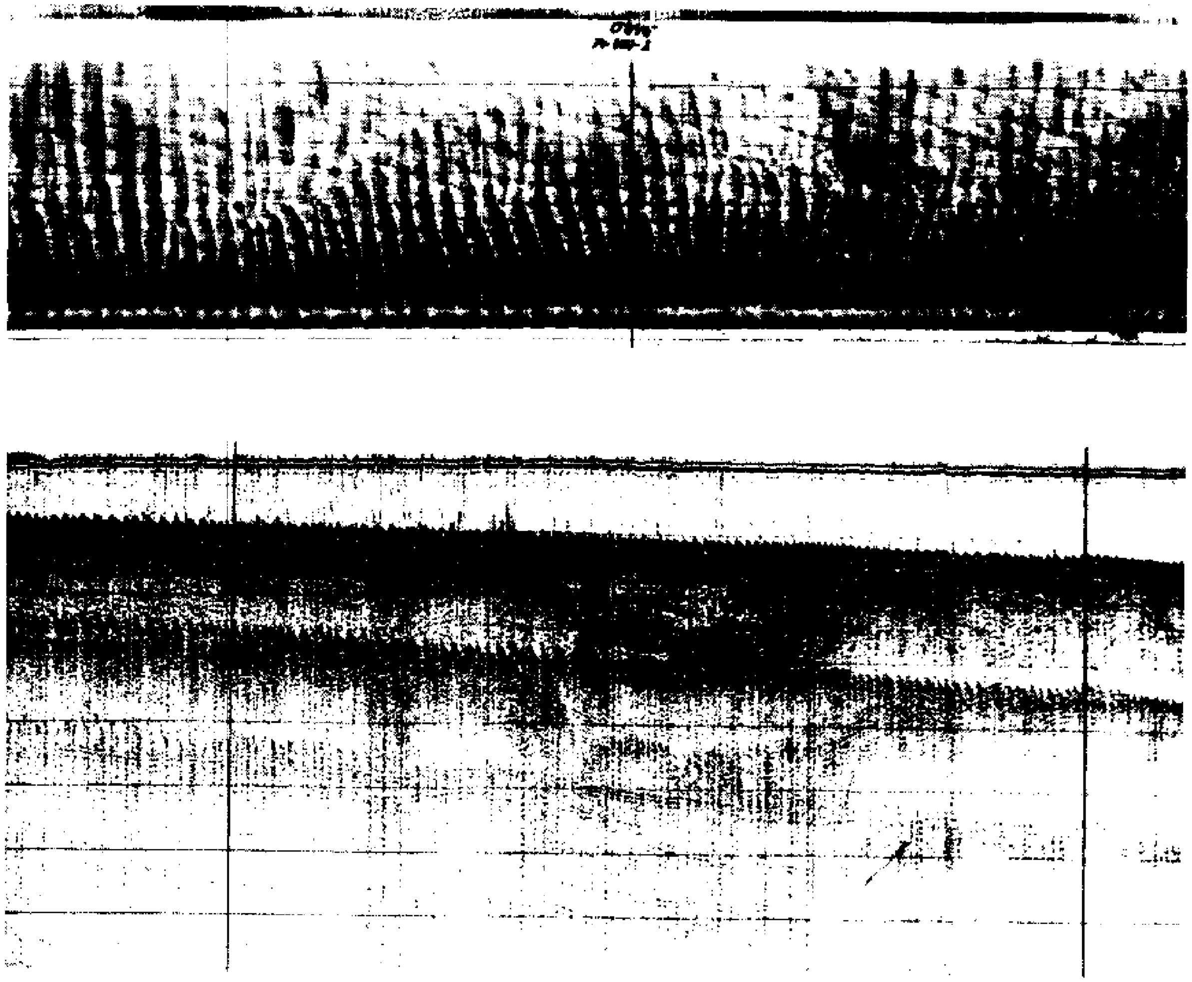


Figure 43. Seismic and side-scan sonar profiles of linear, flood-oriented sand waves in Baymouth Channel, west of Brown Shoal. Note buried fluvial channel in seismic profile.

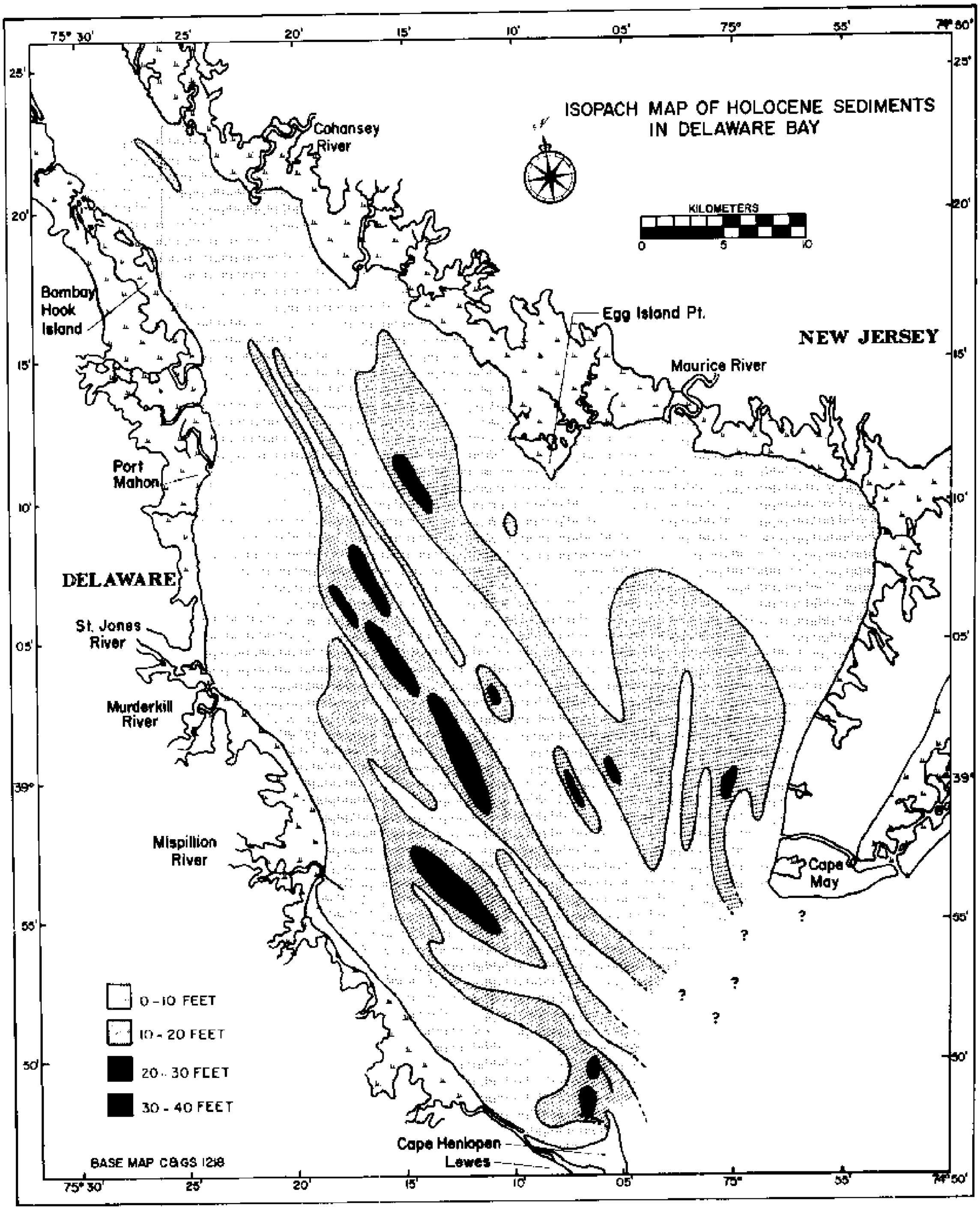

ISOPACH MAP OF HOLOCENE SEDIMENTS IN DELAWARE BAY
KILOMETERS
0 5 10
Cohansey River
Bombay Hook Island
Egg Island Pt.
NEW JERSEY
Maurice River
Port Mahon
DELAWARE
St. Jones River
Murderkill River
Mispillion River
Cape May
0 - 10 FEET
10 - 20 FEET
20 - 30 FEET
30 - 40 FEET
BASE MAP C&GS 1218
Cape Henlopen
Lewes

Figure 44

Mispillion, and Appoquinimink Rivers to be 27, 21, and 19 meters thick respectively (John C. Kraft, personal communication).

The thickness of sediments at the tidal marsh shoreline is 3 to 5 meters greater than the sediment thickness immediately offshore (Richter, 1974). This is attributed to the difference between the height of the marsh surface (0.6 to 1.3 meters above mean low water) and the offshore bottom (0.6 to 3 meters below mean low water), and suggests that 0.6 to 1.0 x 10^6 cubic meters of fine-grain sediment may be eroded each year along the 206 kilometers of bay shoreline.

Summary of Surface and Subsurface Data

Extensive tidal salt marshes and narrow washover barrier beaches form the active depositional margin of Delaware Bay. These transgressive sedimentary lithosomes have migrated landward and vertically with time in response to shoreline erosion and rising sea level. The shorelines of the bay are characterized by active erosion and sediment reworking. With the exception of the recurved spit at Cape Henlopen, there are no prograding geomorphic features associated with the bay or its shoreline.

Grain-size analyses of 411 bottom surface sediments from the bay show a distinctive textural distribution related to bathymetry, where the sediments become finer-grained as depth decreases. Coarse-to-medium sands occur in the tidal channel bottoms, fine-to-very-fine sands make up the linear sand shoals adjacent to the channels, and muds form the tidal marshes at the margins of the bay. Interlaminated muds and fine sands make up the shallow subtidal flats, except in nearshore areas where waves and tidal currents have eroded the fine-grain marsh or estuarine sediment, exposing the underlying coarse Pleistocene sediments. Tidal currents have produced a progressive sorting pattern in the bay, with grain size decreasing in the upbay direction and toward shore.

Tidal currents are also responsible for (1) the extensive trains of flood-oriented sand waves in the tidal channels; (2) the headward erosion of flood tidal channels into the fine-grain estuarine sediments of the bay; and (3) the "tidal current ridges" shaped by and parallel to the tidal currents. The thickness of Holocene sediments in the bay is minimal in the axes of the tidal channels (0-3 meters) and greatest (6-13 meters) under the linear sand shoals adjacent to the tidal channels.

INTERPRETATION

Surface Sediment Distribution

The distribution of surface sediments in Delaware Bay is characterized by two basic patterns: (1) patches of coarse sediments along both shorelines and on the Cape May Shoal Complex; and (2) progressive sorting, whereby the sediments become progressively more poorly sorted, more positively (fine) skewed, and finer-grained in the upbay direction and toward the margins of the bay. The mechanisms responsible for both patterns will be examined.

Nearshore Coarse Sediments

A review of the historical maps of Delaware Bay provides a model for the origin of the gravelly coarse sands near shore on the Jersey Platform, which are oxidized, have a patchy distribution, and are surrounded by or adjacent to soft muddy sediments. Egg Island, originally located south of the present Egg Island Point, measured approximately 37 square kilometers on the Thomas Budd map of the bay dated 1691. The area of the island had subsequently decreased to only 0.06 square kilometer by 1915 (U.S.C.&G.S. chart 1218) and it appears on later editions of the 1218 chart as two muddy subtidal shoals. Egg Island was probably originally isolated from the extensive salt marsh by tidal channels, much as Bombay Hook Island is today. The mud island shoreline was eroded at approximately 9 meters per year by tidal currents and wave action until the island disappeared as a subaerial feature. As waves and currents continue to erode the former island's muddy substrate, the underlying Pleistocene sands and gravels are exposed on the bottom, surrounded by marsh muds not yet eroded. This simple marsh erosion model explains the close proximity of coarse and fine-grain sediments on the Jersey Platform, and illustrates a fundamental process affecting the distribution of coarse sediments in the nearshore areas of the bay.

The coarsest surface sediments in the bay occur on the south flank of the unnamed channel south of Old Bare Shoal. White kaolin-rich sandy gravels occurring in two narrow zones can be traced shoreward more than 15 kilometers from water depths of 0.6 to 3 meters (Strom, 1972). Strom found that similar sediments occur within 0.2 meters of the bottom surface in three piston cores near the two linear zones, and he interpreted them as an outcrop of pre-Holocene sediment beneath the bay.

Cape May Shoal Complex

The Cape May Peninsula is a late Pleistocene ridge which is eroding rapidly in response to wave attack and the Holocene marine transgression. Paleogeographic reconstructions (Kraft, 1971a) and southwest dipping seismic subbottom reflectors (Moody and Van Reenan, 1967) suggest that erosion of the Peninsula has persisted throughout much of the Holocene. The older pre-transgression sediments are overlain by medium-to-coarse sand, gravelly sands and patches of sandy gravel derived from the eroding Peninsula and the southwesterly longshore drift system (Fairchild, 1966; Neiheisel, 1973). Bathymetric changes of the shoals and channels indicate extensive sediment reworking by breaking waves and swift tidal currents. Several lines of evidence indicate that part of the medium and fine sand fraction is winnowed from the shoal complex and transported into the eastern part of the lower bay: these include fine sands in suspension on and north of the shoal complex during maximum flood stage (Oostdam, 1971; Klemas, 1973), a pattern of net landward bottom transport (Figure 15), heavy mineral distribution (Neiheisel, 1973), and the flood orientation of sand waves (Figure 31). The coarser sediment fractions, derived from erosion and longshore transport, remain on the shoal complex as a reworked lag deposit.

Progressive Sorting

The progressive sorting of bay sediments is attributed to the combined effects of decreasing current velocity in the shoreward direction,

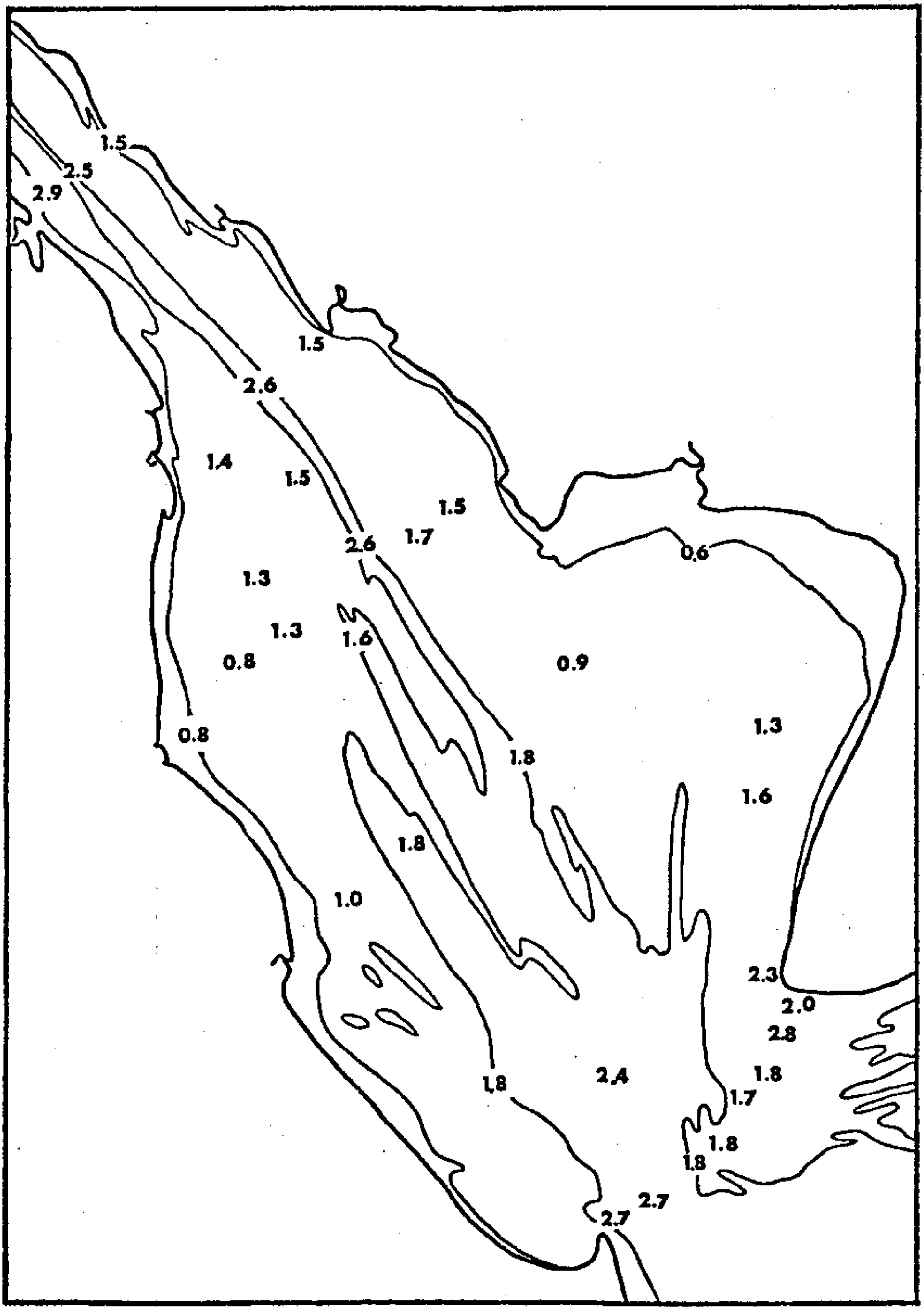


Figure 45. Maximum surface tidal current velocities within Delaware Bay from tidal current chart for Delaware Bay and River (U.S. C. & G.S., 1960). Velocities are given in knots. The six and thirty foot isobaths are shown.

changes in water depth, estuarine circulation and effects of alternating tidal currents on the transport of suspended sediment.

The constriction of the bay mouth by the capes and the Cape May shoal complex results in a high velocity tidal jet which scours the tidal trough and ramp to the bay. Within the bay, the network of flood tidal channels serves as a tidal drain (Price, 1963) which facilitates the movement of ebb and flood waters to and from the tidal inlet. National Ocean Survey tidal current charts (1960) for Delaware Bay show that the maximum tidal current velocity is lower in shallow water than in the deeper tidal channels (Figure 45). As the maximum current velocity decreases, the competence of tidal currents also decreases, a pattern suggested in the sediment distribution maps. The general relationship between decreasing water depth and sediment fining in the (upbay and) shoreward direction appears related to the decreasing competence of tidal currents in shallow waters of the bay.

Sediment deposition from suspension is controlled by the suspended sediment concentration near the bed, the settling velocity, a limiting shear stress above which no sediment is deposited, and the duration of the period of subcritical stress (McCave, 1969). In Delaware Bay, the duration of the subcritical stress or slack water period increases as the maximum current velocity decreases (Oostdam, 1971). The probability of deposition of suspended sediment is therefore greatest outside the tidal channels where the duration of the slack water period is longer. With the increasing duration of the slack water period and decreasing maximum current velocity toward the shore, there is the potential to develop a distance-velocity asymmetry (Van Straaten and Kuenen, 1957; Postma, 1967). Although current meter and suspended sediment data outside the tidal channels are not available, this effect, together with settling and scour lag effects, is thought to cause a net landward transport of sediment with each tidal cycle and to promote the observed accumulation of interlaminated fine sands and muds on the subtidal flats of the bay. These depositional processes are apparently limited near the shoreline by the effects of shoaling waves and longshore currents which increase shear stress conditions, reduce the probability of deposition, and increase the chances for erosion.

Isolated patches of fine-grain mud occur on the flanks and at the heads of all the major tidal channels. In a later section, evidence will be presented that these muds are marsh or fine-grain estuarine deposits which outcrop in the channel.

Mechanisms of Sediment Transport

Particles moving in a fluid may be transported as bed load or traction (particles supported by the bed and other particles moving in the bed layer by rolling, sliding, and sometimes saltation) or as suspended load (particles moving above the bed layer whose weight is continuously supported by the fluid). There is an active interchange between the bed load and suspended load, as well as between the bed load and the bed itself. The instaneous variations in local hydraulic conditions determine when and if a particle of a given size will be transported as bed load or suspended load.

These different sediment transport mechanisms may be represented in the grain-size distribution of a sediment sample by one or more elementary populations, each of which may represent a different transportation mechanism and depositional history (Moss, 1962, 1972; Spencer, 1963; Allen and others, 1972). In this study, each of the clustered groups of sediment samples has been studied to relate the transportation and deposition processes to the observed textural characteristics of the group sediments. The method used was Passega's CM method (Passega, 1957).

- CM Analysis A CM pattern was obtained for 177 unimodal samples in 15 cluster groups by plotting the median sample diameter (M) against the first percentile (C), an approximation of the maximum grain size of the sample (Figure 46). The median grain diameter expresses the average coarseness of the sediment distribution, while C is a measure of the competence of the transporting current. Passega has used the plot of these two parameters to relate sediment texture character with different sedimentary environments (Figure 47).

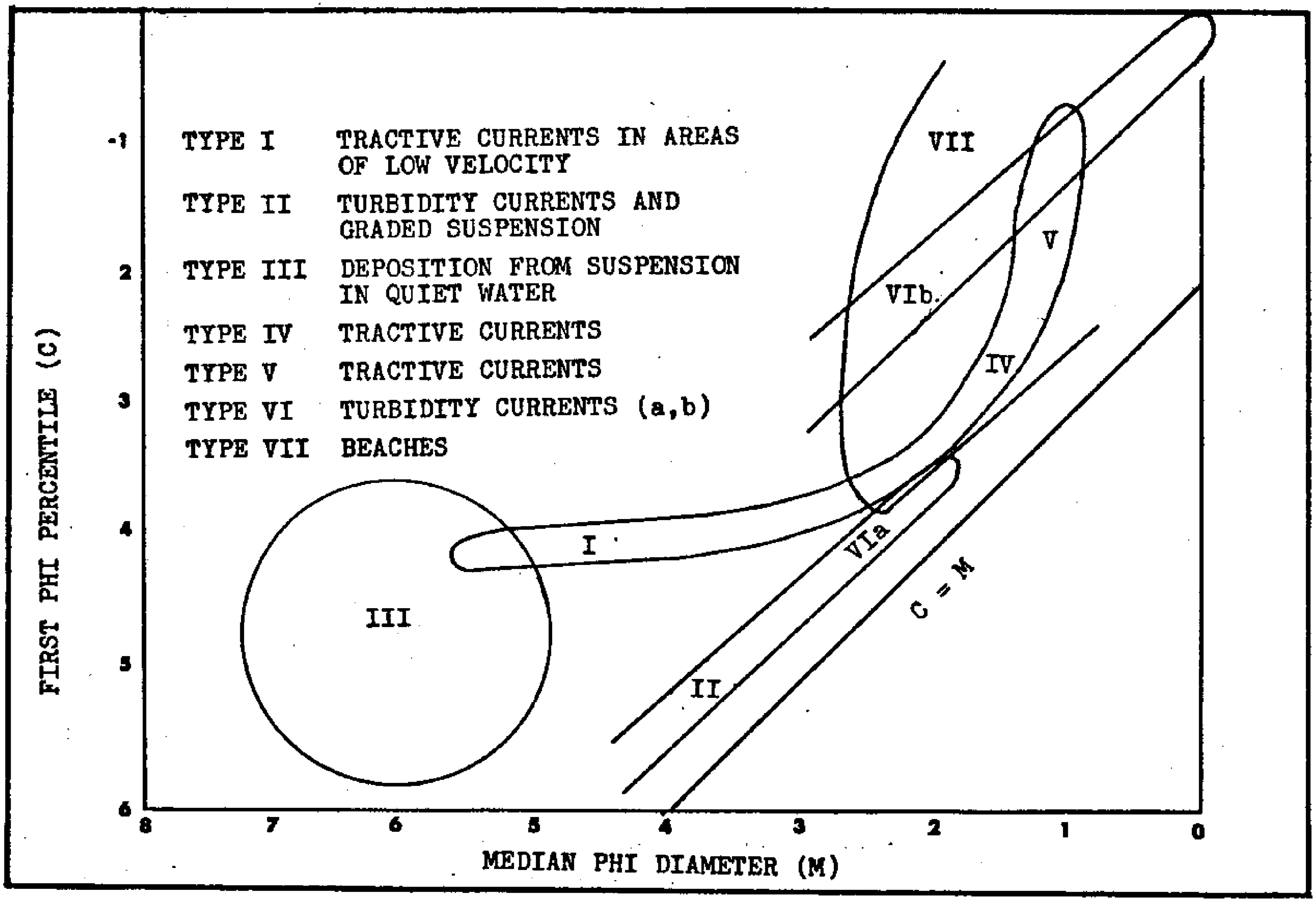


Figure 46. CM diagram and the fields of major sediment transport-deposition mechanisms (after Passega, 1957).

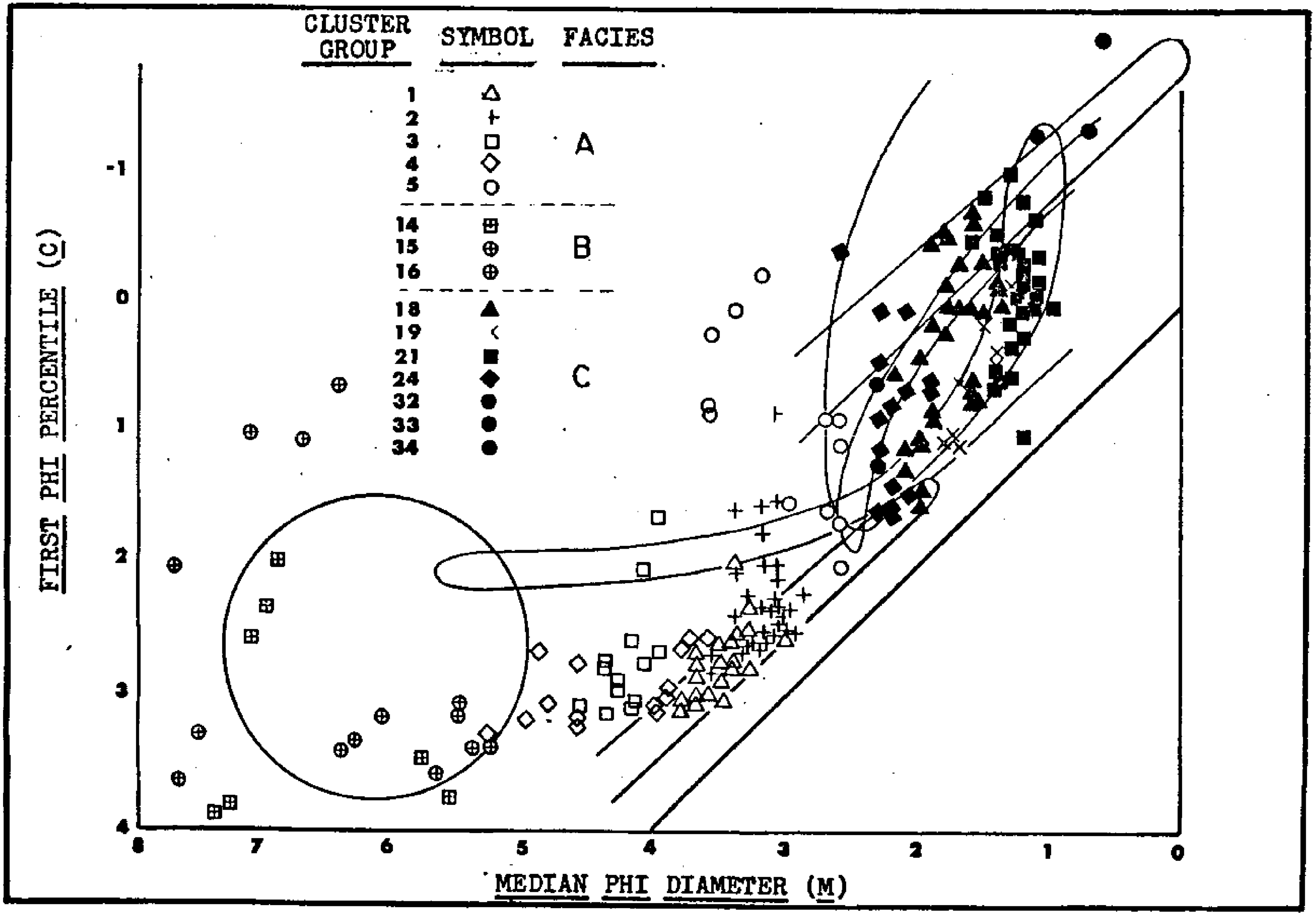


Figure 47. CM plot of individual sediment samples from selected cluster groups from Delaware Bay.

Approximately one-half the samples in cluster Facies A occur on the linear sand shoals or on the flanks of the tidal channels (Figure 28b). On the CM diagram, these sediments plot within and between the fields produced by graded suspension (Type II) and low velocity traction currents (Type I). Passega (1957, p. 1973) indicates that well-sorted Type II sediments may be formed when the velocity of tractive currents decreases gradually and uniformly so that the near bottom suspension remains graded and adjusted to the velocity. The Type I pattern is produced when "very fine particles settle, mixed with intermediate size particles which are placed in suspension in areas of maximum velocity." Graded suspension conditions are expected on the linear shoals and tidal channel flanks as the velocity of tractive currents increases and decreases through the tidal cycle.

Samples from cluster Facies B are scattered in and around CM pattern III, indicating the prevalence of low velocity currents, "quiet water deposition from suspension, and the occasional effects of currents competent to transport fine sand" (Passega, 1957, p. 1973). The higher current velocities are indicated by the variable amounts of sand in the samples (1%-17%) which also accounts for the wide range of C values. Samples from this facies occur in two distinct bay environments: the protected harbor behind Cape Henlopen and the shallow waters of the subtidal flats. The samples behind Cape Henlopen may represent open-water deposition from suspension or, like the samples from the subtidal flats, outcrops of marsh muds exposed by erosion.

Samples from Facies C are interpreted as traction sands, too coarse to be transported in suspension. These samples occur in the bottom of tidal channels and near the margins of the bay. Seismic data indicate that the nearshore and some of the channel samples represent outcrops or reworked pre-transgression sediments. The values of C and M therefore depend upon bottom current velocity, the texture of the parent outcrop, or both. This may account for the wide scatter of CM points from Facies C samples.

Each of the three textural facies in the Delaware Bay represents a mappable sedimentary environment. The characteristics of each facies group is summarized in Table 3. The nature of the sediments in each

TABLE 3

Summary of Characteristics of Major Cluster Groups or Facies

Facies	Textural Characteristics	Areal Distribution	Ranked Physical Processes	Origin of Facies
A	Fine-to-medium sands and muddy sands	Upper bay and margins of lower bay	Saltation Suspension Traction	Reworked estuarine muds and fine sands
B	Muds and sandy muds	(1) Nearshore margins of the bay, especially Delaware shoreline, in upper bay tidal channels, (2) lower bay subcrop, and (3) behind Cape Henlopen	Suspension Saltation Traction	(1) Exposure of subtidal Holocene and (2) pre-Holocene marsh subcrops, (3) possible null point deposition
C	Medium sands to gravelly sands	(1) Lower to midbay tidal channels and nearshore margins of lower bay and upper eastern shoreline, (2) Baymouth Shoal Complex	Traction Saltation Suspension	(1) Reworked and subcropping sediments of fluvial and pre-transgression origin, (2) sediments transported into bay from Continental Shelf

environment depends upon the competence of the tidal currents, the duration of slack water, and the extent of wave activity. The medium-to-coarse sands (0.5 to 2.5 phi) in the tidal channels (Facies C) represent a lag deposit from which the fine-size fractions have been winnowed. The fine sands (3 to 4 phi) eroded from the tidal channels are deposited along with muds on the flanks of the tidal channel, on the linear sand ridges, and on the shallow faults adjacent to the channel (Facies A). Most of the suspended silt and clay size material, if not transported out of the bay, is deposited in the tidal marshes, on the subtidal flats, in the protected waters behind Cape Henlopen, or into the lower tidal river.

Character and Origin of the Linear Sand Shoals

Seven kilohertz seismic reflection profiles were collected across many of the sand shoals in Delaware Bay. One profile across the southern end of Joe Flogger Shoal (Figure 48) shows several features which have been used to interpret the growth and development of this and the other linear shoals in the bay (Figure 49).

The shoal is asymmetric in cross section with well-developed internal cross bedding inclined toward the east, away from the steeper face of the shoal. Bedding on the west side of the shoal is truncated by a reflecting horizon which parallels the upper surface of the shoal. The shoal is a depositional feature lying unconformably over a flat pre-existing seismic basement reflector. There is no evidence that the shoal is a relic feature or related to any pre-existing geomorphic feature. The successive lateral shift of the internal ridge crest positions indicate that the shoal is a laterally mobile bed form in which two distinct stages of growth appear to be involved. The earliest stage is characterized by combined lateral and vertical shifts in the position of the ridge crest, followed by a later stage which is limited to vertical growth. Finally, the migration direction of the shoal, as indicated by the shifting ridge crest and the truncated bedding, has been toward the gentle slope of the shoal. This migration direction contrasts with data showing that "tidal current ridges" of the Atlantic

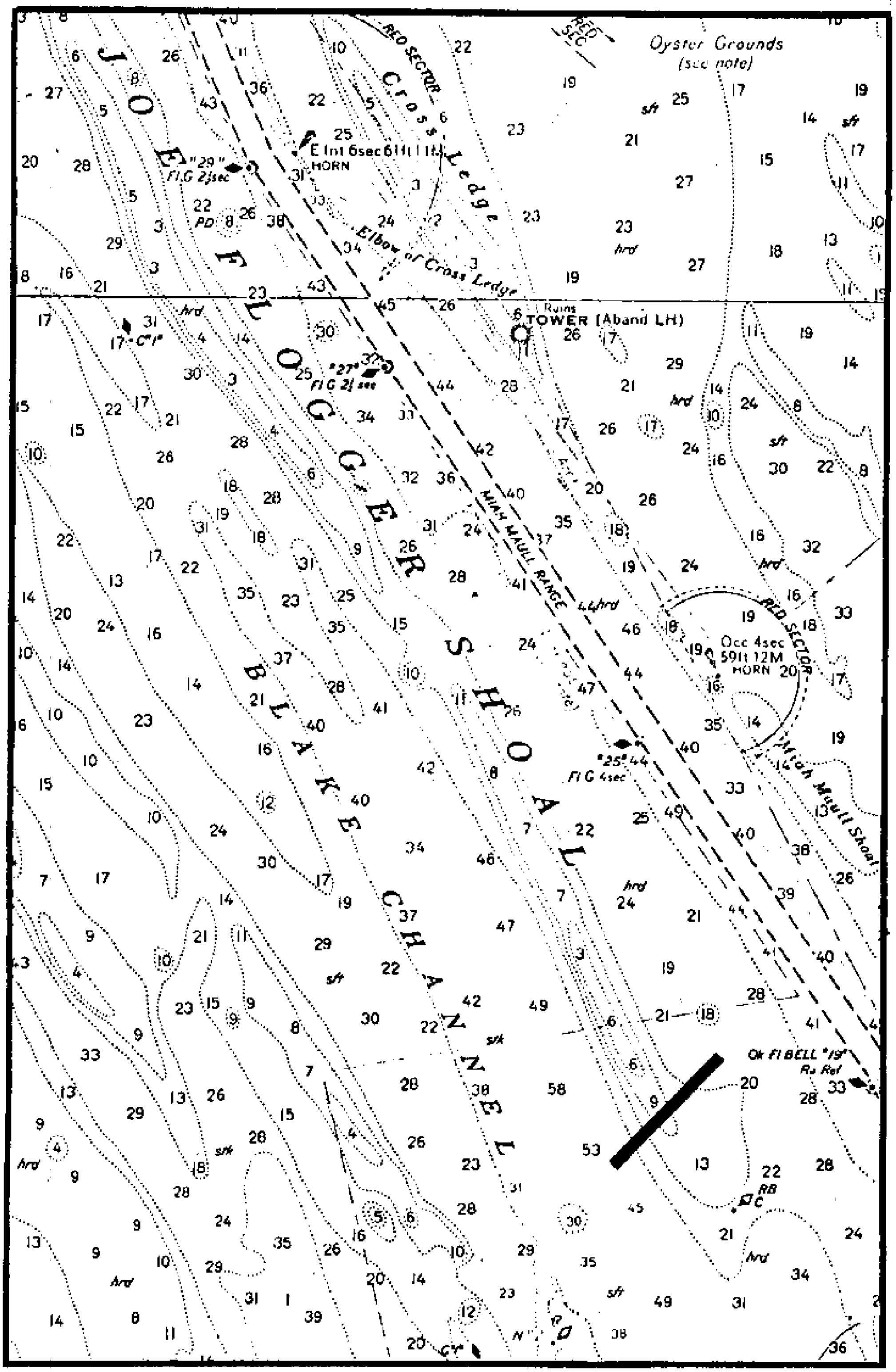


Figure 48. Location of seismic profile across Joe Flogger Shoal.

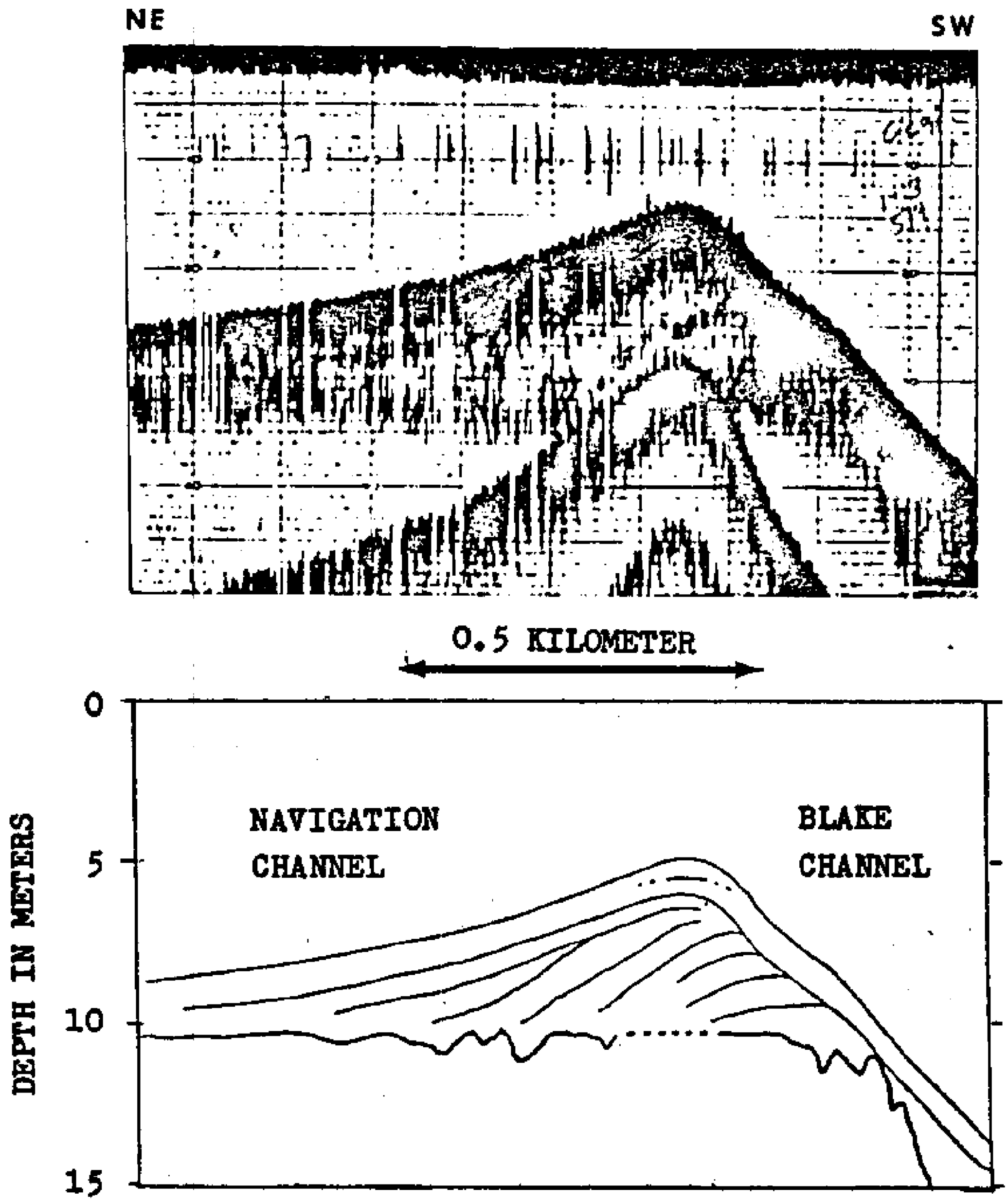


Figure 49. 7 kHz seismic reflection profile across Joe Flogger Shoal.

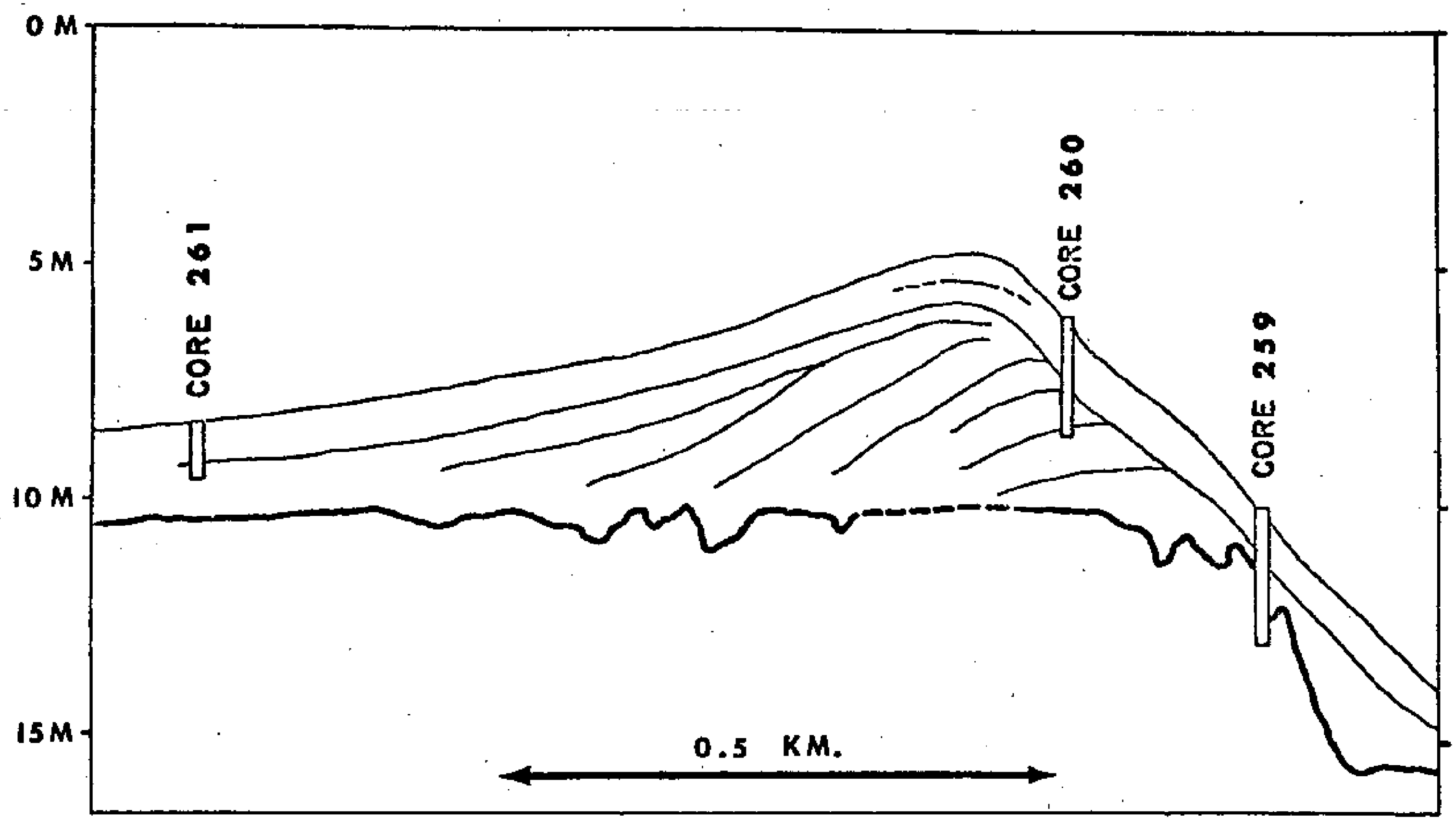


Figure 50. Location of piston cores on Joe Flogger Shoal

open Continental Shelf and the North Sea migrate toward their steeper flank (Houbolt, 1968; Duane and others, 1972).

A series of piston cores along the seismic profile revealed the nature of the reflecting subbottom reflectors (Figure 50). Core 260 from the crest of the shoal penetrated 2 meters of highly stratified fine sand and muddy sand with layers of mud. The horizontal and inclined planar laminae, flaser and wavy bedding, and truncated sets of ripple marks indicate active sediment reworking by currents and/or waves. Moose (1973) observed asymmetric megaripples on the flanks of the tidal channels and, in all cases, the stoss side of the megaripple faced toward the crest of the shoal (Figure 33) indicating sand transport out of the channel onto the shoal. The tidal channels next to the shoals are the source of these sands.

Core 259 on the steep flank of the shoal penetrated 40 centimeters of clean grey-green fine sand overlying a compact dark grey mud with interbedded shell layers and occasional thin laminae of fine sand. This mud unit represents the flat seismic reflector under the shoal and closely resembles the interbedded muds and sands found on the subtidal flats.

The seismic reflection profiles and piston cores from other areas of the bay indicate that the flat muddy substrate under Joe Flogger Shoal is an extensive surface throughout the bay, occurring beneath Crow Shoal, Fourteen Foot Bank, Lower Middle Shoal, Cross Ledge Shoal, Arnold Point Shoal and several smaller unnamed shoals on both sides of the bay (Figures 40 and 41).

A comparison of Coast and Geodetic Survey maps of the bay between 1848 and 1915 confirms that Crow Shoal near Cape May has migrated at least 0.5 kilometer westward, the direction of its gentle flank (Figure 51). The lateral migration of Crow Shoal also resulted in an extensive widening of the Bayshore Channel east of the shoal and a seven-kilometer displacement of the 18-foot isobath in the upbay direction. Long-term changes of other linear shoals include longitudinal extension and the erosion and filling of cross-shoal channels. Changes in the adjacent tidal channels included increases in cross-sectional area, headward erosion and deposition, and the tidal channels.

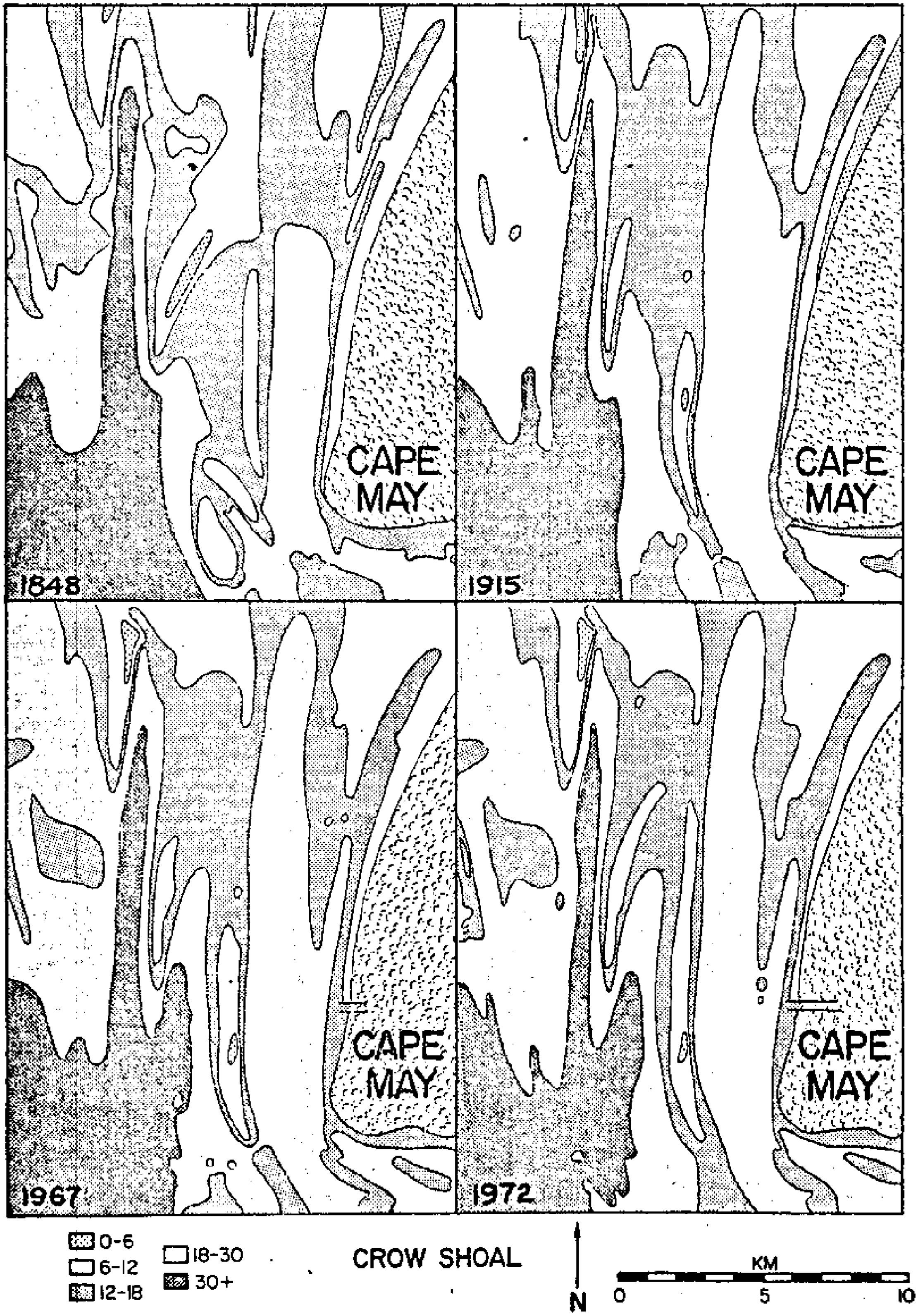


Figure 51. Changes in bathymetry of Crow Shoal and Bayshore Channel between 1848 and 1972.

The development and reworking of the tidal channels and linear sand shoals is attributed to the increased water volume of the bay and the resulting hydraulic changes that must have occurred as the ancestral Delaware channel was drowned by rising sea level. As the transgression progressed, these changes included increased tidal influence and reduced river influence on estuarine circulation, the upbay migration of the head of salt intrusion, increasing water depth and an increase in the volume of water in the estuary, and the increasing width of the shallow subtidal flats.

The low hydraulic efficiency of moving ever larger volumes of water onto and off the muddy subtidal flats by sheet flow was increased by the development of tidal channels. Channel flow reduced boundary friction effects, increased tidal current velocities and increased the competence of the tidal currents to erode and transport sediment. The observed deepening, widening, and extension by erosion in the upbay direction of the Bayshore Channel is a recent sample of this developmental process.

A model for the development and evolution of the linear sand shoals in Delaware Bay can be developed from seismic profiles across the shoals, bathymetric changes, and a small pair of unnamed shoals on the subtidal flats off Kitts Hummock, Delaware (Figure 52). The two shoals are recent features since neither is shown on the 1848 bathymetric chart and only the eastern shoal appears on the 1915 edition of the 1218 chart of the bay. Both shoals are shown on the 1937 edition of the chart. The flood tidal channel has been eroded in an upbay direction into the muddy subtidal flats. Sediment samples from piston cores and water jet borings (Biggs, 1972) indicate that the shoals are composed of very fine grey-green sand and overlie the buried subtidal flat and a tidal marsh sequence with a basal peat. The basal peat occurs on both sides of the tidal channel and overlies a white pre-transgression sand. These geologic relationships are shown on a tracing of a seismic reflection profile across the paired shoals (Figure 53).

During the process of tidal channel development, subtidal flat muds are eroded by the tidal currents and transported from the site in suspension. Fine sands carried in suspension or as bed load are deposited

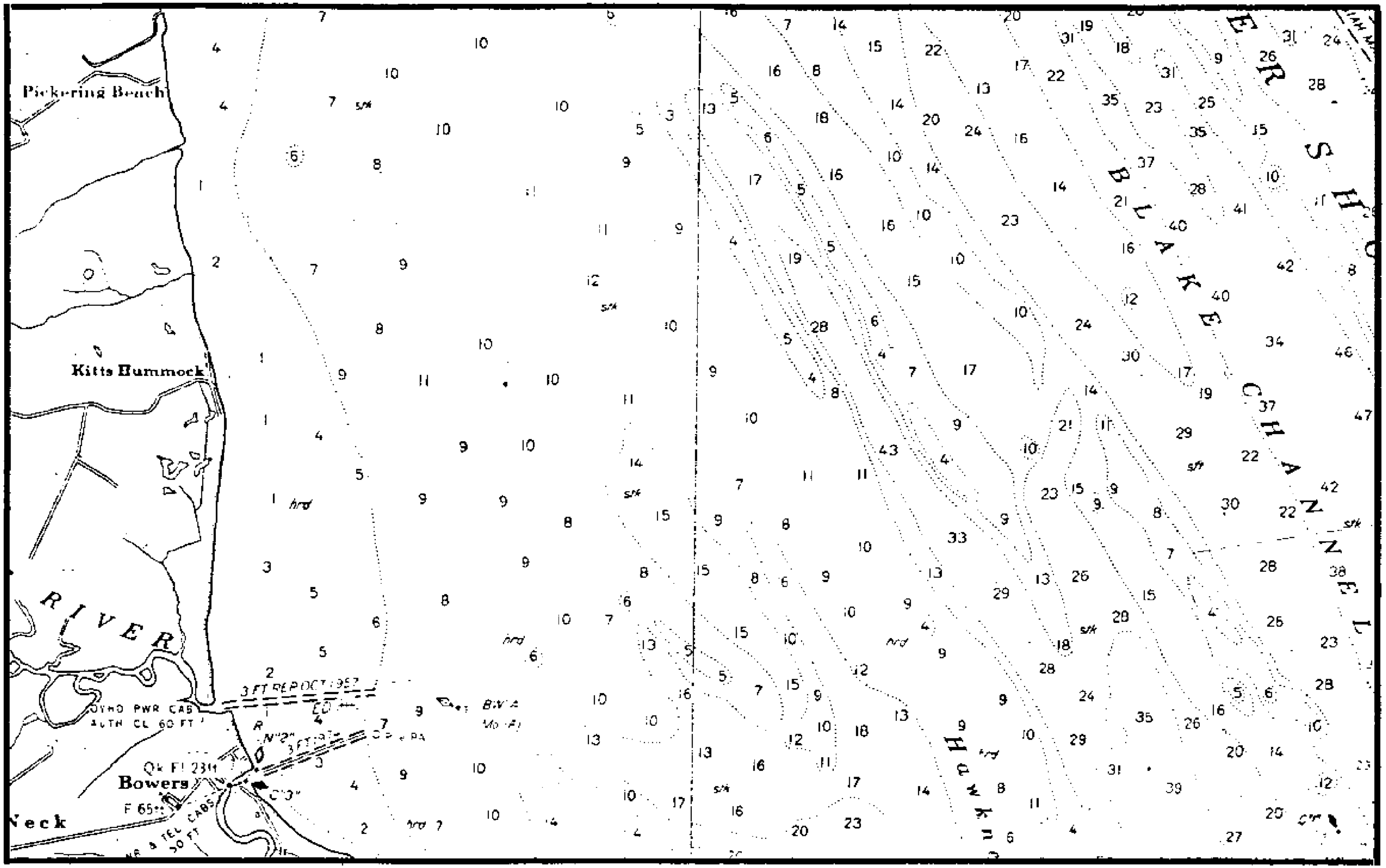


Figure 52. Bathymetric map of Delaware Bay off Kitts Hummock, Delaware (from U.S. C. & G.S. Chart 1218). A flood tidal channel eroded into the muddy subtidal flats is flanked on both sides by small linear sand shoals.

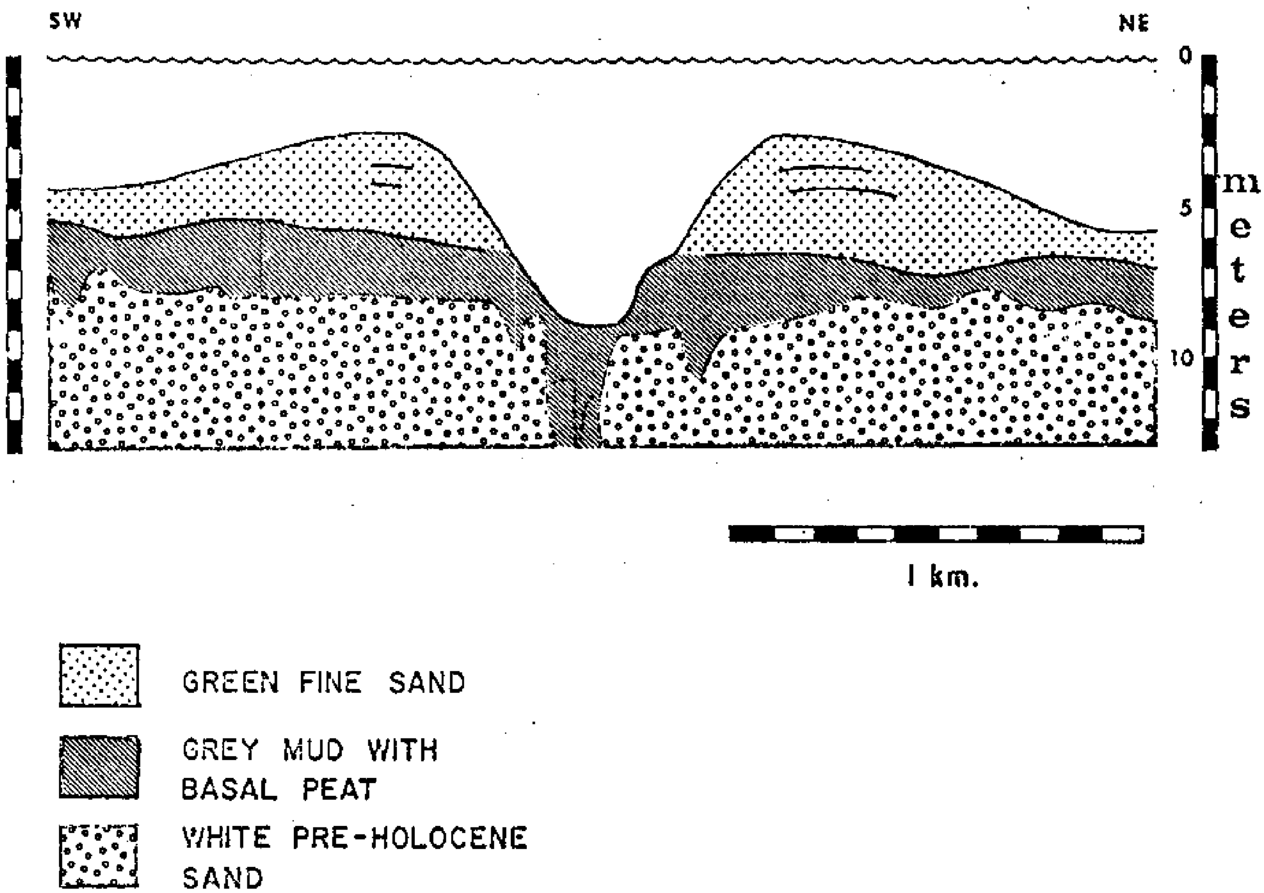


Figure 53. Geologic interpretation of seismic reflection profile across a tidal channel and linear sand shoals off Kitts Hummock, Delaware.

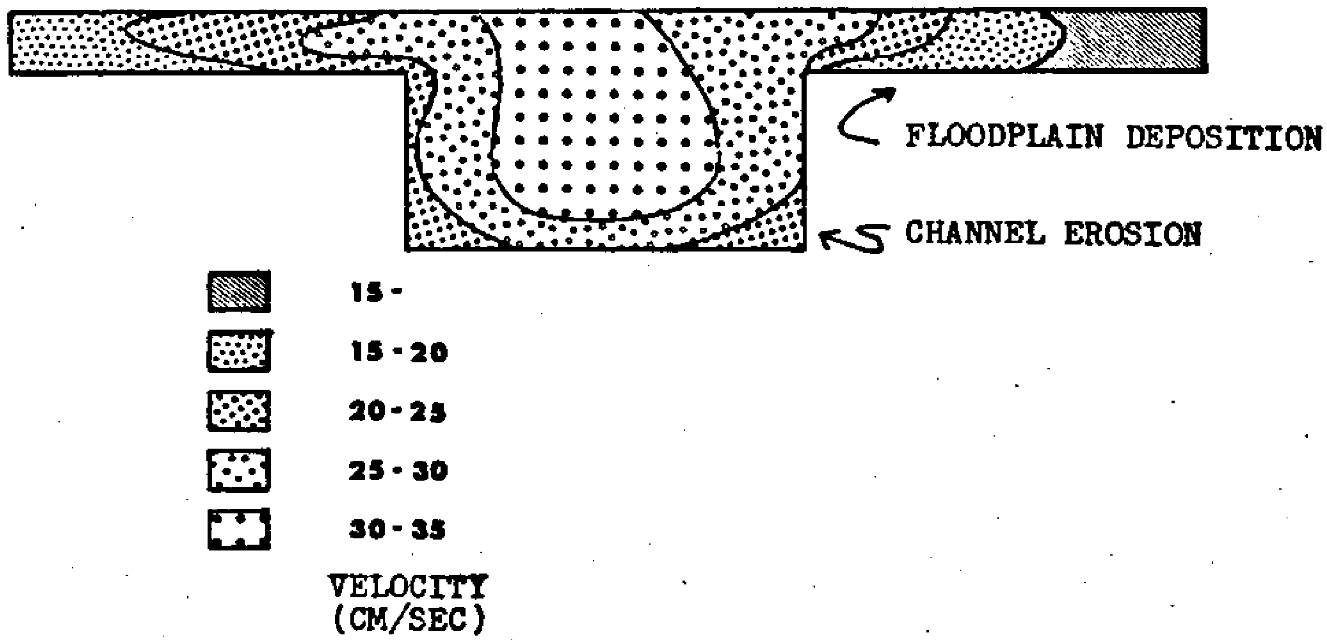


Figure 54. Current velocity distribution within a river channel and over the adjacent flood plain (after Allen, 1970).

along the channel banks as the competency of tidal currents decreases from the channel margin outward (Figure 54). The linear sand shoals are thus formed by hydraulic processes overbank deposition, similar to those by which alluviating streams and rivers build subaerial and submerged natural levees (Russell, 1936; Morgan, 1970), and turbidity currents build natural submarine levees adjacent to submarine canyons (Buffington, 1952; Heezen and Hollister, 1971). The effect of overbank flow may be due to secondary currents or the lateral displacement of flood waters out of the tidal channel due to the convergence of channel banks in the upbay direction.

A model for developing the two stages of growth -- the internal bedding features and the direction of shoal migration observed in Delaware Bay shoals -- can be summarized in terms of two basic processes: (1) levee-like sediment deposition parallel to the banks of the tidal channels; and (2) lateral changes in the position of channel banks by erosion. The resulting shoal and channel development and structure is shown in Figure 55.

Tidal currents eroding headward into the shallow muddy subtidal flats (Figure 55-1) cause deposition of subaqueous levees parallel and adjacent to the tidal channels (Figure 55-2). If channel development occurs by bank erosion as in the case of Bay Shore Channel, the steep flank of the shoal facing the channel and the crest would be undercut and eroded (Figure 55-3). Cross-shoal sediment transport and deposition would bury and preserve the remaining portion of the crest and the entire gentle slope. If continued, this pattern of erosion and burial (Figure 55-4) would explain all the features observed in the seismic profile across Joe Flogger Shoal. Once formed, the shoal could be a self-perpetuating feature as a site of continued deposition (Off, 1963), subject to extensive reworking by tidal currents (Caston, 1972), or could be completely removed by erosion. When the tidal channel erosion at the site has stabilized, shoal development appears to be limited to vertical growth, as in the second growth stage in the Joe Flogger Shoal profile. Several processes acting singly or in combination could be responsible for the vertical stage of shoal growth, including continued

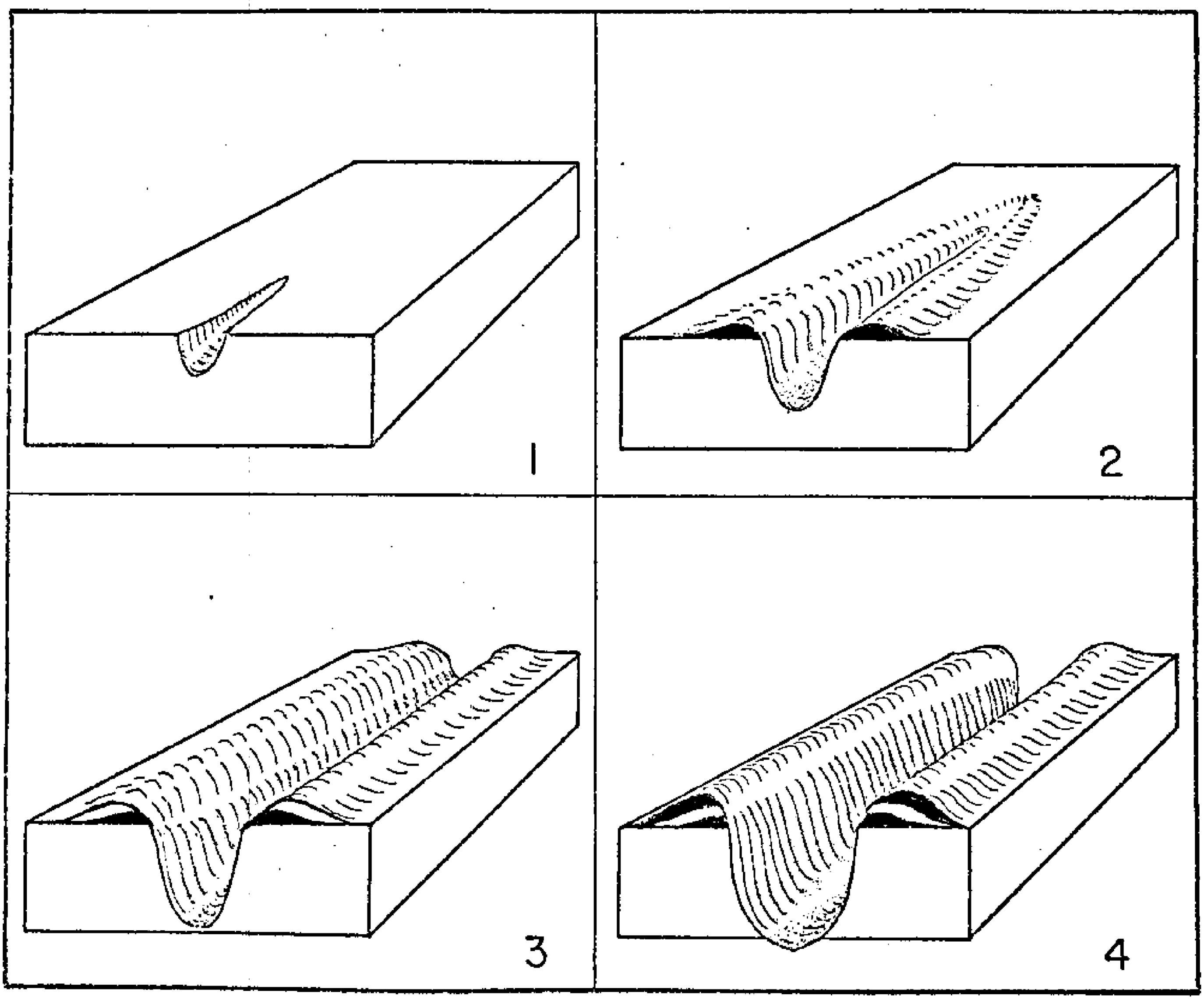


Figure 55. Model for the formation of linear sand shoals in Delaware Bay by headward erosion of tidal channels and overbank deposition of fine sediments.

overbank deposition, effects of storms and lengthwise extension of the shoal.

Summary of the Shoal Development Sequence

The linear sand shoals of Delaware Bay are unique in the sense that they are formed as subaqueous levees by overbank deposition from flood tidal currents. Once the shoal is formed, there does not appear to be any regular ordered sequence of development comparable to the sequence suggested by Caston (1972) for sand banks in the North Sea. Local tidal currents and wave action can apparently alter the shape of the shoal by deposition and erosion. The shoals themselves are dynamic bedforms which are constantly adjusting to the local conditions of dynamic equilibrium, which are themselves changing with the ongoing rise of relative sea level.

A Model of Nearshore Sedimentation

In Delaware Bay, the first stage of development of the complex relationships between surface facies and dynamic processes occurs at the shoreline. Strom (1972) described the relationship in terms of a dynamic balance between an inner and outer zone of construction which are separated by an area called the "abrasion zone," characterized by high bottom turbulence, high energy expenditure and wave action (Figure 56). Shoreline and nearshore sediments eroded by wave action will either be transported in a landward direction or seaward direction in accordance with the "null point" hypothesis of Johnson and Eagleson (1966).

The null point concept provides that the wave-produced hydrodynamic forces on individual bed sediment particles will increase in the shoreward direction. These forces, at some point, may cause sediment particles of a given size to: (a) move in an offshore direction if gravity forces acting on the particle exceed the net fluid forces (over one wave cycle); (b) move in an onshore direction if fluid forces exceed the gravity forces; or (c) oscillate on the bottom with no net motion when the two forces are equal (the null condition). For a given set of hydraulic

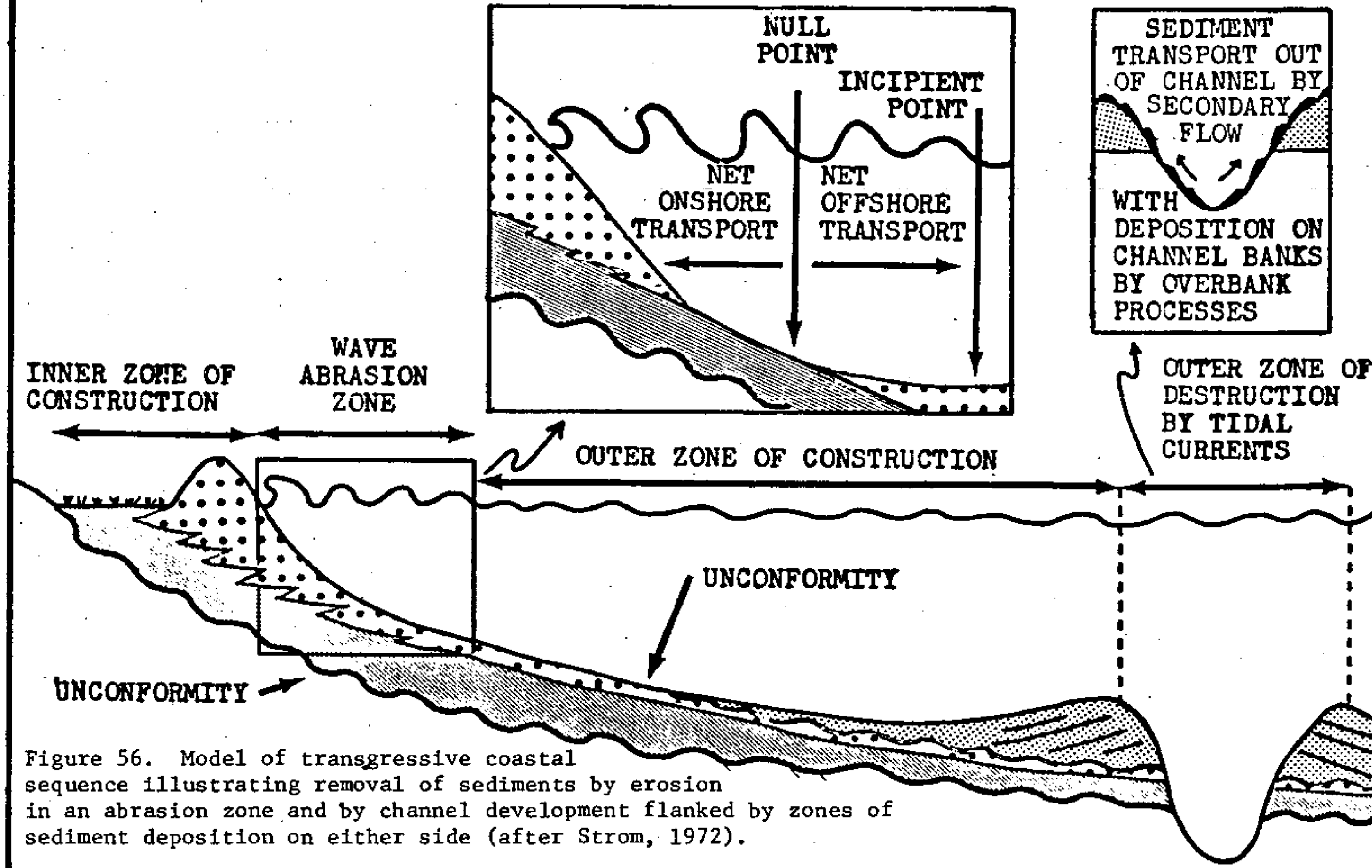


Figure 56. Model of transgressive coastal sequence illustrating removal of sediments by erosion in an abrasion zone and by channel development flanked by zones of sediment deposition on either side (after Strom, 1972).

conditions, the position of the null point, or null line (Swift, 1969), depends upon grain size and lies closer to shore as grain size increases. In Strom's model, the null point separates the abrasion zone from the outer zone of construction. The point where particle motion first begins is called the point or line of incipient sediment motion.

Strom (1972, p. 73) proposed that "when energy input is large compared to the available sediment carpet in the region of shoaling and breaking waves, the grains will be moved out of the abrasion zone, exposing the underlying material to erosion." The eroded sediments may be transported landward into the "inner zone of construction," consisting of the tidal marsh and washover barrier complex. If the sediment is transported offshore as bed load, it may be transported as far as the null point for established sediment motion, which may lie offshore of the point of incipient motion. If the eroded sediments are transported offshore in suspension, the grains may be carried by currents beyond the null point for established sediment motion and deposited in the "outer zone of construction" which "includes all the area of the bay in which sediments are presently accumulating" (Strom, 1973, p. 75).

The extent to which erosion in the abrasion zone occurs will determine what proportion of the transgressive facies in the inner zone of construction is preserved and buried. There may be a total retention, partial retention or total loss of the transgressive sequence (Figure 57), depending upon the thickness of the transgressive sediments, the local rate of relative sea level rise, the sediment supply and the availability of surf and current energy. Different degrees of sediment retention have been suggested to explain the close proximity of dark organic-rich muds and coarse oxidized sands in the nearshore areas of the bay.

Strom (1972, p. 75) suggested that an outer zone of destruction was required to represent completely the dynamics of the transgressive sequence in Delaware Bay. This fourth zone includes the tidal channel currents eroding previously deposited sediments and is illustrated in Figure 56. It is obvious however, that each of the tidal channels

RETENTION OF COASTAL SEDIMENT RECORD IN A TRANSGRESSING SEA

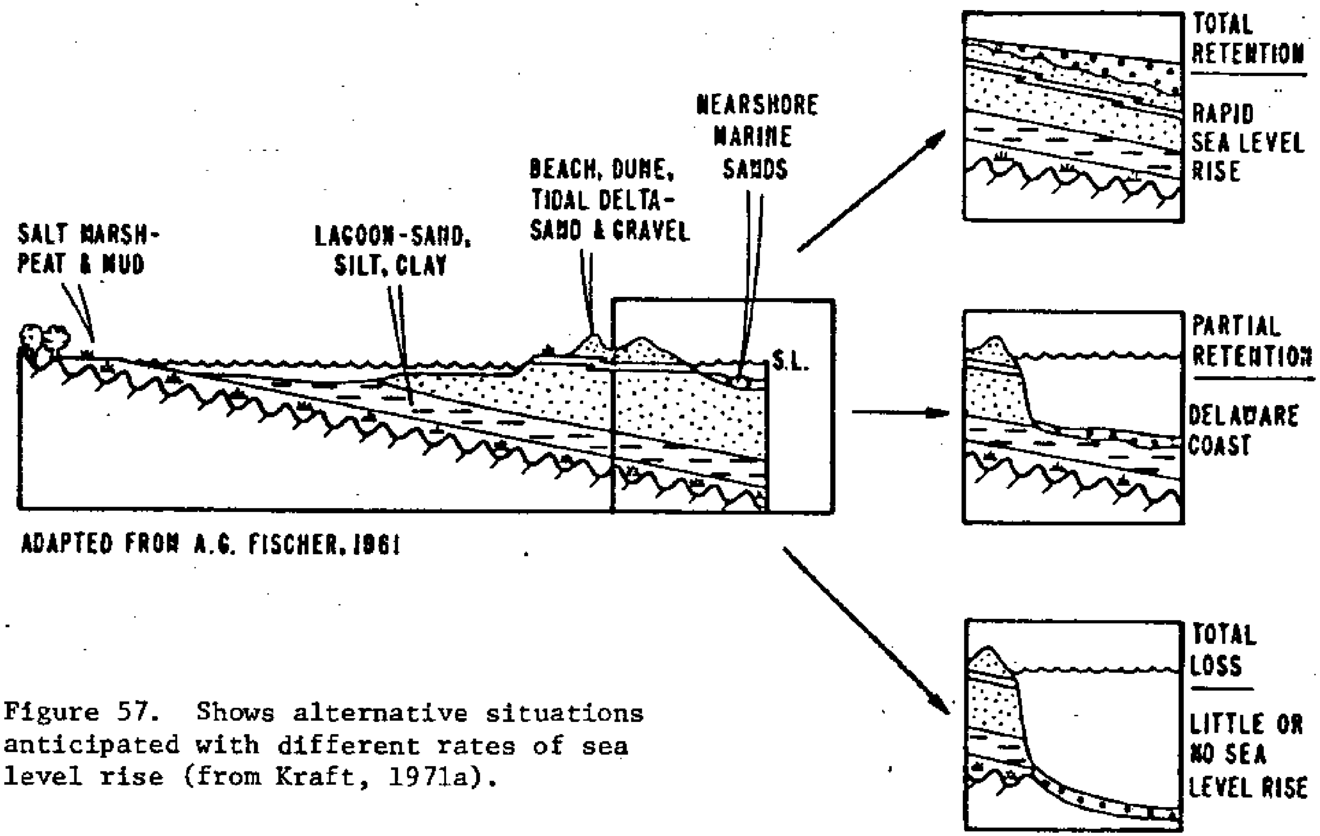


Figure 57. Shows alternative situations anticipated with different rates of sea level rise (from Kraft, 1971a).

constitutes a potential zone of destruction, and the adjacent linear sand shoals zones of construction. This system of tidal channels and linear shoals constitutes the outer zone of reworking. The extensive sediment reworking in the central areas of the bay further complicates the bay stratigraphy.

The Relationships Between Surface and Subsurface Sediments

Introduction

In the preceeding sections, it was shown that the bottom sediments of Delaware Bay generally become finer-grained, more poorly sorted, and increasingly negatively skewed in shallow waters where current velocities are lower and the slack water period is of longer duration. These relationships represent the present "direction" of reworking and adjustment of surface sediments caused by changing conditions of dynamic equilibrium, as sea level has risen during the Holocene. On the Delaware coast, the long-term response of the various sedimentary environments to rising sea level has been a combined vertical and lateral migration in the landward direction (Kraft, 1971a, 1972b; Strom, 1972; Elliott, 1972).

In this section, these relationships, together with criteria to recognize surface textural facies and Walther's Law, have been used to interpret subsurface data in terms of surface textures and facies.

Walther's Law

Johannes Walther, in his Law of the Correlation of the Succession of Facies, summarized a fundamental relationship between recent surface sedimentary environments and buried vertical sequences. Walther's Law was, according to Middleton (1973, p. 979) originally stated as follows:

> The various deposits of the same facies areas and similarly the sum of the rocks of different facies areas are formed beside each other in space, though in cross-section we see them lying on top of each other. As with biotopes, it is a basic statement of far-reaching significance that only those facies and facies areas can be superimposed primarily which can be observed beside each other at the present time.

Furthermore,

> the various facies ... are characterized not only by depositional processes but also by erosional processes (Middleton, 1973, p. 893).

The mid-bay area off Kitts Hummock, Delaware (Figure 52) shows a typical sequence of the sedimentary environments encountered in Delaware Bay, moving from the land in the offshore direction. This sequence, summarized in Table 4, will be used with Walther's Law and the surface sediment distribution to develop an ideal vertical sequence for the transgressive sediments of Delaware Bay, a sequence that will be used

TABLE 4

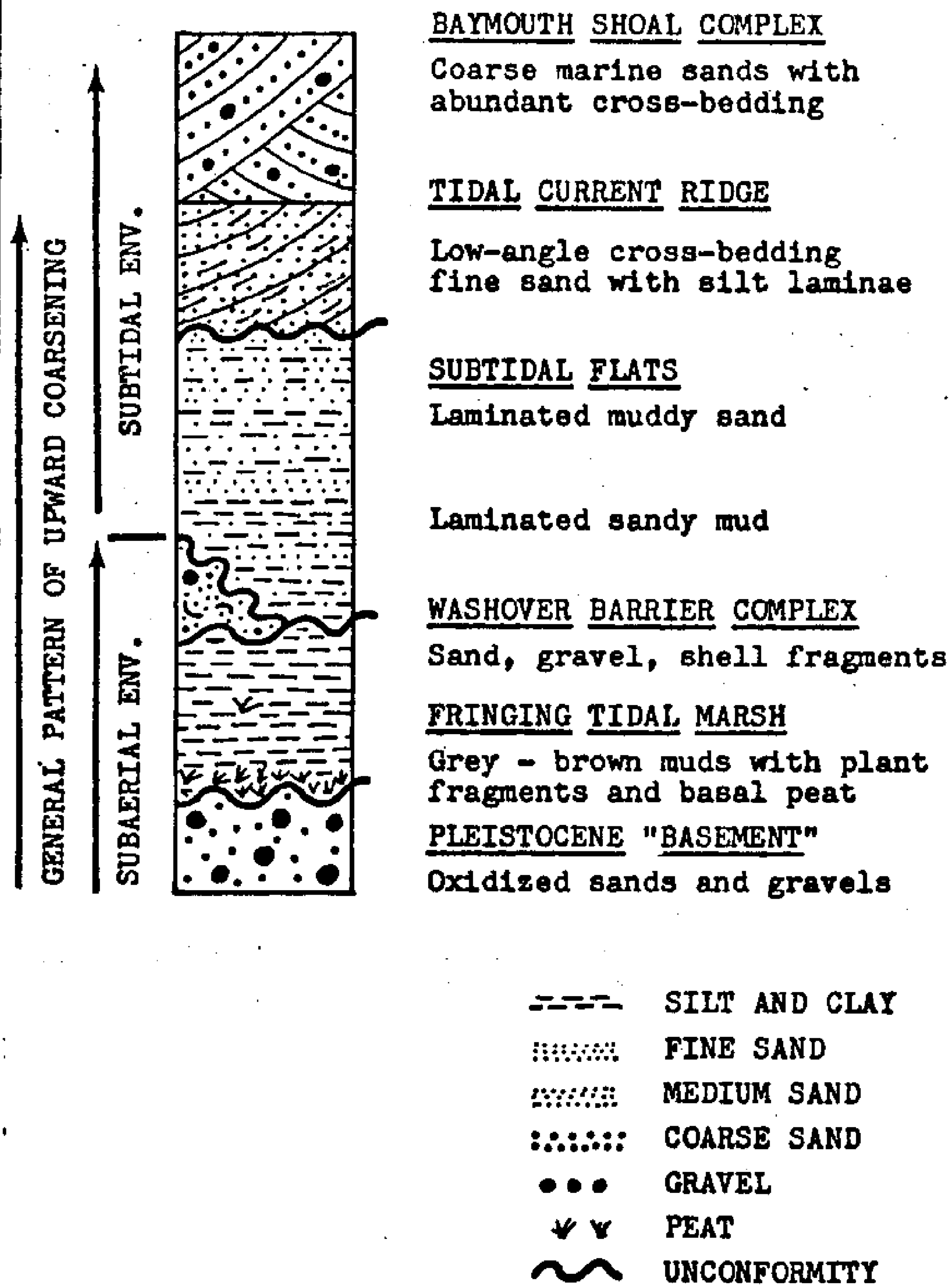
A Typical Sequence of Sedimentary Environments in Delaware Bay

Subaerial Facies				Subtidal Facies					
Pleistocene Surface	Tidal Marsh	Washover Barrier	Shoreline	Subtidal Flats	Linear Sand Shoal	Tidal Channel	Linear Sand Shoal	Subtidal Flat	Tidal Channel

as a standard against which the vertical sediment sequences observed in the piston cores can be compared and interpreted.

In the ideal vertical sediment sequence (Figure 58), the lowermost units are the subaerial facies, consisting of the Pleistocene surface, the tidal marsh, and the washover barrier complex. In a core, the lowest

Figure 58. A conceptual model of an ideal vertical sequence of transgressive sedimentary sediments in Delaware Bay.



of the three units is the Pleistocene surface, generally an oxidized sand or gravelly sand. This coarse "basement" unit is unconformably overlain by a basal peat and the muds of the tidal marsh which typically contains peat layers, organic fragments, burrows, and possibly deposits of shallow lagoons and tidal creeks (Elliott, 1972). The marsh muds may be unconformably overlain by a coarse sandy sequence with lag deposits of shell fragments and gravel, representing the estuarine washover barrier complex at the shoreline (Kraft, 1971b).

An erosional unconformity separates the sediments of the marsh/washover barrier complex from the sediments of the offshore subtidal environments. Outcrops of eroded marsh mud may extend several kilometers from the shoreline (Figure 11) before being buried by the very fine sands and muds of the subtidal flats. These interlaminated deposits are derived by gravity settling from the turbid plumes of suspended sediment seen on ERTS-1 satellite imagery (Klemas and others, 1973a, 1973b). In the subtidal flat sediments, the percentage of mud generally decreases with increasing distance from shore as water depth and current velocity increase. Further from shore, the cross-bedded fine sands of the tidal current ridges unconformably overlie the sand-dominated muds of the outer subtidal flat.

The uppermost unit in the ideal vertical section consists of the coarse sands derived from the Continental Shelf by the net landward transport of bottom currents. These marine sediments are found in the Baymouth Shoal Complex and in the eastern part of the lower bay (Neiheisel, 1973).

The ideal vertical transgressive sequence represents a composite of the different relationships between depositional environments of Delaware Bay. None of the cores collected during this study showed the complete vertical sequence. Core 247 (vibrocore 24) represents the most complete vertical depositional sequence examined in this study, missing only the fine sands of a linear shoal and coarse marine sands. A complete vertical sequence may possibly exist in the eastern part of the lower bay.

Recognition of Facies in Piston Cores

The criteria used to recognize the surface facies groups in the subsurface cores are based on Figure 59. When the average values for the weight percent mud and median diameter of all samples in each cluster group are plotted, there is a distinct separation of the cluster groups into the three facies groups plus a "transition" group. The transition group, comprised of cluster groups 5, 6, 12, 13, and 17, showed a strong geomorphic association with the upper ends of the tidal channels. This group appears to represent a mixing of mud and sands deposited from suspension or derived from channel-bottom deposits or outcrops.

Based on the partitioning of the three facies (Figure 59), the median diameter and the weight percent mud have been used to recognize the facies association of samples in the piston cores which were analyzed. Justification for this procedure is based on the relationship of the partitioned groups to the average grain-size distribution for the bay (Figure 60). Histograms of the averaged grain-size distribution for the bottom and subbottom sediments in Delaware Bay both show distinctly bimodal distributions. The primary mode in both curves lies between 3.0 and 3.5 phi, with a well-developed secondary mode between 1.5 and 2.0 phi. The midpoint between the two modes corresponds to the partitioning "fence" between Facies A and C in Figure 59.

The average weight percent of grades coarser than 0.5 phi is higher in the subsurface than in the surface sediments while the opposite holds for grades finer than 0.5 phi. However, the weight percent of mud is 9 percent higher in subsurface samples which have not been subjected to winnowing of the fines. Winnowing of the surface sediments could partly account for the minor differences between the average surface and subsurface sediment distributions. The strong basic similarity of the two distributions occurs because subsurface sediments are the primary source for most of the surface sediments in the bay. The bulk of the surface sediments are simply former subsurface sediments which have been reworked or exposed as subcrops during the marine transgression.

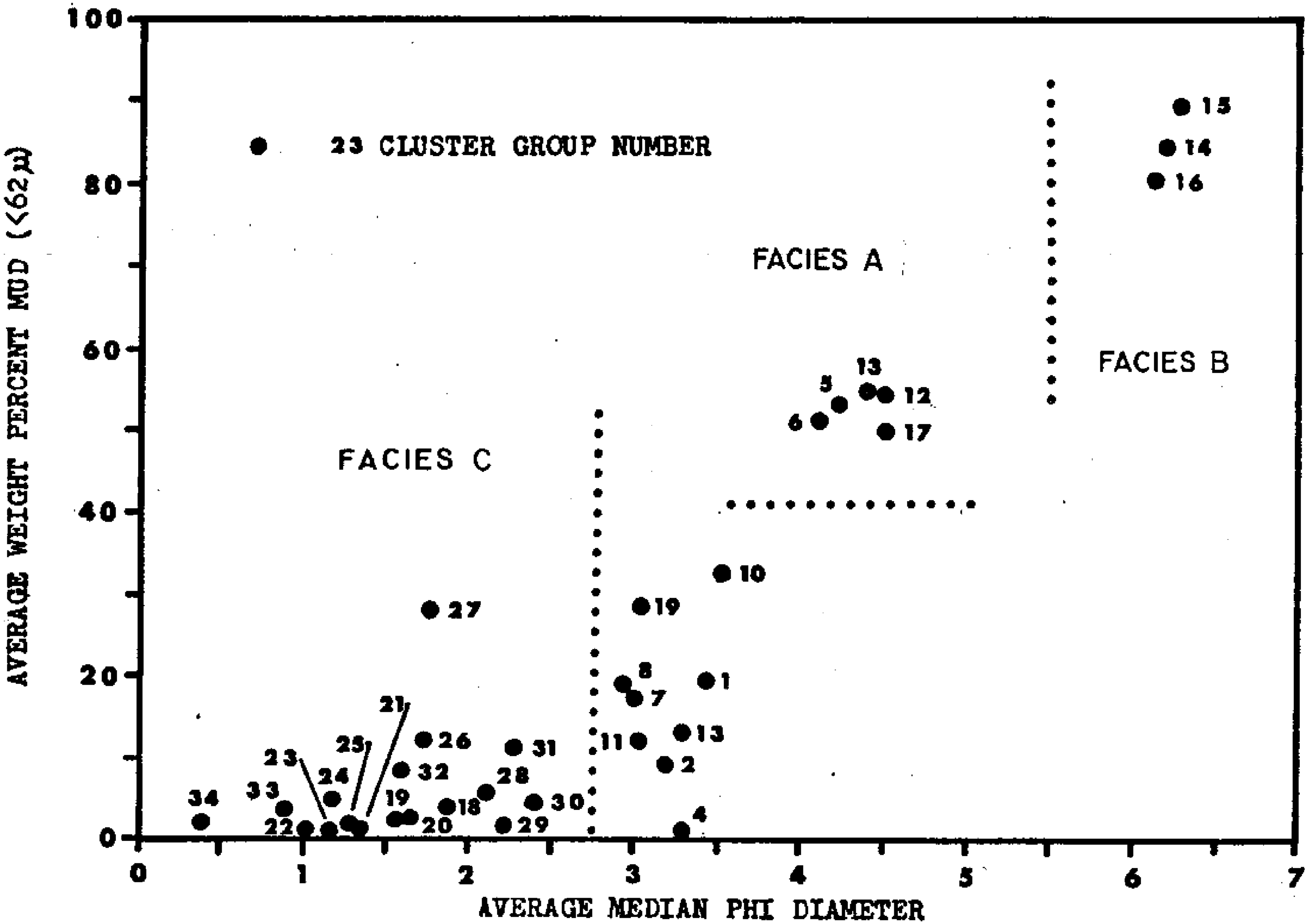


Figure 59. Averaged weight percent mud and median diameter for each cluster group.

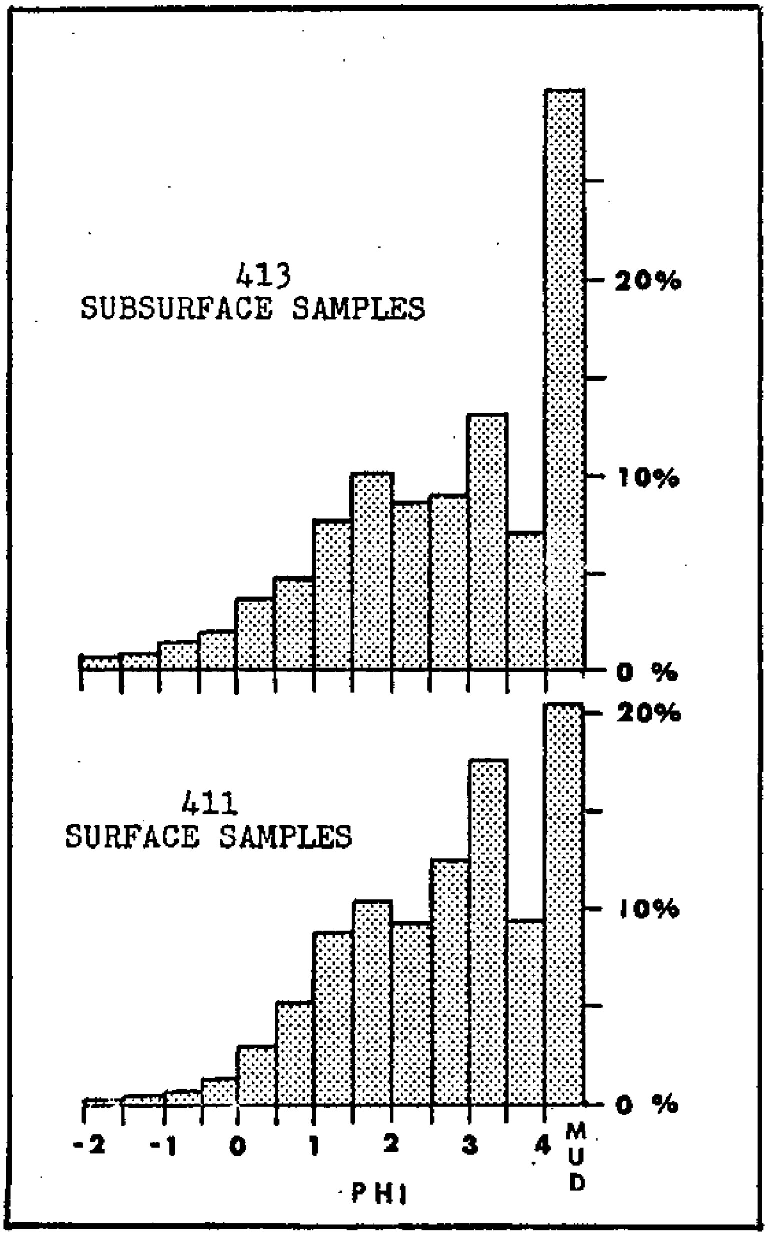


Figure 60. Histograms comparing the average grain-size distribution of surface and subsurface sediments from Delaware Bay.

TABLE 5

Environmental Interpretation of Textural Units in the Ideal Vertical Section

	Description	Facies	Interpretation
A.	Uniform mud	B	Tidal marsh, "quiet water deposition" at null point or head of salt intrusion.
B.	Muds, sandy muds, or muddy sands over coarser sands and interlaminated fine sand and mud	A and/or B over C	Transgressive Holocene or reworked estuarine sediments unconformably overlying pre-Holocene deposits.
C.	Fine sand		
	C.1 Mud-dominated	A	Shallow nearshore deposition, distant from intense channel currents.
	C.2 Sand-dominated	A	Farther offshore, influenced by stronger tidal currents in deeper waters and near tidal channels.
D.	Uniform clean sand		
	D.1 Coarse grain	C	Pre-Holocene, fluvial or marine near mouth of the bay.
	D.2 Fine-grain sand	A	Estuarine or fluvial deposits reworked by tidal currents.
E.	Clean sand over muds, sandy muds, or muddy sands	C over A and/or B	Reworked estuarine, pre-Holocene or marine sands unconformably overlying fine-grain estuarine sediments.

Each subsurface sediment sample from each core in Appendix II was coded and assigned to one of the three cluster groups, based on the median diameter and weight percent mud. The magnitude of each component is indicated at the sample depth according to the following scheme:

(a) the median diameter of the sample is indicated by a letter prefix; C indicates a median diameter coarser than 2.5 phi (177 microns) and F indicates a median diameter finer than than 2.5 phi.

(b) the percentage of mud in the sample is indicated as a numerical suffix to the median diameter code.

This classification scheme was used to interpret the depositional environments and determine the vertical succession pattern in each core.

Interpretation of Vertical Sequences in the Subsurface

The textures and vertical succession of the ideal vertical sediment sequence have been used to interpret the depositional and erosional history of the vertical sequences observed in the cores from Delaware Bay (Appendix II). The basis for this interpretation assumes that the idealized vertical sediment sequence is correct, and that the textures and vertical successions of the ideal vertical sequence constitute definitive criteria by which to interpret similar textures and successions in cores from the bay. The interpretation makes no allowance for possible short-term regressions during the Holocene history of Delaware Bay (Meyerson, 1972), the Hudson River (Weiss, 1974) and the Gulf Coast (Morgan, 1970; Frazier, 1974). Such effects, if present, were not recognized in the seismic or the piston core data from Delaware Bay.

The interpretation of the subsurface data is based upon the five textural groups which make up the ideal vertical sequence and the vertical succession of these groups suggested by the surface sediment distribution maps and Walther's Law. The environmental interpretations of each of the textural groups in the vertical sequence of the bay is summarized in Table 5.

The textural relationships and vertical sequences in subsurface cores from Delaware Bay, though extremely varied and complex, show a remarkable similarity to the ideal vertical sequence. The cores show different combinations of the ideal vertical sequence depending upon: (1) where the core was taken; (2) the length of the core compared to the thickness of the sequences present; and (3) the erosional and depositional history at the core site.

Several commonly observed variations in vertical sequences are summarized in a conceptual cross section (Figure 61), showing the relationship between water depth, vertical lithologic variation, subsurface facies and geomorphology. Cores showing each of the vertical sequences depicted are also listed.

A Model for the Evolution of Delaware Bay

Introduction

Estuarine conditions began in Delaware Bay when the landward-migrating upstream limit of salt intrusion passed between the Capes, approximately 12,000 years ago. After this time, the evolution of Delaware Bay can be considered from three separate yet related viewpoints:

(1) The genetic classification of the sediments in Delaware Bay;
(2) The development of transgressive estuarine environments; and
(3) The development of the present day morphology and subsurface lithologic sequences.

In this section, each of these aspects of the evolution of Delaware Bay will be examined.

The Estuarine Delta

Throughout the geologic literature, many definitions of a delta have been proposed, argued, revised, adopted, and discarded -- largely because, as noted by Guilcher (1963), "the concept of a delta is complex" and "caution is necessary in definition." Recent studies of ancient and modern deltas (Shirley, 1966; Morgan, 1970), while providing a broader understanding of the different types of deltas and the processes which form and shape them, have made clear the lack of a flexible definition. The following re-definition of a delta, proposed by Moore and Asquith

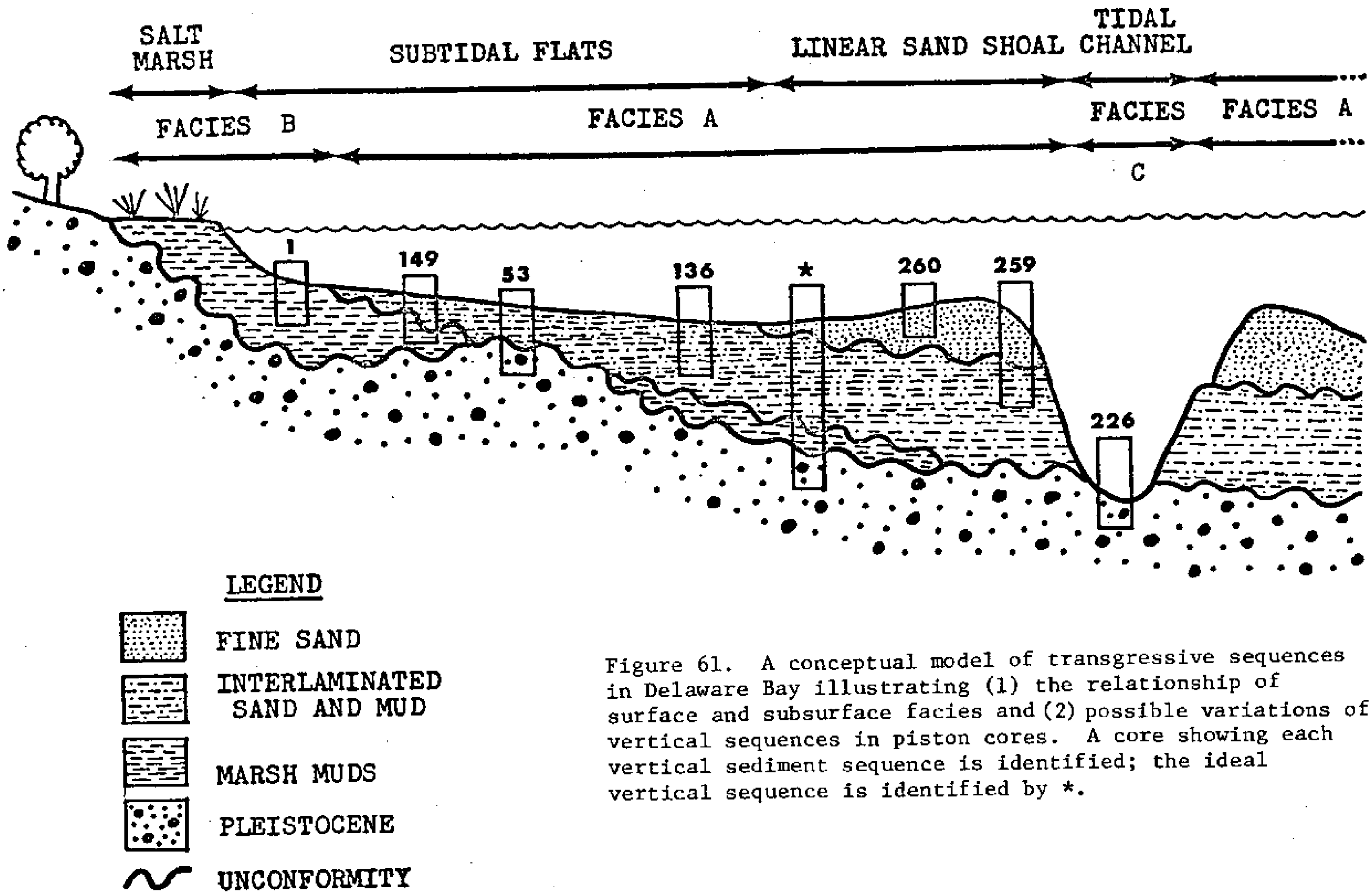


Figure 61. A conceptual model of transgressive sequences in Delaware Bay illustrating (1) the relationship of surface and subsurface facies and (2) possible variations of vertical sequences in piston cores. A core showing each vertical sediment sequence is identified; the ideal vertical sequence is identified by *.

(1971, p. 2566), has been adopted for this study because of its simplicity and flexibility: "The subaerial and submerged contiguous sediment mass deposited in a body of water (ocean or lake) primarily by the action of a river."

The nature of the body of water into which a delta builds may be used as a basis for delta classification (Bernard, 1965). One such delta type is the estuarine delta, about which, compared to other types of deltas, relatively little is known (LeBlanc, 1972). The estuarine delta represents the subaerial and submerged contiguous sediment mass deposited in an estuary, between a river and the sea where estuarine circulation patterns controlling water and sediment movement are affected primarily by the channel configuration and interaction of river discharge, the tide and/or the wind (Figure 62). The relationships between estuarine circulation and sedimentation patterns have been summarized in Table 6.

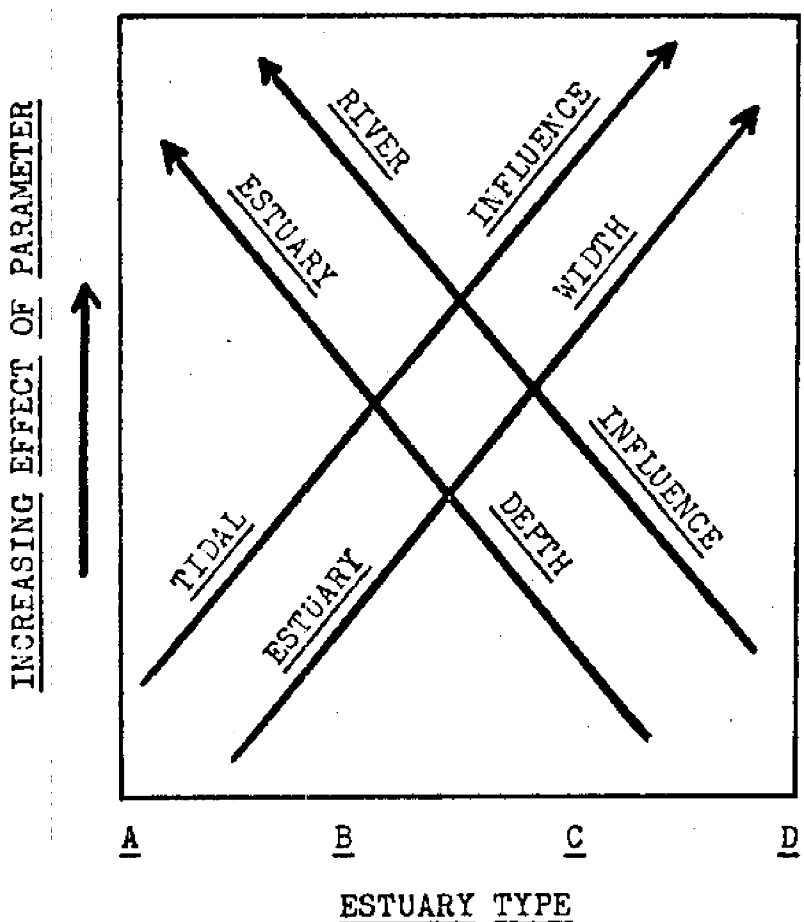


Figure 62. Relationships between estuarine circulation pattern and controlling physical factors (after Kinsman, 1965).

TABLE 6

Summary of Estuarine Circulation Characteristics and Sedimentation Patterns

	Type A HIGHLY STRATIFIED	Type B PARTIALLY MIXED	Type C VERTICALLY HOMOGENEOUS	Type D LATERALLY HOMOGENEOUS
Primary Influence on Estuarine Circulation system	River dominated circulation system	Tidal influence of river dominated circulation system	River influence on tide dominated circulation system	Tide dominated circulation system
Flow Characteristics	Net downstream flow on surface - net upstream flow near bottom	Net downstream flow on surface - net upstream flow near bottom	Upstream on right side of flood direction - downstream on right side of ebb	Slow net seaward flow at all depths
Relative volume of ebb and flood flow	Flow volume up the estuary during flood less than 10X freshwater flow	Flow volume up the estuary during flood greater than 10X freshwater flow	Flow volume up the estuary during flood greater than 10X freshwater flow	Not known
Nature of salt water - fresh water boundary	Bottom salt wedge thinning upstream	Intense mixing across fresh water/ salt water interface	No vertical salinity gradient - lateral gradient due to coriolis force	Laterally and vertically homogeneous with longitudinal salinity gradient
Mixing Pattern	Salt water mixes upward	Salt water mixes upward & fresh water downward	Extensive vertical & lateral mixing	Upstream diffusion
Controls on upstream limit of salt	Related directly to river discharge	River discharge dominates over Tidal effects	River discharge over "long" term and tidal cycle over "short" term	Dominated by tidal excursion
Locus of rapid shoaling	In the vicinity of the salt wedge tip	Between ebb & flood limits of salt in intrusion - the "turbidity maximum" - at the mouths of tributaries	Near upper limit of salt intrusion - on right side of channel going upstream - in channel section with excessive cross-sectional area	Channel section with excessive cross-sectional areas
Examples	Mississippi River	Chesapeake Bay, James River, Savannah River, Charleston Harbor, Miramichi River, Delaware Bay, Gironde Estuary	Thames Estuary Raritan Bay, Gironde Estuary, Delaware Bay	Merrimac Estuary, Piscataqua Estuary

Summarized from Schubel (1971) and Schubel and Pritchard (1972)

Schubel (1971, p. III-4) states that "the estuarine delta grows progressively seaward in the estuary extending the realm of the river, and thereby progressively displacing the intruding sea out of the semi-enclosed basin." Schubel further states that the nature of sediment transport and deposition in the estuarine delta depends upon several factors, including climate, the rate of sediment influx, the stability of relative sea level, and estuarine circulation -- especially the relative influence of the tide and river discharge.

Schubel's statement about the progressive seaward growth is valid for the case of the prograding estuarine delta, such as those of the Gulf Coast and southeastern Atlantic coast, with a high sediment influx rate. The statement does not hold for the estuarine delta in which the rate of sediment influx to the estuary is low, relative sea level is rising, and the influence of the tide is greater than that of the river. Under these conditions, the locus of active estuarine sediment deposition would migrate landward up the drowned river valley as the progressive influence of the sea advanced into the semi-enclosed coastal basin. (In some cases, there may not be an adequate sediment supply to build the irregular prograding shoreline normally associated with a "true" delta.) This is the situation with the "submerged delta of the Delaware," a term used by Mitchell (1886, p. 267) to describe Delaware Bay. The sediments of the Chesapeake Bay and Hudson River can also be viewed in the context of a submerged estuarine delta.

Several stratigraphic classification systems for deltas which depend on an understanding of primary depositional processes responsible for genetic facies are based on the observation that the ratio of sediment supply to available marine energy affects the gross facies composition of a delta system (Wright and Coleman, 1973; Scott and Fisher, 1969). The delta classification of Scott and Fisher (1969, p. 29) emphasizes "such features as kind and abundance of specific process-linked facies, sand body geometry and trend, and facies distribution both in tracts and vertical sequence," as described below:

<u>High Constructive Deltas</u>: with a preponderance of fluvially influenced facies

Lobate type: lobate delta front sand geometry

Elongate type: elongate or bar-finger sand geometry

<u>High Destructive Deltas</u>: with a preponderance of marine facies

Wave-dominated: cuspate, strike oriented sand trend

Tide-dominated: commonly digitate or elongate tidal sand bodies

Tide-dominated marine processes are the primary mechanism affecting the morphology and internal stratigraphy of the estuarine delta (Galloway, 1975).

Today, the active fluvially-influenced facies in the Delaware estuary are associated with the tidal river between the Smyrna River and head of tide (Figure 19e). However, the long-term rate of sediment accumulation in the tidal river has been too low, relative to the rise of sea level, to cause progradation of the Delaware estuarine delta. The location of the fluvially-influenced depocenter has migrated from a position of the Continental Shelf during the low stand of sea level, through Delaware Bay to its present position in response to the ongoing Holocene transgression (Swift, 1973; Kraft and others, 1973b), and more recently, the activities of man. The important point is that the active center of the fluvial deposition in the Delaware Estuary is no longer in Delaware Bay, but in the tidal river.

In the context of the ongoing Holocene marine transgression, Delaware Bay represents the high destructive, tide-dominated portion of the Delaware estuarine delta. The low sediment supply to the bay and the high tidal energy flux have produced a submerged delta mass subject to extensive tidal channel erosion and sediment reworking.

Tide-dominated, destructive delta systems with higher sediment influx rates than that of the Delaware have been described by Scott and Fisher (1969, p. 14):

> In high destructive deltas, sediment input is moderate to marine reservoir energy, and accordingly, the bulk of these systems are built up of fluvially introduced

> sediment contemporaneously reworked by marine processes. Specific kind of marine processes, whether mainly waves or tides, determines main types....In tide-dominated, high destructive deltas, fluvially introduced sediments are reworked by tidal currents into a series of digitate sand units radiating from the front of the river mouth. Muds and fine-grained sediments accumulate inland, forming extensive mangrove swamps or tidal flats that prograde the tidal sand bars. Modern examples of these deltas are the Irrawaddy, Mekong, Frazier, Gulf of Papua deltas, and several other eastern Asiatic coastal deltas.

There are, however, several important differences between the Delaware and those deltas described above by Scott and Fisher. The differences include:

(1) The transgressive tidal marsh and washover barrier complex form the only subaerial portion of the Delaware delta.

(2) There are no prograding shorelines or depositional facies associated with the Delaware Estuary.

(3) The bulk of the sediment mass comprising the Delaware delta is submerged.

(4) The Pleistocene headland restrictions at the mouth of Delaware Bay have led to the development of flood tidal channels and digitate sand bodies which radiate from the bay entrance rather than from the river mouth.

These characteristics of the Delaware Estuary can be regarded as a first step in the synthesis of a depositional model for the transgressive estuarine delta.

Development of Transgressive Estuarine Environments

At the end of the last Wisconsin glacial advance, the presence of glaciers within the Delaware River drainage basin and the increased rates of melting must have greatly increased the volumes of meltwater and the competence of the Delaware River. During the low stand of sea level, estuarine conditions in the Delaware River must have existed within the Delaware Shelf Valley seaward of the present bay mouth on the Continental Shelf, while freshwater conditions probably existed in the present area of Delaware Bay.

During the Holocene, in response to rising relative sea level and a reduction of periglacial meltwater discharge, the locus of constructive, estuarine-delta deposition began to migrate landward up the Delaware Shelf Valley. This transgressive depositional stage was presumably followed by the development and subsequent landward migration of destructive deltaic sedimentation patterns as the influence of transgressive marine facies increased. These two contemporaneous yet separate and distinct estuarine delta facies have migrated up the ancestral Delaware Valley to their present positions (Figure 63). Swift (1973) referred to this migration track as an estuary retreat path. It is not now possible to pinpoint when the upstream limit of ocean-derived salt first passed between Capes May and Henlopen into Delaware Bay. The existence of tidal conditions in the Hudson River 12,000 years B.P., and salinity levels high enough to support foraminifers about 11,500 years B.P. at the Narrows of New York Bay (Weiss, 1974) provides a possible time framework for similar conditions in Delaware Bay.

The course of the developing transgressive estuarine conditions in Delaware Bay can be traced by analogy with present conditions in the estuary above the bay. This approach was used by Kraft and others (1973b) to study the evolution of middle-late Holocene morphology of the Delaware estuary. In this sequence, Pleistocene and Holocene fluvial deposits are first buried by fine-grain transgressive estuarine sediments. The estuarine deposits are subsequently eroded and reworked by tidal currents, then buried by marine sediments derived from the Continental Shelf.

The tidal Delaware River above Philadelphia is a modern analogue of conditions that existed in Delaware Bay 12,000 years B.P. Sediment transport is dominated by the river flow and the net sediment transport is seaward. Clastic deposition generally predominates and, except for deposition in fringing tidal marshes, most fine-grain sediments are deposited below Philadelphia. Between the head of salt and the null point, fine-grain estuarine sediments are deposited over the underlying fluvial sands and gravels. This estuarine depocenter, supplied from both landward and seaward directions, has migrated landward in response to changing hydraulic conditions and the ongoing marine transgression (Figure 64).

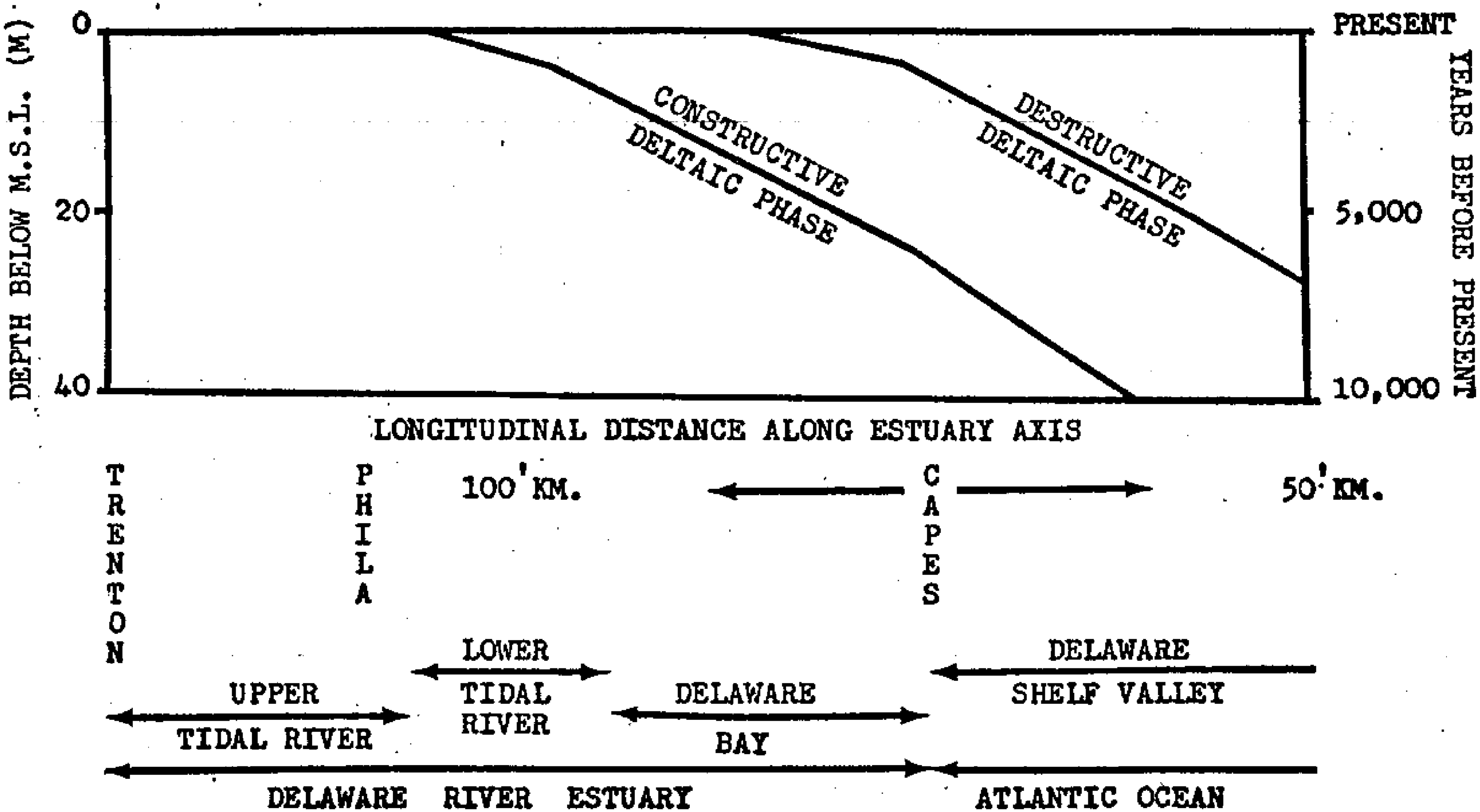


Figure 63. A model illustrating the transgressive migration of delta facies in the Delaware Estuary to their present positions in response to rising sea level during the Holocene epoch.

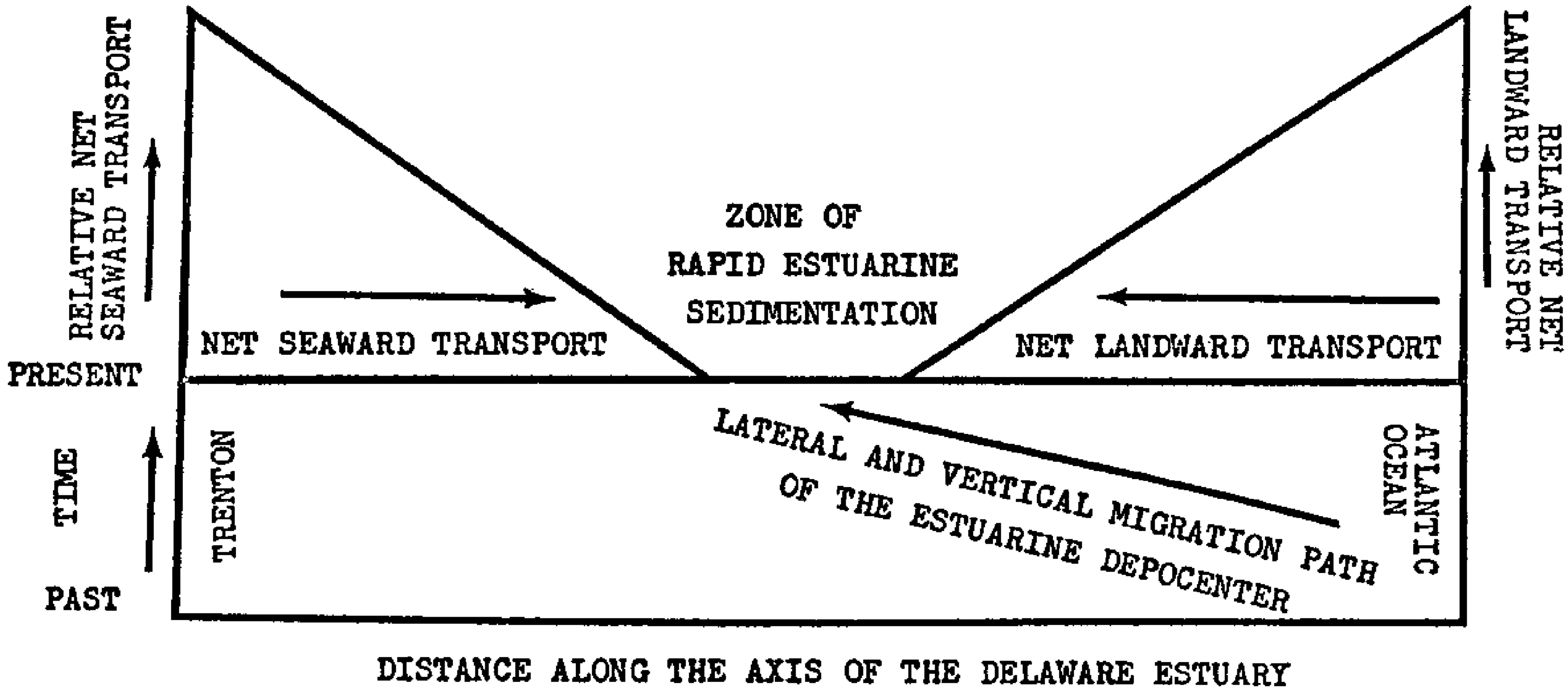


Figure 64. A model illustrating the transgressive migration of the Delaware Estuary depocenter in response to rising sea level during the Holocene epoch.

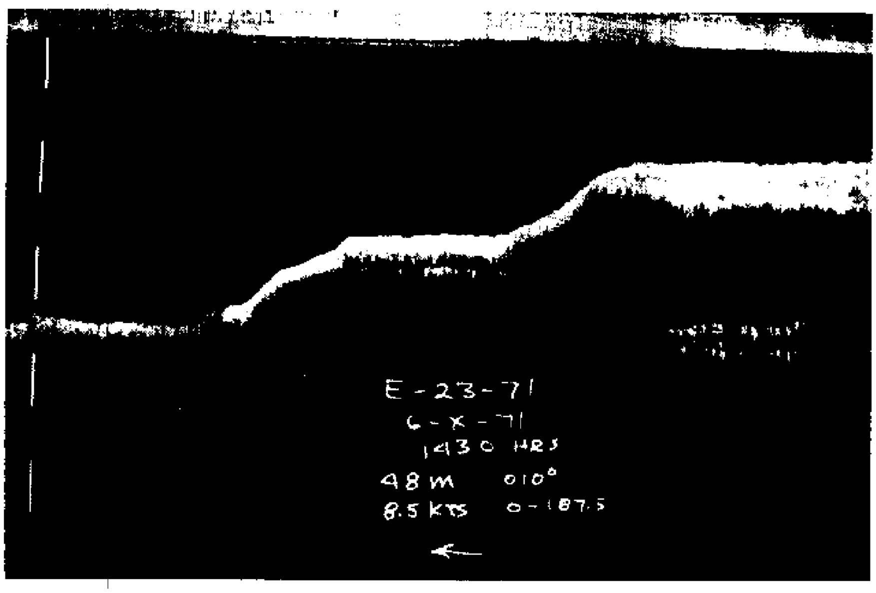


Figure 65. 3.5 kHz seismic reflection profile shows outcrops of pre-Holocene sediments overlain by a thin veneer of more recent sediments. Center of the photograph is at 38-50.3° N. latitude and 75-04.0° W. longitude.

Below the null point, the influence of landward transport of bottom sediments increases toward the mouth of the bay. In the Delaware today, the upper limit of landward transported ocean-derived microfauna is the head of the bay, and heavy mineral suites characteristic of the Continental Shelf occur in the eastern part of the lower bay (Neiheisel, 1973). These transgressive shelf sediments overlie the estuarine muds and coarser fluvial deposits. Today, all three lithosomes are present in the subsurface of Delaware Bay.

The effects of tidal currents have become increasingly important in modifying the estuarine environments of Delaware Bay as sea level has risen during the Holocene. Today, in the upper and middle bay, tidal currents are reworking the fine-grain estuarine sediments. In the lower bay, where the effects of tidal currents are most intense, tidal currents have modified the estuarine sediments in several distinct ways:

(1) The silt and clay-size materials have been winnowed from the surface sediments, except in nearshore and protected areas.

(2) Flood tidal currents have eroded the Holocene estuarine sediments to expose the underlying pre-transgression sediments (Figures 65 and 66) such as in cores 130, 74, and 226.

(3) Flood tidal currents have transported sediments derived from the Continental Shelf into the eastern part of the lower bay (Figure 67). These marine sediments form a flood tidal delta and overlie the fine-grain estuarine sediments deposited during the earlier stages of bay development (cores 55, 57, and 73).

(4) Reworked fine sediments have been transported seaward along the ebb-dominated currents on the western side of the bay. Oostdam (1971) reported a net seaward transport of suspended sediment at the bay mouth, and the heavy mineral assemblages on the Continental Shelf outside the south of the bay mouth indicate that they were derived from the bay (Figure 67). Seismic reflection profiles in the western part of the lower bay show well-developed, eastward-dipping internal bedding on the flanks of the tidal channels (Figures 37, 38, and 39). These inclined beds are not related to similar structures on the linear sand shoals, but represent the accumulation

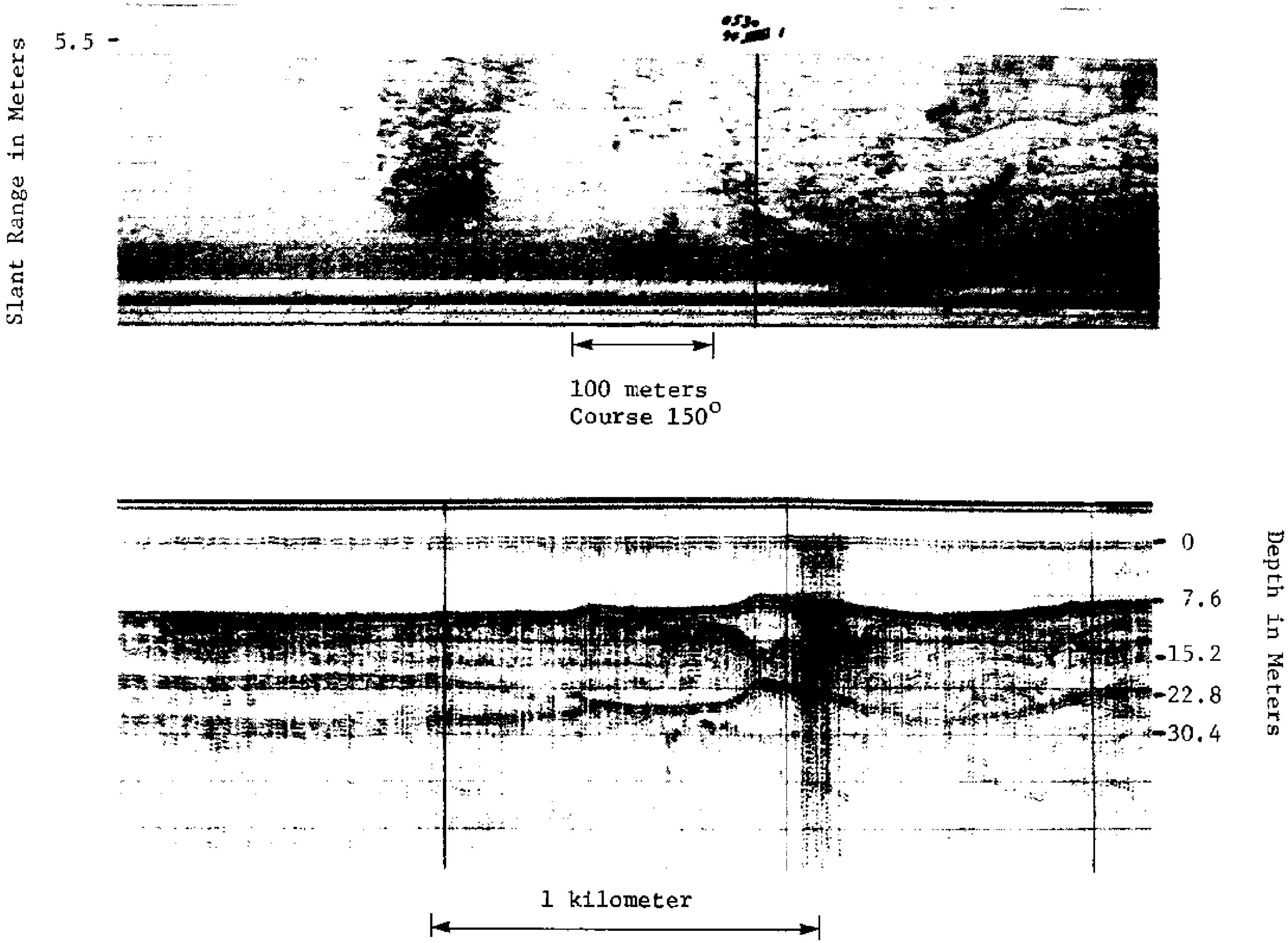


Figure 66. A dark patch of gravel on the side scan sonar record correlates with an outcropping seismic subbottom reflector and gravelly bottom sediment texture east of Brandywine Shoal (see Figure 27).

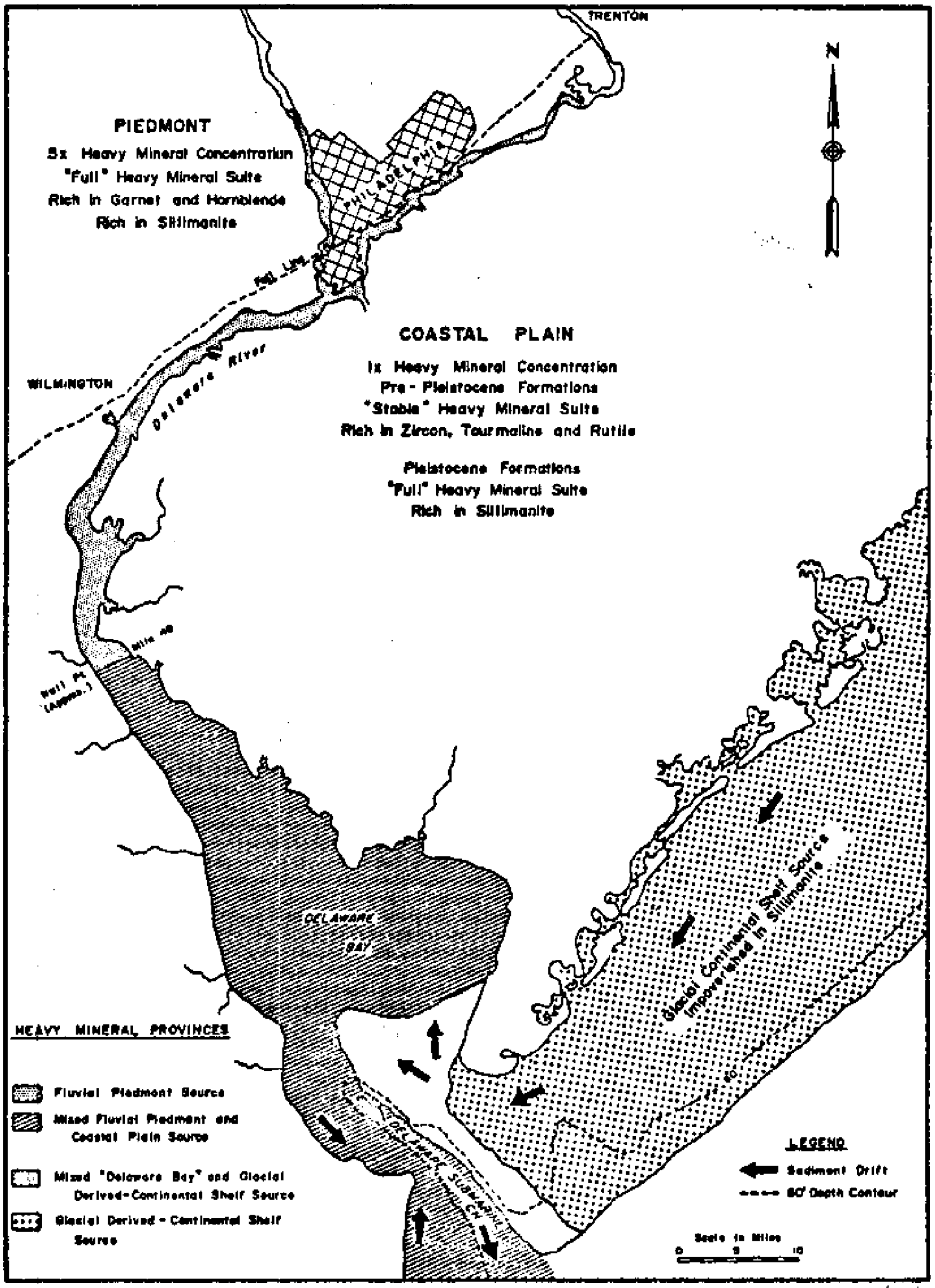


Figure 67. Sediment sources and dispersal directions of sand-size sediment in the Delaware Estuary based on heavy mineral assemblages (from Neiheisel, 1973).

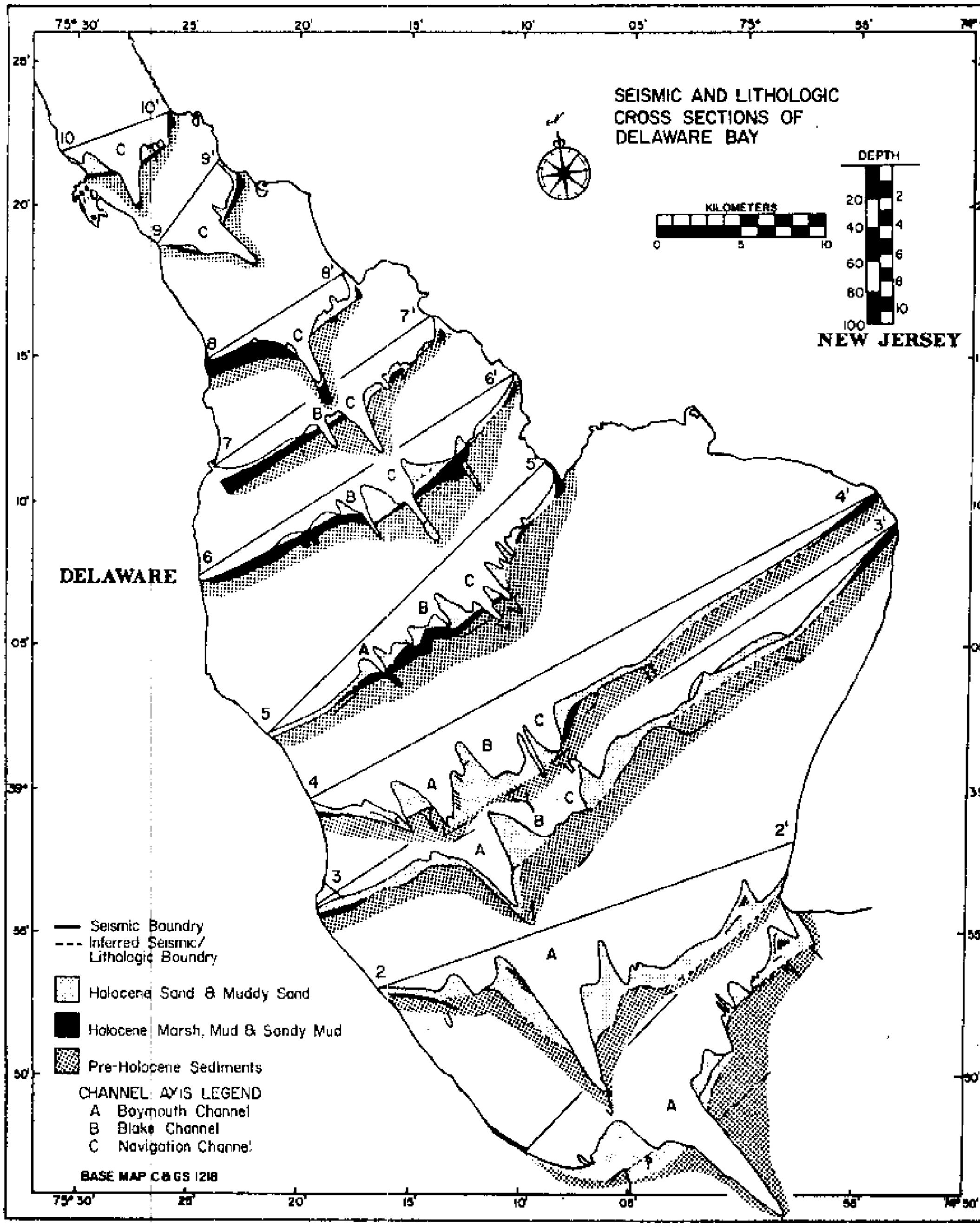


Figure 68. Stacked profiles across Delaware Bay showing bathymetry, lithology and seismic subbottom structures.

of fine sands transported seaward along the western side of the bay by Coriolis-influenced ebb tidal currents. The magnitude of this net non-tidal westward transport is 6.2 cm/sec. (Dennis Polis, personal communication). These sediments are either derived from the tidal river or from the reworked bed of the bay. Consequently, the marine-derived flood tidal delta is not present on the western side of the lower bay. Marine sands derived from the Continental Shelf and transported northward by littoral drift occur on Cape Henlopen.

The Development of Delaware Bay Morphology

The development of the present-day morphology of Delaware Bay has resulted from the modification of the pre-Holocene terrain and transgressive Holocene depositional environments by changing dynamic conditions. The present relationships of the bay morphology, bathymetry, and subsurface environments are interpreted in a series of cross sections (Figure 68) based upon seismic data and subsurface lithology. The early stages of bay development, previously discussed in this section, are depicted in Figure 69 and shown by geomorphic comparison with cross sections of the present-day Delaware estuary (Figure 70).

Evidence from Chesapeake Bay and the Hudson River estuary suggests that the first effects of the Holocene rise of sea level in Delaware Bay was the increasing influence of the tide at the bay mouth, approximately 12,000 years B.P. (Figure 69-1). The presence of foraminifera (Weiss, 1974), pollen assemblages, and radiocarbon dating (Owens and others, 1974) indicates saline conditions began between 10,000 and 12,000 years B.P., followed by drowning of the ancestral river valleys and the rapid accretion of fine-grain estuarine sediments. It seems likely that similar conditions began in the Delaware Estuary about the same time.

The earliest evidence for the Holocene transgression is from the sample 55 (PC-10E) on the eastern flank of the Baymouth Channel. A carbonaceous mud, in what is interpreted to be a washover barrier sequence at a depth of 26 meters, gave a radiocarbon date of 9570 $\pm$ 145 years B.P.

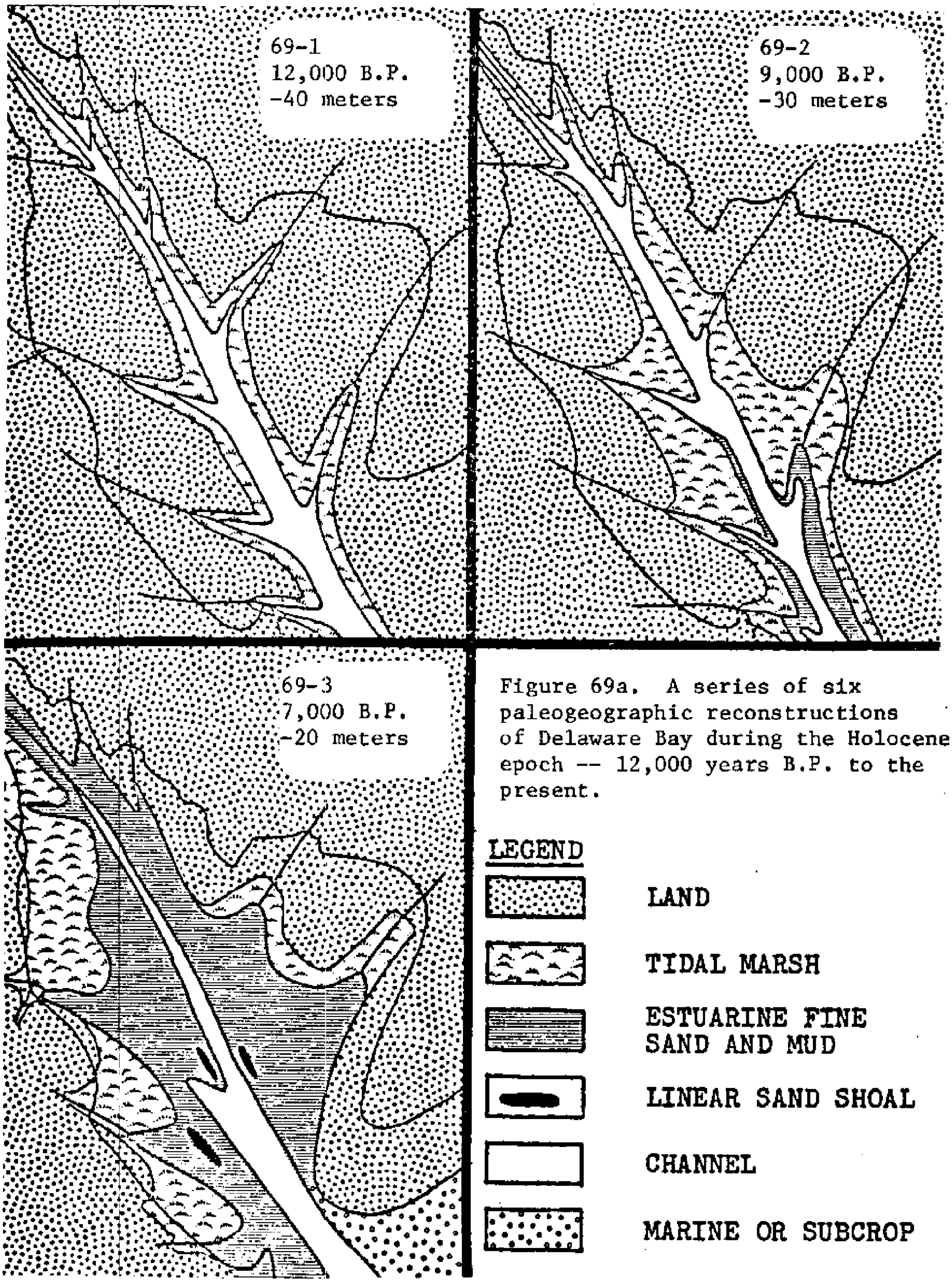
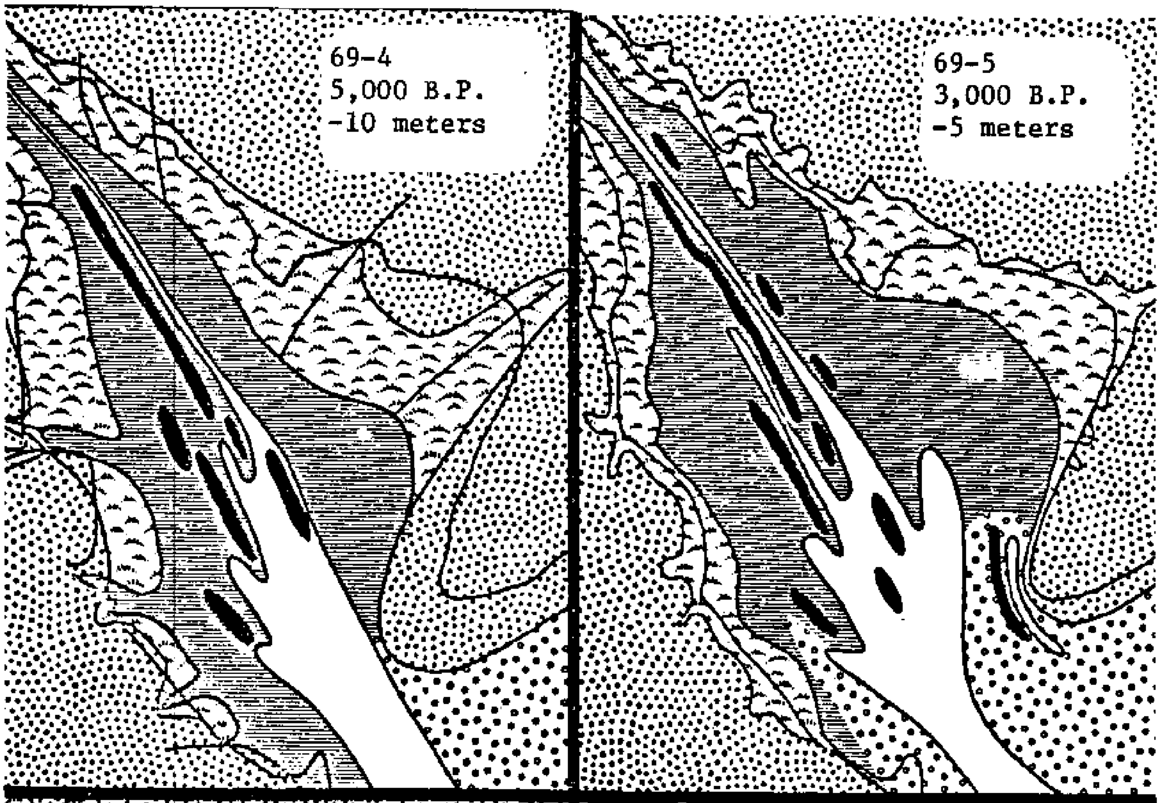


Figure 69a. A series of six paleogeographic reconstructions of Delaware Bay during the Holocene epoch -- 12,000 years B.P. to the present.



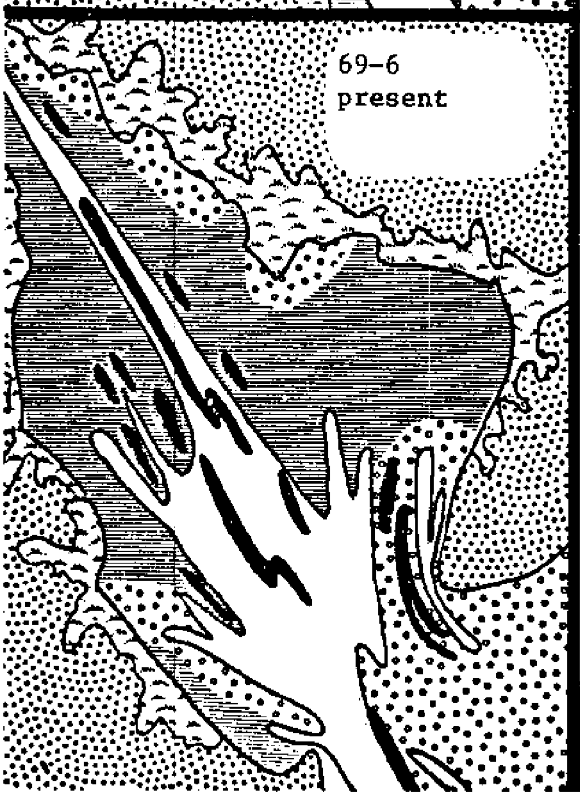
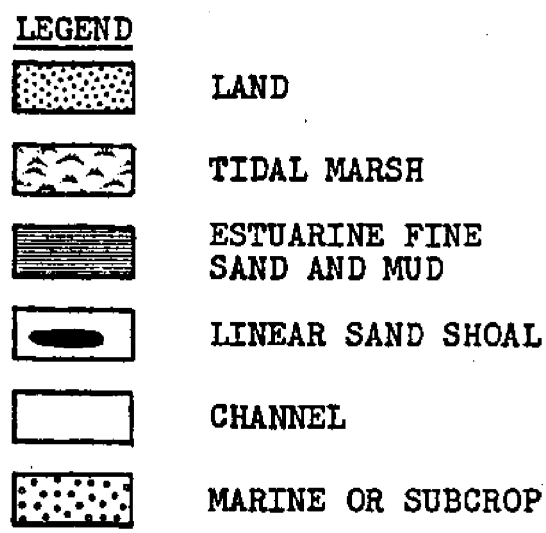


Figure 69b. A series of six paleogeographic reconstructions of Delaware Bay during the Holocene epoch -- 12,000 years B.P. to the present.



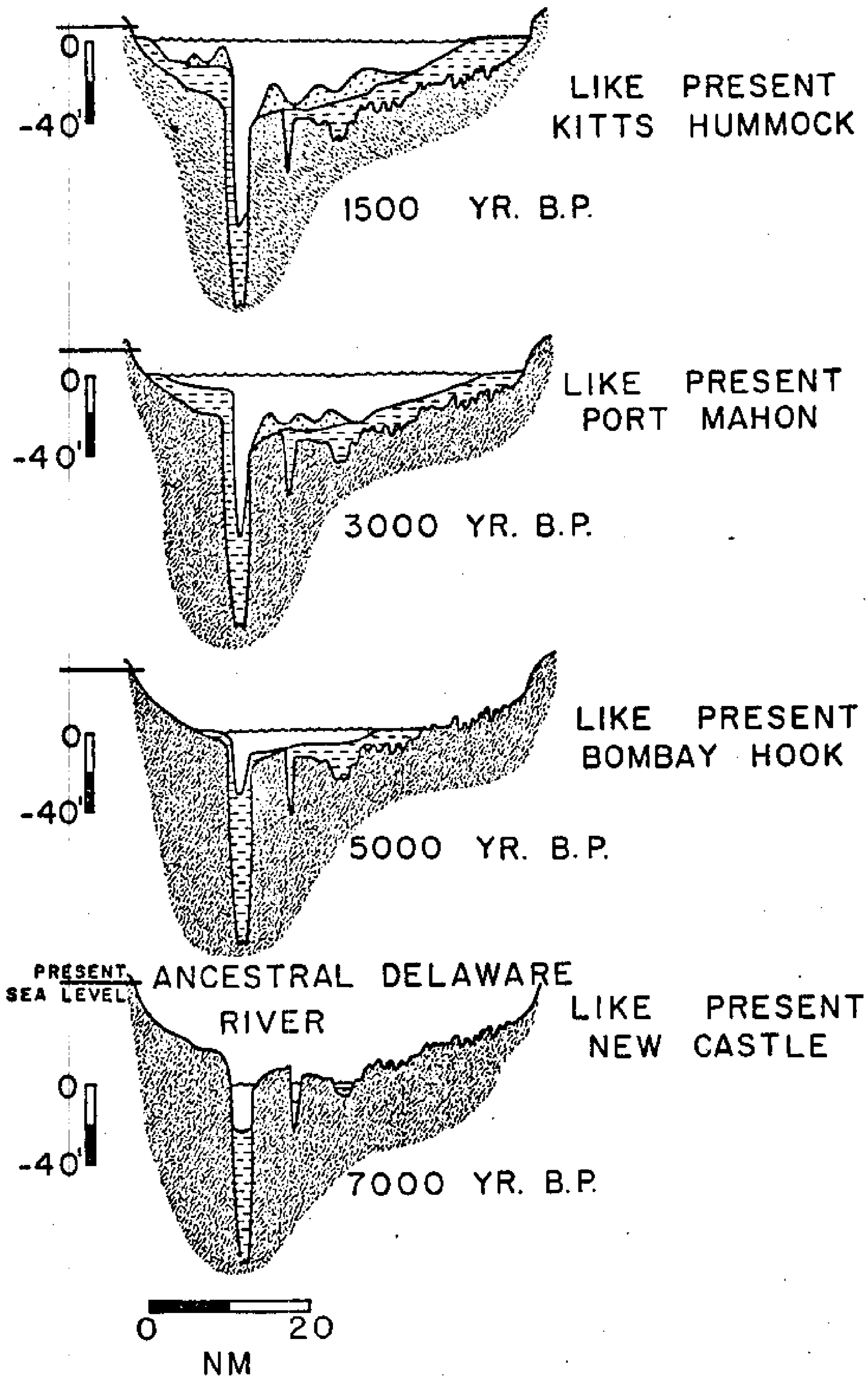


Figure 70. Geomorphic profiles of the present Delaware Estuary interpreted as analogues to early stages of Delaware Bay (from Kraft and others, 1973).

A dark estuarine clayey-silt interbedded with fine to very fine sand in a core from mid-channel 86 km above the mouth of the bay is dated at about 10,000 years B.P. (Owens and others, 1974). The clayey-silt extends to a depth of 35 meters and overlies a gravelly sand of possible fluvial origin. This core may correlate with sample 151 (PC-56E) of similar lithology in the lower bay west of Brown Shoal at a water depth of 32 meters.

With the continued rise of sea level and the rapid deposition of fine-grain estuarine sediments, the incised ancestral river valleys began to fill with sediments (Figures 69-2 and 69-3) derived from the Coastal Plain formations, metamorphic rock fragments from the Peidmont, and glacial outwash deposits (Neiheisel, 1973; Owens and others, 1974). Tidal currents and limited wave action eroded the tidal marshes which had developed along the margins of the estuary, either exposing the underlying pre-transgression sediments or forming a subcrop of eroded marsh in the nearshore areas. In most cases, these subcrops were subsequently buried by interlaminated fine sands and muds deposited from suspension; they are analogous to the subtidal flats near the margins of the bay today.

As the transgression progressed, the tidal channels at the mouth of the bay carried increasingly larger volumes of water in and out of the bay. In order to increase the hydraulic efficiency of moving the ever-larger volumes of water onto and off the shallow subtidal flats, flood tidal channels began to develop in those parts of the bay. Initially, erosion of the new channels was probably in an upbay direction as the influence of the tide on estuarine circulation in the bay increased and the influence of the river decreased (Figure 69-4). The development of flood channels into the subtidal flats led to higher current velocities and an increased competence of the currents to rework, erode, and transport sediments. Mud eroded from the subtidal flats was either transported into the tidal marshes, transported out of the bay, or redeposited on the bay bottom. Coarser sands remained in the tidal channels as lag deposits or reworked subcrops of fluvial or Pleistocene sediments. Fine sand eroded from the tidal channels was transported out of the channel and deposited along the subtidal banks of the channel as the competence of flood tidal currents decreased away from the channel margin. These fine sands, deposited by levee-like overbank processes, form the linear sand ridges of the bay and must have closely followed the development of the flood tidal channels. Linear shoal formation probably began in the central part of the bay, then proceeded in the upbay direction and toward the margins of the bay as sea level rose (Figure 69-5).

In the course of these developments, the pre-Holocene terrain and Holocene fluvial sediments were first buried by fine-grain estuarine or marsh sediments. These fine-grain sediments were subsequently eroded and reworked by tidal currents which became increasingly important as sea level rose. Prior to this, fluvial currents were the only significant source for reworking the fluvial and estuarine sediments deposited behind, and protected by, the Cape May Peninsula. Conditions within this protected environment began to change as the transgression progressed over the low gradient land surface and fluvial influence decreased. As sea level continued to rise, shoreline erosion led to an increase in the fetch over the bay; it increased the potential for and effectiveness of shoreline erosion by waves, and increased the necessity for further tidal channel development.

As the tidal influence on estuarine circulation increased behind the Capes, so did the net landward transport capacity of flooding bottom currents. Sediments from the Continental Shelf, the southward-moving littoral transport system along the New Jersey coast, and erosion products from the Cape May Peninsula were transported into the eastern side of the lower bay. These marine-derived sediments overlie the sandy muds and reworked fine estuarine sediments in the lower bay. A similar, though more restricted situation exists along the western side of the bay. During the past 2000 years (Kraft, 1971a), littoral drift sediments moving northward along the Delaware shoreline have been deposited at the mouth of the bay to form the Cape Henlopen spit complex (Figures 69-5 and 69-6).

SUMMARY AND CONCLUSIONS

The morphological features, sediment distribution, and estuarine circulation patterns of Delaware Bay today are the most recent stage in an evolving pattern which began as sea level started to rise at the end of the last Wisconsin ice advance. At that time, the locus of fine-grain estuarine deposition began to migrate landward within the incised Delaware River valley on the Continental Shelf as sea level rose. Most of the fine-grain sediment accumulated between the upstream limit of ocean salt and the null point, where predominately landward- and predominately seaward-flowing bottom waters converge. Most of the time since this transgressive estuarine depocenter passed between the ancestral Capes May and Henlopen (approximately 10,000 to 12,000 years ago), Delaware Bay has been the site of active deposition of sediments derived from the Delaware River and the Coastal Plain. The resulting sediment mass, or estuarine delta, was characterized by muds and interlaminated muds and fine sands. Coarser sands were probably deposited within the bay during periods of flooding. These sediments, representing the constructive phase of estuarine delta deposition, began to fill the protected river valley and topographic basin behind the Cape May Peninsula.

Wave erosion of the tidal marsh complex at the margins of the estuary produced a shallow subtidal subcrop of marsh mud along the shoreline. Offshore and below the effective wave basin, fine sediments were deposited over the eroded marsh substrate, forming extensive subtidal flats throughout most of the bay.

As relative sea level continued to rise, estuarine circulation and sediment distribution patterns began to change in the following ways:

(1) Tidal influence in the bay increased until tidal currents replaced river discharge as the dominant factor controlling the estuarine circulation pattern.

(2) The landward transport of bottom sediments by flood tidal currents became more important as tidal influence increased.

(3) As the surface area of the bay increased, the volume of tidal water passing between the Capes also increased.

(4) The null point and associated locus of fine-grain estuarine deposition continued to migrate up the estuary as a result of rising sea level, and perhaps, of decreased river flows.

With the migration of the active estuarine depocenter out of Delaware Bay into the tidal river, the direction of the dominant energy flux changed from seaward to landward. The sedimentary processes in the bay began to change from constructive to destructive, characterized by extensive sediment reworking and the development of flood tidal channels. As the tidal influence increased at the bay mouth, flood tidal currents began to erode channels headward into the muddy substrate of the lower bay. Mud which eroded during channel development was removed in suspension and either deposited elsewhere within the bay, the tidal marsh, or the tidal river, or transported out to sea. The medium-to-coarse sands remained in the channel bottom as a lag deposit. Fine sand was transported out of the tidal channel by secondary currents and deposited as subtidal levees beside and parallel to the channel. These levees, or linear sand shoals, are similar to natural fluvial and submarine levees, except that they are formed by flood tidal currents.

These dynamic tidal processes have produced a surface sediment textural distribution which reflects the reworked estuarine delta, subcrops of the tidal marsh, and fine-grain deposition in quiet protected waters. The coarse-grain sediments represent subcrops or lag deposits of pre-transgression sediments and marine sediments transported into the bay by flood tidal currents. The textural facies interpreted from the results of a cluster analysis have been identified in piston cores and provide evidence, together with changes in bathymetric maps, for the complex relationships between bottom morphology and subsurface sediments.

The long-term trend, or direction of reworking, in the bay is indicated by the pattern of progressive sorting in all the sediment texture maps. These reflect a decreasing grain-size trend in the upbay direction -- that is, from the high energy area to the low energy level. However, this is not the direction of net sediment transport for all the sediment grades present because, in an estuarine system, the net sediment transport direction of different grain sizes depends upon:

(1) the elapsed time that each grain size is moving during the tidal cycle, beginning when the critical erosion velocity is exceeded to the moment when movement ceases;

(2) the effects of the Coriolis force on tidal currents; and

(3) the individual grain size and local dynamic conditions, including current velocity, the extent of vertical mixing, and the degree of net seaward transport at the surface and net landward transport at the bottom.

In Delaware Bay, heavy mineral studies (Neiheisel, 1973), tidal current data, sand wave orientation, and geomorphic changes all indicate a well-developed landward transport of the medium-to-coarse sediments in the tidal channels and on the eastern side of the bay. However, heavy mineral studies, geomorphic changes, and seismic reflection profiles indicate a net seaward transport of sand on the western side of the lower bay, some of which is lost to the Continental Shelf margin through the Baymouth Channel. Similarly, Oostdam (1971) calculated that the net seaward flux of suspended matter is from the mouth of the bay to the Continental Shelf. Because of these complex conditions, it is very difficult to determine quantitatively whether the direction of net sediment transport is from Delaware Bay to the Continental Shelf or from the Shelf into the bay.

The observed changes in morphology and bathymetry indicate that Delaware Bay is not in equilibrium with present sea level. This is due to several factors:

(1) the volume and rate of sediments contributed by eroding shorelines, the tidal river, tributaries to the bay, and the Continental Shelf to the bay are low;

(2) the continued rise of local relative sea level and the associated increase of tidal effects on estuarine circulation patterns and tidal current velocities; and

(3) the tidal jet effects at the mouth of the bay caused by the topographic restrictions of Cape May and Cape Henlopen.

These combined factors result in a net sediment influx to the bay which is low compared to the available energy from waves and tidal currents. Wave-eroded sediments from the shorelines may be transported by tidal currents into the tidal marshes, into the bay, or out to sea. The dissipation of tidal energy causes extensive erosion and reworking of bottom sediments. As long as sediment input to the bay is low, "self-digestion" of the bay margins and the bay bottom will persist, and prevent the establishment of long-term equilibrium with sea level and subsequent development of a subaerial or prograding estuarine delta.

This pattern could be reversed if: (1) relative sea level were to fall and/or river discharge to increase, causing a reduction in tidal influence and the seaward migration of the estuarine depocenter into the bay from the tidal river; or if (2) the Cape May Peninsula were breached if relative sea level continued to rise.

In conclusion, the model proposed in this study for the transgressive estuarine delta is simple in concept. However, the details of the model are complex, involving the adjustments and interactions of fluvial, estuarine, and marine environments to changing conditions of dynamic equilibrium; they warrant further investigation. Some particularly interesting areas of study include the following:

(1) Quantitative changes in the local and net long-term erosion and deposition when the new National Ocean Service bathymetric survey of the bay is completed.

(2) The mechanism(s) responsible for sediment transport out of the tidal channels.

(3) A complete description of the distribution and character of bedforms in the bay.

(4) The nature, distribution, and age of pre-Holocene subcrops at the bottom and margins of the tidal channels.

(5) Seismic reflection mapping of the Pleistocene sediments and structures in the bay, particularly the distribution of the buried channels.

(6) Refinement of the existing sediment budgets for the estuary and bay.

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APPENDIX I

PHYSICAL AND STATISTICAL PARAMETERS FOR SURFACE SAMPLES

APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CORE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT OSIS	1ST %ILE PHI	1ST %ILE (MM)
1	PC 5E71	PC	57	38-48.60	75-05.60	0.1	10.9	37.5	51.5	89.0	(G)M	7.10	7.77	3.29	0.17	1.37	-0.34	1.26
2	T 1-1	G	62	38-49.15	75-02.80	0.0	93.3	2.1	4.6	6.7	S	1.38	1.37	1.52	0.23	2.41	-0.88	1.84
3	T 1-2	G	70	38-49.80	75-04.05	0.0	86.4	3.9	9.7	13.6	MS	1.49	1.55	2.37	0.28	1.94	-0.97	1.95
4	T 1-3	G	55	38-50.75	75-03.10	0.0	94.6	2.3	3.1	5.4	S	2.62	2.58	0.59	0.12	1.66	1.01	0.50
5	T 1-4	G	40	38-51.90	75-01.90	0.0	95.5	2.2	2.4	4.6	S	2.27	2.25	0.75	0.05	1.22	0.65	0.64
6	RSE71-43	G	14	38-51.55	75-00.45	2.5	97.4	0.1	0.0	0.1	(G)S	1.20	1.13	0.72	-0.24	1.23	-1.55	2.94
7	T 1-5	G	25	38-52.20	75-00.80	0.0	99.1	0.9	0.0	0.9	S	0.88	0.88	0.67	-0.11	1.50	-0.93	1.91
8	T 1-6	G	32	38-53.65	75-00.00	0.0	100.0	0.0	0.0	0.0	S	1.40	1.25	0.79	-0.37	1.64	-0.93	1.91
9	T 1-7	G	9	38-53.85	74-59.70	0.0	99.0	1.0	0.0	1.0	S	2.18	2.18	0.45	0.00	0.98	1.16	0.45
10	T 1-8	G	40	38-55.00	74-58.50	0.0	96.2	3.8	0.0	3.8	S	1.31	1.28	1.36	-0.01	0.90	-0.96	1.94
11	T 1-9	G	14	38-55.45	74-58.20	0.0	99.0	1.0	0.0	1.0	S	1.01	0.93	0.85	-0.13	1.14	-0.92	1.89
12	RNS-76	G	6	38-47.20	75-07.85	0.0	13.4	77.4	9.2	86.6	SM	5.42	5.42	1.70	0.20	1.45	2.65	0.16
13	RNS-77	G	10	38-47.40	75-07.70	0.0	15.1	70.9	13.9	84.9	SM	5.48	5.48	1.98	0.22	1.61	2.21	0.22
14	RNS-78	G	10	38-47.50	75-07.40	0.0	12.5	76.5	11.5	87.5	SM	5.42	5.48	1.87	0.19	1.64	1.88	0.27
15	RNS-79	G	11	38-47.90	75-07.15	0.0	7.6	68.8	23.6	92.4	M	5.65	6.49	2.59	0.43	1.70	2.56	0.17
16	RNS-81	G	25	38-48.15	75-06.95	8.4	91.0	0.6	0.0	0.6	GS	1.73	1.62	1.09	-0.37	2.09	-3.41	10.66
17	PC 1E71	PC	90	38-50.00	75-04.70	0.5	97.5	2.1	0.0	2.1	(G)S	1.27	1.35	1.04	0.15	1.10	-0.84	1.79
18	RNS-1	G	7	38-47.85	75-09.05	0.0	64.0	30.6	5.4	36.0	MS	3.60	4.05	1.86	0.28	1.35	0.09	0.94
19	RNS-3	G	8	38-48.00	75-08.00	0.0	59.6	29.6	10.8	40.4	MS	3.75	4.39	2.12	0.63	1.39	2.37	0.19
20	RNS-4	G	6	38-48.15	75-08.05	0.0	56.0	36.5	7.6	44.0	MS	3.88	4.46	1.76	0.64	1.21	2.52	0.17
21	RNS-12	G	17	38-48.90	75-07.80	0.0	77.7	17.0	5.3	22.3	MS	2.79	3.54	1.68	0.67	1.72	1.55	0.34
22	RNS-11	G	18	38-49.05	75-07.45	0.0	99.7	0.3	0.0	0.3	S	1.75	1.75	0.44	0.01	1.20	0.64	0.64
23	RNS-10	G	14	38-49.10	75-07.35	0.0	100.0	0.0	0.0	0.0	S	1.41	1.44	0.44	0.06	1.04	0.15	0.90
24	RNS-9	G	21	38-49.15	75-07.20	0.5	99.5	0.0	0.0	0.0	(G)S	1.23	1.18	0.62	-0.20	1.10	-0.85	1.81
25	RNS-8	G	22	38-49.20	75-07.00	0.0	98.5	1.5	0.0	1.5	S	1.75	1.86	0.62	0.17	1.06	0.03	0.98
26	RNS-7	G	17	38-49.30	75-07.00	0.2	99.8	0.0	0.0	0.0	(G)S	1.32	1.29	0.59	-0.14	1.22	-0.68	1.61
27	RNS-6	G	18	38-49.50	75-06.80	0.9	99.1	0.0	0.0	0.0	(G)S	1.02	0.92	0.70	-0.24	1.08	-0.98	1.97
28	RNS-5	G	22	38-49.80	75-06.55	2.1	97.9	0.0	0.0	0.0	(G)S	1.14	1.05	0.74	-0.26	1.06	-1.00	2.00
29	PC42E72	PC	60	38-50.20	75-05.40	18.8	80.9	0.4	0.0	0.4	GS	1.36	0.96	1.92	-0.67	1.41	-3.94	15.31
30	PC 3E71	PC	140	38-51.10	75-04.70	0.6	98.7	0.7	0.0	0.7	(G)S	1.35	1.23	0.97	-0.17	1.05	-0.96	1.94
31	PC 4E71	PC	40	38-52.30	75-03.70	0.0	96.4	3.6	0.0	3.6	S	2.92	2.96	0.46	0.15	1.14	1.69	0.31
32	PC43E71	PC	20	38-53.60	75-01.50	0.3	98.1	1.6	0.0	1.6	(G)S	1.98	2.09	0.80	0.21	0.79	0.30	0.81
33	PC5[illegible]-72	PC	26	38-55.80	74-59.60	2.3	97.5	0.2	0.0	0.2	(G)S	0.96	0.92	0.62	-0.13	1.25	-1.74	3.34
34	PC49E71	PC	27	38-56.70	74-59.70	2.0	95.8	2.3	0.0	2.3	(G)S	1.65	1.77	1.18	-0.15	0.98	-1.93	3.80
35	RNS-20	G	4	38-48.20	75-10.80	5.0	94.3	0.7	0.0	0.7	GS	1.26	1.20	0.85	-0.23	1.61	-1.00	2.00
36	RNS-19	G	5	38-48.25	75-10.75	0.0	99.9	0.1	0.0	0.1	S	1.78	1.86	0.63	0.18	0.79	0.25	0.84
37	RNS-21	G	9	38-48.40	75-10.65	0.0	84.0	8.3	7.7	16.0	MS	3.04	2.80	2.05	0.07	2.50	-0.32	1.25
38	RNS-22	G	12	38-48.50	75-10.45	0.0	31.8	52.0	16.2	68.2	SM	5.05	5.22	2.21	0.35	1.34	2.11	0.23
39	RNS-23	G	14	38-48.60	75-10.35	0.0	24.2	64.1	11.7	75.8	SM	5.21	5.23	1.97	0.25	1.39	2.64	0.16
40	RNS-24	G	15	38-48.80	75-10.25	0.0	35.3	56.6	8.1	64.7	SM	4.78	4.96	1.[illegible]	0.33	1.15	2.17	0.22
41	RNS-26	G	13	38-49.20	75-09.85	0.0	75.6	14.4	10.0	24.4	MS	3.30	3.38	1.54	0.50	1.56	2.50	0.18
42	RNS-27	G	11	38-49.35	75-09.65	0.0	60.4	26.9	3.7	39.6	MS	3.52	3.89	1.38	0.62	1.01	2.07	0.24
43	RNS-37	G	20	38-49.60	75-08.75	0.0	72.8	16.2	11.0	27.2	MS	3.33	3.09	2.44	0.48	2.35	0.12	0.92
44	RNS-36	G	21	38-49.70	75-08.55	0.0	57.5	34.0	8.5	42.5	MS	3.81	4.41	1.91	0.62	1.29	2.22	0.21
45	RNS-35	G	14	38-49.90	75-08.35	0.0	99.8	0.3	0.0	0.3	S	2.13	2.13	0.50	-0.02	0.98	1.02	0.49
46	RNS-34	G	11	38-50.10	75-08.25	0.0	99.9	0.1	0.0	0.1	S	2.03	1.98	0.5[illegible]	-0.11	0.98	0.72	0.61
47	RNS-33	G	15	38-50.20	75-07.95	0.0	99.8	0.2	0.0	0.2	S	2.16	2.11	0.4[illegible]	-0.09	1.06	1.04	0.49
48	RNS-32	G	17	38-50.35	75-07.60	0.0	99.9	0.1	0.0	0.1	S	1.22	1.22	0.6[illegible]	0.02	0.94	0.04	0.97
49	RNS-31	G	17	38-50.50	75-07.50	0.2	99.8	0.0	0.0	0.0	(G)S	1.17	1.16	0.65	-0.04	1.02	-0.48	1.40

APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CODE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT OSIS	1ST %ILE PHI	1ST %ILE (MM)
50	RNS- 30	G	17	38-50,70	75-07,50	1,5	98,5	0,0	0,0	0,0	(G)S	0,8[illegible]	0,80	0,71	-0,05	0,93	-1,00	2,00
51	RNS- 29	G	19	38-52,80	75-07,50	4,1	95,9	0,0	0,0	0,0	(G)S	0,94	0,79	0,94	-0,25	0,86	-1,00	2,00
52	RNS- 28	G	19	38-52,90	75-07,40	9,3	90,7	0,0	0,0	0,0	GS	0,67	0,55	1,09	-0,19	0,61	-1,89	3,70
53	PC 4E71	PC	36	38-50,45	75-07,10	0,0	94,1	2,1	3,8	5,9	S	2,53	2,48	0,88	0,16	1,52	1,15	0,45
54	RSE71-35	G	50	38-51,00	75-07,15	0,0	99,0	1,0	0,0	1,0	S	2,01	2,03	0,60	0,07	1,19	0,59	0,76
55	PC10E71	PC	65	38-51,15	75-05,60	0,0	99,5	0,5	0,0	0,5	S	1,44	1,48	0,60	0,13	1,32	-0,21	1,16
56	RSE71-36	G	95	38-52,00	75-06,05	0,2	99,0	0,8	0,0	0,8	(G)S	1,56	1,44	0,97	0,10	1,11	-0,80	1,74
57	PC 2E71	PC	113	38-52,10	75-05,70	0,7	91,8	7,5	0,0	7,5	(G)S	2,14	2,15	1,29	0,08	1,48	-0,67	1,63
58	RSE71-37	G	85	38-52,60	75-05,40	1,2	97,3	1,6	0,0	1,6	(G)S	2,36	2,22	0,88	-0,24	1,02	-1,16	2,24
59	RSE71-38	G	49	38-53,75	75-04,35	0,1	98,3	1,6	0,0	1,6	(G)S	2,55	2,46	0,65	-0,23	1,21	0,35	0,78
60	RNS- 13	G	3	38-49,95	75-11,50	0,0	84,5	12,7	2,7	15,5	MS	1,97	2,30	1,59	0,46	1,92	0,19	0,88
61	RNS- 14	G	7	38-49,20	75-11,25	0,4	98,3	1,3	0,0	1,3	(G)S	1,44	1,46	0,67	0,09	1,24	-0,21	1,15
62	RNS- 16	G	8	38-49,60	75-11,00	0,0	100,0	0,0	0,0	0,0	S	3,22	3,06	0,63	-0,40	1,12	0,00	1,00
63	RNS- 18	G	8	38-49,90	75-10,70	0,0	99,5	0,4	0,0	0,4	(G)S	1,49	1,40	0,62	-0,07	1,34	0,05	0,97
64	RNS- 50	G	13	38-49,95	75-10,40	0,5	95,4	4,1	0,0	4,1	(G)S	1,38	1,42	0,92	0,09	0,95	0,01	0,99
65	RNS- 49	G	13	38-49,85	75-10,15	0,0	72,3	16,8	10,9	27,7	MS	2,97	3,86	2,41	0,68	1,46	0,80	0,58
66	RNS- 60	G	14	38-50,00	75-09,90	0,1	100,0	0,0	0,0	0,0	S	2,57	2,40	0,91	-0,24	0,90	0,23	0,85
67	RNS- 61	G	17	38-50,20	75-09,35	0,5	99,5	0,0	0,0	0,0	(G)S	2,29	2,08	1,10	-0,26	0,98	-0,85	1,80
68	RNS- 62	G	14	38-50,35	75-09,00	0,0	99,1	0,9	0,0	0,9	S	2,24	2,25	0,48	0,11	1,47	1,17	0,44
69	RNS- 63	G	15	38-50,50	75-08,90	0,4	99,5	0,1	0,0	0,1	(G)S	1,05	1,30	0,67	-0,14	0,98	-0,78	1,72
70	RNS- 64	G	8	38-50,80	75-08,85	0,0	100,0	0,0	0,0	0,0	S	1,64	1,58	0,46	-0,16	1,13	0,17	0,89
71	RNS- 65	G	18	38-51,00	75-08,85	1,2	98,4	0,4	0,0	0,4	(G)S	0,53	0,53	0,80	-0,01	0,97	-1,00	2,00
72	RNS- 66	G	25	38-51,45	75-08,80	4,6	94,6	0,6	0,0	0,6	(G)S	1,59	1,39	0,97	-0,41	1,39	-1,00	2,00
73	PC11E71	PC	85	38-52,65	75-05,70	0,0	79,9	9,7	10,3	20,1	MS	2,88	3,45	2,13	0,56	2,63	0,34	0,79
74	PC 9E71	PC	34	38-53,45	75-04,80	0,0	69,1	22,3	8,5	30,9	MS	3,44	3,78	1,44	0,50	1,84	1,13	0,46
75	T 2-34	G	40	38-55,25	75-03,60	0,0	96,1	3,9	0,0	3,9	S	1,75	1,68	1,27	-0,08	1,17	-0,90	1,67
76	RSE71-39	G	40	38-55,45	75-02,65	0,0	93,1	6,9	0,0	6,9	S	3,19	3,15	0,74	-0,03	1,94	0,94	0,52
77	T 2- 4	G	34	38-56,20	75-03,35	0,0	70,3	23,7	6,0	29,7	MS	3,68	3,83	1,29	0,49	2,51	2,51	0,17
78	PC 8E71	PC	46	38-56,50	75-01,80	0,0	74,0	14,8	11,2	26,0	MS	3,45	4,16	1,81	0,77	2,93	2,41	0,19
79	RSE71-40	G	25	38-57,00	75-01,00	0,0	92,9	7,2	0,0	7,2	S	3,14	3,04	0,96	-0,17	2,15	-0,24	1,18
80	SGS72-133	G	7	38-57,00	75-00,75	0,0	98,5	1,5	0,0	1,5	S	3,00	3,00	0,49	-0,00	0,96	1,92	0,26
81	PC48E71	PC	22	38-56,80	75-00,00	2,3	97,2	0,5	0,0	0,5	(G)S	1,57	1,63	0,71	0,04	1,61	-1,00	2,00
82	SGS72-134	G	19	38-57,25	75-00,20	0,0	99,6	0,4	0,0	0,4	S	2,57	2,52	0,48	-0,12	1,02	1,53	0,35
83	PC37E71	PC	17	38-57,90	75-00,80	0,0	49,9	24,6	25,4	50,1	SM	4,01	5,57	[illegible]	0,72	1,06	1,03	0,49
84	RSE71-41	G	18	38-58,00	75-00,05	0,0	93,6	6,4	0,0	6,4	S	3,12	3,09	[illegible]	0,09	1,57	1,76	0,30
85	SGS72-135	G	21	38-57,60	74-59,20	0,0	97,4	2,6	0,0	2,6	S	2,58	2,56	0,61	-0,16	1,42	0,23	0,85
86	T 2- 5	G	21	38-58,10	74-58,95	0,0	53,2	21,2	25,6	46,8	MS	3,76	5,19	3,13	0,74	1,06	2,01	0,25
87	SGS72-136	G	19	38-58,70	74-58,20	0,1	99,1	0,8	0,0	0,8	(G)S	2,36	2,14	0,90	-0,37	1,23	-0,40	1,32
88	RNS- 51	G	5	38-49,60	75-12,65	0,0	99,6	0,4	0,0	0,4	S	2,19	2,02	0,77	-0,33	1,05	-0,00	1,00
89	RNS- 52	G	6	38-49,90	75-12,55	24,1	74,9	1,0	0,0	1,0	GS	1,80	0,49	[illegible]	-0,61	0,87	-4,00	16,00
90	RNS- 53	G	8	38-49,95	75-12,50	9,1	82,5	4,1	4,3	[illegible]	GS	1,11	1,36	2,10	0,24	1,33	-2,00	4,00
91	RNS- 54	G	8	38-50,10	75-12,40	6,9	92,9	0,1	0,0	[illegible]	GS	1,00	0,75	[illegible]	-0,46	1,34	-2,00	4,00
92	RNS- 55	G	7	38-50,25	75-12,20	0,7	99,3	0,0	0,0	0,0	(G)S	1,22	1,11	[illegible]	-0,22	0,97	-0,92	1,90
93	RNS- 56	G	10	38-50,40	75-11,90	0,5	99,4	0,2	0,0	0,2	(G)S	1,24	1,16	[illegible]	-0,23	0,95	-0,82	1,76
94	RNS- 57	G	7	38-50,45	75-11,50	2,2	97,6	0,1	0,0	0,1	(G)S	0,81	0,75	0,70	-0,18	1,11	-1,00	2,00
95	RNS- 58	G	13	38-50,45	75-11,10	0,3	99,7	0,0	0,0	0,0	(G)S	1,15	1,09	[illegible]	-0,19	1,05	-0,80	1,74
96	RNS- 48	G	8	38-50,80	75-10,50	0,0	100,0	0,0	0,0	0,0	S	1,60	1,55	0,43	-0,17	1,08	0,11	0,93
97	RNS- 47	G	11	38-51,00	75-10,45	2,9	97,0	0,1	0,0	0,1	(G)S	1,33	1,23	0,78	-0,25	1,13	-1,00	2,00
98	RNS- 46	G	11	38-51,20	75-10,40	0,9	98,9	0,2	0,0	0,2	(G)S	1,42	1,34	0,56	-0,21	1,16	-0,95	1,93

APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CODE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT-OSIS	1ST %ILE PHI	1ST %ILE (MM)
99	RNS- 45	G	8	38-51,30	75-10,25	0,0	100,0	0,0	0,0	0,0	S	1,29	1,27	0,51	-0,11	1,19	-0,20	1,15
100	RNS- 44	G	12	38-51,40	75-10,20	0,1	99,9	0,0	0,0	0,0	(G)S	1,16	1,11	0,49	-0,14	1,09	-0,25	1,19
101	RNS- 43	G	20	38-51,55	75-10,20	27,5	71,4	1,1	0,0	1,1	GS	0,12	-0,22	1,85	-0,18	1,14	-3,85	14,39
102	RNS- 42	G	23	38-51,70	75-09,60	4,4	95,1	0,4	0,0	0,4	(G)S	1,13	0,99	0,83	-0,34	1,25	-1,80	3,47
103	RNS- 41	G	20	38-51,75	75-09,45	0,0	99,8	0,2	0,0	0,2	S	1,09	1,03	0,63	-0,13	0,97	-0,63	1,55
104	RNS- 40	G	23	38-51,85	75-09,25	6,7	93,2	0,2	0,0	0,2	GS	1,07	0,82	1,08	-0,36	0,89	-2,00	4,00
105	RNS- 39	G	25	38-51,95	75-09,10	20,9	78,5	0,6	0,0	0,6	GS	0,62	0,34	1,40	-0,27	0,76	-2,00	4,00
106	RNS-38	G	32	38-52,00	75-08,70	1,3	98,5	0,2	0,0	0,2	(G)S	1,30	1,18	0,77	-0,27	1,10	-1,00	2,00
107	T 2- 2	G	73	38-53,10	75-07,35	0,3	96,8	0,8	2,1	2,9	(G)S	1,36	1,55	1,07	0,24	0,89	-0,63	1,54
108	T 2- 3	G	53	38-54,35	75-05,40	0,4	95,5	1,8	2,7	4,5	S	2,19	1,78	1,49	-0,32	0,87	-0,96	1,94
109	FC44E71	PC	36	38-55,20	75-04,40	0,1	98,9	1,0	0,0	1,0	(G)S	1,88	1,89	0,60	0,01	1,35	-0,44	1,36
110	RNS- 67	G	4	38-50,90	75-14,00	0,0	75,6	17,6	6,8	24,4	MS	2,67	3,01	1,76	0,76	2,29	1,29	0,41
111	RNS- 68	G	7	38-51,00	75-13,70	0,1	99,5	0,4	0,0	0,4	(G)S	1,65	1,73	0,69	0,12	1,13	0,07	0,95
112	RNS- 69	G	7	38-51,25	75-13,10	0,0	99,2	0,8	0,0	0,8	S	1,75	1,82	0,76	0,04	0,94	0,08	0,95
113	RNS- 70	G	8	38-51,50	75-12,65	0,0	99,5	0,5	0,0	0,5	S	1,40	1,42	0,50	0,04	1,07	0,05	0,97
114	RNS- 71	G	9	38-51,75	75-12,20	1,4	97,5	1,1	0,0	1,1	(G)S	0,69	0,69	0,73	0,02	0,95	-1,00	2,00
115	RNS- 72	G	14	38-52,00	75-11,75	3,8	64,3	25,5	6,4	31,9	(G)MS	3,31	3,20	2,77	0,03	1,00	-2,00	4,00
116	RNS- 73	G	18	38-52,20	75-11,40	3,1	78,1	10,8	7,9	18,8	(G)MS	2,56	2,62	2,58	0,22	1,49	-2,00	4,00
117	RNS- 74	G	25	38-52,50	75-10,80	0,0	100,0	0,0	0,0	0,0	S	3,18	3,14	0,47	-0,00	0,92	1,80	0,29
118	RNS- 75	G	27	38-52,70	75-10,30	0,0	45,2	45,3	9,5	54,8	SM	4,37	4,73	1,98	0,50	1,25	1,96	0,26
119	PC12C71	PC	35	38-54,00	75-09,90	0,0	71,6	15,0	13,4	28,4	MS	3,41	4,06	2,09	0,72	2,58	2,05	0,24
120	RNS- 82	G	2	38-51,70	75-14,65	0,2	99,1	0,7	0,0	0,7	(G)S	1,58	1,56	0,75	-0,04	1,06	-0,42	1,33
121	RNS- 83	G	2	38-52,00	75-14,20	0,0	99,5	0,5	0,0	0,5	S	1,73	1,72	0,48	-0,05	1,09	0,50	0,71
122	RNS- 84	G	5	38-52,15	75-13,90	0,0	99,0	1,0	0,0	1,0	S	1,40	1,42	0,50	0,05	1,10	0,05	0,97
123	RNS- 85	G	14	38-52,40	75-13,50	8,8	88,4	2,8	0,0	2,8	GS	1,04	1,01	1,51	-0,10	1,51	-3,44	10,88
124	RNS- 86	G	15	38-52,70	75-13,10	0,0	85,2	13,0	1,8	14,8	MS	3,25	3,16	1,14	0,06	2,41	1,05	0,48
125	RNS- 88	G	21	38-53,20	75-12,50	0,0	45,1	48,1	6,7	54,9	SM	4,30	4,66	1,69	0,42	1,02	2,17	0,22
126	RNS- 89	G	25	38-53,55	75-12,00	0,0	38,1	55,1	6,8	61,9	SM	4,65	4,86	1,64	0,33	1,01	2,61	0,16
127	RNS- 90	G	19	38-54,00	75-11,25	0,0	100,0	0,0	0,0	0,0	S	3,40	3,44	0,31	0,15	0,77	2,52	0,17
128	RNS- 91	G	12	38-54,35	75-10,85	0,0	98,0	2,0	0,0	2,0	S	3,21	3,15	0,41	-0,18	1,56	1,52	0,35
129	RNS- 92	G	18	38-54,50	75-10,50	0,0	91,4	1,4	7,2	8,6	S	3,11	3,10	1,21	0,40	4,46	2,17	0,22
130	VC17	VC	85	38-55,95	75-09,65	0,0	5,5	43,5	51,0	94,5	M	7,07	7,41	3,07	0,29	1,13	0,65	0,64
131	VC18	VC	42	38-55,30	75-09,55	0,4	91,5	2,7	5,5	8,2	(G)S	2,24	2,26	1,40	0,29	2,52	-0,29	1,23
132	VC19	VC	27	38-55,90	75-06,85	0,0	99,7	0,3	0,0	0,3	S	2,23	2,21	0,40	0,00	1,31	1,24	0,42
133	PC21E71	PC	29	38-58,70	75-01,50	0,0	92,4	7,6	0,0	7,6	S	3,09	3,10	0,64	0,26	1,66	1,30	0,41
134	S7S72-137	G	16	38-58,80	75-00,80	0,0	94,0	6,0	0,0	6,0	S	3,24	3,25	0,49	0,17	1,76	2,51	0,17
135	PC51F-72	PC	26	38-59,40	74-59,90	0,0	65,1	22,0	12,9	34,9	MS	3,57	4,40	2,20	0,74	1,65	1,69	0,31
136	PC20E71	PC	24	38-59,20	75-59,50	0,0	27,3	37,1	35,7	72,7	SM	5,76	6,56	3,15	0,41	0,86	2,67	0,16
137	RSE71-42	G	20	38-59,15	74-58,85	0,0	91,9	8,1	0,0	8,1	S	3,15	3,12	0,77	0,09	1,81	0,56	0,68
138	RNS- 93	G	6	38-53,15	75-15,90	0,0	99,4	0,6	0,0	0,6	S	2,25	2,24	0,68	-0,04	0,99	0,50	0,71
139	RNS- 94	G	6	38-53,35	75-15,60	2,0	97,6	0,3	0,0	0,3	(G)S	1,06	1,03	0,74	-0,09	1,25	-1,00	2,00
140	RNS- 95	G	10	38-53,65	75-15,10	23,3	70,4	5,5	0,8	6,3	GS	0,77	0,57	2,46	-0,08	1,17	-3,88	14,70
141	RNS- 96	G	12	38-53,90	75-14,60	0,0	61,5	33,7	4,8	38,5	MS	3,60	4,53	1,37	0,51	0,97	0,69	0,54
142	RNS- 97	G	12	38-54,35	75-13,90	0,0	72,9	22,5	4,6	27,1	MS	3,49	4,03	1,18	0,73	1,53	2,48	0,18
143	VC20	VC	16	38-54,20	75-13,45	1,0	73,5	14,0	11,6	25,5	(G)MS	3,37	3,59	2,60	0,25	3,40	-1,00	1,99
144	RNS- 98	G	9	38-54,60	75-13,40	0,0	64,9	29,2	5,9	35,1	MS	3,70	4,28	1,46	0,68	1,18	2,56	0,17
145	RNS- 99	G	22	38-54,85	75-12,95	0,0	68,9	26,6	4,5	31,1	MS	3,51	4,04	1,37	0,56	1,13	2,09	0,24
146	RNS-100	G	8	38-55,20	75-12,45	0,0	97,1	2,9	0,0	2,9	S	3,24	3,20	0,38	-0,12	1,55	1,67	0,32
147	RNS-101	G	6	38-55,30	75-12,25	0,0	98,6	1,4	0,0	1,4	S	3,13	3,08	0,40	-0,14	1,06	1,83	0,28

APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS,

CORE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT OSIS	1ST %ILE PHI	1ST %ILE (MM)
148	RNS-102	G	19	38-55,40	75-11,80	0,0	78,4	17,4	4,2	21,6	MS	3,43	3,81	1,15	0,60	2,20	2,17	0,22
149	PC13E71	PC	40	38-56,30	75-11,30	0,0	90,3	9,7	0,0	9,7	S	3,06	3,14	0,78	0,35	1,75	1,96	0,26
150	T 3- 3	G	110	38-56,15	75-09,75	0,0	94,9	1,0	4,1	5,1	S	1,85	1,75	1,22	-0,09	1,54	-0,91	1,88
151	PC5NE-72	PC	105	38-56,80	75-10,20	0,0	94,0	6,0	0,0	6,0	S	1,74	2,05	0,93	0,51	1,28	0,12	0,92
152	T 3- 4	G	10	38-56,45	75-07,95	0,0	99,2	0,8	0,0	0,8	S	2,00	2,00	0,34	-0,02	0,76	1,05	0,48
153	T 3- 5	G	43	38-57,30	75-06,90	0,0	96,8	1,3	1,9	3,2	S	2,28	2,20	0,76	-0,15	0,96	0,13	0,91
154	PC4NE71	PC	23	38-59,10	75-02,20	0,0	98,5	1,5	0,0	1,5	S	2,79	2,76	0,57	-0,17	1,43	1,01	0,50
155	SGS72-138	G	20	39-[illegible],25	74-59,25	0,0	33,5	27,2	39,3	66,5	SM	5,82	6,77	3,48	0,41	0,70	1,81	0,29
156	RNS-103	G	2	38-54,20	75-17,00	1,8	85,9	8,5	2,9	11,5	(G)MS	2,57	2,51	1,41	0,10	1,56	-1,00	2,00
157	RNS-104	G	4	38-53,40	75-16,65	10,8	84,7	3,4	1,1	4,5	GS	0,43	0,45	1,39	0,03	1,83	-3,55	11,67
158	RNS-105	G	9	38-54,75	75-16,25	0,0	81,3	15,2	3,5	18,7	MS	3,40	3,65	1,01	0,54	2,29	1,07	0,48
159	RNS-106	G	6	38-55,10	75-15,80	0,0	96,6	3,4	0,0	3,4	S	2,67	2,92	0,57	0,04	1,46	0,96	0,51
160	RNS-107	G	7	38-55,30	75-15,35	0,0	96,5	3,5	0,0	3,5	S	3,13	3,09	0,44	-0,06	1,09	1,64	0,32
161	RNS-108	G	8	38-55,50	75-14,90	0,0	83,2	12,8	4,0	16,8	MS	3,40	3,56	0,86	0,57	2,49	2,50	0,18
162	RNS-109	G	10	38-55,85	75-14,40	0,0	78,1	19,5	2,6	21,9	MS	3,43	3,61	1,05	0,63	2,09	2,52	0,17
163	RNS-110	G	21	38-56,00	75-14,20	0,0	64,4	31,8	3,8	35,6	MS	3,70	4,26	1,25	0,61	0,94	2,53	0,17
164	RNS-112	G	10	38-55,35	75-13,90	0,0	97,9	2,1	0,0	2,1	S	3,05	3,04	0,39	0,05	0,91	1,86	0,28
165	RNS-113	G	6	38-55,50	75-13,70	0,0	99,2	0,8	0,0	0,8	S	3,05	3,03	0,33	-0,05	0,74	2,21	0,22
166	RNS-114	G	15	38-55,60	75-13,55	0,0	79,9	15,5	4,6	20,1	MS	3,36	3,52	1,34	0,33	2,08	1,60	0,33
167	PC4SE71	PC	21	38-56,90	75-12,90	0,0	81,1	18,9	0,0	18,9	MS	2,33	2,78	1,49	0,50	1,20	0,90	0,54
168	T 4- 3	G	22	38-57,10	75-13,30	0,0	92,0	4,7	3,3	8,0	S	2,14	2,37	0,91	0,52	1,81	1,14	0,45
169	PC14E71	PC	30	38-57,50	75-12,80	0,0	91,2	8,8	0,0	8,8	S	3,14	3,06	0,95	-0,01	1,75	0,86	0,55
170	PC15E71	PC	55	38-57,80	75-11,70	5,7	90,8	3,5	0,0	3,5	GS	2,26	2,23	1,19	-0,24	1,88	-2,80	7,14
171	T 4- 5	G	32	38-59,20	75-09,04	0,0	100,0	0,0	0,0	0,0	S	2,00	2,02	0,38	0,15	0,89	1,12	0,46
172	PC18E71	PC	42	38-58,00	75-10,45	0,0	99,4	0,6	0,0	0,6	S	2,34	2,39	0,39	0,13	1,07	1,53	0,34
173	PC19E71	PC	43	38-57,90	75-09,50	0,0	98,2	1,8	0,0	1,8	S	2,38	2,44	0,48	0,16	1,14	1,11	0,46
174	PC16E71	PC	47	38-57,80	75-07,50	0,1	97,1	2,8	0,0	2,8	(G)S	2,67	2,66	0,60	-0,05	1,29	0,11	0,93
175	VC22	VC	25	38-58,50	75-06,30	0,5	98,3	1,2	0,0	1,2	(G)S	2,53	2,47	0,63	-0,17	1,18	0,42	0,75
176	PC17E71	PC	85	38-58,40	75-05,50	0,0	77,3	9,9	12,8	22,7	MS	1,53	2,68	3,02	0,68	1,75	-0,43	1,35
177	T 3- 6	G	38	38-59,50	75-02,50	0,0	94,9	3,2	2,0	5,2	S	1,91	2,20	0,98	0,41	0,81	0,58	0,67
178	SGS72-100	G	12	39-01,00	75-00,10	0,0	87,8	6,9	5,3	12,2	MS	3,29	3,35	0,96	0,43	3,39	2,12	0,23
179	T 3- 7	G	21	39-01,25	74-59,25	0,0	19,1	45,0	35,9	80,9	SM	5,50	6,55	2,99	0,52	0,85	3,05	0,12
180	T 3- 8	G	18	39-02,35	74-57,20	0,0	87,0	5,9	7,1	13,0	MS	1,60	1,72	2,22	0,30	2,10	-0,94	1,92
181	RNS-149	G	2	38-54,60	75-17,75	0,7	94,3	3,8	1,3	5,1	(G)S	3,05	2,67	1,11	-0,49	1,14	-0,40	1,32
182	RNS-148	G	7	38-55,00	75-17,45	0,0	70,5	23,7	5,8	29,5	MS	3,57	3,65	2,09	0,15	1,86	0,19	0,88
183	RNS-147	G	7	38-55,40	75-17,20	0,0	66,5	27,6	5,9	33,5	MS	3,73	4,28	1,46	0,67	1,29	2,57	0,17
184	RNS-150	G	2	38-55,15	75-18,15	0,0	85,0	12,4	2,6	15,0	MS	3,04	2,61	1,48	-0,13	0,95	0,02	0,99
185	RNS-151	G	1	38-55,80	75-18,50	0,0	47,9	44,5	7,6	52,1	SM	4,14	4,53	1,97	0,38	1,20	1,11	0,46
186	RNS-152	G	3	38-55,00	75-17,95	3,2	96,6	0,2	0,0	0,2	(G)S	0,97	0,84	0,71	-0,29	1,20	-1,00	2,00
187	RNS-120	G	10	38-55,15	75-16,30	0,0	74,4	19,7	5,9	25,6	MS	3,49	4,02	1,37	0,71	2,41	2,42	0,19
188	RNS-119	G	13	38-55,50	75-16,05	0,0	81,8	14,2	4,0	18,2	MS	3,41	3,64	0,[illegible]	0,57	2,39	2,19	0,22
189	RNS-118	G	12	38-55,80	75-15,80	0,0	97,7	2,3	0,0	2,[illegible]	S	3,07	3,04	0,[illegible]	-0,02	1,01	1,50	0,35
190	RNS-117	G	13	38-56,25	75-15,35	0,0	61,9	32,5	5,6	38,1	MS	3,76	4,33	1,62	0,64	1,02	2,52	0,17
191	RNS-116	G	19	38-56,45	75-15,05	0,0	90,2	9,8	0,0	9,8	S	3,14	2,90	1,[illegible]3	-0,12	1,26	1,02	0,49
192	RNS-115	G	17	38-56,65	75-14,25	0,0	77,1	19,1	3,8	22,9	MS	3,41	3,66	1,[illegible]	0,66	2,12	2,50	0,18
193	PC52E-72	PC	25	38-59,80	75-11,40	0,0	97,9	2,1	0,0	2,1	S	2,88	2,91	0,43	0,08	1,09	1,62	0,33
194	PC43E71	PC	65	38-50,20	75-05,40	2,0	97,3	0,3	0,0	0,3	(G)S	1,52	1,29	0,[illegible]	-0,13	1,23	-1,00	2,00
195	T 4- 9	G	40	38-59,85	75-08,40	0,3	96,9	1,7	1,1	2,8	(G)S	1,49	1,01	1,02	0,16	0,93	-0,68	1,60
196	T 3- 7	G	18	39-0[illegible],50	75-05,20	0,0	96,5	1,4	2,1	3,5	S	2,82	2,88	0,40	0,23	1,41	2,03	0,25

APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CORE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT OSIS	1ST %ILE PHI	1ST %ILE (MM)
197	VC25	VC	21	39-01,80	75-04,90	0,2	98,0	1,8	0,0	1,8	(G)S	2,29	2,25	0,87	-0,09	0,83	0,20	0,87
198	T 4- 8	G	22	39-01,95	75-03,70	0,0	95,8	2,2	2,0	4,2	S	2,79	2,78	0,66	-0,00	0,99	1,16	0,45
199	PC22F71	PC	54	39-02,10	75-02,40	1,7	63,5	22,3	12,6	34,8	(G)MS	3,61	4,06	2,49	0,37	2,42	-1,00	2,00
200	SGS72-139	G	22	39-03,05	74-59,10	0,0	52,9	30,0	17,1	47,1	MS	3,94	4,67	2,42	0,73	1,31	1,60	0,33
201	SGS72-140	G	13	39-02,95	74-56,65	1,1	95,0	3,9	0,0	3,9	(G)S	2,26	2,15	0,65	-0,20	1,24	-1,00	2,00
202	SGS72-112	G	9	38-57,55	75-16,30	0,0	85,3	14,7	0,0	14,7	MS	3,37	3,45	0,79	0,34	2,19	1,67	0,31
203	SGS72-113	G	13	38-58,30	75-15,10	0,4	81,1	11,1	7,4	18,5	(G)MS	3,18	2,79	2,05	-0,12	1,21	-0,86	1,62
204	SGS72-114	G	20	38-58,70	75-14,65	0,0	62,5	25,9	11,6	37,5	MS	3,65	4,18	1,76	0,61	1,72	1,80	0,29
205	SGS72-115	G	50	38-59,36	75-13,75	0,0	96,9	3,1	0,0	3,1	S	2,70	2,73	0,54	0,14	0,99	1,51	0,35
206	T 5- 4	G	28	39-00,50	75-11,80	0,0	94,4	5,6	0,0	5,6	S	2,63	2,51	0,96	-0,13	1,00	0,27	0,83
207	SGS72-146	G	17	39-01,40	75-08,20	0,0	99,4	0,6	0,0	0,6	S	1,97	2,04	0,50	0,31	1,06	1,07	0,48
208	SGS72-145	G	17	39-02,50	75-06,00	0,0	97,4	2,6	0,0	2,6	S	3,02	3,03	0,40	0,16	0,94	2,16	0,22
209	T 4- 9	G	11	39-02,75	75-02,70	0,0	92,4	6,2	1,4	7,6	S	3,27	3,30	0,63	0,29	2,24	2,17	0,22
210	T 4-10	G	22	39-03,15	75-01,95	0,0	86,7	13,3	0,0	13,3	MS	3,42	3,48	0,55	0,26	1,36	2,39	0,19
211	SGS72-141	G	11	39-03,85	75-00,90	0,0	98,6	1,4	0,0	1,4	S	2,99	3,00	0,35	0,09	0,81	2,12	0,23
212	T 4-11	G	14	39-04,25	74-59,70	0,0	79,6	12,6	7,9	20,4	MS	3,42	3,66	1,28	0,65	3,46	2,40	0,19
213	SGS72-101	G	14	38-59,10	75-16,90	0,0	86,5	8,4	5,1	13,5	MS	3,09	3,19	0,99	0,50	2,82	2,05	0,24
214	SGS72-201	G	27	38-59,90	75-15,00	0,0	81,7	18,3	0,0	18,3	MS	3,37	3,59	0,86	0,53	2,07	1,66	0,32
215	T 5- 5	G	40	39-01,70	75-09,30	0,6	97,0	2,5	0,0	2,5	(G)S	2,11	2,14	0,62	0,08	1,24	-0,07	1,05
216	T 5- 6	G	22	39-02,35	75-08,05	0,0	93,6	4,2	2,2	6,4	S	3,15	3,14	0,58	0,23	1,75	2,15	0,23
217	SGS72-144	G	21	39-03,10	75-05,60	0,0	98,0	2,0	0,0	2,0	S	2,84	2,77	0,65	-0,17	0,68	1,18	0,44
218	T 5- 7	G	27	39-04,05	75-05,00	0,5	91,0	8,5	0,0	8,5	(G)S	2,58	2,72	0,76	0,46	1,31	0,48	0,72
219	SGS72-143	G	18	39-04,00	75-03,60	0,0	97,3	2,7	0,0	2,7	S	3,14	3,10	0,39	-0,03	1,03	2,07	0,24
220	SGS72-142	G	18	39-04,15	75-02,25	0,0	96,2	3,8	0,0	3,8	S	3,19	3,15	0,38	-0,04	1,24	2,50	0,18
221	SGS72-132	G	15	39-04,85	74-58,75	0,0	60,1	20,8	19,0	39,9	MS	3,60	4,89	2,39	0,78	1,25	2,61	0,16
222	T 4-12	G	7	39-05,45	74-56,90	0,0	16,2	40,3	43,5	83,8	SM	6,52	6,90	3,06	0,33	0,93	3,02	0,12
223	SGS72-102	G	11	39-00,50	75-17,50	0,0	80,1	12,2	7,8	19,9	MS	3,44	3,69	1,30	0,59	3,19	1,36	0,39
224	SGS72-103	G	29	39-00,80	75-16,75	0,0	50,2	30,2	19,6	49,8	MS	4,00	5,02	2,39	0,74	1,52	2,23	0,21
225	SGS72-104	G	11	39-01,55	75-16,20	0,0	95,9	4,1	0,0	4,1	S	2,80	2,83	0,57	0,15	1,00	1,81	0,29
226	PC25F71	PC	36	39-01,75	75-15,40	0,7	96,6	2,7	0,0	2,7	(G)S	1,77	1,64	0,94	-0,11	1,15	-0,82	1,76
227	SGS72-105	G	16	39-02,10	75-13,55	0,2	97,9	1,9	0,0	1,9	(G)S	1,76	1,81	1,11	0,03	0,97	-0,69	1,62
228	SGS72-107	G	39	39-02,65	75-12,20	0,0	98,0	2,0	0,0	2,0	S	2,34	2,28	0,73	-0,08	1,12	0,63	0,65
229	SGS72-108	G	28	39-03,05	75-11,20	0,0	97,4	2,6	0,0	2,6	S	2,71	2,71	0,59	0,01	1,12	0,78	0,58
230	SGS72-109	G	20	39-03,20	75-10,90	0,0	94,8	0,2	0,0	0,2	S	2,38	2,44	0,70	0,22	1,06	1,25	0,42
231	PLSSF-72	PC	36	39-03,30	75-09,70	0,0	87,4	12,6	0,0	12,6	MS	2,90	3,06	[illegible]	0,50	2,08	2,00	0,25
232	PC23F71	PC	35	39-03,40	75-09,10	0,3	94,4	5,3	0,0	5,3	(G)S	2,86	2,93	[illegible]	0,25	1,39	1,10	0,47
233	PC24F71	PC	33	39-03,50	75-09,20	0,0	96,5	3,5	0,0	3,5	S	2,84	2,90	0,47	0,20	1,27	1,49	0,36
234	SGS72-110	G	16	39-04,60	75-07,45	0,0	94,8	3,0	2,2	5,2	S	3,12	3,07	0,53	-0,08	1,33	1,54	0,34
235	T 5- 8	G	5	39-05,40	75-02,30	0,0	91,9	8,1	0,0	8,1	S	3,22	3,23	0,58	0,24	1,74	2,33	0,20
236	SGS72-131	G	8	39-06,95	74-59,40	0,0	83,9	9,1	7,1	16,1	MS	3,35	3,47	1,[illegible]1	0,54	3,54	1,50	0,34
237	T 5-10	G	7	39-08,30	74-56,60	0,0	48,2	32,6	19,2	51,8	SM	4,12	5,06	2,53	0,70	1,53	2,52	0,17
238	SGS72-202	G	28	39-01,50	75-17,85	0,0	48,4	30,7	21,0	51,5	SM	4,16	5,37	2,75	0,72	1,22	2,11	0,23
239	T 7- 1	G	31	39-01,95	75-18,10	0,1	69,0	22,6	8,4	31,0	(G)MS	2,41	2,80	2,51	0,42	1,07	-0,10	1,07
240	SGS71-78A	G	44	39-02,05	75-15,65	5,3	88,3	6,4	0,0	6,4	GS	2,16	2,25	1,59	-0,15	2,90	-3,91	14,99
241	SGS71-78B	G	44	39-02,05	75-15,65	29,2	55,9	8,8	6,1	14,9	GMS	1,61	0,97	3,17	-0,09	1,10	-3,00	8,00
242	SGS72-106	G	8	39-02,90	75-13,75	0,0	99,9	0,1	0,0	0,1	S	2,31	2,35	[illegible]	0,06	1,14	1,14	0,45
243	PC25F71	PC	33	39-03,60	75-13,00	0,0	83,6	16,4	0,0	16,4	MS	3,31	3,37	[illegible]	0,28	1,94	1,58	0,33
244	T 6- 5	G	40	39-03,90	75-10,05	0,0	94,9	2,4	2,7	5,1	S	2,81	2,88	[illegible]	0,20	1,90	1,23	0,43
245	T 6- 6	G	21	39-04,55	75-09,30	0,0	85,5	14,5	0,0	14,5	MS	2,66	2,85	[illegible]	0,31	0,84	1,17	0,44

APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CORE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT OSIS	1ST %ILE PHI	1ST %ILE (MM)
246	T 6- 7	G	22	39-04,80	75-08,75	0,0	95,5	4,5	0,0	4,5	S	2,86	2,93	0,48	0,23	1,29	1,69	0,31
247	VC24	VC	21	39-05,30	75-09,00	0,5	86,8	5,7	6,9	12,7	(G)MS	3,36	3,59	1,39	0,36	4,55	0,56	0,68
248	T 6- 8	G	14	39-07,10	75-04,35	0,0	69,5	21,2	9,3	30,5	MS	3,67	4,01	1,31	0,60	3,18	2,50	0,18
249	SGS72-133	G	8	39-09,05	75-01,02	0,0	85,4	7,4	7,2	14,6	MS	3,27	3,55	1,16	0,50	4,32	2,51	0,18
250	T 6- 9	G	7	39-09,80	74-58,70	0,0	76,6	13,4	10,0	23,4	MS	3,28	3,67	1,67	0,68	3,32	2,08	0,24
251	SGS72-203	G	9	39-02,90	75-20,30	0,0	56,4	23,2	20,3	43,6	MS	3,84	5,14	2,62	0,73	1,27	1,18	0,44
252	SGS72-115	G	23	39-03,00	75-18,95	0,0	98,6	1,4	0,0	1,4	S	2,34	2,40	0,35	0,19	1,02	1,17	0,45
253	SGS71-77A	G	13	39-02,85	75-16,90	0,0	67,3	17,6	15,1	32,7	MS	3,71	4,57	2,06	0,76	1,68	2,53	0,17
254	T 7- 3	G	40	39-03,15	75-15,90	1,7	96,6	1,6	0,0	1,6	(G)S	1,55	1,36	0,29	-0,34	1,35	-1,29	2,45
255	T 7- 4	G	12	39-03,70	75-14,60	0,0	97,2	2,8	0,0	2,8	S	2,78	2,81	0,47	0,12	1,27	1,68	0,31
256	T 7- 5	G	55	39-04,20	75-13,50	0,0	22,8	41,8	35,4	77,2	SM	5,49	6,45	3,05	0,50	0,89	2,76	0,15
257	T 7- 6	G	42	39-05,25	75-11,35	1,5	95,0	3,5	0,0	3,5	(G)S	1,48	1,46	1,71	-0,60	1,35	-0,65	1,57
258	SGS71- 76	G	29	39-03,95	75-14,95	0,0	89,0	11,0	0,0	11,0	MS	3,26	3,50	0,74	0,31	2,17	2,00	0,25
259	PC30E71	PC	31	39-05,20	75-13,70	0,0	68,4	21,6	10,0	31,6	MS	3,73	4,14	1,80	0,62	2,68	2,13	0,23
260	PC29E71	PC	18	39-05,35	75-13,60	0,0	92,4	7,6	0,0	7,6	S	3,20	3,21	0,61	0,24	1,86	2,15	0,23
261	PC31E71	PC	26	39-05,40	75-12,80	0,0	87,9	12,1	0,0	12,1	MS	3,26	3,51	0,75	0,55	2,21	2,15	0,23
262	PC39E71	PC	28	39-04,30	75-10,00	0,0	91,2	8,8	0,0	8,8	S	3,25	3,27	0,66	0,28	2,30	1,94	0,26
263	SGS72-111	G	9	39-07,40	75-08,20	0,0	99,8	0,2	0,0	0,2	S	2,14	2,09	0,35	-0,11	0,99	1,05	0,48
264	T 7- 7	G	10	39-08,40	75-05,30	0,0	94,9	3,1	2,0	5,1	S	1,66	1,67	0,17	0,22	2,04	0,29	0,62
265	T 7- 8	G	6	39-10,35	75-01,50	0,0	81,7	12,0	6,3	18,3	MS	2,95	3,27	1,25	0,70	2,19	1,83	0,28
266	SGS71- 80	G	29	39-04,95	75-16,50	4,3	93,1	2,6	0,0	2,6	(G)S	1,35	1,29	1,15	-0,15	1,29	-2,49	5,63
267	SGS71- 81	G	25	39-05,20	75-16,55	0,0	97,7	2,3	0,0	2,3	(G)S	0,76	0,75	0,61	0,09	1,22	-0,49	1,40
268	SGS72-117	G	9	39-04,00	75-22,50	0,0	14,4	54,0	31,6	85,6	SM	5,67	6,37	2,57	0,47	1,10	3,13	0,11
269	SGS72-118	G	12	39-04,60	75-20,60	0,0	85,4	14,6	0,0	14,6	MS	3,41	3,48	0,73	0,39	2,02	2,53	0,17
270	SGS72-119	G	12	39-05,15	75-19,40	0,0	84,4	15,6	0,0	15,6	MS	3,36	3,42	0,79	0,37	1,98	2,25	0,21
271	SGS72-120	G	31	39-05,50	75-18,40	0,0	67,5	19,4	13,2	32,5	MS	3,76	4,31	1,85	0,72	2,69	2,76	0,15
272	SGS72-121	G	32	39-05,55	75-18,15	0,0	96,3	3,7	0,0	3,7	S	2,02	1,91	0,59	-0,08	1,48	-0,36	1,28
273	SGS72-122	G	9	39-05,75	75-17,75	0,0	99,4	0,6	0,0	0,6	S	2,41	2,47	0,38	0,32	0,96	1,77	0,29
274	SGS71- 82	G	23	39-06,00	75-16,80	0,0	99,2	0,8	0,0	0,8	S	1,54	1,37	0,57	0,10	1,00	0,13	0,92
275	SGS72-123	G	43	39-06,80	75-14,90	0,0	92,9	3,2	3,9	7,1	S	3,18	3,17	0,71	0,30	2,46	2,50	0,18
276	SGS72-124	G	8	39-06,95	75-14,45	0,0	99,0	1,0	0,0	1,0	S	2,62	2,48	0,37	0,13	1,13	2,02	0,25
277	SGS72-125	G	25	39-07,20	75-13,75	0,0	86,4	6,1	7,5	13,6	MS	3,37	3,45	1,43	0,29	5,18	0,46	0,73
278	PC54E-72	PC	25	39-07,30	75-13,60	0,0	64,6	18,1	17,3	35,4	MS	3,61	4,74	2,52	0,79	1,51	2,23	0,21
279	PC53E-72	PC	40	39-07,20	75-12,80	6,9	90,8	3,2	0,0	3,2	GS	1,52	1,77	1,45	0,09	1,16	-1,98	3,96
280	SGS72-126	G	24	39-08,40	75-11,50	0,7	98,4	0,8	0,0	0,8	(G)S	1,72	1,77	0,99	0,06	1,24	-0,90	1,86
281	SGS72-127	G	19	39-09,15	75-10,45	0,0	95,0	3,1	1,9	5,0	S	2,16	2,27	1,09	0,14	0,71	0,38	0,77
282	SGS72-128	G	5	39-10,20	75-08,20	12,2	76,1	5,6	6,0	11,7	GMS	1,85	1,75	2,19	-0,02	5,14	-3,00	8,00
283	SGS72-129	G	7	39-10,65	75-04,65	0,0	41,1	19,2	39,7	58,9	SM	5,74	6,18	3,38	0,28	0,74	1,55	0,34
284	T 8- 1	G	9	39-05,00	75-21,60	0,0	62,5	34,3	3,2	37,5	MS	3,58	3,77	0,74	0,31	0,79	2,25	0,21
285	SGS72-204	G	11	39-05,95	75-20,70	0,0	4,0	42,7	53,3	96,0	M	7,44	8,06	3,17	0,27	0,73	3,53	0,09
286	SGS71- 26	G	15	39-06,45	75-19,45	0,0	86,7	11,5	1,8	13,3	MS	3,49	3,50	0,55	0,12	1,29	1,87	0,27
287	SGS71- 74	PC	22	39-05,90	75-19,10	0,0	86,5	13,5	0,0	13,5	MS	2,06	2,35	1,47	0,39	1,09	0,10	0,93
288	SGS71- 75	G	46	39-06,15	75-18,85	0,0	94,3	5,7	0,0	5,7	(G)S	2,39	2,43	1,04	0,08	1,00	0,21	0,87
289	SGS71-83A	G	24	39-07,20	75-17,20	0,0	30,4	38,8	30,8	69,6	SM	5,41	6,03	2,71	0,44	0,99	3,02	0,12
290	SGS71-83B	G	24	39-07,20	75-17,20	0,0	40,0	43,0	17,1	60,1	SM	4,43	5,05	2,12	0,58	1,55	2,60	0,16
291	PC27E71	PC	24	39-07,00	75-16,90	0,8	87,0	12,2	0,0	12,2	(G)MS	1,40	1,84	1,74	0,44	0,93	-0,48	1,40
292	T 8- 4	G	16	39-06,95	75-16,15	0,0	36,2	38,8	25,0	63,8	SM	4,60	5,61	2,62	0,62	1,08	2,60	0,14
293	T 8- 5	G	34	39-07,30	75-15,40	0,0	32,0	42,3	25,7	68,0	SM	4,61	5,79	2,74	0,67	1,11	2,64	0,14
294	T 8- 6	G	42	39-06,50	75-13,80	0,0	91,9	5,4	2,7	8,1	S	2,22	2,29	1,45	0,20	1,12	-0,34	1,27

APPENDIX I . DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CODE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT OSIS	1ST %ILE PHI	1ST %ILE (MM)
295	T 8- 7	G	30	39-08,85	75-12,00	0,0	93,9	4,0	2,1	6,1	S	3,28	3,32	0,53	0,21	1,85	1,81	0,29
296	T 8- 8	G	12	39-09,15	75-11,30	0,0	99,6	0,5	0,0	0,5	S	1,62	1,58	0,59	-0,08	1,08	0,38	0,77
297	T 8- 9	G	18	39-10,35	75-09,25	0,0	93,0	4,2	2,8	7,0	S	1,09	1,05	1,36	0,18	2,34	-0,94	1,91
298	SGS71- 39	G	16	39-10,70	75-09,80	1,3	87,7	7,6	3,4	11,0	(G)MS	2,71	2,49	1,53	-0,11	1,70	-1,39	2,62
299	SGS71- 25	G	6	39-06,60	75-20,35	0,0	47,9	52,1	0,0	52,1	SM	4,12	4,21	1,70	0,05	0,90	0,96	0,51
300	SGS71- 26	G	12	39-07,00	75-21,05	0,0	12,4	59,1	28,5	87,6	SM	5,30	6,07	2,53	0,53	1,18	1,22	0,43
301	SGS71- 27	G	10	39-07,60	75-20,05	0,0	86,8	9,5	3,7	13,2	MS	3,45	3,42	0,75	0,16	1,63	2,07	0,24
302	SGS71- 30	G	17	39-07,75	75-18,55	0,0	62,9	33,2	3,9	37,1	MS	3,64	4,01	0,90	0,45	1,44	2,96	0,13
303	SGS71- 31	G	21	39-08,10	75-17,65	0,0	75,9	15,6	8,5	24,1	MS	3,57	3,67	1,43	0,63	3,49	2,11	0,23
304	SGS71- 31	PC	21	39-08,10	75-17,65	0,0	84,6	8,9	6,5	15,4	MS	3,49	3,52	1,23	0,46	4,14	1,99	0,25
305	SGS71- 32	G	15	39-08,15	75-17,45	0,0	83,3	9,9	6,8	16,7	MS	3,41	3,52	1,10	0,52	3,24	2,24	0,21
306	SGS71- 33	G	33	39-08,40	75-16,65	0,0	89,7	9,4	0,9	10,3	MS	3,07	2,98	1,11	0,01	1,63	0,40	0,76
307	SGS71- 34	G	10	39-08,75	75-15,85	0,0	99,7	0,3	0,0	0,3	S	3,15	3,11	0,37	-0,08	0,99	2,02	0,25
308	SGS71- 35	G	45	39-09,05	75-14,75	0,6	99,1	0,3	0,0	0,3	(G)S	2,04	2,12	1,06	0,02	0,88	-0,85	1,81
309	SGS71- 36	G	16	39-09,35	75-14,10	0,5	95,8	3,8	0,0	3,8	(G)S	2,24	2,27	1,10	-0,01	0,90	-0,73	1,65
310	SGS71- 37	G	15	39-10,10	75-12,50	0,1	99,8	0,1	0,0	0,1	(G)S	1,24	1,24	0,46	0,02	1,06	0,10	0,93
311	SGS71- 38	G	11	39-10,90	75-11,50	0,5	98,9	0,6	0,0	0,6	(G)S	1,45	1,41	0,55	-0,10	1,16	-0,48	1,40
312	SGS72-205	G	10	39-07,95	75-22,40	0,0	35,3	43,1	21,6	64,7	SM	5,02	5,81	2,69	0,53	1,27	2,58	0,17
313	SGS72-206	G	9	39-09,20	75-21,50	0,0	22,7	49,7	27,6	77,3	SM	5,65	6,46	2,96	0,45	1,09	2,55	0,17
314	T10- 2	G	15	39-09,60	75-20,45	0,0	21,0	59,3	19,7	79,0	SM	4,61	5,52	2,34	0,69	2,09	2,64	0,16
315	SGS71- 85	PC	16	39-09,70	75-19,10	0,0	50,6	28,8	20,6	49,4	MS	3,99	5,15	3,03	0,59	1,37	0,30	0,61
316	SGS71- 84	PC	19	39-06,75	75-18,25	0,0	46,0	30,4	23,6	54,0	SM	4,39	5,66	2,96	0,65	1,23	1,22	0,43
317	PC32E71	PC	21	39-10,30	75-18,00	0,6	81,5	13,7	4,7	18,5	MS	3,58	3,66	0,85	0,46	2,39	2,55	0,17
318	SGS71- 86	PC	21	39-09,80	75-17,40	0,0	93,0	7,0	0,0	7,0	S	2,52	2,59	1,04	0,20	0,97	0,78	0,58
319	T 9- 4	G	12	39-09,50	75-16,65	0,0	96,4	3,6	0,0	3,6	S	3,24	3,24	0,41	0,03	1,25	2,51	0,18
320	T 9- 5	G	40	39-10,05	75-15,50	0,0	96,9	3,1	0,0	3,1	S	3,20	3,17	0,42	-0,01	1,10	2,10	0,23
321	T 9- 6	G	26	39-10,65	75-14,20	0,0	93,1	4,7	2,3	6,9	S	3,25	3,26	0,62	0,28	2,32	2,38	0,19
322	PC38E71	PC	25	39-11,30	75-12,80	0,2	94,5	5,3	0,0	5,3	(G)S	2,40	2,36	1,16	-0,04	0,80	-0,24	1,18
323	T 9- 7	G	16	39-11,95	75-11,60	0,0	97,5	2,5	0,0	2,5	S	1,50	1,53	0,70	0,10	1,08	0,03	0,98
324	SGS72-207	G	13	39-11,00	75-22,40	0,0	42,5	24,5	33,1	57,5	SM	5,39	5,42	3,43	0,14	0,81	0,74	0,60
325	SGS71- 72	PC	9	39-11,75	75-20,75	0,0	38,4	38,5	23,1	61,6	SM	4,90	5,65	2,90	0,52	1,27	1,37	0,39
326	SGS71- 73	PC	11	39-10,95	75-20,60	0,0	52,4	29,3	18,3	47,6	MS	3,96	5,07	2,50	0,77	1,34	2,56	0,17
327	SGS71- 87	PC	20	39-11,15	75-18,60	0,0	55,2	17,9	26,9	44,8	MS	3,63	5,34	3,55	0,61	0,97	1,13	0,46
328	PC36E71	PC	20	39-11,10	75-18,50	1,8	76,2	17,4	4,6	22,0	(G)MS	1,84	2,54	2,76	0,52	1,60	-1,00	2,00
329	T10- 6	G	18	39-12,75	75-14,35	0,0	94,2	4,1	1,7	5,8	S	3,27	3,29	0,55	0,17	1,66	1,63	0,32
330	T10- 7	G	10	39-13,95	75-12,10	0,0	97,5	2,5	0,0	2,5	S	1,02	0,88	0,94	-0,20	1,05	-0,96	1,94
331	SGS71- 10	G	9	39-11,95	75-22,20	0,2	65,4	19,1	15,3	34,4	(G)MS	2,01	3,33	2,83	0,69	0,92	-0,20	1,15
332	SGS71- 9	G	10	39-12,60	75-21,05	0,0	3,2	65,6	31,3	96,8	M	5,62	6,24	2,32	0,52	1,06	3,20	0,11
333	SGS71- 59	PC	13	39-13,00	75-20,55	0,0	73,3	26,7	0,0	26,7	MS	3,61	3,99	1,04	0,59	1,52	2,57	0,17
334	SGS71- 86	G	11	39-13,10	75-20,20	0,0	56,7	23,9	19,4	43,3	MS	3,46	4,69	2,59	0,77	1,22	2,01	0,25
335	SGS71- 7	G	28	39-13,25	75-19,85	0,0	90,7	9,3	0,0	9,3	S	2,68	2,60	1,21	0,04	1,20	0,20	0,87
336	SGS71-6A8	G	14	39-13,30	75-19,70	0,0	95,1	3,7	1,2	4,9	S	3,25	3,25	0,40	0,02	1,43	2,08	0,24
337	SGS71- 6	G	10	39-13,35	75-19,55	0,0	89,4	10,6	0,0	10,6	MS	3,27	3,29	0,78	0,23	1,94	1,04	0,49
338	SGS71- 5	G	15	39-13,60	75-19,05	0,0	96,0	4,0	0,0	4,0	S	3,20	3,16	0,41	-0,03	1,19	1,67	0,32
339	SGS71- 57	PC	50	39-13,95	75-18,35	0,0	99,9	0,1	0,0	0,1	S	3,31	3,30	0,49	-0,16	1,26	1,16	0,45
340	SGS71- 4A	G	50	39-14,00	75-18,25	0,1	87,3	8,3	4,4	12,7	(G)MS	2,97	2,76	1,47	0,05	1,46	0,22	0,66
341	SGS71- 3	G	25	39-14,15	75-17,90	3,0	81,9	7,2	7,9	15,1	(G)MS	3,35	3,36	1,35	0,25	3,78	-2,69	6,44
342	T11- 5	G	15	39-14,45	75-17,55	0,8	64,4	25,1	9,8	34,9	(G)MS	3,73	3,90	1,81	0,35	2,92	-0,29	1,22
343	SGS71- 2	G	29	39-14,70	75-16,75	0,0	84,9	8,4	6,7	15,1	MS	3,45	3,50	1,06	0,44	3,41	1,18	0,44

APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CORE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT OSIS	1ST %ILE PHI	1ST %ILE (MM)
344	SGS71- 18	G	18	39-15,00	75-15,40	0,0	85,5	7,5	7,0	14,5	MS	2,32	2,45	1,71	0,33	1,65	-0,05	1,04
345	T11- 7	G	14	39-15,75	75-15,35	0,0	88,3	6,4	5,3	11,7	MS	1,63	1,82	1,91	0,31	1,59	-0,91	1,90
346	SGS71- 67	PC	13	39-12,35	75-22,75	0,0	56,5	14,9	28,6	43,5	MS	3,35	5,33	3,51	0,78	0,86	0,64	0,55
347	SGS71- 67	G	13	39-12,35	75-22,75	0,0	57,0	19,1	23,9	43,0	MS	3,32	5,07	3,28	0,76	1,06	0,84	0,56
348	SGS71- 68	PC	14	39-13,05	75-22,40	0,0	14,7	49,8	35,5	85,3	SM	6,15	7,02	3,19	0,40	0,91	1,18	0,44
349	SGS71- 69	PC	14	39-13,55	75-22,05	0,0	56,5	19,1	25,4	43,5	MS	3,73	5,01	3,71	0,52	0,92	0,24	0,85
350	SGS71- 70	PC	14	39-13,60	75-21,70	0,0	24,8	46,2	29,0	75,2	SM	5,64	6,43	3,27	0,55	1,11	1,18	0,44
351	SGS71- 71	PC	12	39-13,25	75-21,30	0,0	68,6	31,4	0,0	31,4	MS	3,26	3,62	1,58	0,33	0,92	1,07	0,48
352	SGS71- 60	G	12	39-13,90	75-21,10	0,0	72,5	21,6	6,0	27,5	MS	3,26	3,24	1,68	0,19	1,44	0,66	0,64
353	SGS71- 60	PC	12	39-13,90	75-21,10	0,0	77,2	15,4	7,4	22,8	MS	3,17	3,25	1,84	0,26	1,75	0,64	0,64
354	SGS71-61A	G	12	39-14,30	75-21,70	0,0	91,8	8,1	0,0	8,1	(G)S	1,87	2,10	1,49	0,56	3,62	0,22	0,86
355	SGS71-61A	G	12	39-14,30	75-21,70	0,0	91,2	8,8	0,0	8,8	S	1,87	2,10	1,05	0,44	2,05	0,16	0,90
356	SGS71-61B	G	12	39-14,30	75-21,70	0,0	48,3	36,4	15,3	51,7	SM	4,09	4,36	2,62	0,30	1,76	0,64	0,64
357	SGS72-209	G	18	39-14,72	75-20,20	2,6	93,8	3,6	0,0	3,6	(G)S	1,89	2,09	0,95	0,25	1,12	-3,00	8,00
358	SGS72-208	G	9	39-14,15	75-22,80	0,0	31,9	41,4	26,7	68,1	SM	4,89	5,59	2,76	0,45	1,05	1,54	0,34
359	SGS71- 62	G	15	39-14,80	75-21,90	0,0	48,3	39,0	12,7	51,7	SM	4,10	4,66	1,90	0,53	1,08	2,09	0,24
360	SGS71- 48	G	15	39-15,35	75-22,30	0,0	81,8	12,8	5,3	18,2	(G)MS	1,99	2,48	1,81	0,52	1,25	0,05	0,97
361	SGS71- 49	G	24	39-15,65	75-21,75	0,0	70,5	19,8	9,7	29,5	MS	3,50	4,05	1,64	0,61	1,99	0,52	0,70
362	MCSSF71	PC	19	39-15,70	75-21,50	0,0	12,5	45,9	41,8	87,7	SM	6,59	7,16	3,08	0,37	0,98	2,76	0,15
363	SGS71-50	G	22	39-15,85	75-21,35	0,3	91,1	7,4	1,1	8,6	(G)S	1,47	1,81	1,43	0,45	1,98	-0,54	1,45
364	SGS71- 51	G	50	39-16,10	75-20,60	1,9	97,4	0,7	0,0	0,7	(G)S	1,93	2,12	0,81	0,24	1,29	-2,84	7,15
365	SGS71- 52	G	18	39-16,65	75-19,75	0,0	68,3	18,6	13,0	31,6	(G)MS	3,66	4,45	1,91	0,71	1,64	0,82	0,57
366	SGS71- 53	G	12	39-17,25	75-18,95	3,0	94,1	2,9	0,0	2,9	(G)S	1,60	1,56	1,38	-0,05	1,20	-1,57	2,96
367	SGS71- 54	G	17	39-17,55	75-18,80	0,1	99,6	0,2	0,0	0,2	(G)S	0,75	0,75	0,45	-0,01	1,05	-0,41	1,33
368	SGS71- 55	G	12	39-17,25	75-17,75	0,0	30,7	39,9	29,4	69,3	SM	6,23	5,72	3,42	-0,07	1,02	0,21	0,86
369	SGS71-47B	G	11	39-15,00	75-23,40	0,4	81,2	14,3	4,1	18,4	(G)MS	1,92	2,47	1,83	0,48	1,71	-0,72	1,64
370	SGS71- 63	G	14	39-15,85	75-22,70	0,1	78,9	14,2	6,8	21,0	(G)MS	2,08	2,67	2,05	0,54	1,35	0,05	0,97
371	SGS71- 64	G	19	39-16,25	75-23,00	0,4	52,6	40,9	6,5	47,4	MS	3,84	4,35	1,83	0,58	0,65	1,27	0,42
372	MCSSF71	PC	28	39-16,80	75-22,80	0,0	79,2	9,8	11,0	20,8	MS	3,54	3,93	1,89	0,67	3,80	1,75	0,30
373	SGS71- 65	G	18	39-16,70	75-23,40	0,0	70,9	20,4	8,7	29,1	MS	2,93	3,60	2,13	0,50	1,13	0,35	0,79
374	SGS72-221	G	14	39-17,05	75-28,10	2,1	94,6	3,3	0,0	3,3	(G)S	1,71	1,79	1,27	0,06	0,94	-1,00	2,00
375	T12- 1	G	6	39-17,40	75-24,75	0,0	27,4	44,0	28,7	72,7	SM	5,04	6,09	3,35	0,43	1,15	0,77	0,59
376	SGS72-210	G	4	39-18,15	75-21,50	0,0	48,3	24,8	26,9	51,7	SM	4,21	5,63	3,41	0,58	1,05	0,94	0,52
377	T12- 2	G	30	39-18,10	75-23,85	0,0	81,5	9,7	8,8	18,5	MS	1,18	1,78	2,80	0,50	1,85	-0,96	1,95
378	SGS72-220	G	12	39-19,00	75-22,00	0,0	72,6	12,0	15,4	27,4	MS	3,16	4,20	2,37	0,80	1,95	1,67	0,32
379	SGS72-219	G	6	39-20,10	75-23,50	0,0	70,5	16,0	13,5	29,5	MS	3,15	4,07	2,17	0,73	1,59	0,89	0,54
380	SGS72-218	G	11	39-20,40	75-22,80	0,3	56,1	17,7	25,9	43,6	(G)MS	3,63	4,75	3,37	0,52	0,95	0,03	0,98
381	SGS71- 19	G	11	39-19,40	75-25,75	0,4	12,3	62,4	24,9	87,3	(G)M	5,46	6,01	2,44	0,43	1,45	1,08	0,47
382	SGS71- 46	PC	35	39-19,65	75-25,50	0,0	22,2	52,7	25,1	77,8	SM	5,58	6,23	2,93	0,40	1,36	2,59	0,17
383	SGS71- 45	PC	49	39-19,90	75-25,20	0,0	21,8	31,3	46,9	78,2	SM	6,70	6,75	4,27	0,04	0,84	0,22	0,86
384	SGS71- 21	G	50	39-20,00	75-25,10	0,0	3,8	37,9	58,3	96,2	M	7,54	8,26	2,79	0,32	0,99	1,52	0,35
385	SGS71- 22	G	25	39-20,25	75-24,75	1,6	41,1	32,9	24,4	57,3	(G)M	4,61	5,44	2,70	0,54	1,10	-2,69	6,45
386	SGS71- 44	G	14	39-20,50	75-24,55	1,0	96,7	2,3	0,0	2,3	(G)S	1,51	1,50	0,65	-0,37	1,60	-1,00	2,00
387	SGS71- 23	G	17	39-20,90	75-24,35	26,8	71,8	1,4	0,0	1,4	GS	1,06	0,56	2,06	-0,34	0,72	-3,00	8,00
388	SGS71- 24	G	11	39-21,20	75-24,10	0,0	99,7	0,3	0,0	0,3	S	1,85	1,84	0,53	0,02	1,00	0,46	0,73
389	SGS71- 90	G	15	39-21,20	75-24,10	0,9	91,9	4,5	2,7	7,2	(G)S	1,92	1,97	1,25	0,17	1,94	-0,94	1,92
390	SGS71- 43	G	15	39-21,50	75-23,85	0,6	96,9	2,4	0,0	2,4	(G)S	1,85	1,79	0,78	-0,17	1,17	-0,84	1,79
391	SGS71- 88	G	13	39-21,70	75-23,40	0,0	97,0	3,0	0,0	3,0	S	1,56	1,72	0,37	0,34	1,49	0,14	0,91
392	SGS71- 92	G	18	39-20,05	75-66,80	0,6	22,9	33,4	43,0	76,4	(G)M	6,37	6,58	4,26	0,08	0,89	-0,60	1,51

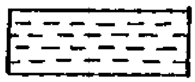
APPENDIX I DELAWARE BAY SURFACE SEDIMENT PHYSICAL DATA AND TEXTURAL PARAMETERS.

CODE NO.	SAMPLE NO.	TYPE	WATER DEPTH (FT)	NORTH LATITUDE	WEST LONGITUDE	% GRAV	% SAND	% SILT	% CLAY	% MUD	FOLK TEXT.	PHI MEDIAN DIA.	PHI MEAN DIA.	STD. DEV.	SKEW-NESS	KURT-OSIS	1ST %ILE PHI	1ST %ILE (MM)
393	SGS71- 91	G	17	39-20,05	75-26,85	0,2	72,2	11,8	15,8	27,6	(G)MS	3,15	3,90	5,0	0,49	1,86	-0,37	1,29
394	SGS71- 89	G	20	39-20,15	75-26,85	0,0	10,1	40,4	49,5	89,9	SM	6,96	7,71	3,49	0,23	0,84	1,02	0,49
395	SGS72-212	G	11	39-21,20	75-28,45	0,0	35,4	54,7	9,9	64,6	SM	4,31	4,28	1,41	0,20	1,73	0,70	0,62
396	SGS72-211	G	39	39-21,50	75-26,90	0,0	4,8	41,5	53,7	95,2	M	7,27	7,98	2,93	0,32	0,88	3,11	0,12
397	MC34671	PC	31	39-21,55	75-26,75	0,0	1,3	43,9	54,8	98,7	M	7,62	8,19	3,12	0,25	0,72	3,79	0,07
398	SGS72-217	G	7	39-22,20	75-30,00	0,9	92,7	6,4	0,0	6,4	(G)S	1,81	2,00	1,21	0,28	1,38	-0,95	1,93
399	SG-71- 12	G	9	39-22,40	75-29,65	0,0	82,1	10,7	7,3	17,9	MS	3,48	3,68	1,11	0,63	3,15	2,54	0,17
400	SG-71- 11	G	16	39-22,50	75-29,05	0,0	60,7	25,8	13,5	39,3	MS	3,84	4,55	1,65	0,71	1,60	2,60	0,17
401	SG-71- 13	G	50	39-22,55	75-28,15	0,5	99,4	0,1	0,0	0,1	(G)S	1,67	1,60	0,47	-0,20	1,22	-0,25	1,19
402	SG-71- 14	G	18	39-22,80	75-27,30	25,4	73,1	1,5	0,0	1,5	GS	1,24	0,86	1,51	-0,17	0,61	-1,00	2,00
403	SG-71-18A	G	17	39-22,85	75-26,75	1,1	87,6	10,4	0,9	11,3	(G)MS	1,81	2,06	1,63	0,30	1,16	-1,11	2,16
404	SG-71- 15	G	15	39-23,00	75-26,35	0,0	74,1	15,9	10,0	25,9	MS	3,45	4,12	1,66	0,70	2,40	1,25	0,42
405	SG-71- 17	G	27	39-23,10	75-26,10	0,0	48,5	25,1	26,4	51,5	SM	4,25	5,29	2,76	0,62	1,02	1,19	0,44
406	SG-71- 16	G	16	39-23,15	75-25,90	0,0	0,6	38,3	61,1	99,4	M	7,65	8,14	2,71	0,27	1,04	4,04	0,06
407	SG-71- 40	G	20	39-23,30	75-26,85	0,1	96,3	3,6	0,0	3,6	(G)S	1,82	1,90	0,59	0,29	1,77	-0,41	1,33
408	SGS72-213	G	23	39-23,35	75-28,65	0,0	12,6	41,5	46,8	87,4	SM	6,85	7,62	3,09	0,26	1,33	0,99	0,50
409	SGS72-216	G	13	39-23,95	75-30,60	0,0	25,6	45,1	29,3	74,4	SM	5,33	5,94	2,69	0,44	1,01	2,67	0,16
410	SGS72-214	G	14	39-25,20	75-24,00	0,0	43,6	30,8	25,6	56,4	SM	4,43	5,49	2,77	0,62	1,12	1,42	0,37
411	SGS72-215	G	35	39-25,50	75-31,20	0,0	27,2	40,2	32,6	72,8	SM	5,45	6,23	2,98	0,45	0,96	2,68	0,16

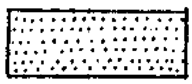
APPENDIX II

CORE DESCRIPTIONS

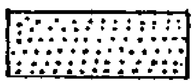
Legend for symbols used for Delaware Bay core descriptions



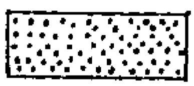
Mud



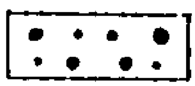
Fine Sand



Medium Sand

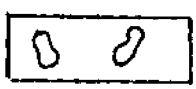


Coarse Sand



Gravel

Peat or Plant Fragments



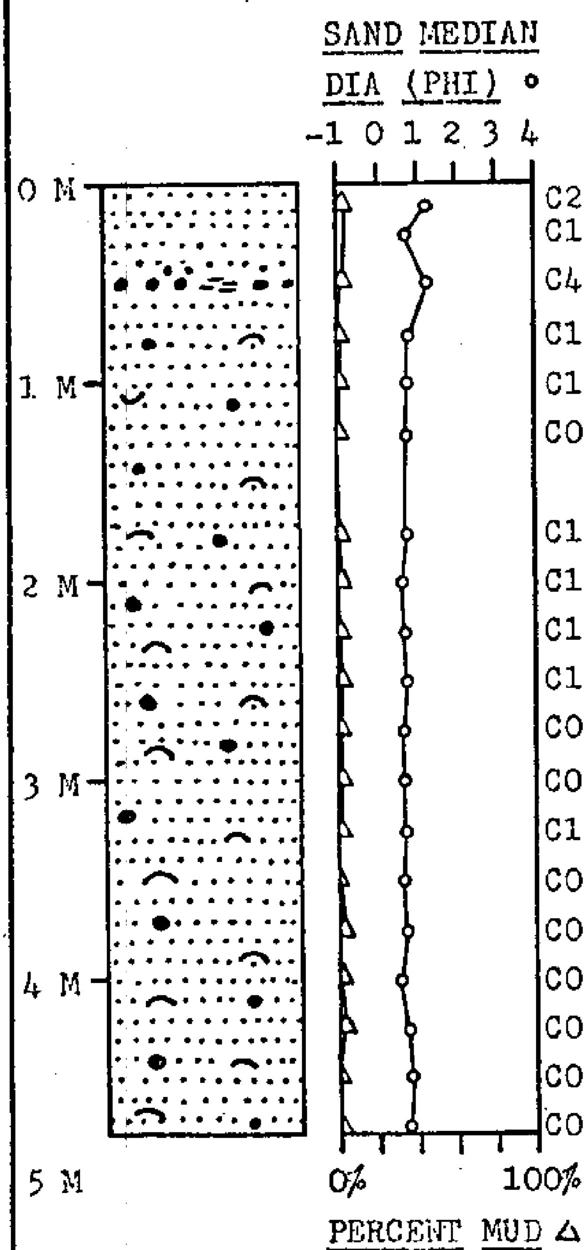
Burrow

Pelecypod Shells

Gastropod Shell

o Phi Median Diameter of the Sand and Gravel Size Fraction

Δ Weight Percent Mud



SAMPLE 17 (PC-1)

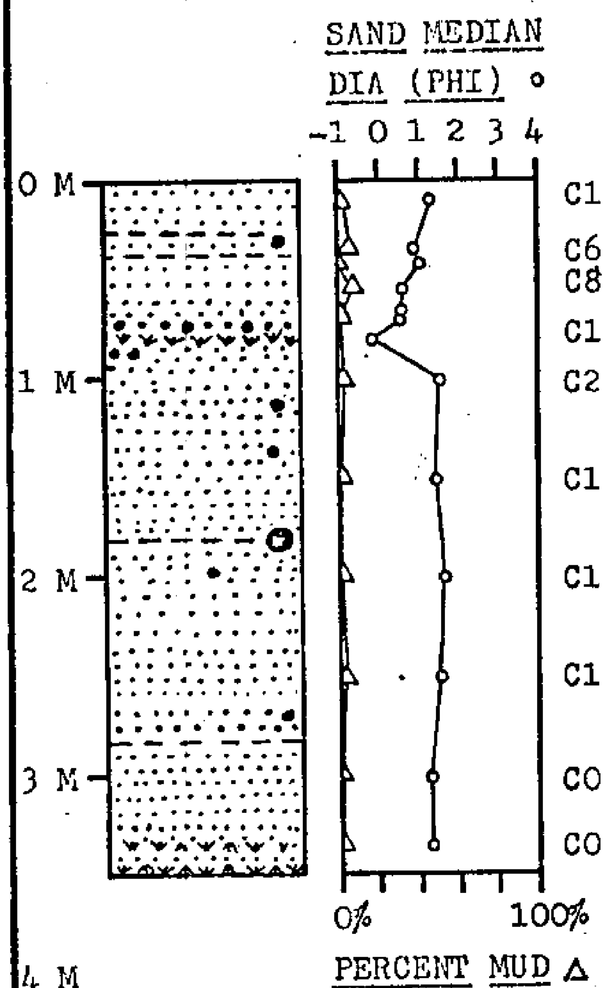
WATER DEPTH 17.3 M.

LAT. 38-50.00 N.

LONG. 75-04.70 W.

- Medium to coarse iron-stained quartz sand throughout the core
- Poorly sorted with granules, pebbles and abraded shell fragments

SAMPLE 30 (PC-3)
WATER DEPTH 42.8 M.
LAT. 38-51.10 N.
LONG. 75-04.70 W.

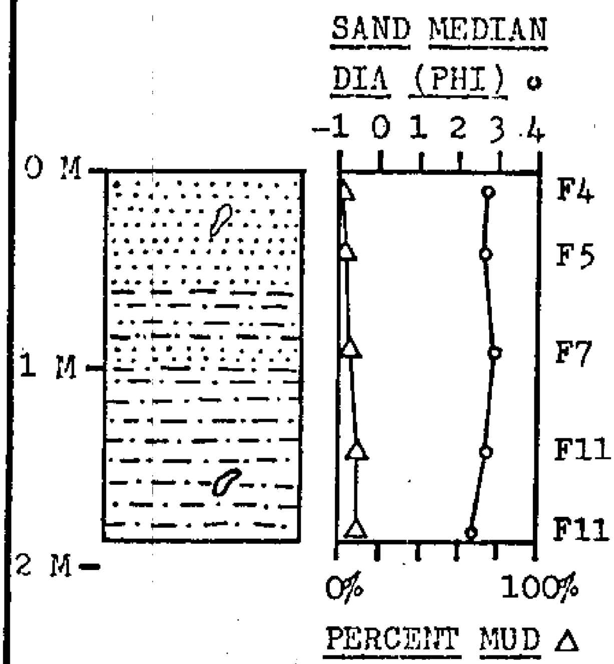


0-0.8 m. Upward fining sequences of v. crse. to med. sand with muscovite flakes (2-3 mm.) and two thin mud laminae. Basal granules over 1 cm. layer of peat at 0.8 meters.

0.8-1.6 m. Uniform structureless med. sand with scattered organic fragments.

1.6-3.5 m. Uniform med. sand with v. high % of opaque minerals and large mica flakes. ½ cm. thick mud layer with 2 cm. dia. granule at 1.8 m. Upward fining sequence at 2.9-2.6 m. At 3.3 m. two 5 cm. layers of organic fragments separated by 10 cm. med. sand.

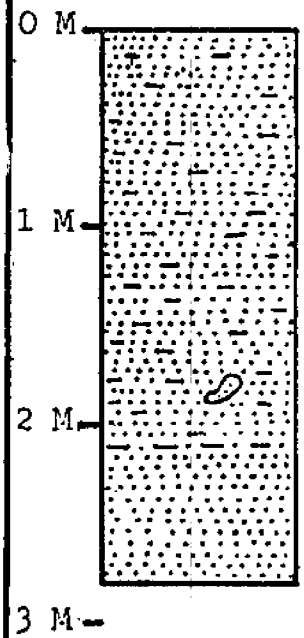
SAMPLE 31 (PC-6)
WATER DEPTH 12.2 M.
LAT. 38-52.30 N.
LONG. 75-03.70 W.



-Uniform grey green fine sand, structureless except for one burrow.

-Dark grey sequence of interlaminated sand and mud overlying a muddy sand.

SAMPLE 32 (PC-43)
WATER DEPTH 6.1 M.
LAT. 38-53.60 N.
LONG. 75-01.50 W.



-Uniform grey greey fine sand mottled with streaks of grey green mud.

-One burrow filled with clean white fine sand.

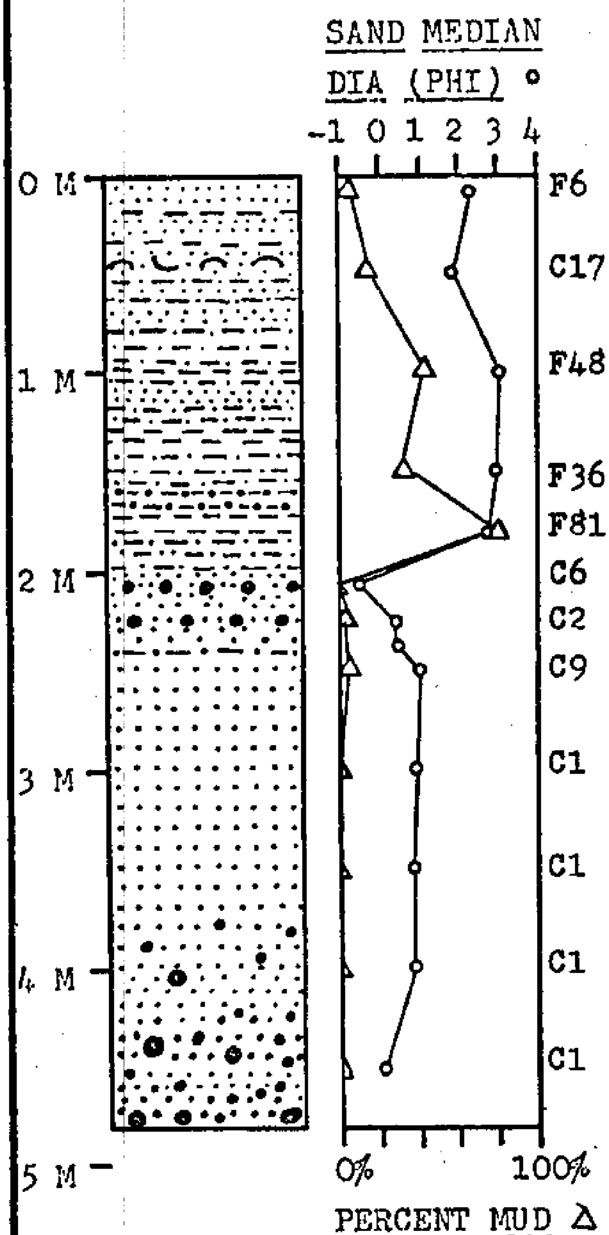
-A thin laminae of mud overlying clean structureless greenish grey fine sand.

SAMPLE 53 (PC-4)

WATER DEPTH 11.0 M.

LAT. 38-50.85 N.

LONG. 75-07.10 W.



-Sequence of interlaminated fine to medium grey green sand and grey green mud. Percentage of sand decreases with depth.

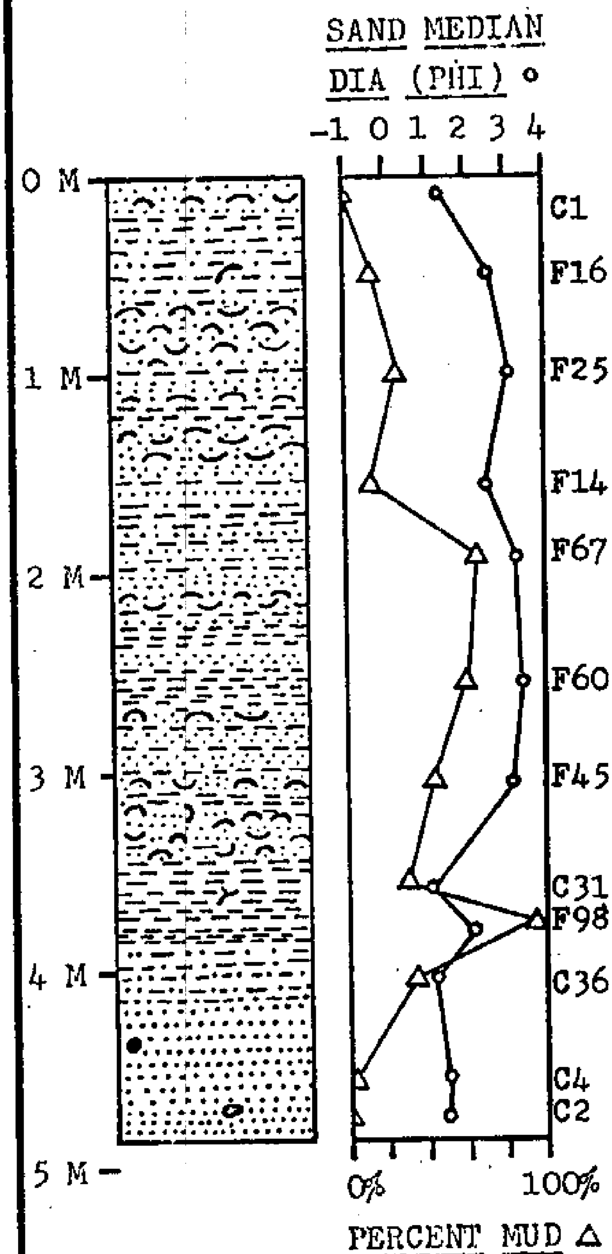
-At 1.6 meters, a 10 cm. layer of muddy coarse sand overlying a 4 cm. layer of mud.and very coarse sand and pebble mixture in a muddy matrix.

2.4-4.8 m. White uniform structureless coarse sand

-Very low in opague minerals but high in glauconite, shell fragment at 4.9 m.

-Basal 80 cm. of core consists of two upward-fining sequences of gravel

-Granules 3-4 cm. in dia. grade upward to very coarse and coarse sand. Fines are notably absent in both sequences.



SAMPLE 55 (PC-10)
WATER DEPTH 20.0 M.
LAT. 38-51.15 N.
LONG. 75-05.60 W.

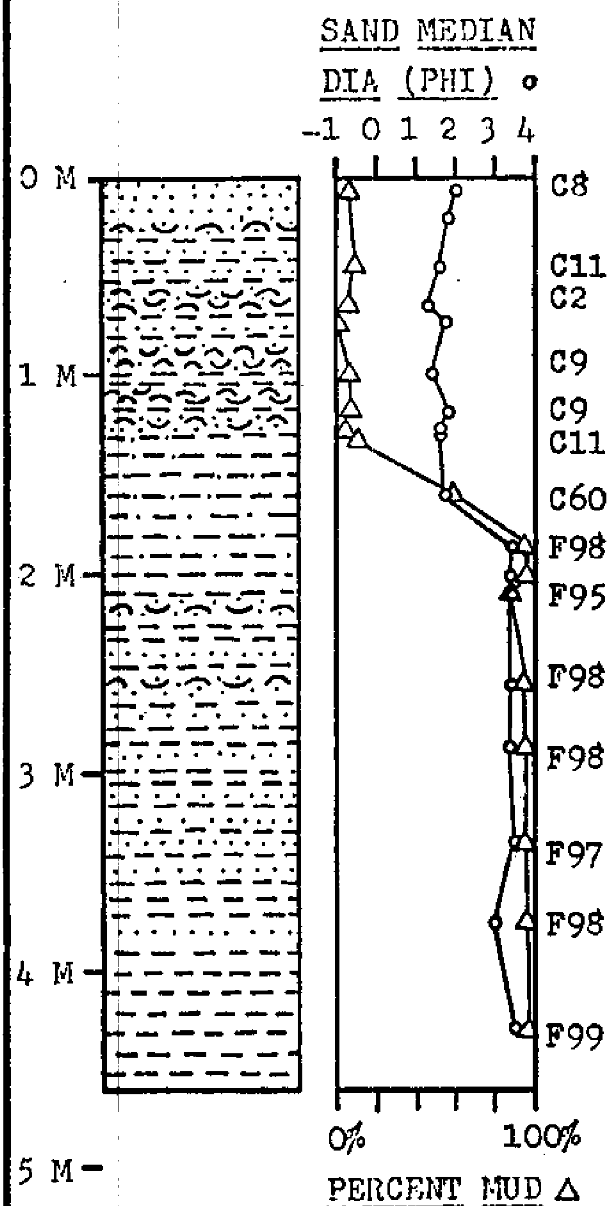
0-1.6 m. Upward coarsening sequence of alternating muddy fine and muddy medium sand with layers of shell fragments.

1.6-3.8 m. Upward fining sequence of alternating fine sands and muds with layers of shell fragments.

3.8-4.2 m. Radiocarbon age date of dark brown carbonaceous mud is 9580 ± 145 years B.P. overlying a dark grey muddy medium to coarse sand

4.2-4.8 Clean structureless grey green medium sand.

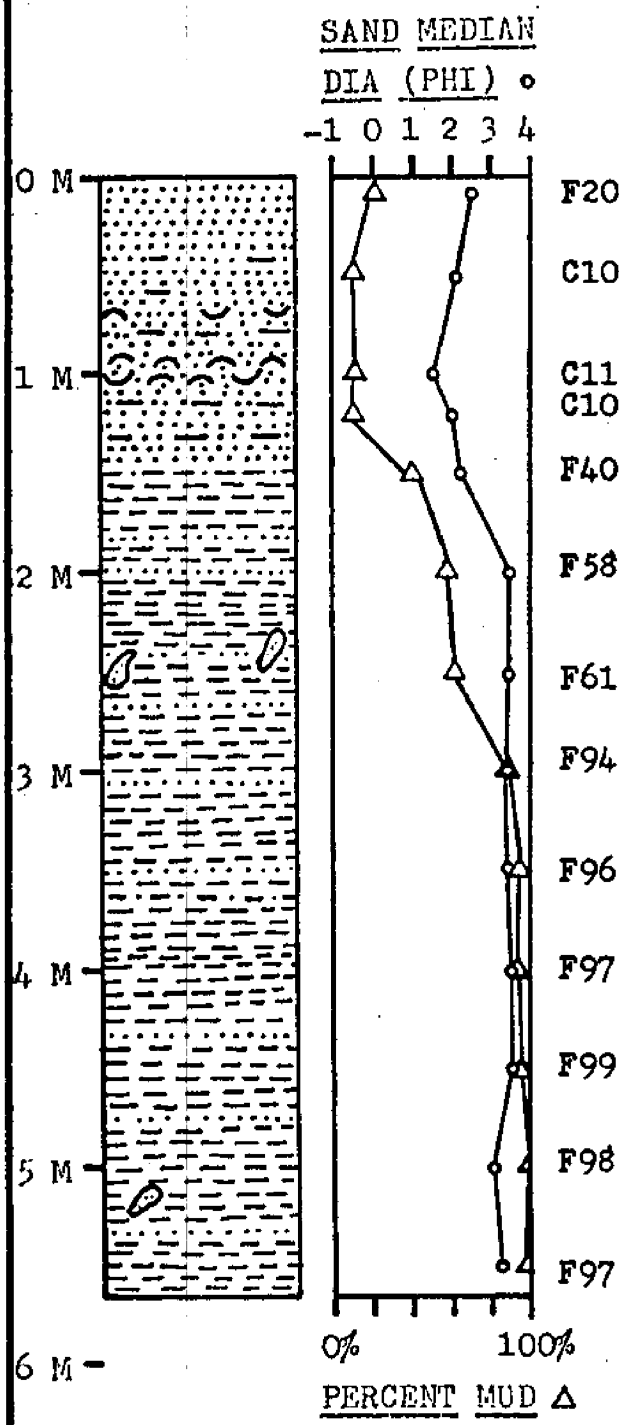
SAMPLE 57 (PC-2)
WATER DEPTH 33.5 M.
LAT. 38.52.10 N.
LONG. 75-05.70 W.



0-1.2 m. Fine grey green sand with interlaminated mud and shell layers

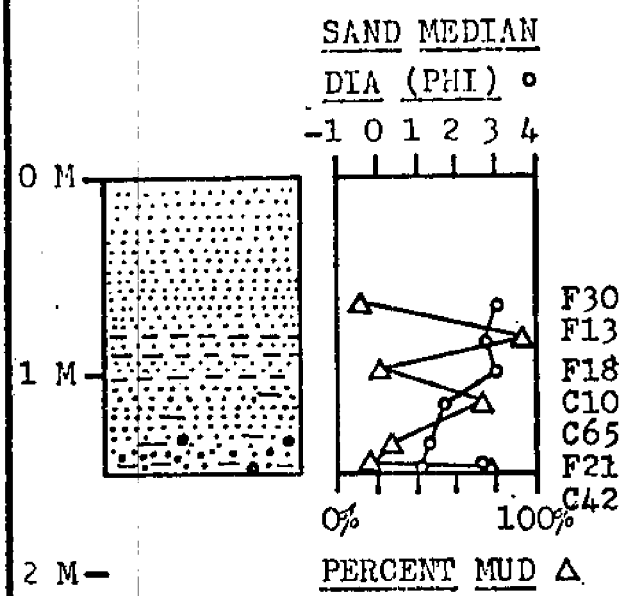
1.2-4.6 m. A distinct break separates a uniform dark grey green mud from the overlying sequence. Mud is structureless but has laminae of very fine sand and two coquina layers at 2.13 m. and 2.52 m.

SAMPLE 73 (PC-11)
WATER DEPTH 28.0 M.
LAT. 38-52.65 N.
LONG. 75-05.70 W.



0-1.4 m. Clean and muddy fine and medium sands with scattered shell fragments, and a very distinct break at 1.4 m.

1.4-5.6 m. Fine grain mud with laminae of very fine sand throughout to 4.6 meters. The frequency of sand laminae decreases with increasing depth in the core. Occasional sand-filled burrows.

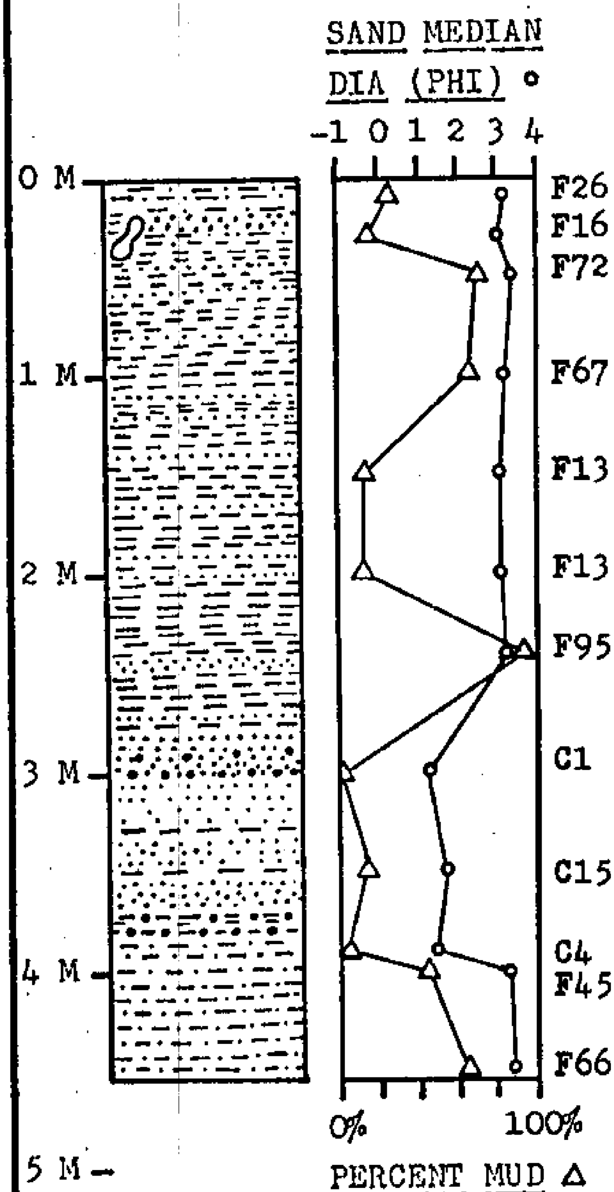


SAMPLE 74 (PC-9)
WATER DEPTH 10.3 M.
LAT. 38-53.45 N.
LONG. 75-04.80 W.

0-0.76 m. "Soupy" fine to very fine grey green sand over a compact grey green fine-medium sand with coarse sand laminae, which at the base contains an oxidized orange mud chip from the underlying pre-Holocene sediment sequence.

0.76-1.6 m. Light blue grey silt grades down to an orange silt then back to light blue grey. At 1.39 meters, a thin bedded brownish orange layer overlies a 3 cm. upward fining sequence of coarse to fine olive sand which overlies 7 cm. of light blue grey mud with orange laminae.

SAMPLE 78 (PC-8)
WATER DEPTH 14.0 M.
LAT. 38-56.50 N.
LONG. 75-01.80 W.

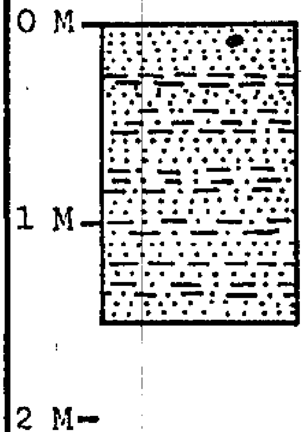


0-2.8 m. Fine to very fine sand interlaminated with dark grey green mud. The sequence is mud-dominated Very thin mud laminae appeared on wetting at 1.0 and 2.4 meters.

2.8-3.0 Upward coarsening sequence of grey green medium to coarse sand.

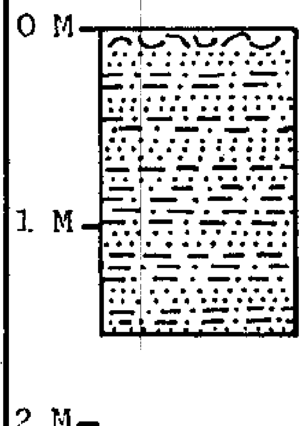
3.0-3.8 m. Medium to fine muddy sand overlies a clean medium to fine sand with a very coarse muddy sand with shell fragments at the base.

3.8-4.5 m. Muddy very fine sand with occasional thin laminae of light grey green fine sand.



SAMPLE 81 (PC-48)
WATER DEPTH 6.7 M.
LAT. 38-56.80 N.
LONG. 75-00.00 W.

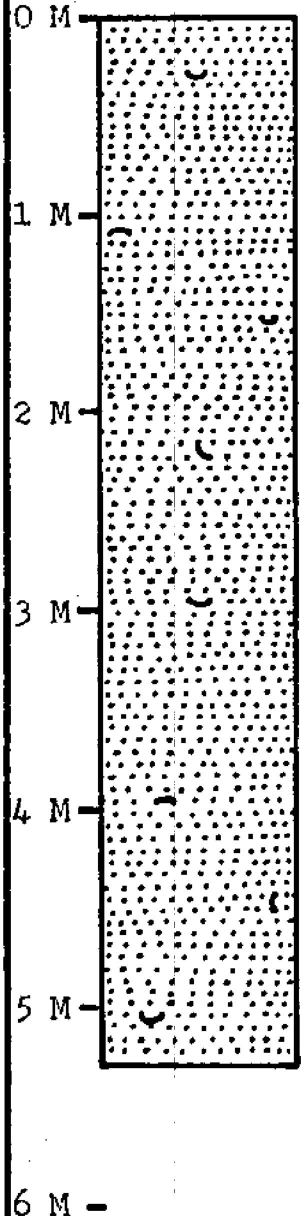
-A clean oxidized layer of medium sand containing a 3 cm. rounded coal fragment overlies a 2 cm. layer of dark grey mud and a sequence of alternating muddy sands and clean fine sand The percentage of mud increases with increasing depth in the core.



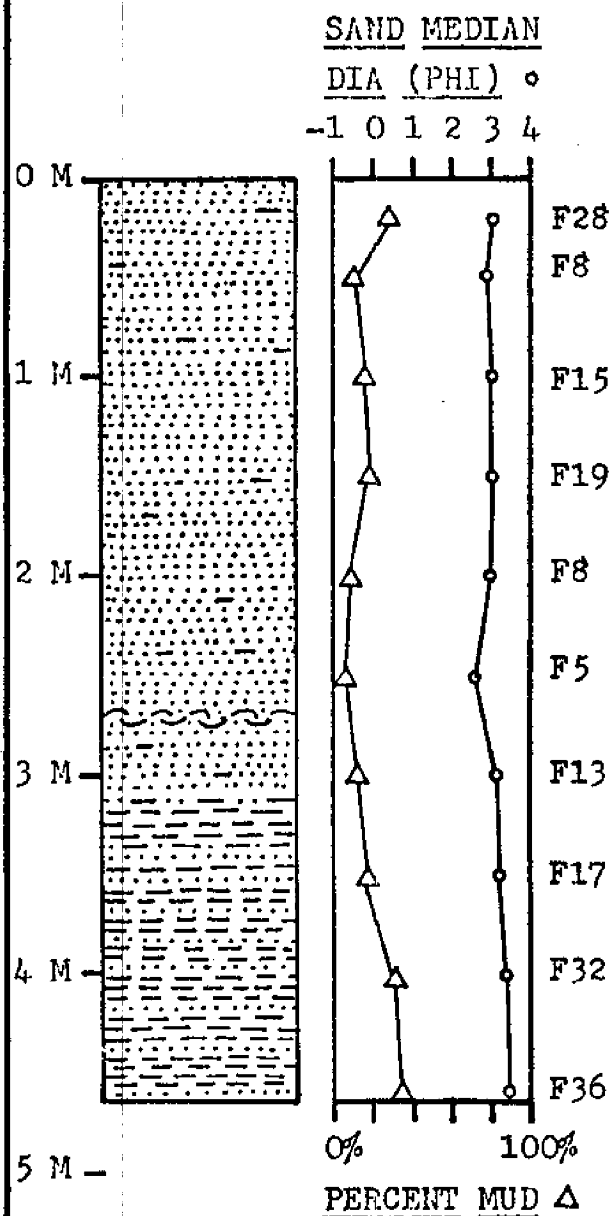
SAMPLE 83 (PC-47)
WATER DEPTH 5.2 M.
LAT. 38-57.90 N.
LONG. 75-00.80 W.

-A surficial layer of broken *Ensis* shell fragments overlies a sequence of alternating clean white fine sand, mud, and muddy sand.

SAMPLE 109 (PC-44)
WATER DEPTH 11.5 M.
LAT. 38-55.20 N.
LONG. 75-04.40 W.



-A uniform structureless grey green medium sand with scattered small shell fragments and mica flakes.

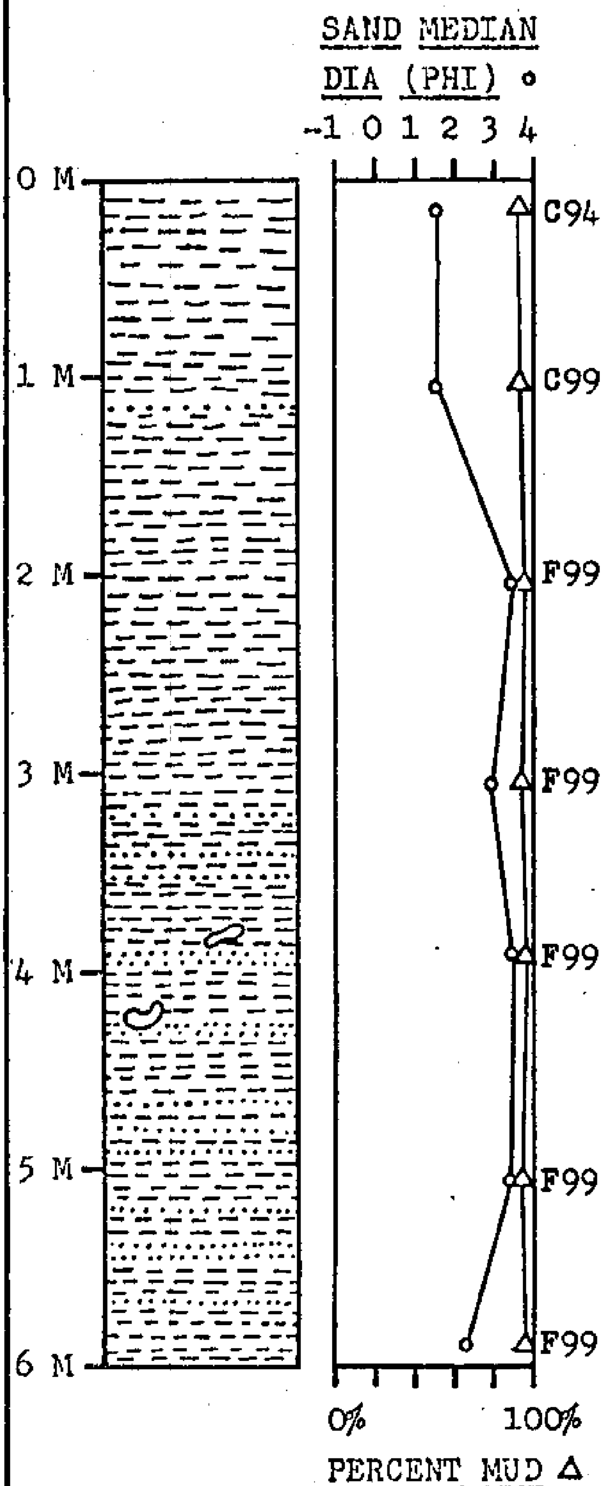


SAMPLE 119 (PC-12)
WATER DEPTH 10.6 M.
LAT. 38-54.00 N.
LONG. 75-09.90 W.

0-3.1 m. Fine to very fine muddy sand without structures or variation.

3.1-4.6 m. Alternating layers of fine to very fine sand and mud. The frequency and thickness of the mud layers increases with increasing depth in the core.

SAMPLE 130 (VC-17)
WATER DEPTH 25.8 M.
LAT. 38-55.95 N.
LONG. 75-09.45 W.



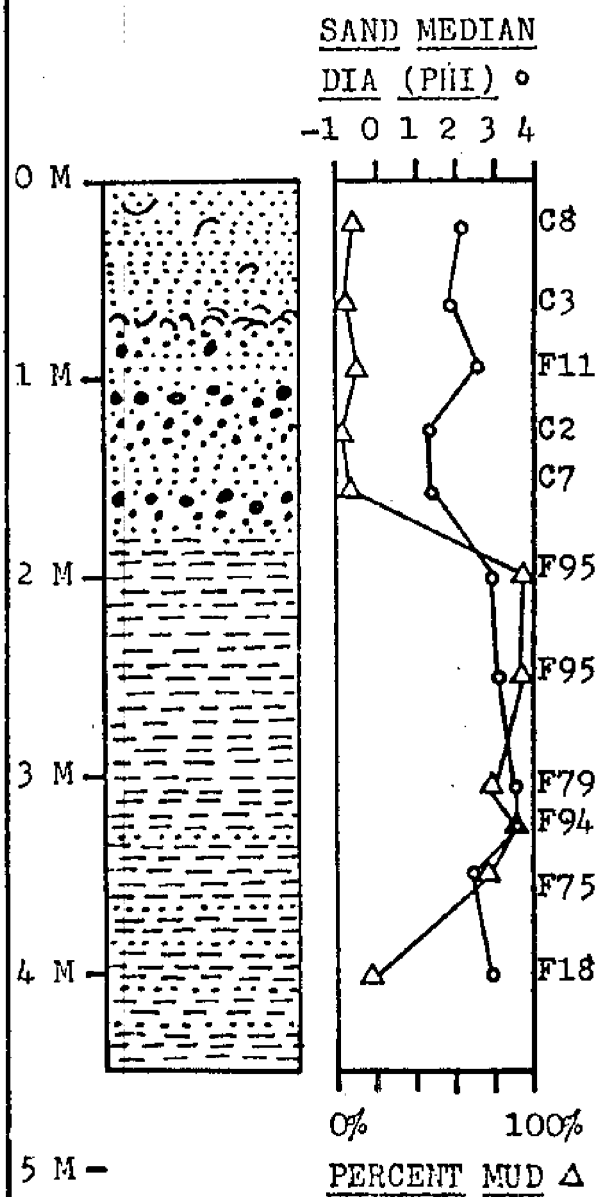
-An extremely fine grain sediment sequence throughout its length. Thin laminae of very fine sand occur in the middle and lower sections of the core. The results of a pollen analysis at 0.54 m. are listed in Table 8.

SAMPLE 131 (VC-18)

WATER DEPTH 12.8 M.

LAT. 38-55.30 N.

LONG. 75-09.55 W.



0-1.8 m. Three upward coarsening sediment sequences of grey medium sand, shell fragments and pebbles with a distinct textural break at 1.8 meters.

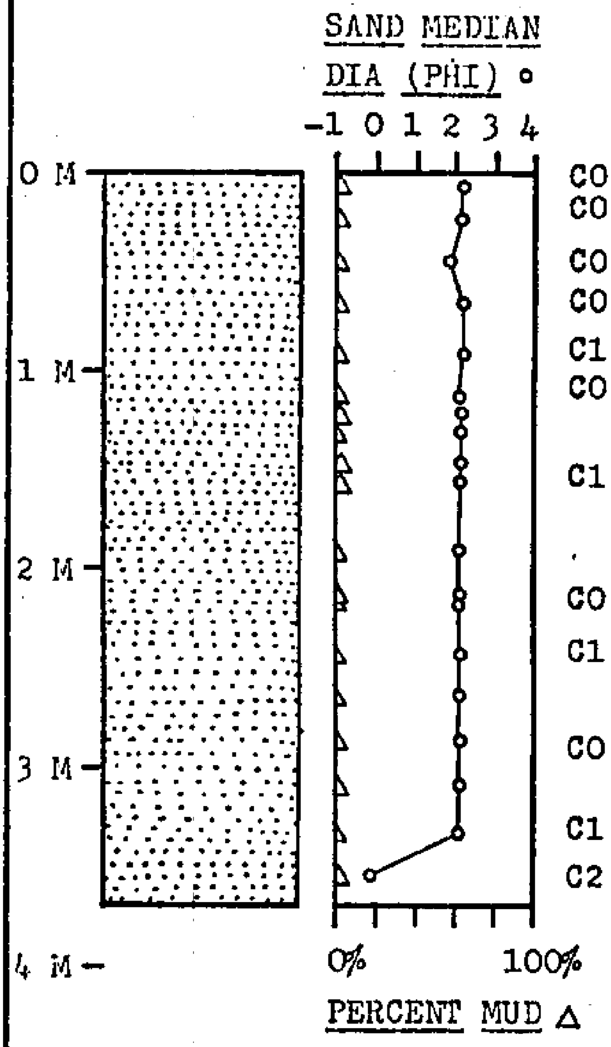
1.8-4.3 m. Mud dominated sequence of interlaminated brownish grey and brownish red mud and fine sand.

<u>SAMPLE 132 (VC-19)</u>

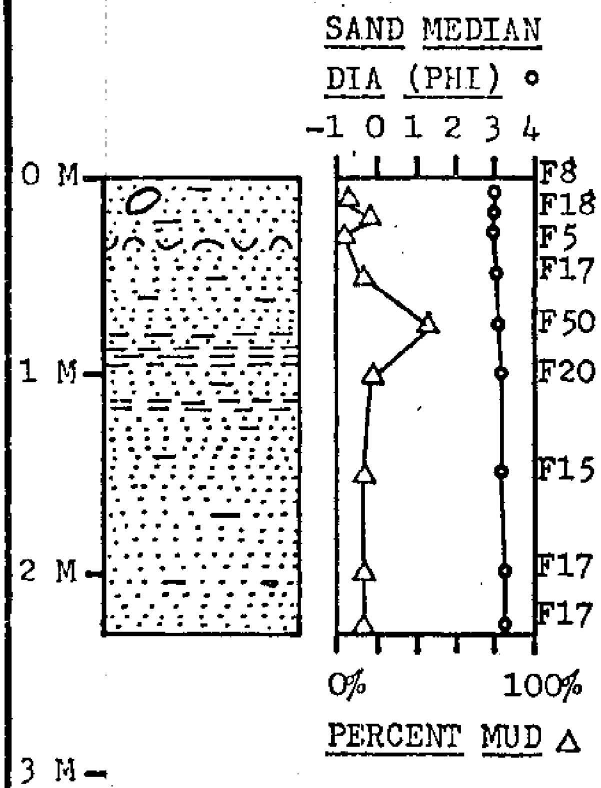
WATER DEPTH 8.2 M.

LAT. 38-55.90 N.

LONG. 75-06.85 W.

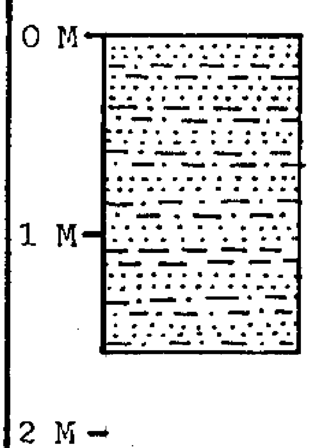


-Uniform light brown sand fine to medium sand that is rich in opaque minerals.



SAMPLE 133 (PC-21)
WATER DEPTH 8.8 M.
LAT. 38-58.70 N.
LONG. 75-01.50 W.

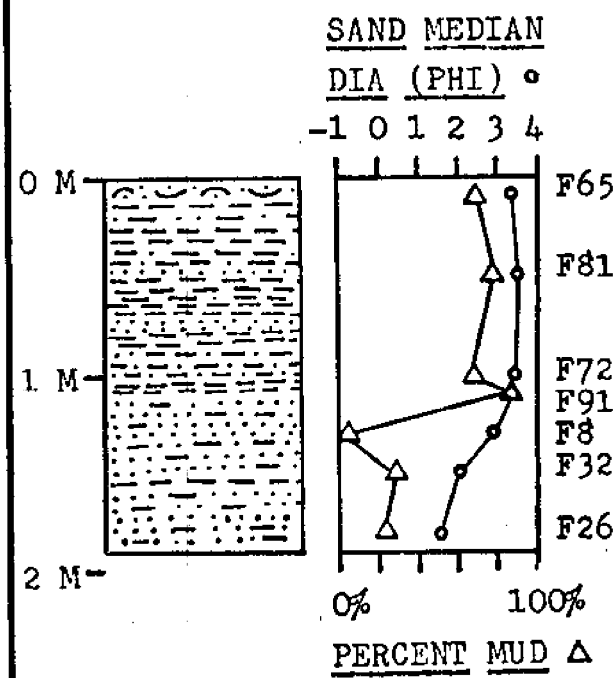
-A sequence of alternating layers of fine sand and muddy sand with occasional layers of sandy mud. Possible bioturbation in the upper 0.7 meters.



SAMPLE 135 (PC-51)
WATER DEPTH 7.9 M.
LAT. 38-59.30 N.
LONG. 74-59.90 W.

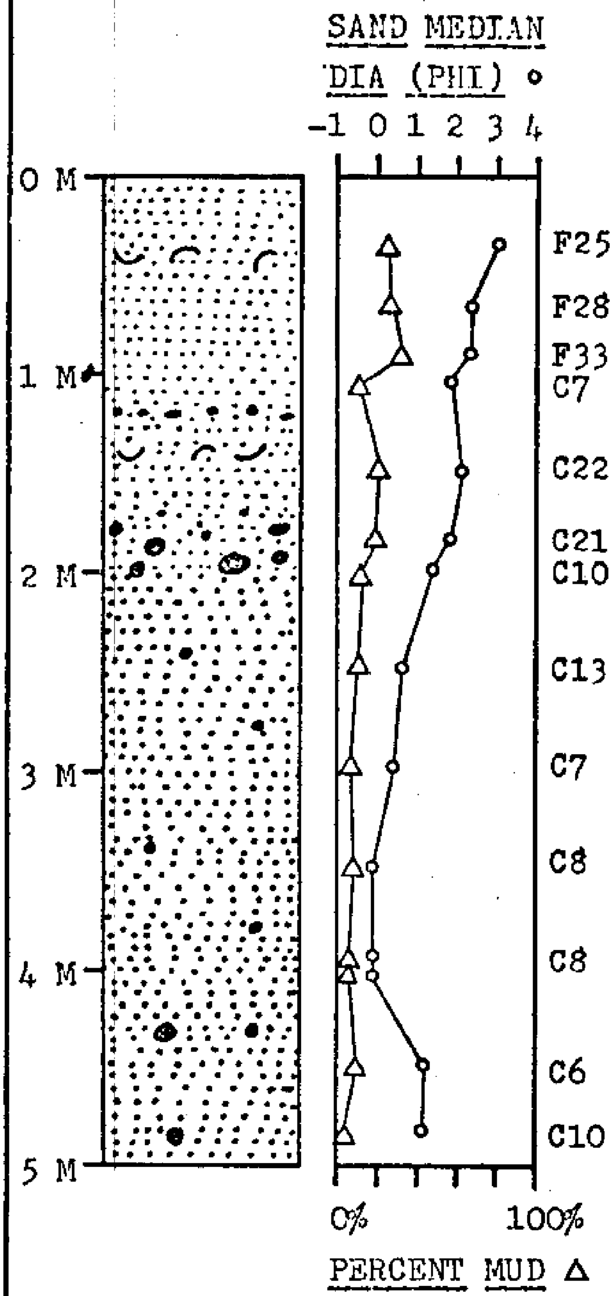
-An alternating sequence of clean fine grey green sand, mud, and muddy sand.

SAMPLE 136 (PC-20)
WATER DEPTH 7.3 M.
LAT. 38-59.20 N.
LONG. 75-59.20 W.



-Surficial shell fragments overlie a mud dominated sequence of interlaminated fine to very fine sand and mud to 1.1 meters Lower section of core is also interlaminated fine sand and mud but is sand dominated.

SAMPLE 143 (VC-20)
WATER DEPTH 4.9 M.
LAT. 38-54.20 N.
LONG. 75-13.45 W.

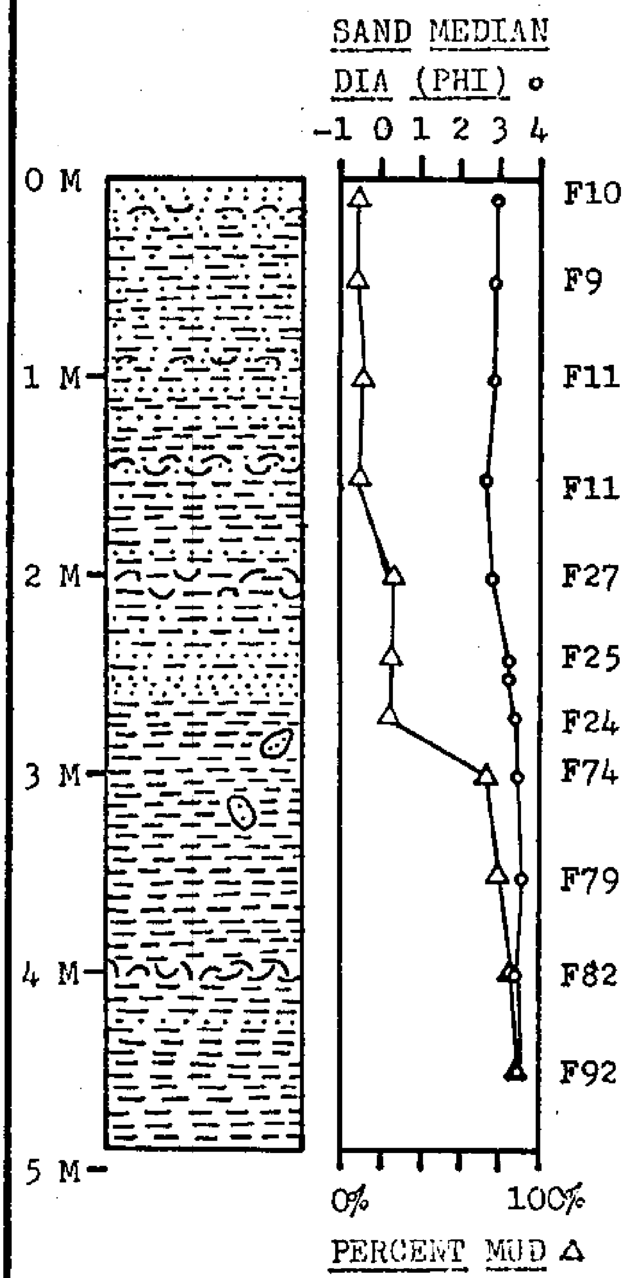


0-1.0 m. Grey fine muddy sand with scattered shell fragments.

1.0-2.0 m. Grey coarse sand with scattered shell fragments and abundant pebbles increasing with increasing depth.

2.0-5.0 m. White coarse to very coarse sand with abundant pebbles scattered throughout. White color is due to presence of white clay but is variable from light grey to dark yellow-orange.

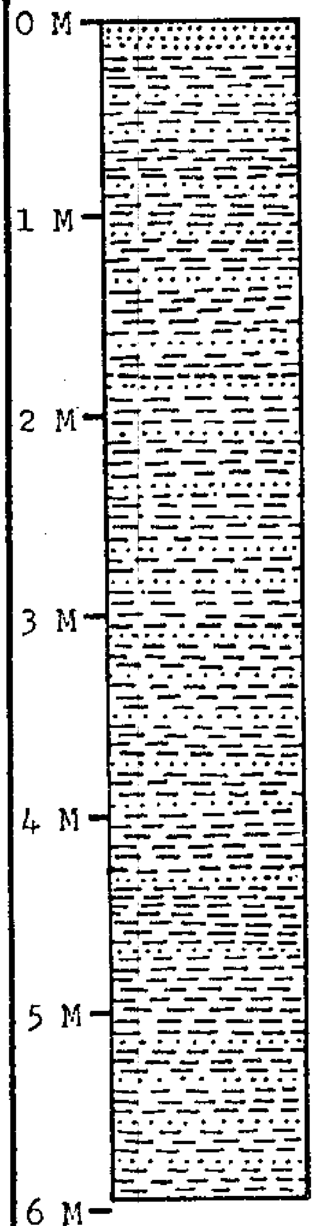
SAMPLE 149 (PC-13)
WATER DEPTH 12.2 M.
LAT. 38-56.30 N.
LONG. 75-11.30 W.



0-2.6 m. Sequence of interlaminated muddy fine sand, clean fine sand, and mud with sandy shell layers and evidence of bioturbation.

2.6-4.9 m. Distinctive dark grey mud with occasional laminae of fine sand and layers of shell fragments.

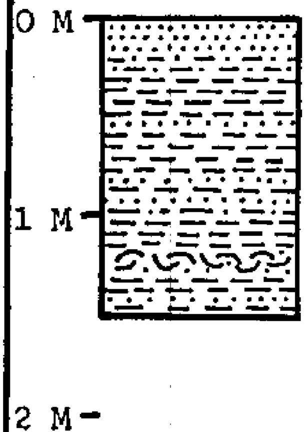
<u>SAMPLE 151 (PC-56)</u>
WATER DEPTH 32.0 M.
LAT. 38-56.80 N.
LONG. 75-10.20 W.



0-0.07 m. Oxidized medium to coarse sand with muddy sand layers

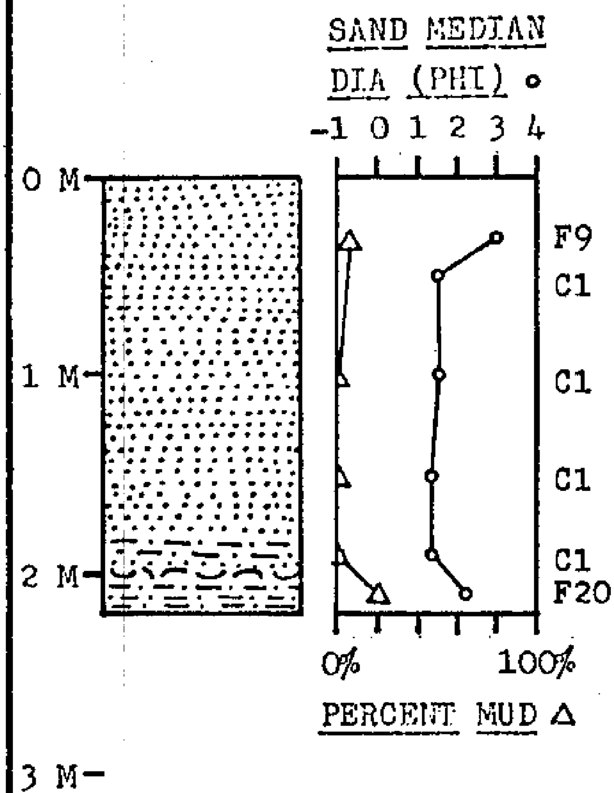
0.07-5.93 m. Dark grey mud with laminae (1mm to 8 mm thick) of clean white very fine sand.

SAMPLE 167 (PC-45)
WATER DEPTH 6.4 M.
LAT. 38-56.90 N.
LONG. 75-12.90 W.



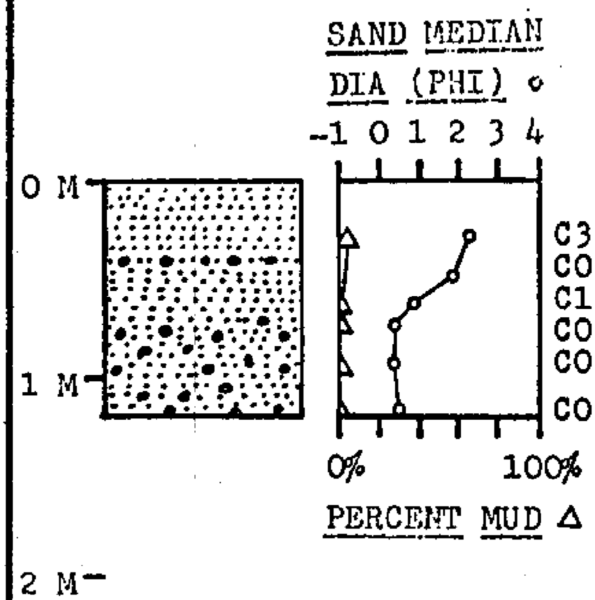
35 cm. of clean fine to medium grey green sand overlying a distinct sequence of dark grey mud with interlaminated fine sand and muddy sand layers less than 2 cm. thick. *Mulinia* and *Nucula* valves at 1.2 meters. Core closely resembles core 259 from Joe Flogger Shoal.

SAMPLE 169 (PC-14)
WATER DEPTH. 9.1 M.
LAT. 38-57.80 N.
LONG. 75-12.80 W.



-Very fine grey green sand overlies a grey green medium sand with very high concentration of opague minerals. Sand is well sorted and structures are absent. Sequence overlies finer grained muddy sand.

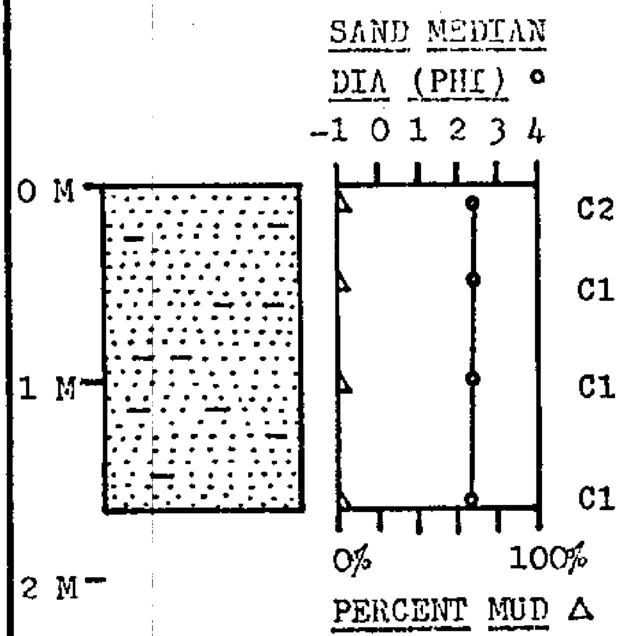
SAMPLE 170 (PC-15)
WATER DEPTH 16.7 M.
LAT. 38-57.80 N.
LONG. 75-11.70 W.



-Well sorted, structureless light grey green fine sand with a basal pebble layer. Sequence overlies upward fining sequence of very poorly sorted pebbly very coarse sand grading upward into a clean well sorted white medium sand.

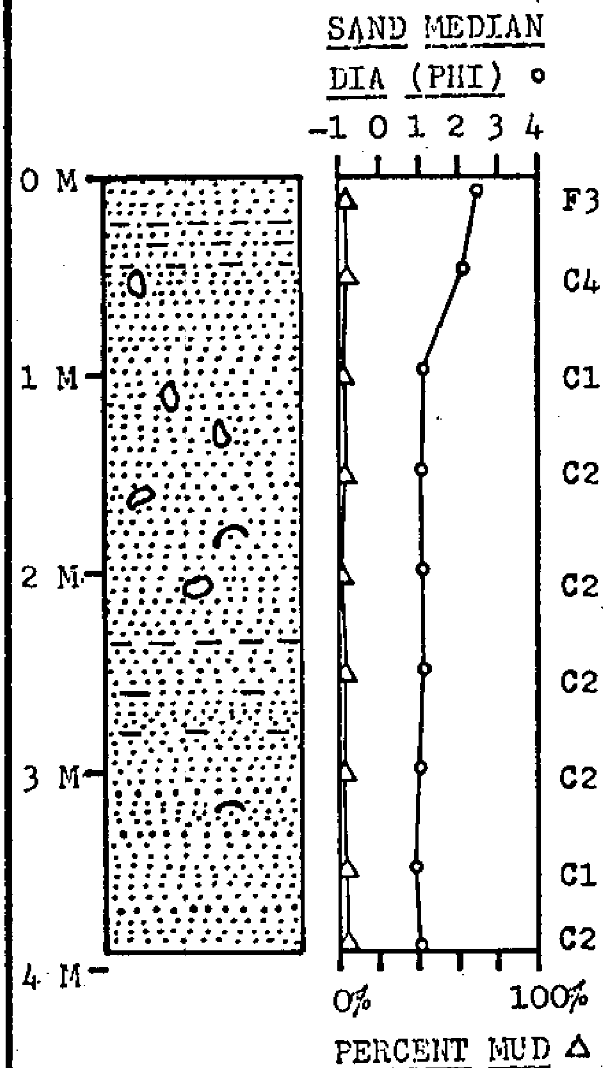
-Boundry correlates with seismic subbottom reflector at fix 643.

SAMPLE 173 (PC-19)
WATER DEPTH 13.1 M.
LAT. 38-57.80 N.
LONG. 75-09.50 W.



-Uniform, clean fine grey green sand with high opaque mineral concentration. No structures but scattered muddy patches.

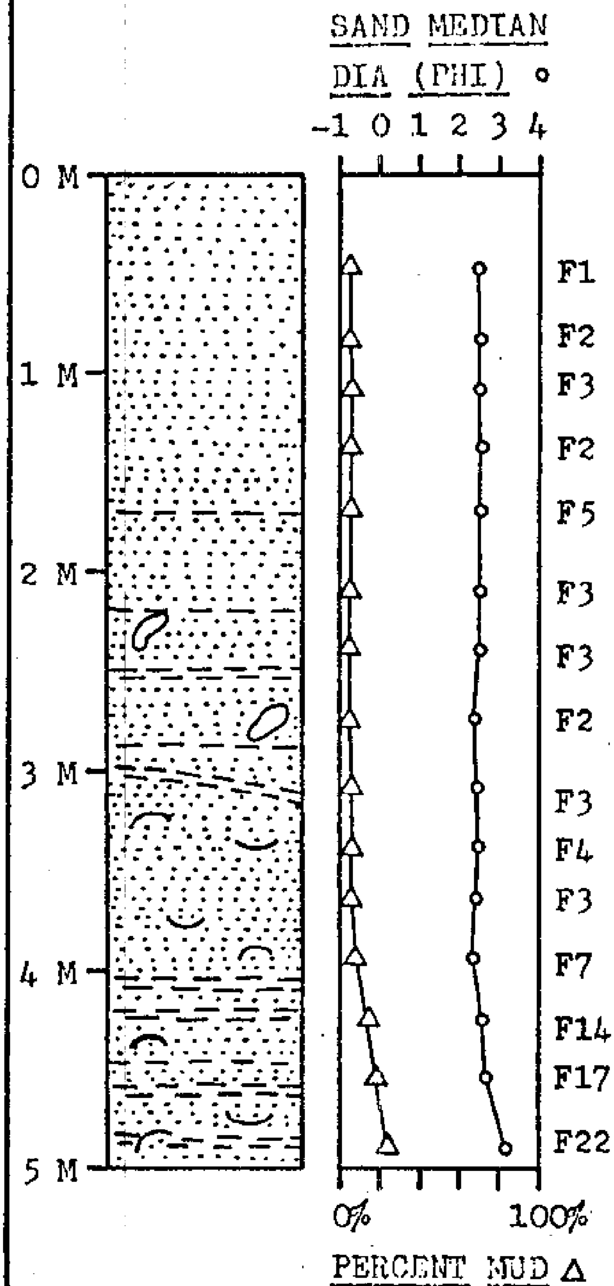
SAMPLE 174 (PC-16)
WATER DEPTH 14.3 M.
LAT. 38-57.80 N.
LONG. 75-07.50 W.



0-1.4 m. Grey green fine sand with layers of muddy sand and mud. Muddy streaks and mud filled burrows suggest reworking and bioturbation.

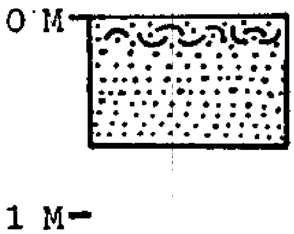
1.4-3.9 m. Grey green medium sand with muddy patches and mud laminae. Oyster shell fragments at 1.8 and 3.2 meters. Layers of coarse sand at 3.1, 3.3, and 3.7 meters.

SAMPLE 175 (VC-22)
WATER DEPTH 7.6 M.
LAT. 38-58.80 N.
LONG. 75-06.30 W.



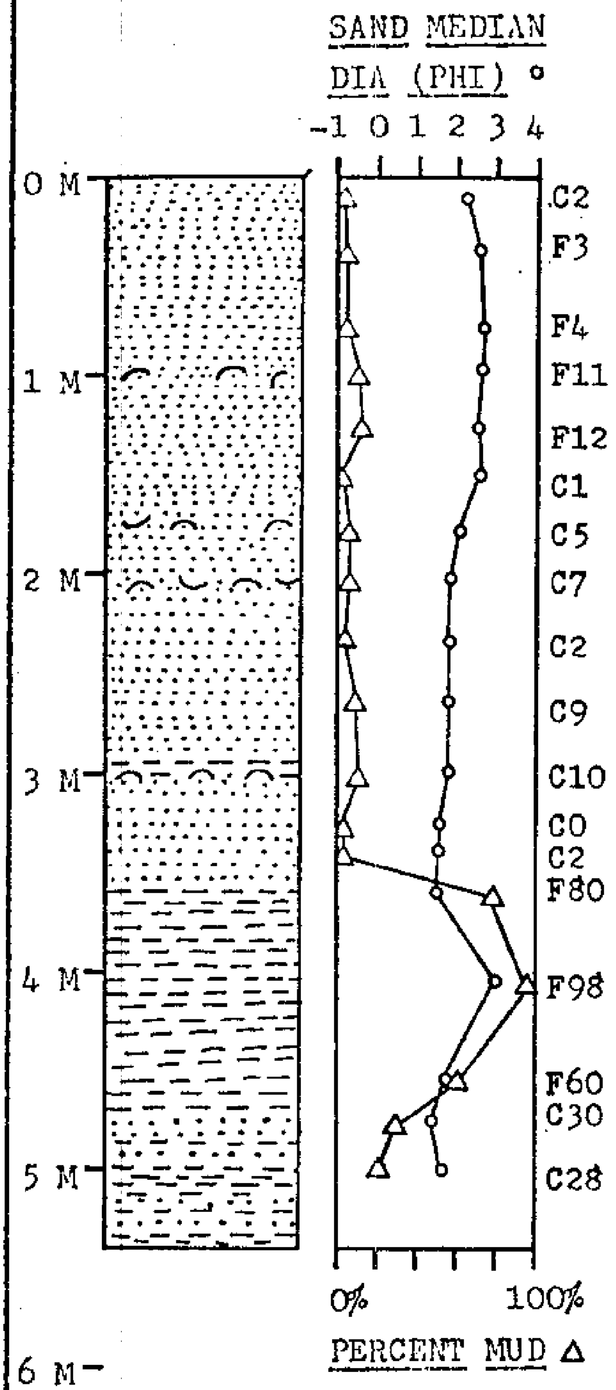
-Monotonous clean grey green sand with scattered muddy streaks and mud laminae.

SAMPLE 193 (PC-52)
WATER DEPTH 7.0 M.
LAT. 38-59.80 N.
LONG. 75-11.40 W.



-Clean grey green medium sand overlies a sandy shell layer and a clean structureless sand which grades downward to fine sand.

SAMPLE 197 (VC-23)
WATER DEPTH 6.4 M.
LAT. 39-01.80 N.
LONG. 75-04.90 W.



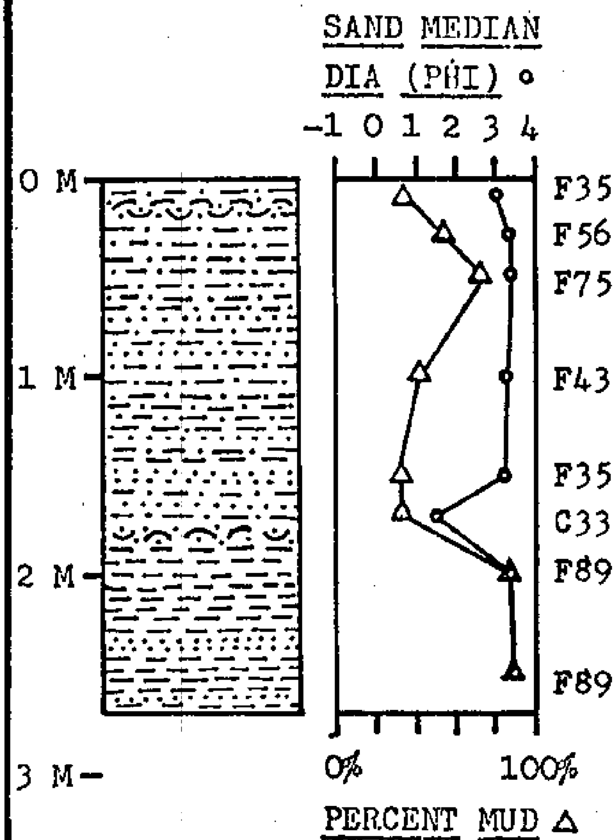
0-1.5 m. Clean grey green fine sand with occasional shell fragments.

1.5-3.5 m. Clean grey green medium sand with shell fragments and grey green mud laminae.

3.5-4.7 m. Hom ogeneous dark grey mud without structures.

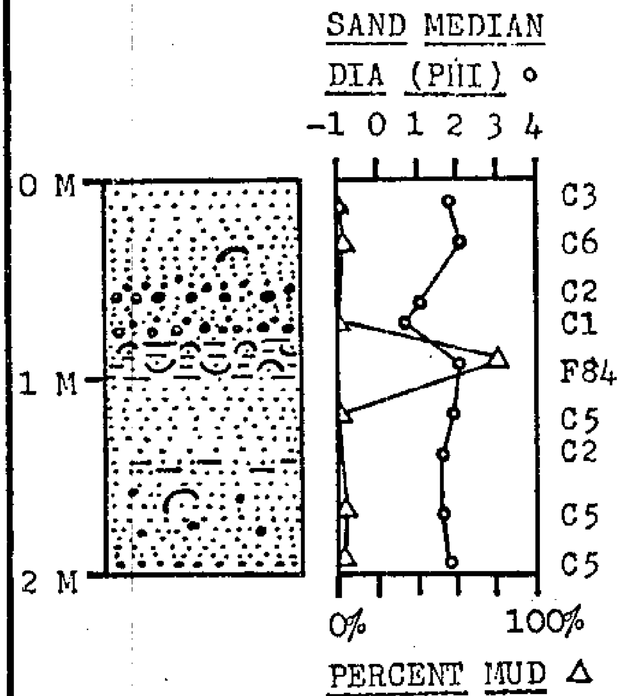
4.7-5.4 m. Layers of interlaminated medium sand and sandy mud.

SAMPLE 199 (PC-22)
WATER DEPTH 11.5 M.
LAT. 39-02.10 N.
LONG. 75-02.40 W.



0-1.8 m. Very fine sand and muddy sand layers. Percentage of mud increases toward the top of the core. Shell layer at core top.

1.8-2.7 m. Distinctive break separates dark grey mud with laminae of fine sand.



SAMPLE 226 (PC-26)

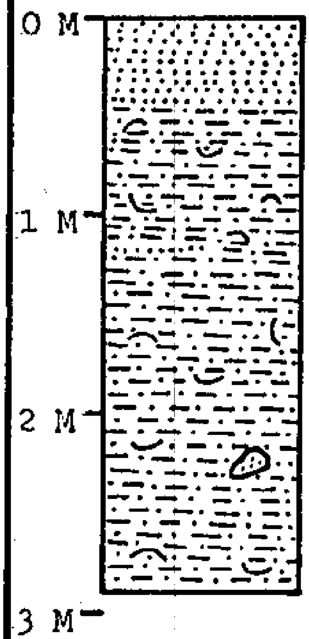
WATER DEPTH 11.5 M.
LAT. 39-01.75 N.
LONG. 75-15.40 W.

0-0.8 m. Medium to coarse oxidized orange sand.

0.8-1.0 m. Oyster shells in a stiff dark grey mud matrix. Radiocarbon age date of the shell material was greater than 40,000 years B.P.

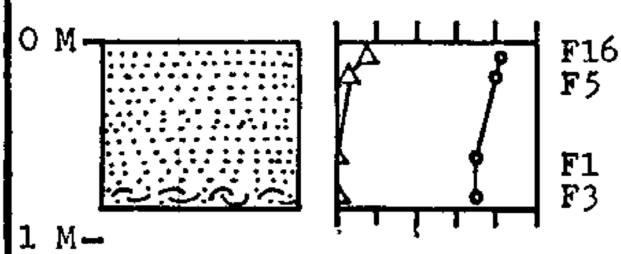
1.0-2.0 m. Uniform, structureless oxidized medium sand with occasional shell fragments and mud flakes in the sand matrix.

SAMPLE 231 (PC-55)
WATER DEPTH 10.9 M.
LAT. 39-03.30 N.
LONG. 75-09.70 W.



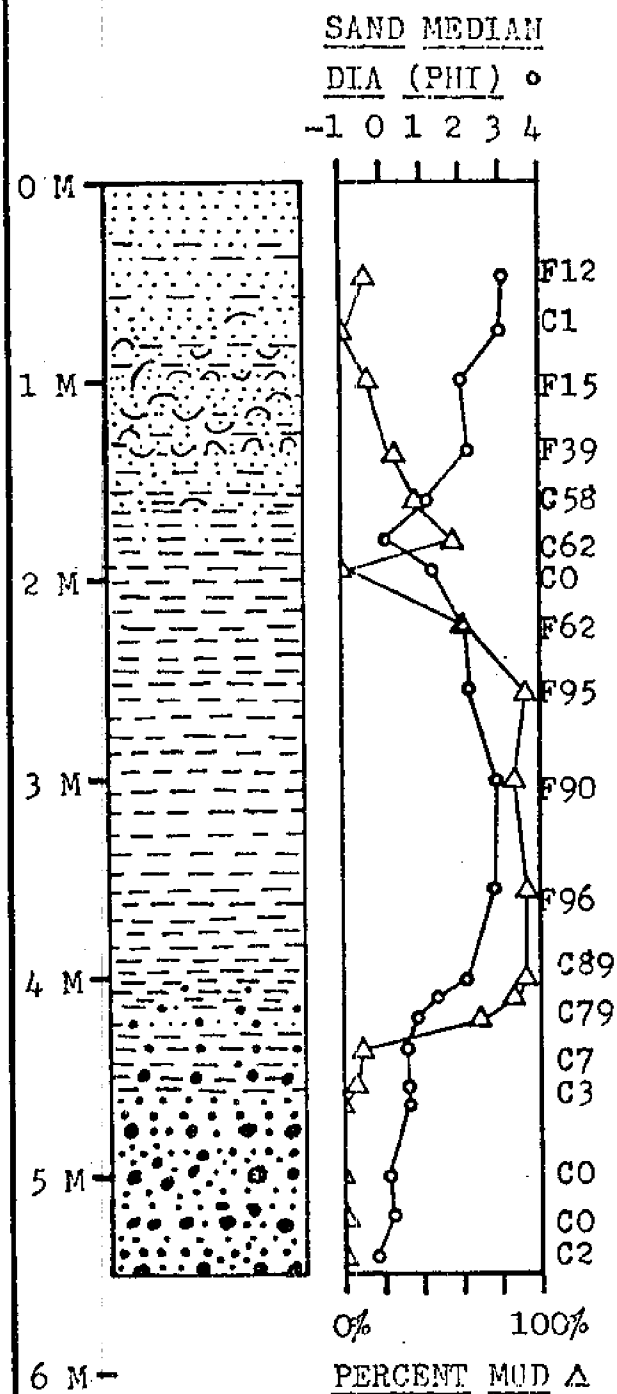
-Clean to muddy fine grey sand overlying a uniform dark grey sandy mud with scattered shell fragments laminae of fine sand and one sand filled burrow.

SAMPLE 243 (PC-25)
WATER DEPTH 10.0 M.
LAT. 39-03.00 N.
LONG. 75-13.00 W.



-Upward fining structureless grey green fine sand with basal shell fragment layer in sandy matrix.

SAMPLE 247 (VC-24)
WATER DEPTH 6.4 M.
LAT. 39-05.30 N.
LONG. 74-05.30 W.

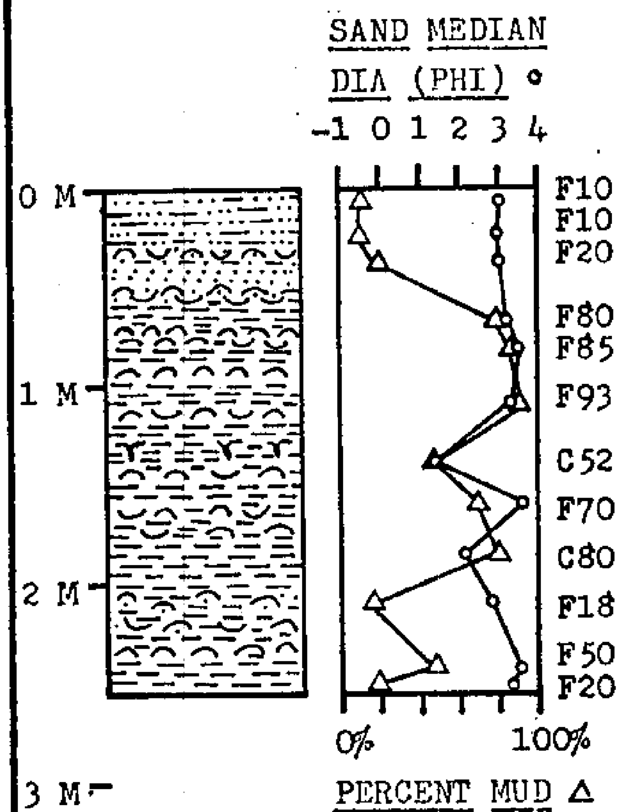


0-1.0 m. Muddy fine sand with shell fragments (*Ensis*, *Mullinia*, *Nucula*, and *Crassostrea*).

1.0-4.0 m. Sandy grey green mud grading downward into a uniform fine grain mud.

4.0-5.5 m. Bleached zone of mixed coarse sand and mud overlies 20 cm. upward fining sequences of white granules and medium sand.

SAMPLE 259 (PC-30)
WATER DEPTH 9.4 M.
LAT. 39-05.20 N.
LONG. 75-13.70 W.

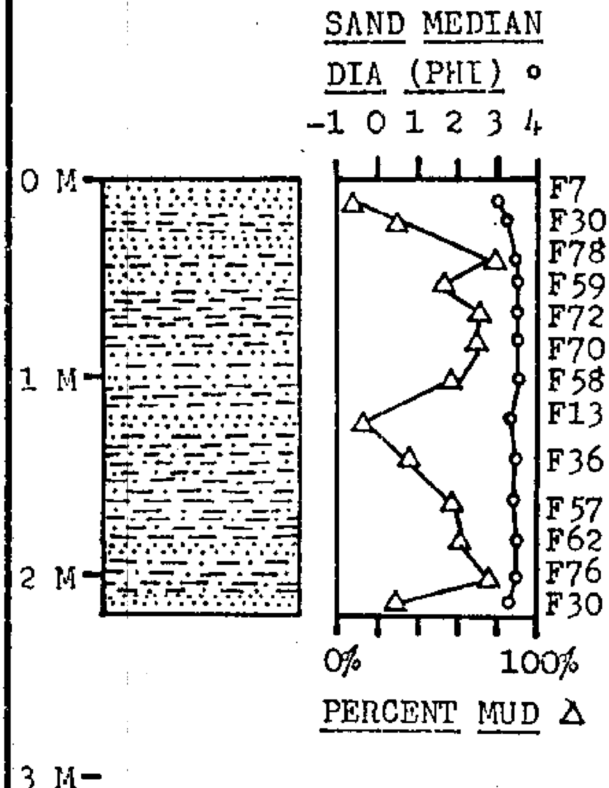


0-0.3 m. Grey green very fine muddy sand.

0.3-2.5 m. Distinct boundry contact separates soft, dark grey mud from overlying sands. Mud contains layers of broken shell fragments and shells with both v valves attaches. Plant fragments are scattered throughout.

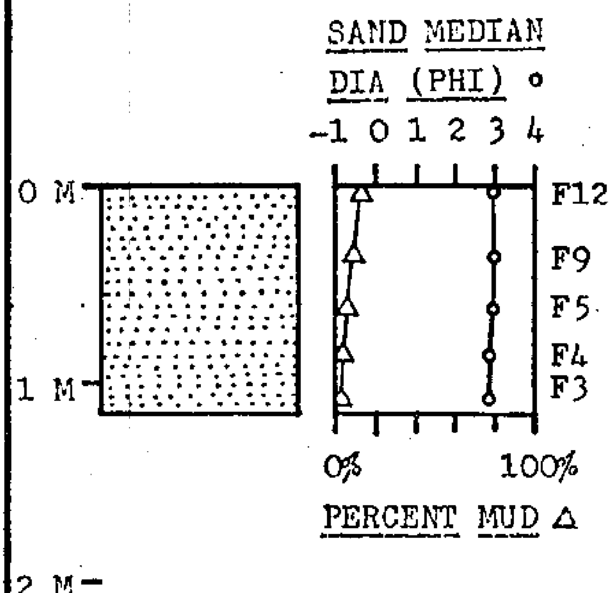
-Radiocarbon analyses of in-place Mulinia and Nucula valves at 46-54 cm. and 70-74 cm. gave age dates of 2,685 ± 90 years B.P. and 2,855 ± 90 years B.P. respectively.

SAMPLE 260 (PC-29)
WATER DEPTH 5.5 M.
LAT. 39-05.35 N.
LONG. 75-13.60 W.



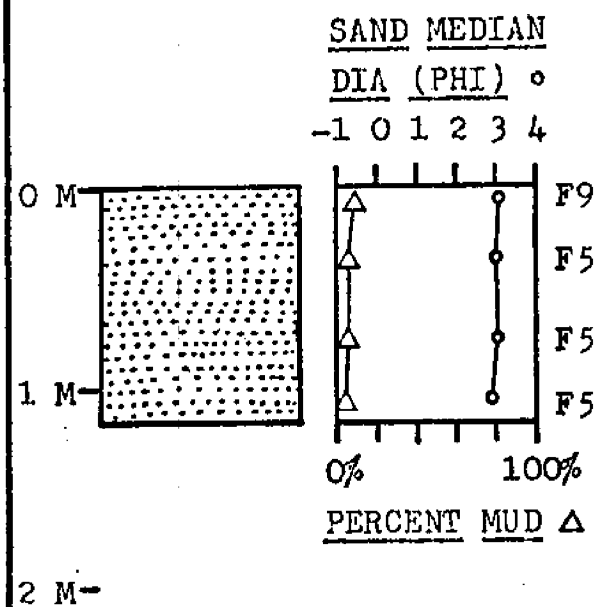
-Alternating layers of clean white fine to very fine sand with grey green muddy sands and grey green mud.

SAMPLE 261 (PC-31)
WATER DEPTH 7.9 M.
LAT. 39.05.40 N.
LONG. 75-12.80 W.



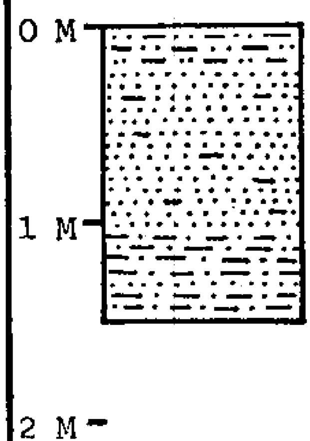
Uniform structureless grey green fine sand.

SAMPLE 262 (PC-39)
WATER DEPTH 8.5 M.
LAT. 39-06.30 N.
LONG. 75-10.00 W.



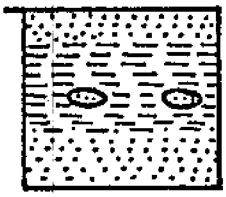
-Uniform, structureless well sorted grey green fine sand.

SAMPLE 278 (PC-54)
WATER DEPTH 7.6 M.
LAT. 39-07.30 N.
LONG. 75-13.60 W.



-One meter of light grey fine sand with muddy streaks and mud laminae overlying a basal dark grey mud with sandy streaks.

SAMPLE 279 (PC-53)
WATER DEPTH 12.2 M.
LAT. 39-07.20 N.
LONG. 75-12.80 W.



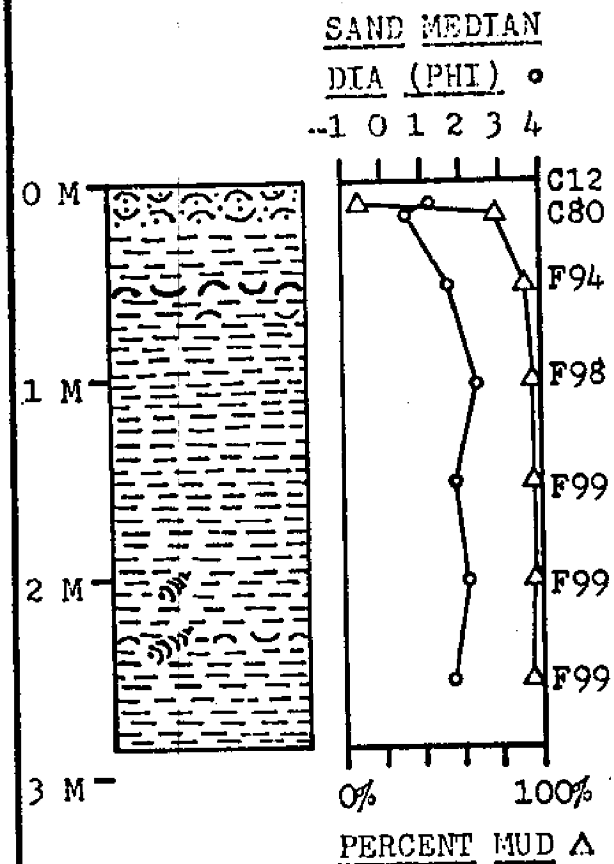
-Clean oxidized medium sand overlies a massive dark grey mud with two very thin laminae of very fine sand and sand-filled burrows. This sequence overlies a thin muddy medium to coarse light grey sand and a clean grey green medium sand.

SAMPLE 291 (PC-27)

WATER DEPTH 7.3 M.

LAT. 39-07.00 N.

LONG. 75-16.90 W.



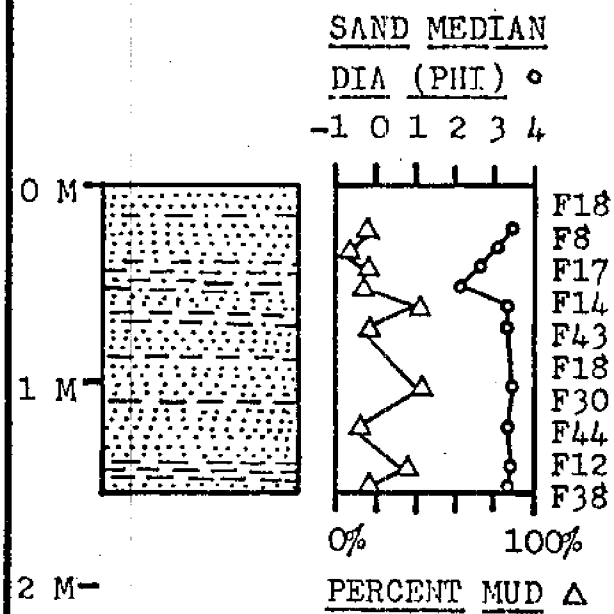
-A coquina of small shell fragments in a fine to medium sand matrix overlies a massive dark grey mud which contains shell layers at 0.5 m. and oyster shell fragments and gastropod shells at 2.0 and 2.3 meters.

SAMPLE 317 (PC-32)

WATER DEPTH 6.4 M.

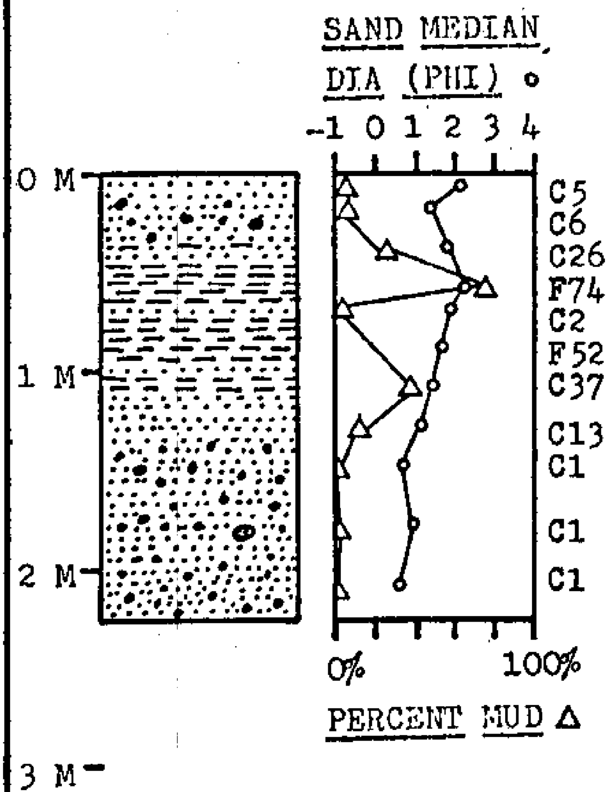
LAT. 39-10.30 N.

LONG. 75-18.00 W.



-Upper ½ meter shows upward fining sequence in uniform grey green fine sand and overlies beautifully interlaminated sequence of fine sand and muddy fine sand with mud laminae.

SAMPLE 322 (PC-38)
WATER DEPTH 7.6 M.
LAT. 39-11.30 N.
LONG. 75-12.80 W.

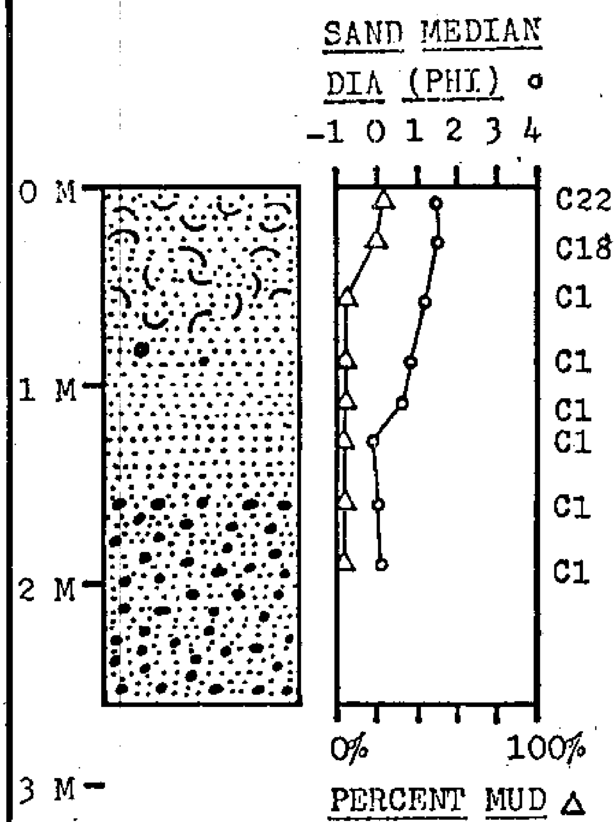


0-0.5 m. Layers of grey green fine sand and coarse sand with pebbles.

0.5-1.1 m. Light grey mud layers bedded with thin upward fining sand sequences

1.1-2.3 m. Upward fining sequences of very coarse sands grading to medium sand. Pebbles scattered throughout.

SAMPLE 328 (PC-36)
WATER DEPTH 6.1 M.
LAT. 39-11.10 N.
LONG. 75.18.50 W.

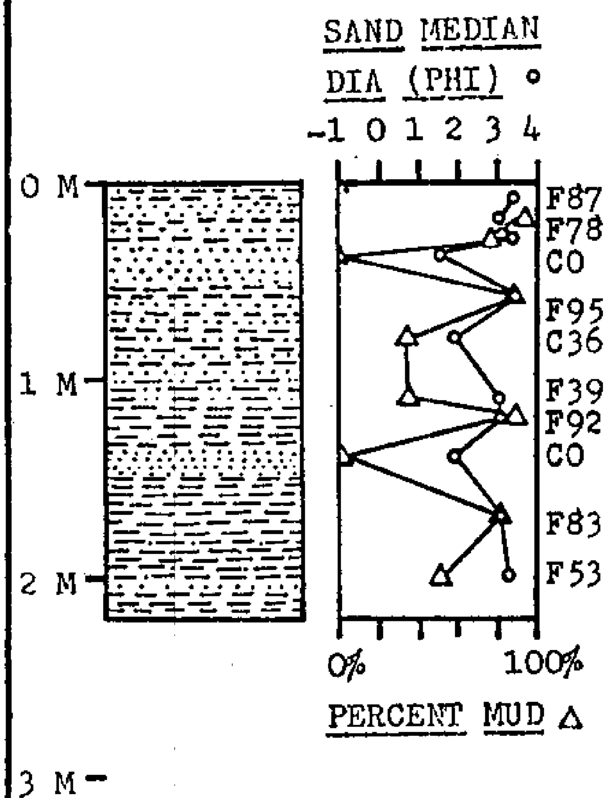


0-0.7 m. Shell fragments in a grey green muddy sand matrix.

0.7-1.5 m. Upward fining sequence of light grey green coarse to medium sand.

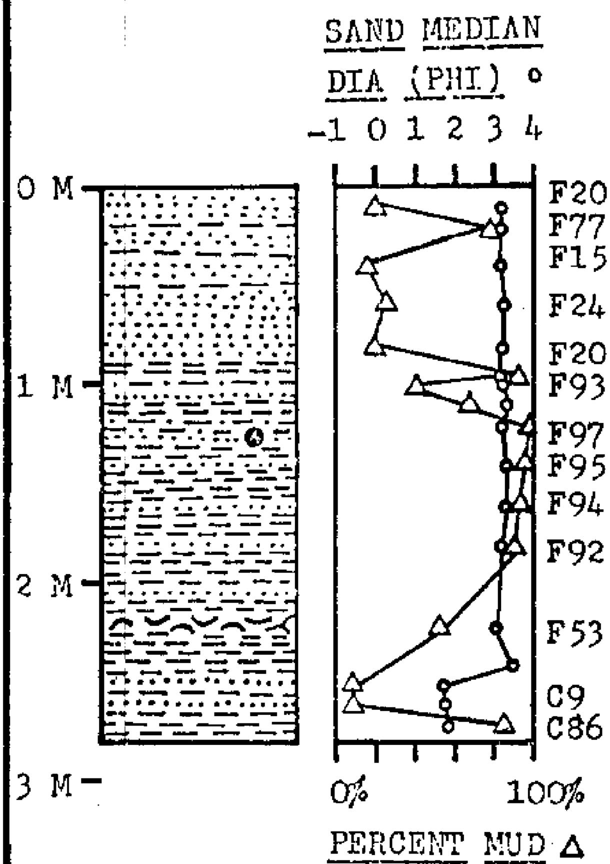
1.5-2.6 m. Medium to very coarse pebbly sand. No structures or bedding sequences are visible.

SAMPLE 362 (PC-35)
WATER DEPTH 5.8 M.
LAT. 39-15.70 N.
LONG. 75-21.50 W.



-Sequence of interlaminated fine to coarse clean sands, muds, and muddy sands.
-Top sand layer contains slag and coal fragments.
-Most of the mud laminae show very thin laminae on wetting.

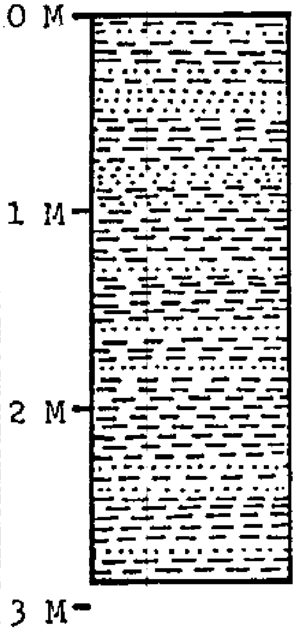
SAMPLE 372 (PC-33)
WATER DEPTH 8.5 M.
LAT. 39-16.80 N.
LONG. 75-20.80 W.



0-1.1 m. Fine to very fine grey green sand with a few mud laminae.

1.1-2.8 m. Dark grey mud with one large quartz pebble at 1.3 m, large fragments of oyster shell at 2.2 m., layers of medium sand at 2.5 and 2.6 meters. Very thin laminae of fine white sand occur throughout the sequence.

SAMPLE 397 (PC-34)
WATER DEPTH 9.4 M.
LAT. 39-21.55 N.
LONG. 75-26.75 W.



-Alternating layers of dark grey mud and clean coarse white sand overlie a dark grey mud with many thin laminae of fine to very fine white sand.