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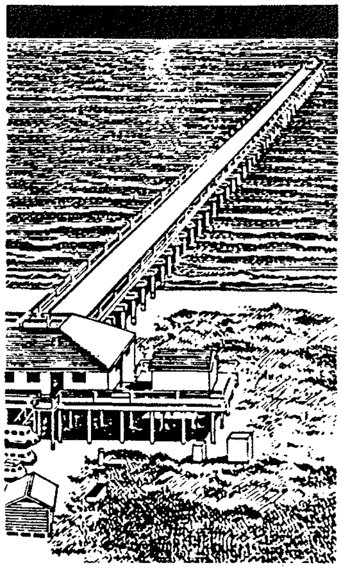

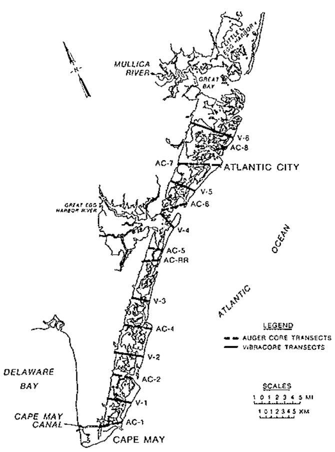

TECHNICAL REPORT CERC-90-2

HOLOCENE DEPOSITIONAL HISTORY OF THE SOUTHERN NEW JERSEY BARRIER AND BACKBARRIER REGIONS

by

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The subsurface stratigraphy of the backbarrier region of southern New Jersey was examined to determine the Holocene depositional history. The study area extends from Brigantine to Cape May and includes seven barrier islands and an extensive backbarrier region. Vibracores, augercores, surface samples, historical maps and charts, and radiocarbon dates were used to document the patterns of sedimentation.

The Holocene backbarrier stratigraphy is characterized by a fining upward sequence that consists of a basal marsh or lagoon, overlain by a sand facies, tidal flats, marshes, tidal channels, and shallow lagoons. These data reflect a change from higher to lower energy backbarrier conditions that resulted as the barrier islands migrated landward throughout the Holocene transgression.

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A relative sea-level envelope has been developed based on radiocarbon dates from this study and other published results. Sea level has risen 11 m in the last 6,000 years at an average rate of approximately 1 mm/year. Regional data indicate that the rate of sea-level rise slowed after 2,000 years B.P. This change in rate, in conjunction with a continuous sediment supply, resulted in increased intertidal sedimentation and the establishment of salt marshes.

Sources of sediment to the backbarrier region have changed through time. During the late Pleistocene, rivers and streams deposited sediments along the landward margin. In contrast, modern coastal plain rivers contribute very little sediment to the backbarrier. As sea level rose throughout the Holocene, erosion of the coastal headland to the north and the adjacent continental shelf contributed sediment to the seaward portion of the backbarrier region. Presently, the continental shelf, shoreface, and beaches supply the majority of sediment to the backbarrier system. Marine-derived sediment is transported to the west through tidal inlets and redistributed by tidal currents.

Stratigraphic and geomorphologic evidence forms the basis for a model of Holocene backbarrier evolution and suggests that there are two different foundations to the marshes within the study area. First, the marshes located landward of the lagoons and adjacent to the upland formed on fluvially derived sediment deposited after the late Pleistocene sea level lowstand. Second, the marshes located seaward of the lagoons and adjacent to the barrier islands formed on marine-derived sediment deposited during late Holocene time. The numerous small lagoons represent a boundary between the two marsh environments. Although the position of the lagoons has remained relatively constant through time, they have shallowed and decreased in total area as energy conditions in the backbarrier region have decreased.

Historical inlet data indicate that the total number of inlets has decreased since the 1700s. This trend should continue as the backbarrier region becomes progressively more infilled by tidal flat and marsh sedimentation, thus reducing the tidal prism and decreasing inlet efficiency.

PREFACE

This report was published to improve the understanding of backbarrier environments and to document the depositional history of the southern New Jersey backbarrier region. The research was carried out between 1981 and 1984 by the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), under the Barrier Island Sedimentation Studies Work Unit 31655 as part of the Protection and Restoration Research Program. Funding was provided by Headquarters, US Army Corps of Engineers (HQUSACE). The HQUSACE Technical Monitors were Messrs. John H. Lockhart and John G. Housley.

The report was prepared by Ms. Marie A. Ferland under the general supervision of Dr. C. Everts, Chief, Coastal Processes and Structures Branch. Dr. S. Kimball was the Principal Investigator from 1983 to 1986, and Dr. Donald Stauble has been Principal Investigator since 1987. This work was conducted under the direct supervision of Drs. Everts and Stauble and under the general supervision of Mr. H. Lee Butler, Chief, Research Division, CERC; Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and Dr. James Houston, Chief, CERC. Reviews were provided by Dr. K. Finkelstein, CERC; Dr. G. M. Ashley, Rutgers University; and Mr. S. J. Williams, CERC. Mr. D. Prins, Dr. Finkelstein, Ms. L. Hulmes, and Ms. D. McCleary collected cores in the field. Dr. Kimball, Mr. L. Scott, Ms. J. Brennan, Ms. K. Foster, Miss J. Neeson, and Mr. J. Roberts, CERC, assisted in manuscript preparation. Dr. B. Zaitlin, Univeristy of Sydney, provided suggestions during this research. Helicopter overflights of the study area were provided by the staff at Davidson Airfield, Fort Belvoir, VA, and Fort Dix, NJ. The staff at the Wetlands Institute facilitated field work in 1984.

The research results contained in this report were also documented in a Master of Science thesis written by Ms. Ferland in 1984.

Commander and Director of WES during the publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
fathoms	1.8288	metres
feet	0.3048	metres
tons (2,000 pounds, mass)	907.1847	kilograms

HOLOCENE DEPOSITIONAL HISTORY OF THE SOUTHERN NEW JERSEY BARRIER AND BACKBARRIER REGIONS

PART I: INTRODUCTION

Background

1. Barrier islands are the dominant geomorphic feature along much of the mid-Atlantic coast of the United States. Barrier islands provide a physical buffer between the ocean and the low-lying coastal zone. Mitigation of natural hazards, such as storms, is important since much of the population lives near the coast. Barrier islands and the associated backbarrier lagoons and marshes are also important breeding areas for marine and estuarine fish and birdlife.

2. Barrier island morphology changes in response to physical factors such as rising relative sea level, decreasing sediment supply, and locally intense storms. Recent barrier island research (Leatherman 1979, Heron et al. 1984, Oertel and Leatherman 1985) has indicated that various geologic regions of the Atlantic coast are quite different in their geomorphologic development. Consequently, it is necessary to study many regions to understand the short- and long-term evolution of coastal barrier systems.

3. The goals of this study are to expand the knowledge of the distribution of backbarrier sediments in southern New Jersey (Figure 1), determine the potential sources of sediment to the backbarrier region, and develop an evolutionary model for Holocene backbarrier sedimentation. To achieve these goals, surface and shallow subsurface sediments are described in terms of their sedimentologic and stratigraphic characteristics. In addition, historical and geological changes in sea level, backbarrier morphology, inlet location, and the areal extent of certain environments are analyzed and discussed.

4. Regional sea-level data have been extended by radiocarbon-14 (C14) age dating of organic-rich samples. These data have been collated with existing radiocarbon dates to reconstruct the relative sea-level history of southern New Jersey. From the sea-level data and the stratigraphic and sedimentologic evidence, a theory of Holocene evolution (during the last 10,000 years) is developed for the backbarrier region.

5. The southern New Jersey barrier islands are highly developed, and

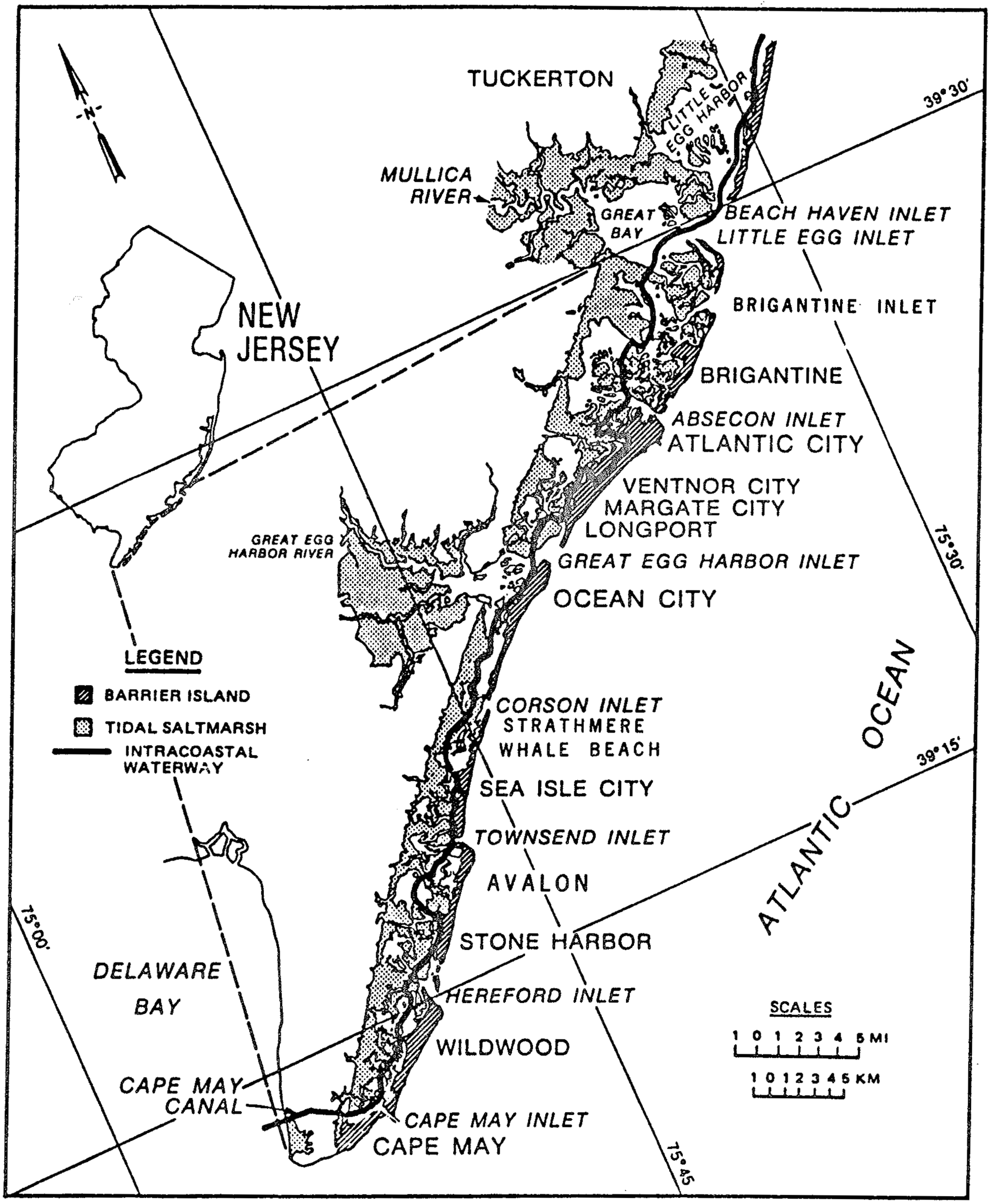

Figure 1. Location of the study area, Brigantine to Cape May, New Jersey

recent expansion has encroached upon the backbarrier marshes. A greater understanding of the subsurface deposits and Holocene depositional history is required before coastal resources can be adequately and responsibly managed.

This is especially important at a time when the coastal region is undergoing ever intensifying pressure from society.

Regional Setting

6. The study area is located in southern New Jersey, extending 75 km from Brigantine to Cape May (Figure 1). The coastline trends generally northeast-southwest, although the orientation of individual islands varies from this trend. The mean tidal range is 1.3 m at the ocean shoreline and 1.2 m in the lagoons and tidal channels landward of the barrier islands. Mean tidal ranges at different locations in the backbarrier study area vary depending on the distance from inlets, the geometry of the lagoon, and the position relative to the wind fetch. The limits of the study area are the barrier island foreshore to the east and the contact with the mainland to the west (Figure 2).

7. The entire New Jersey coast is composed of sandy beaches and can be separated into four geomorphological units (Haupt 1906, Johnson 1919, Fisher 1967). The study area is delineated entirely within Unit IV, the Barrier Island Chain, of Fisher's (1967) compartment model, to facilitate a systematic investigation of the surface and subsurface depositional environments.

8. Geomorphic features occurring in the study area include barrier islands, backbarrier marshes, tidal channels, intertidal flats, lagoons (Figure 2), and the tidal inlets that separate the barrier islands. There are seven barrier islands, the length and width of which range from 10 to 20 km and 1 to 5 km, respectively. By comparison, the width of the backbarrier region varies from 3 to 10 km with the widest region located at the northern limit of the study area. The lagoons are also largest in the north and decrease in size toward Cape May. The backbarrier is bounded to the west by a sharp linear contact with the upland, which is 2 to 3 m higher in elevation than the marsh surface. The upland is composed of Pleistocene sands and gravels (MacClintock and Richards 1936, MacClintock 1943) of both fluvial and marine origin.

9. The salt marshes are dissected by tidal channels of varying dimensions. Size depends on distance from the inlets, with the largest channels (in width and depth) occurring closest to the inlets. Approximately 10 to 15 percent of the backbarrier consists of shallow open lagoons with

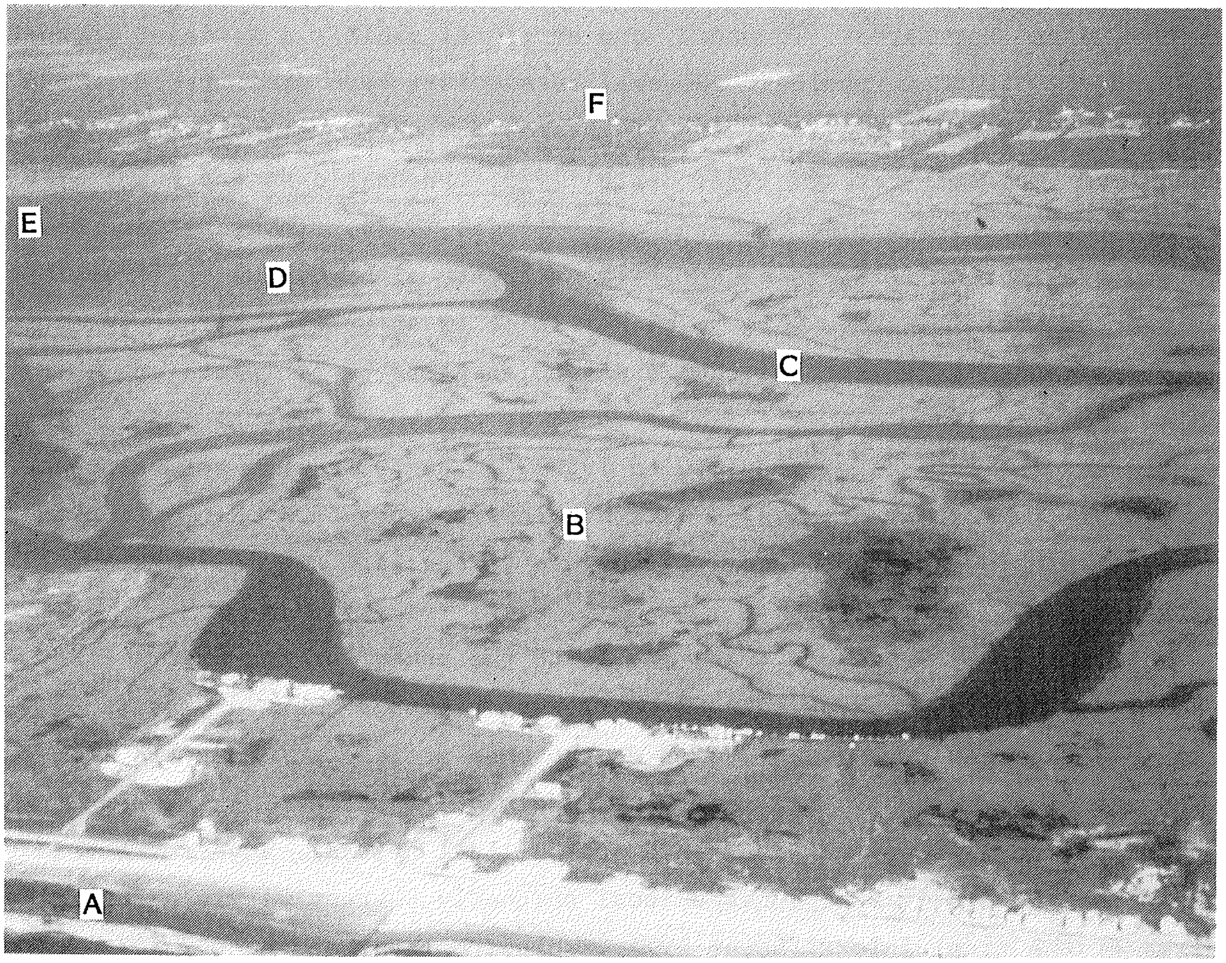

Figure 2. Geomorphic features within the study area: (a) barrier island foreshore, (b) salt marsh, (c) tidal channel, (d) intertidal flat, (e) lagoon, and (f) mainland (view is to the west northwest)

marsh islands. The average area of the lagoons is approximately 3 sq km, but the areas vary from <1 to 10 sq km. The marshes are largely undeveloped except along the causeways, which connect the barrier islands to the mainland, and along the landward side of the barrier island.

10. There are seven inlets, two of which are jettied (Absecon and Cape May Inlets, also called Cold Spring Harbor), three have groins within the inlet throat (Great Egg Harbor, Townsend, and Hereford), and two do not have engineering structures (Brigantine and Corson) (Figure 1). Several of these inlets are dredged regularly to provide adequate depths for commercial and recreational boat traffic. In addition, the Intercoastal Waterway is located

just landward of the barrier islands and is maintained by periodic dredging.

11. Five of the seven tidal inlets of the study area (Brigantine, Absecon, Great Egg Harbor, Townsend, and Hereford) exhibit a dominant southerly downdrift offset morphology. Several researchers have presented data and hypotheses to explain the formation of these offsets (Hayes, Goldsmith, and Hobbs 1970; Goldsmith et al. 1975; Oertel 1975; Lynche-Blosse and Kumar 1976; Boothroyd 1978; FitzGerald, Hubbard, and Nummedal 1978). The coastline north and south of Corson Inlet is essentially straight, although the inlet exhibits a slight downdrift offset, while Cape May Inlet is an updrift offset inlet. Shoreline change data indicate that areas adjacent to these inlets are most subject to geomorphic change (US Army Corps of Engineers (USACE) 1956). This fact is evident for the period 1840 to 1955. In contrast, the central reach of each of the barrier islands is more stable with long-term changes due to shoreface erosion and short-term changes due to specific storms or human activity.

12. The net longshore transport is to the south for the entire study area (McMaster 1954, Caldwell 1966, Charlesworth 1968). However, seasonal reversals do occur during the summer months when prevailing winds are from the south and cause northerly transport. In addition, there are variations in the regional southerly longshore currents at ebb-tidal deltas. Wave refraction around ebb-tidal deltas produces a local northerly current within a few kilometres of the tidal inlets (Hayes 1975; Ashley, Halsey, and Buteux 1986). The continental shelf and geostrophic currents are generally to the south (Bumpus 1973) along the entire northeast Atlantic coast.

13. The wind and wave climate along the southern New Jersey coast changes seasonally. Prevailing winds are from the south and west from April through September, at 22 to 45 km/hr, and from the west and northwest from October to March (Charlesworth 1968). In contrast, dominant winds blow from the northeast at an average speed of 32 km/hr. Northeast winds occur about twice as often as winds from any other direction when the wind speed exceeds 45 km/hr (USACE 1956). Average wave height and period are 0.8 m and 7.0 sec, respectively (USACE 1956), and waves approach the coast from the northeast through southeast octants with the largest waves approaching from the northeast (Charlesworth 1968).

14. Hurricanes are the most severe type of storm that affects New Jersey. The extent of damage depends on the path of the storm, the time of

passage relative to high tide, and the direction and force of the wind. Extratropical storms, often called "northeasters," are second in intensity only to hurricanes. The March 1962 extratropical storm produced 4-m waves that resulted in significant damage to the coastal zone (Charlesworth 1968). There has been an increase in the number of damaging storms from two or three per year in the 1920's to more than seven per year in the early 1960's (Mather, Adams, and Yashioka 1964). Hayden (1975) estimates that 35 to 40 winter storms each year are strong enough to erode beaches.

15. The ocean shoreline in New Jersey is eroding at a relatively constant rate of 1.5 m/year (Dolan et al. 1979) to 1.0 m/year (May, Dolan, and Hayden 1983). This is true except in the region adjacent to tidal inlets where the rates of erosion and accretion are much more variable over both the shorter (annual) and longer term (100 years). New Jersey's erosion rate is comparable with that of North Carolina (1.0 m/year) and is much less than the Virginia barrier islands (3 to 15 m/year) (Dolan et al. 1979; Rice, Niedarda, and Brett 1976). The local sediment supply, island orientation, and wave climate can cause locally higher erosion rates.

16. The Mullica and Great Egg Harbor Rivers provide the only significant inputs of freshwater from the mainland (Figure 1). The Mullica River-Great Bay system forms the northern boundary of the study, and the Great Egg Harbor River discharges near the center of the study area. Several small creeks discharge into the backbarrier and are located at irregular intervals along the mainland shoreline.

17. The Pleistocene-age Cape May Formation is the only coastal plain geological formation relevant to this research. Early field work by Salisbury (1896) culminated in describing and naming the Cape May Formation. Further detailed examination (Salisbury and Knapp 1917, MacClintock and Richards 1936, MacClintock 1943, Gill 1962) resulted in the subdivision of the formation into fluvial-deltaic, shallow marine and estuarine episodes of deposition. The fluvial-deltaic unit, the only unit that is exposed at the surface, is composed of poorly sorted sands and well-rounded gravels as large as 5 cm in diameter (MacClintock and Richards 1936, Gill 1962). East of the Cape May Peninsula, the marine unit is found at depth overlain by Holocene barrier and backbarrier sediments (Gill 1962). Marine fossil evidence supports the hypothesis that the Cape May Formation is Sangamon in age (125,000 years Before Present (B.P.)), and thus, the sea level has not been higher than its present

level (MacClintock 1943, Richards and Judson 1965) since the Sangamon Stage.

Pertinent Literature

18. The salt marshes, which comprise the greatest extent of the backbarrier region, were first investigated in the 19th century. Mudge (1862) and Shaler (1895) developed theories on the evolution of lagoons from open-water bodies to marsh-filled systems. Davis (1910, 1911) investigated the geological significance of salt-marsh formation and discussed evidence for recent subsidence. Since these early studies, the physical characteristics and development of salt marshes have been studied by Johnson (1919), Knight (1934), Chapman (1938, 1974), Bouma (1963), Bloom and Stuiver (1963), Bloom (1964), Redfield (1964, 1972), Kraft (1971), Pestrong (1972), Morton and Donaldson (1973), Cooper (1974), Harrison and Bloom (1977), and Frey and Basan (1978).

19. The New Jersey coast provided an example for several early models. Johnson (1919) discussed the development of shorelines by using the variations in backbarrier width and the number of tidal inlets to characterize the stages of backbarrier maturity. He also discussed the relationship between sedimentation trends in the lagoon and distance from the source headland and the importance of longshore transport to the evolution of barrier systems.

20. Johnson's (1919) observations provided a foundation upon which Lucke (1934b) further developed the theory of the evolution of lagoons and outlined the general morphology of the barrier island complex. With specific reference to New Jersey and New York, Lucke suggested that inlets are the principal avenue of sand transport into lagoons. Sedimentation subsequently occurred in the lagoons, and salt marshes developed as sediments accreted to intertidal levels. Lucke also discussed the importance of inlet processes and inlet migration to the evolution of lagoons.

21. Fischer (1961) discussed transgressive stratigraphy and used the central New Jersey coast as an example. Fischer (1961) built on Lucke's (1934a, b) conclusion that marine-derived sediment, which was transported through tidal inlets, was significant to the infilling of the lagoons. In addition, Fischer (1961) hypothesized that the transgressive stratigraphic record would represent a small proportion of the sediment previously deposited, depending on changes in tidal range and sea-level rise.

22. Fischer (1964) originally described his coastal compartment model using New Jersey and several other east coast regions as examples. This idea followed logically from earlier work by Johnson (1919). The model delineates five coastal compartments that are distributed between Massachusetts and North Carolina. Each is composed of four geomorphic units: (a) a northward accreting spit, (b) a headland, (c) a barrier spit with few inlets, and (d) numerous barrier islands separated by tidal inlets (Figure 3).

23. Much of the literature about coastal New Jersey has addressed sediment source and transport. Sediments of the mid-Atlantic continental shelf have been examined by Alexander (1934); Frank and Friedman (1973); Hollister (1973); McClennen (1973); Stahl, Koczan, and Swift (1974); Field et al. (1979); and Meisburger and Williams (1980, 1982). These studies show that surficial sediments consist of 90 to 95 percent moderately well-sorted medium-grained sand that has probably been reworked during the Holocene transgression. Clay and silt are found less frequently on the seafloor and outcrop as relict lagoonal deposits (Stahl, Koczan, and Swift 1974) or finer grained fluvial sediments. McClennan (1973) attributed the absence of silt and clay in the upper 20 cm to modern reworking of New Jersey shelf sediments.

24. The textures and sources of New Jersey beach sediments have been investigated in several comprehensive studies. MacCarthy (1931) examined the sediment texture of New Jersey and New York beaches and found a nodal zone at Manasquan Inlet. North and south of this zone the sediments became finer. Subsequent studies by Ashley, Halsey, and Buteux (1986) and Buteux (1982) have shown that the nodal zone varies seasonally and annually. MacCarthy (1931) also concluded that inlets and estuaries were effective barriers to longshore transport and that erosion of the shoreface supplied sediment to the beaches. Colony (1932) and McMaster (1954) studied the texture and composition of New Jersey beach sands and concluded that the continental shelf was the source of beach sand. Several researchers using a variety of analytical and sedimentological techniques (Sherif, Charlesworth, and Milband 1973; Cataldo 1980; Schroeder 1982) concurred with McMaster (1954) that the continental shelf is a source for beach sediment.

25. Biederman (1962) and Charlesworth (1968) compared sediments alongshore and perpendicular to the coast in a number of barrier and backbarrier environments. Biederman (1962) found that mean grain size decreased from north to south, which supported the theory of net transport to the south from

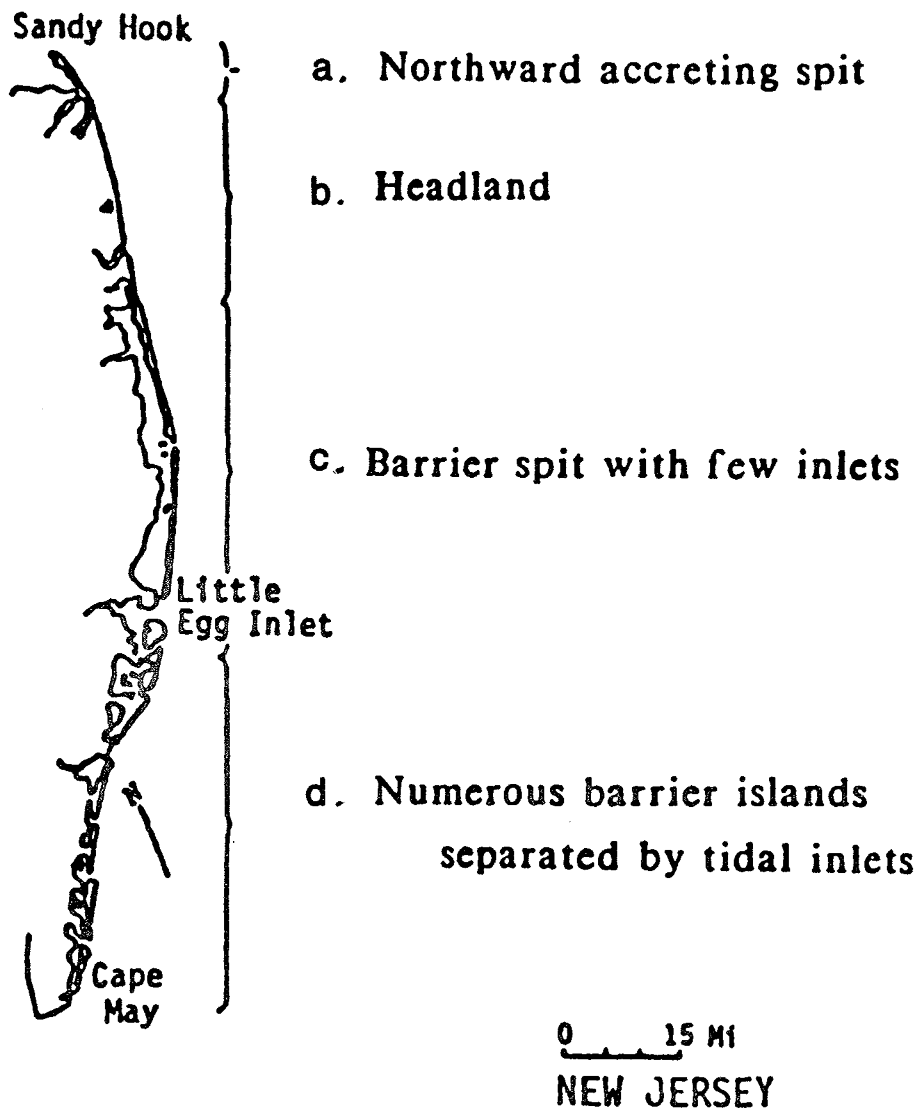

Figure 3. Coastal compartments of the New Jersey coast (after Fisher 1967 and Swift 1969)

a northerly source area (Johnson 1919, Lucke 1934b). Charlesworth (1968) noted a landward decrease in grain size of surface samples when moving away from an inlet. This suggests a net landward transport of sediment on flood-tidal deltas and their associated shoals.

26. Modern processes that are active on the mid-Atlantic continental shelf have been studied by Howe (1962); Bumpus and Lauzier (1965); Bumpus (1973); McClennen (1973); Stubblefield et al. (1975); Lavelle et al. (1978); and Butman, Noble, and Folger (1979). There is a southerly current active on the New Jersey shelf throughout the fall, winter, and spring when northeast

winds prevail (Bumpus and Lauzier 1965, McClennen 1973). Storms drive shelf waters landward and southward as they are constrained by the shoreline (Stubblefield et al. 1975). A reversal in this pattern of surface currents is most likely to occur during the summer months when the water column is highly stratified and southerly winds prevail (Bumpus 1973). As a result of dominant southerly shelf currents, bottom sediment transport is primarily alongshore and to the south.

27. The New Jersey continental shelf is mantled with a ridge and swale topography (Duan et al. 1972; McKinney, Stubblefield, and Swift 1974; Stahl, Koczan, and Swift 1974; Field and Duane 1976; Stubblefield and Swift 1976; and Stubblefield, Kersey, and McGrail 1983). These ridges are large accumulations of sand that are oriented obliquely to the coast. At least the upper portion of the ridges is reworked by currents. Active reworking of sediments of the inner shelf is important to the issue of beach and backbarrier sediment source and onshore transport.

28. Previous studies of southern New Jersey backbarriers lagoons and tidal channels have concentrated on suspended and bed-load surface sediments rather than the subsurface sediments (Kelley 1980, 1983; Kran 1975; Levy 1978). Kran (1975) found that changes in suspended sediment concentrations suggested net landward transport of sediment, derived from erosion along channels and the upper marsh surface. Levy (1978) concluded that sediment accumulation rates and mean particle size of sediment depended on the distance from large tidal channels. Kelley (1983) documented the transport of sediment from the northeastern region of Delaware Bay, around Cape May, and into the backbarrier of the southern Cape May Peninsula (Figure 1).

29. The distribution of subsurface sediments in selected environments has been examined through coring. Kelley (1975) collected short cores to study lagoon bottom sediments and found a decrease in grain size and organic content away from tidal channels and a sedimentation rate of 0.5 to 1.0 cm/year. Thorbjarnarson et al. (1985) also collected short cores in a lagoon and concluded that historical sedimentation rates were 0.1 to 0.5 cm/year. At this latter rate, it would take 100 to 400 years to completely infill the lagoon. Meyerson (1972) studied the pollen content of marsh sediment collected in cores taken in the marshes of western Cape May. The general stratigraphy was described, and the environmental responses to sea-level fluctuations were discussed. Zeff (in preparation) examined the salt-marsh stratigraphy

and the channel morphology in the Stone Harbor region (Figure 1) to determine the sedimentary facies of a tidal channel network in the salt marsh.

30. Stratigraphic studies have been carried out in the Brigantine-Tuckerton region (Figure 1). Daddario (1961) described a lagoon deposit along a shore-normal transect at Brigantine. He described four primary depositional environments and developed a model of the deposition of the area. Although Daddario's stratigraphic section was limited to a single transect, this was the first stratigraphic study of the southern New Jersey backbarrier complex. Force (1968) collected cores along two transects in the Tuckerton marshes. The results of the study are limited in areal extent, and this prevents extrapolation to the adjacent marshes to the south. Although these studies describe the stratigraphy of several specific areas, a comprehensive study is needed to document long-term changes in the southern New Jersey backbarrier region.

Field Data Collection and Analysis

Field methods

31. Aerial reconnaissance flights over the study area were taken to locate potential coring sites and to observe the spatial relationships of geomorphic features. Oblique photographs were taken of the entire study area during May 1981, June and August 1982, and June and August 1983. The aerial photographs documented ephemeral events, such as marsh peat exposed on the shoreface.

32. Cores taken during May and June of 1981 provide the primary data base for this study. A total of 68 cores were taken; of these, 24 are vibracores (V) and 44 are augercores (AC). An average of 4 cores were taken along each of the 15 shore-normal transects (Figure 4). The transects begin on the ocean beach (core 1), extend across the backbarrier marshes (cores 2 and 3) to the marsh-upland contact (core 4 or 5). Transects primarily follow along causeways to allow easy access with the coring equipment; however, caution was exercised so that undisturbed core sites were chosen.

33. The vibracore method was described by Finkelstein and Prins (1981) and yields a core of 8-cm diam of variable length. The backbarrier cores ranged from 3 to 7 m in length (average = 4.5 m), whereas the beach face cores ranged from 1 to 2 m in length. Cores collected on the beach were much

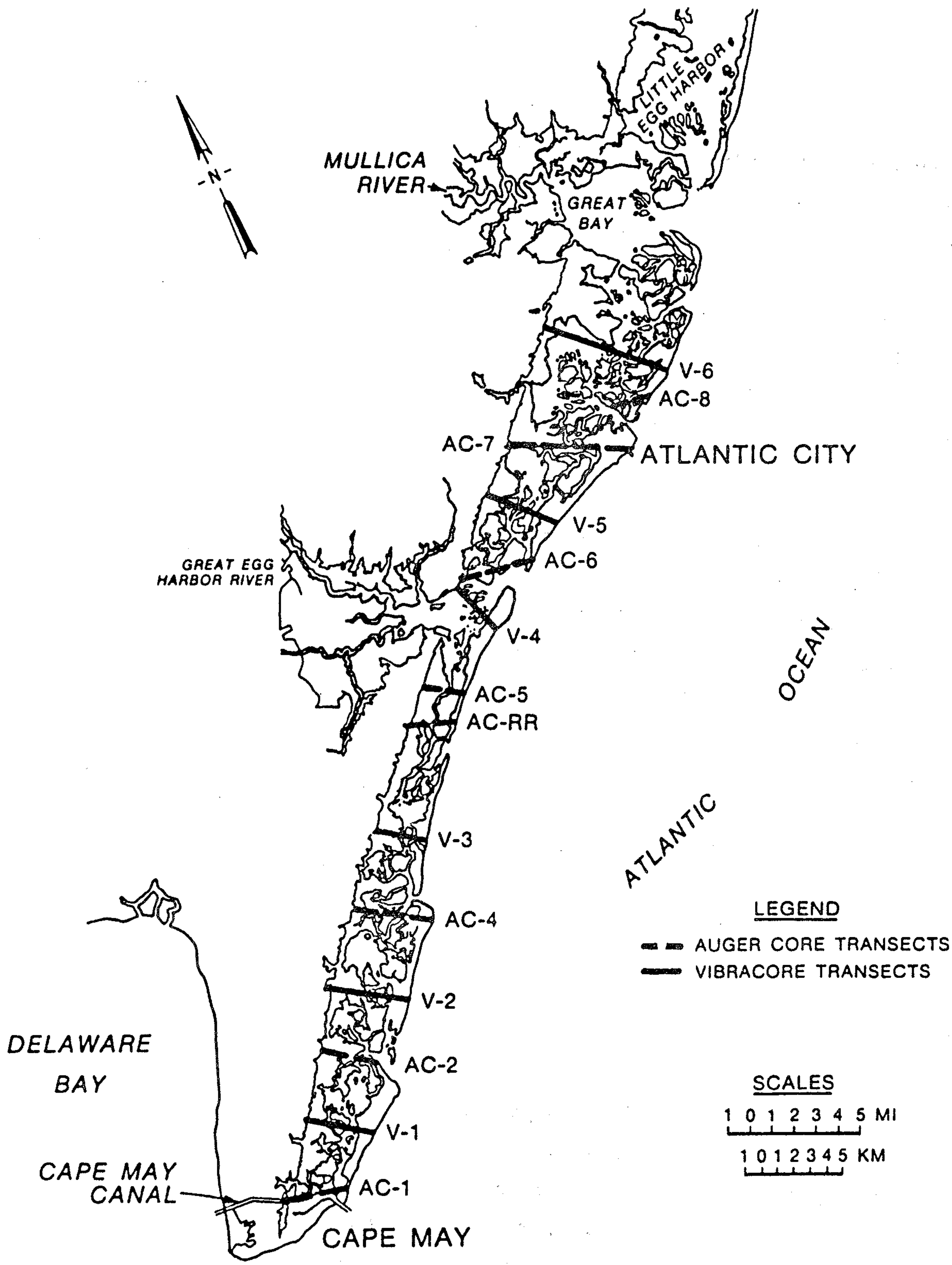

Figure 4. Locations of the vibracore and augercore transects

shorter because of penetration problems in sand. After collection, the cores were labeled and cut into approximately 3-m lengths and returned to the laboratory for analyses.

34. The hand-held Eijkelkamp gouge auger penetrates to a depth of 10 m and produces 1-m lengths of core. In this study, cores ranged from 1 to 3 m in length (average = 3.5 m). The 44 cores were described in the field and sampled at approximately 1-m intervals, except where changes in lithology necessitated more frequent sampling. The 1-m core sections were photographed before being sampled, if the lithology warranted. Samples were then returned to the laboratory and analyzed.

35. Eleven additional augercores were taken during the summer of 1984, adjacent to the mainland-marsh contact. Core locations were selected to delineate the extent of the hypothesized pre-Holocene sediments. These cores were logged in the field, and each lithologic unit was sampled.

36. Surface grab samples were taken in the lagoons and tidal channels with a PONAR 6-in.* sampler. The sampling was accomplished from a boat in 1- to 8-m water depths. Sample location was predetermined at 1- to 2-km intervals from nautical charts and amended as necessary in the field.

37. Box cores were taken in various modern environments such as tidal flats and marshes. All cores were opened, photographed, and sampled in the field.

38. Pre-Holocene sediments were examined along cut banks of the Cape May canal and exposed sand and gravel deposits on the mainland. Photographs and samples were taken to be compared with possible pre-Holocene sediments identified in the cores.

Laboratory methods

39. The vibracores were split and allowed to dry slightly to highlight differences in grain size. The cores were then logged, photographed, and sampled at each lithologic unit, or at an average of 0.5- to 1.0-m interval. The cores were logged at the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station, according to grain size, percentage of organic content by volume, identification of the amount and type of macrofauna, and the percentage of opaque minerals present. Ten organic-rich samples were selected for radiocarbon dating.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

40. Grain size analyses were performed on each core sample. Vibracore and auger samples were wet-sieved, and the fine fraction was pipetted (Folk 1974). The sand fraction was analyzed using a Rapid Sediment Analyzer.

41. All box core, pre-Holocene, and grab samples collected in 1984 were analyzed by hydrometer and sieve analyses, after wet-sieving (USACE 1970). Changes in the methods of analyses were necessary due to the availability of equipment. Representative fractions of vibracore samples were reanalyzed using the hydrometer and sieve analyses to calibrate the methods against one another. The results indicated an acceptable correlation between the two sets of methods for determining the percentage of sand, silt, and clay; thus, the results of both methods will be compared throughout this study.

42. Several samples were preliminarily examined for heavy mineral composition and concentration. No trends were immediately found. Resources did not permit analysis of each sample. Frank and Friedman (1973) examined New Jersey inner continental shelf sediments for heavy mineral proportions and found no regional trend. The entire study area fell within the hornblende zone described by McMaster (1954).

43. Radiocarbon dates of vibracore samples were provided by Beta Analytic Inc. of Coral Gables, FL. Of the 10 samples dated, 6 were taken in organic-rich muddy substrates of *Spartina alterniflora* marsh, one was a sandy peat, one was a wood fragment, one was shell fragments, and one was an oyster shell in growth position.

44. Historical maps and charts were used to document recent changes in the distribution of depositional environments. The US Coast and Geodetic Survey Topographic and Hydrographic sheets, National Oceanographic and Atmospheric Administration (NOAA) Nautical Charts, and US Geological Survey Topographic Sheets provide the data base.

45. Shoreline change maps produced by the USACE (1956) were examined to determine the lateral extent of inlet migration for the period 1840 to 1955. In addition, historical changes in inlet location were also documented.

PART II: BACKBARRIER STRATIGRAPHY

46. Analyses and descriptions of surface and subsurface sediments permitted the identification of the following 10 facies or depositional environments: beach, tidal marsh, tidal channel, mud flat, mixed flat, modern lagoon, sand facies, pond, fluvial delta, and one pre-Holocene unit. Several of these are not seen at the present surface in the backbarrier region. Information about specific vibracores may be found in Appendix A.

Surface and Subsurface Facies Descriptions

47. The composition of backbarrier sediment varies between fine-grained mud to coarse-grained sand and pebbles, with fine sand representing the dominant grain size (Table 1). Higher proportions of mud (silt and clay) are found in the upper 2 to 3 m of the subsurface. Higher proportions of shells and shell fragments are also found in specific environments, such as tidal flats. In addition, the proportion of organics by volume also increases in specific environments, such as the tidal marshes.

48. The beaches in the study area are composed of predominantly fine, well-sorted sand. Sediments are generally thin-bedded and planar with recurring heavy mineral laminations. Scattered small shell fragments and organic matter are also common. Disarticulated bivalves (*Ensis directus*, *Anaderra odulus*) or large fragments of shell are less common.

49. Mean grain size for all sediment samples decreases very slightly to the south, from Brigantine to Cape May. A trend of decreasing grain size with depth is evident in all beach cores. In two instances, the cores were taken on beaches that had been artificially nourished in the past (cores 4-1 and 3-1). In both of these cores, there is a contact between fine-medium sand near the surface and fine sand at depth. The fine sand near the bottom of the cores resembles the beach samples from other cores taken during this study.

50. Beach deposits are at least 1.5 to 2.0 m thick though shallow penetration of these cores prevented determination of the total thickness of sand, which is probably much greater. Whale Beach, north of transect V-3 (Figure 4) and opposite Ludlam Bay, is one of the few locations where lagoonal deposits crop out on the beach face, exposing fine-grained organic-rich sediments. At this location, the barrier is relatively narrow and is occasionally

Table 1

Sedimentary Facies and Their Dominant Characteristics as Determined from Vibracore Data

Facies Name	Average Grain Size % Sand:Silt:Clay	Bioturbation	Sedimentary Structure
Beach	100:0:0	None	Parallel bedding
Tidal marsh	20:44:36	Thorough	Massive deposit
Tidal channel	undetermined		
Mud flat	30:42:28	Moderate	Sand-filled burrows and lenses
Mixed flat	80:11:9	Moderate	Sand/mud laminate
Modern lagoon	81:12:7	Thorough	Essentially massive
Sand facies	96:3:1	Rare	Mud lenses
Pond	88:3:10	None	Parallel bedding
Fluvial delta	88:8:4	None	Fining upward sequences
Pre-Holocene	96:4:trace	None	Massive

overwashed during large storms. This is contrary to most beaches in the study area, which are rarely, if ever, overwashed. Beach width varies throughout the study area between 25 and 400 m depending on proximity to tidal inlets, season, and the effects of structural development.

Tidal marsh

51. Salt marshes represent the most areally extensive environment presently seen in the backbarrier complex (Figures 5-10). *Spartina alterniflora* dominates the low marsh, which represents 95 percent of the total marsh area. *Spartina patens* inhabits the high marsh, which is adjacent to the upland and the causeways. Subsurface marsh deposits are recognized by the dark grey muddy substrate and visible roots, stems, and leaves. Intense bioturbation destroys primary bedding and results in a massive, relatively structureless deposit. Macrofauna likely to be present include *Littorina irrorata*, *Mytilus edulis*, and *Ilyaanassa obsoleta*. The sand:silt:clay ratio is 20:44:36

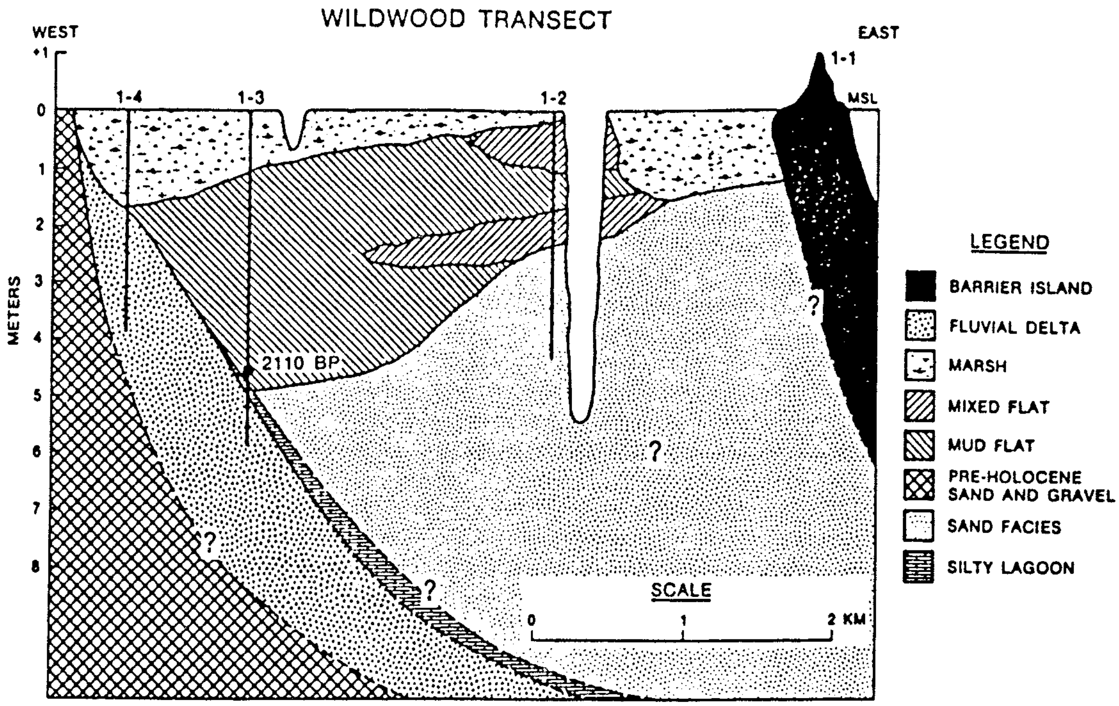

Figure 5. Wildwood cross section V-1

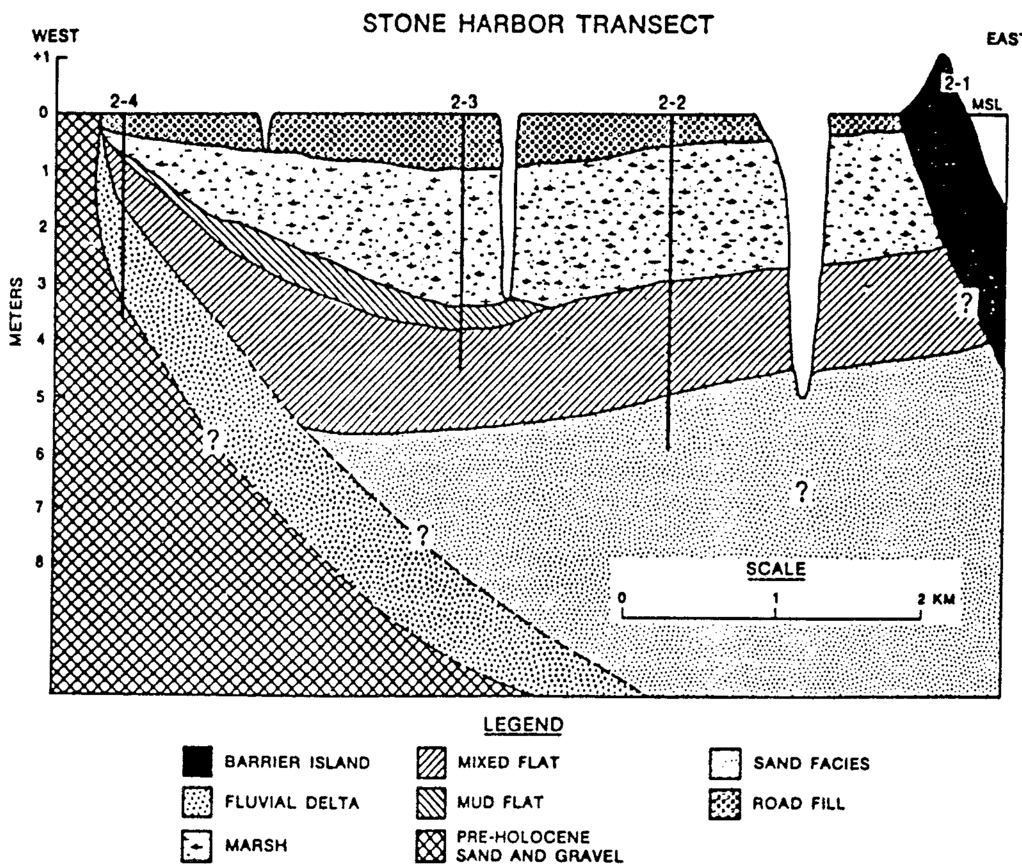

Figure 6. Stone Harbor cross section V-2

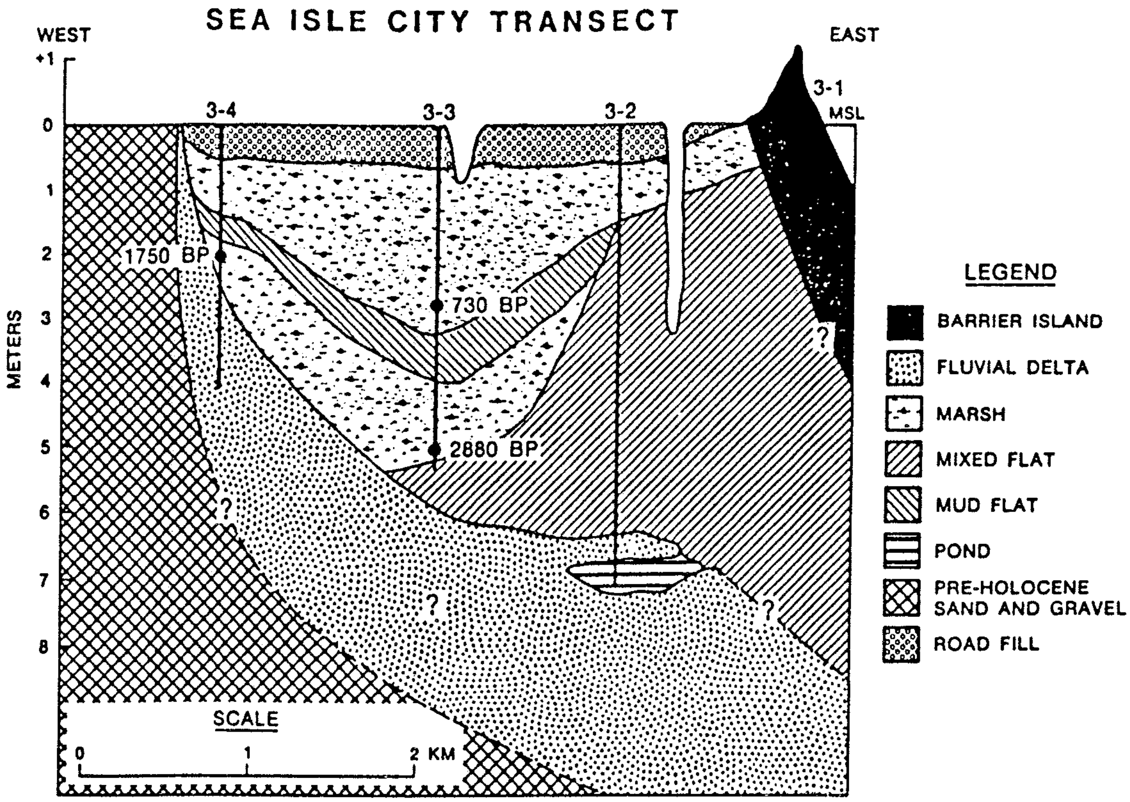

Figure 7. Sea Isle City cross section V-3

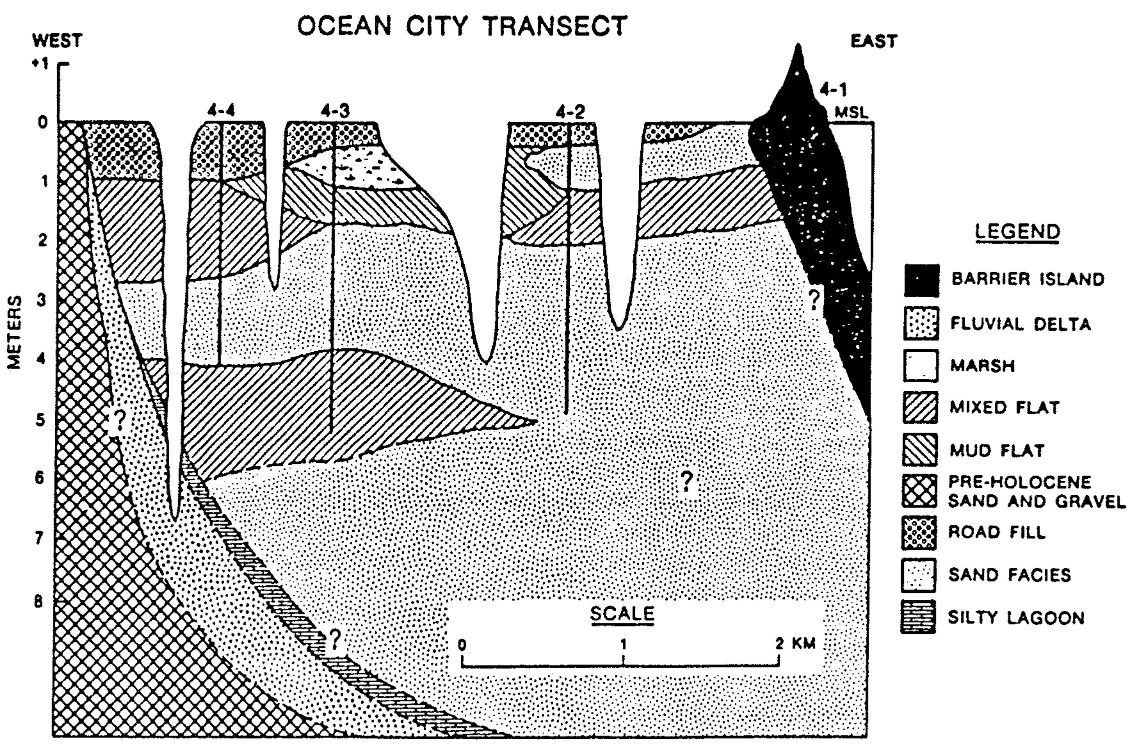

Figure 8. Ocean City cross section V-4

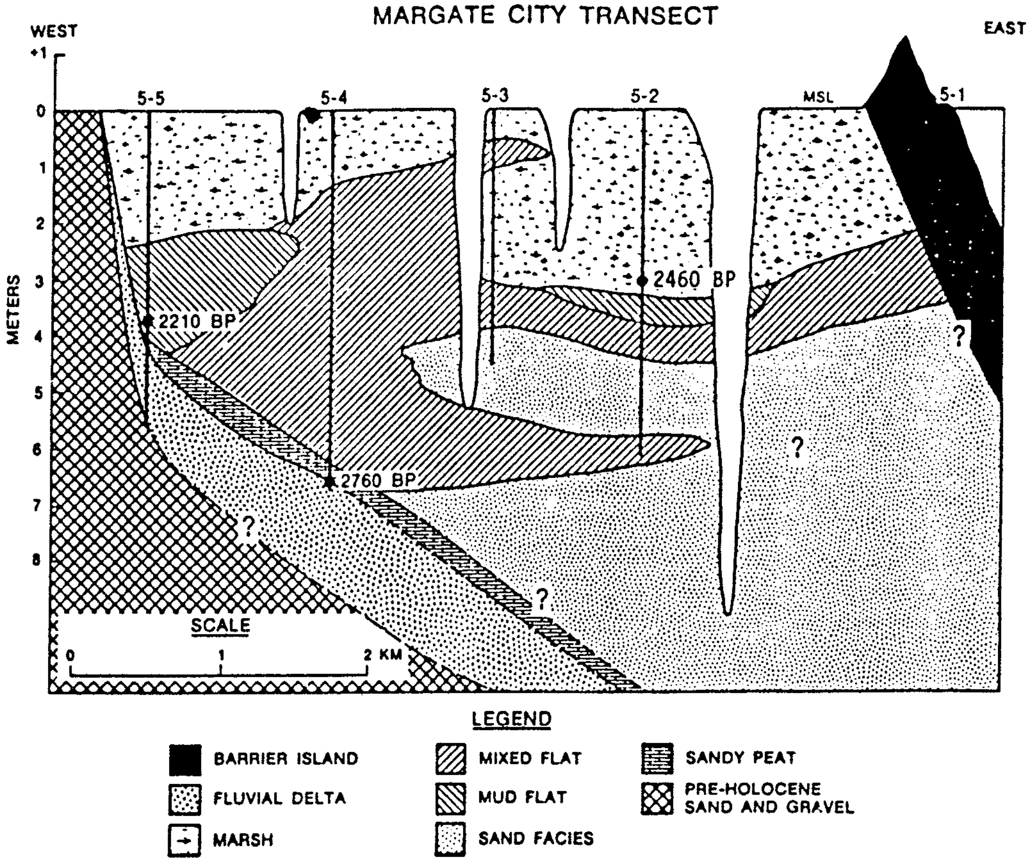

Figure 9. Margate City cross section V-5

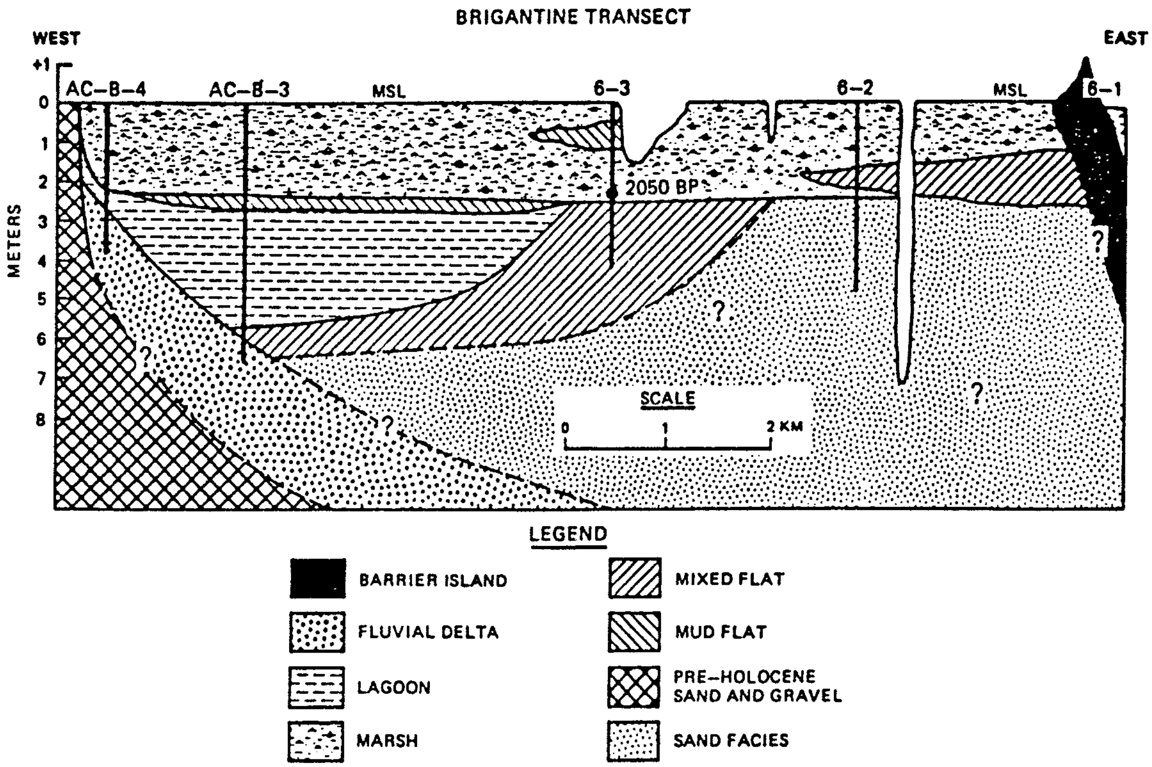

Figure 10. Brigantine cross section V-6

percent. The sand is predominantly fine and moderately well sorted.

52. Coarser mean grain size of the sand fraction in the marsh substrate occurred at several locations. Marshes frequently developed on coarse sand and gravel fill that was artificially emplaced during the construction of causeways. In addition, marshes located in the landward part of the transect developed on coarse fluvial-deltaic sediment (described in the following paragraphs). In each case, the contact marsh contains coarser sediment, whereas subsequent marsh deposition is composed of fine-grained sediment. The development of salt marsh seems to depend on the intertidal position and the relatively protected position, not on grain size of the initial substrate.

53. Organic content was variable in the marsh deposits but generally decreased down the core. The deepest marsh deposits were found in the central to landward cores of the backbarrier.

Tidal channel

54. Tidal channels of varying dimension are a prominent feature in the marshes. Size, expressed as both width and depth, generally decreases away from the tidal inlets. Vibracore locations were chosen on the cut bank of tidal channels to avoid coring through a disrupted stratigraphic sequence. This minimized the chance of encountering tidal-channel facies at depth. In any case, tidal-channel deposits were not identifiable in the vibracores based on characteristics such as pebble and/or shell lags and coarser grained sediments, noted by other researchers (Reineck and Singh 1980).

55. Grab samples taken in tidal channels varied greatly in grain-size distributions, depending on current velocity within the channel and distance from an inlet. Thus, a representative sediment sample from a tidal channel could not be identified.

Mud flat

56. Mud flats are intertidal deposits found within and around the periphery of a lagoon and generally low-energy environments. This proximity to lagoons can create uncertainty in delineating sediments from these two environments in the subsurface data. Mud flats were recognized by their generally fine-grain size with sand:silt:clay ratios of 30:42:28 percent. The sand fraction is almost entirely (99 percent) fine sand. Other significant characteristics are the presence of sand lenses and organic fragments and intense bioturbation that destroys most of the primary bedding. These characteristics were earlier identified and described by Klein (1977) and

Reinleck and Singh (1980). Macrofauna are usually present and include *Crassostrea virginica*, *Mercenaria mercenaria*, and *Ilyanassa obsoleta*. Sand-filled burrows are also common, although high degrees of bioturbation can prohibit detection of any specific primary structures.

Mixed flat

57. Mixed flats are intertidal to shallow subtidal deposits composed of silt and fine sand. These mixed flats occur in regions exposed to intermediate tidal current and wave energy and are characterized by finely laminated sand and mud (Klein 1977, Reineck and Singh 1980). In the cores, bedding was moderately disturbed by bioturbation, yet individual sand and mud laminae were usually evident. The higher energy of this environment, as compared with mud flats, deters some bioturbators. Presently, there is a paucity of mixed tidal flats in the study area, most likely due to the relatively low-energy conditions that persist.

Modern lagoon

58. Sediments from existing lagoons are characteristically composed of finely laminated mud (Reineck and Singh 1980). However, a lagoonal facies was difficult to identify in the vibracores. This is most likely due to the high degree of bioturbation that removes almost all evidence of primary bedding, resulting in a massive deposit. Consequently, lagoonal deposits and sediments deposited on mud flats resemble one another. Macrofauna commonly found in lagoons are *E. directus*, *M. mercenaria*, and *Spisula solidissima*. Some of these macrofauna also inhabit the mud flat.

59. Grab samples taken in modern lagoons indicated at least two different grain-size distributions, depending on spatial proximity to a tidal inlet. Distal lagoons located far from an inlet, or having areas of relatively deep water, contained significant proportions of silt and clay (43 and 30 percent, respectively) and only 2-percent sand. Lagoons proximal to inlets contained much higher percentages of sand (81 percent), which was predominantly fine sand with small percentages of medium and coarse fractions.

Sand facies

60. A sand facies was repeatedly recognized at the base of many of the seaward vibracores at depths ranging from 2 to 6 m and thicknesses of 0.5 to 3.0 m. The clean sand was predominantly fine with less than 5-percent medium and coarse sand present. Mud comprised less than 5 percent of the total sample, and the percentage of mud decreased with depth in almost all cases.

The mud tended to occur as lenses resembling the extreme of flaser bedding (Reineck and Singh 1980). No other sedimentary structures were identified. Generally, the sand was not bioturbated, except within thin mud lenses that represent lower energy conditions. Macrofaunae were rare within this unit, but when present included *E. directus*, *C. virginica*, and *Modioilus demissus*.

61. The physical characteristics and areal extent of the sand facies suggest several different depositional environments. It may represent a tidal flat where sand was deposited by relatively swift tidal currents that prevented deposition of clay and silt (Van Straaten 1961, Klein 1977). Similarly, deposition could have occurred in shallow and frequently wave-agitated water under low intertidal or subtidal conditions and would be called a high-energy lagoon environment (Lucke 1935, Fischer 1961, Ruby 1981, Finkelstein and Ferland 1987). Lastly, the sand facies may represent flood tidal-delta deposits, given the geomorphic, stratigraphic, and spatial relationship to the barrier island. Each of these depositional environmental interpretations is appropriate for some, but not all, of the sand facies occurrences. The sand facies is therefore interpreted to represent an amalgamation of sand flat, high-energy lagoon, and relict flood tidal-delta deposits.

Pond

62. A distinctive sequence of evenly laminated, undisturbed sediment occurs at the base of core 3-2 (Figure 7 and Appendix A). The sediment is predominantly fine sand with small percentages of mud and organic material occurring as distinct brown laminae. Extreme color changes are evident throughout the unit. There is not evidence of bioturbation, and no macrofauna were found.

63. The limited extent and depth (6.8 m) in conjunction with the well-laminated sediment suggests a quiet water depositional environment, resembling a pond. This facies was distinguished from the lagoon facies by the generally sandy texture and lack of bioturbation. Low regions in the pre-Holocene topography, which were subsequently flooded during the transgression, could support a pondlike environment. Given the limited occurrence of this feature, it is not known whether this represents late-Pleistocene or early Holocene deposition.

Fluvial delta

64. Coarse sand and gravel were found at depths of 1.5 to 6.0 m in the landward cores of four of the six vibracore transects (Figures 4-7 and 9) and

at similar depths in the augercores taken adjacent to the upland. The coarse sediments occurred at the base of core 2-3 fining-upward beds (thickness of up to 0.5 m) and are interpreted as deltaic deposits that were washed from the upland. Sediment samples are moderate to poorly sorted and contain 11.7 percent of sediment greater than 2 mm. The granule-to-pebble fraction is well rounded, predominantly quartz, and often iron-stained. The degree of iron staining decreases upsection, in conjunction with the fining-upward beds.

65. Sedimentologic characteristics, such as the poorly sorted and coarse texture, 12-percent pebble-to-granule fractions, and a range of 0- to 37-percent silt and clay in various samples, were used to distinguish and interpret this environment, as no modern analog exists in the backbarrier system. In addition, the location of these sediments immediately adjacent to the mainland (Figure 5), which is dissected by many small creeks, provides additional support for fluvial deposition.

Pre-Holocene sediments

66. The surficial sediments of the Cape May Peninsula and most of the southern New Jersey mainland shoreline are composed of unconsolidated sediments of the Cape May Formation. The sediments are relatively clean, poorly sorted sand and gravel that are oxidized and orange in color.

67. In the vibracores, the pre-Holocene to Holocene contact was identified by a sharp contact between partially oxidized coarse sand and gravel and thoroughly oxidized loose sand and gravel. The sediments above the contact are slightly muddy and contain trace amounts of organic matter, while pre-Holocene sediments are dry, organic-free and also contain no macrofauna. Textural comparisons between samples in the vibracores and the surficial peninsula sediments of the Cape May Formation outcropping on the mainland showed that both contained coarse sand and gravel that was moderately well rounded and poorly sorted. In addition to similar grain-size distribution, all of the samples were moderately to thoroughly oxidized and yellow-orange in color.

Backbarrier Stratigraphic Transects

68. Vibracore and augercore data were compiled to produce six shore-normal cross sections (Figures 5-10). Augercore data were especially utilized to clarify the interpretation of depositional environments along the marsh-upland boundary. In addition, engineering test boring results (Craig Testing

Laboratories 1979; New Jersey Department of Transportation 1967, 1972; New Jersey Highway Authority 1953, 1970) provided information about the subsurface to depths of approximately 10 to 15 m below mean sea level.

Wildwood

69. The Wildwood transect is approximately 5 km wide, and vibracore data extend to a depth of 6 m (Figure 5). The base of the Holocene sequence, beneath the barrier island, is a grey silt unit at a depth of approximately 10 m (Craig Testing Laboratory 1979, New Jersey Highway Authority 1953). Overlying the silt, which is probably an early transgressive lagoonal sequence, is a thick sequence of homogeneous fine sand. The sand facies thins to the west, where it abuts the Pleistocene upland. The seaward portion of the cross section contains marsh and mixed flat sediments, while mud flat and possibly lagoonal deposition dominate the 2- to 5-m depths to the west. Fluvial-deltaic deposits are encountered adjacent to the upland at increasing depths as one moves to the east. The entire transect is capped with a well-developed marsh and tidal channel system.

Stone Harbor

70. The Stone Harbor transect is approximately 6 km wide with vibracore data to a depth of 6 m (Figure 6). A basal sand facies was encountered in the seaward to central part of the backbarrier. This high-energy sandy unit is overlain by mixed tidal flats that extend across the entire transect. At the upland-marsh contact, coarse fluvial-deltaic sediments are evident at depths of 1.5 to 2.0 m. The landward core (core 2-4) contains pre-Holocene sediments at the base and shows evidence of the pre-Holocene to Holocene unconformity. Tidal salt marshes, 2 to 3 m thick, are found at and near the surface. The road-fill unit represents coarser sands and gravels brought in as fill before construction of the causeways and bridges.

Sea Isle City

71. The Sea Isle City transect is 4 km wide and 7.2 m deep by maximum vibracore penetration (Figure 7). Fluvial-deltaic deposits are important in this transect, as they were encountered at depth almost 3 km from the mainland (core 3-2, Appendix A). The base of the same core contained the only example of the pond facies, thought to be a low-energy early Holocene deposit. The occurrence of the sand facies is inferred from data in other transects. Overlying the fluvial-deltaic sediments, in the seaward part of the transect, is a thick sequence of mixed flat deposits. In contrast, a lower energy salt

marsh-mud flat sequence is seen to the west. Salt marsh and a surficial road-fill unit cap the entire cross section.

Ocean City

72. The Ocean City transect is approximately 5 km wide with vibracore data to a depth of 5 m (Figure 8). The transect crosses Great Egg Harbor Bay and is adjacent to Great Egg Harbor Inlet. Both of these geomorphic features have been important to the development of the region.

73. The cross section is dominated by the sand facies that was most likely deposited during high-energy lagoon conditions. Test boring data indicated light grey, fine sand to a depth of 13 m, interpreted to be deposited in a paleo-Great Egg Harbor Bay. A basal unit of silty lagoon sediment is identified at approximately 13 m (New Jersey Department of Transportation 1972). This unit separates the high-energy lagoon sand facies from underlying fluvial-deltaic deposits. A mixed tidal flat developed on top of fluvial-deltaic deposits in the landward portion of the transect. A varied assemblage of mixed flat, mud flat, and salt marsh environments are seen in the upper 2 m on the cross section. This variation represents changes in depositional environment associated with migration of great Egg Harbor Inlet. As the inlet migrated, flood-tidal deltas were deposited and provided substrate for intertidal flats and marshes. Road fill, associated with the causeway, and salt marsh are found at the surface today.

Margate City

74. The transect at Margate City is 6 km wide with vibracore data to a 6.7-m depth (Figure 9). Test boring data (New Jersey Department of Transportation 1967, 1972) were used to delineate the sand facies at 7 to 10 m. In addition, a peat layer was encountered at 12 to 14 m throughout the area. This peat is a lithologic equivalent of the sandy peat that overlies fluvial-deltaic deposits in the landward part of the transect. Coarse-grained sediments are found at increasing depths with increasing distance from the upland. The sand facies and mixed flat environments occupy intermediate depths in the cross section. These grade laterally and vertically into mud flat and salt-marsh deposits. Salt marshes and tidal channels dominate the present environment.

Brigantine

75. The Brigantine transect is 10 km wide, which is the widest back-barrier region with the study area (Figure 10). Vibracores were taken in the

seaward half of the transect, and augercores were taken near the upland-marsh contact. Subsurface test boring data (New Jersey Department of Transportation 1967) indicate a thick, fine sand to depths of 12 to 13 m. This sand facies was also encountered in the vibracores (core 6-2, Appendix A). Mixed flat and quiet lagoon sediments occur as time-equivalent facies in the landward portion of the transect. A thin deposit of a mixed flat environment was noted directly west of the barrier island. Proximity to a historical inlet location suggests that these sediments might represent the distal portion of a flood-tidal delta. Salt-marsh and mud flat environments form the upper 2 m of the cross section and are seen at the surface today.

PART III: BACKBARRIER SEDIMENTATION

Fluvial Input

76. Fine-grained sediments dominate the deposition presently occurring in the backbarrier region. A possible source for these sediments is the Cape May Peninsula, which is drained by several river systems and is immediately adjacent to the backbarrier region.

77. US Geological Survey (USGS) Water Resources Data (1979, 1983) were examined to determine average discharge for major rivers and streams in the study area (Figure 11). Data from each of the four rivers are contained in Table 2.

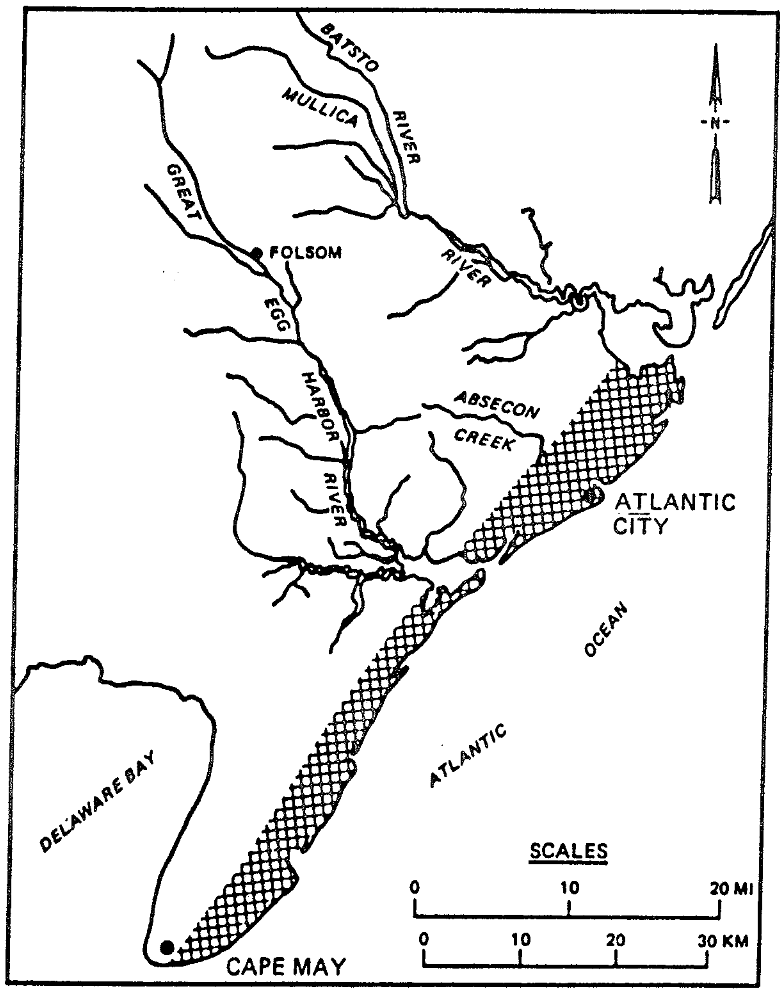

Figure 11. Locations of the major rivers in the study area

Table 2

Discharge and Suspended Sediment Data for the Major Rivers of Study Area (USGS 1979, 1983)

River	Average Discharge m^3/sec	Length of Record years	Max/Min Discharge m^3/sec	Suspended Sediment tons/year	Volume $m^3/year$
Batsto River	3.5	56	36.7/2	802	615
Mullica River	3.1	26	51.5/0.2	706	541
Absecon Creek	0.8	46	8.3/0.0	170	130
Great Egg Harbor River	3.2	58	40.3/0.4	738	566

78. Discharge data and suspended sediment concentrations for the Great Egg Harbor River were available for 1979. This quantity and the volumetric equivalent, calculated on the basis of 1.2 tons = 0.92 cu m (Schubel and Carter 1976), are tabulated to illustrate the quantity of sediment contributed annually to the backbarrier region by way of rivers (Table 2). Suspended sediment data were not readily available for most of the rivers. Consequently, average annual suspended sediment concentrations have been extrapolated from the Great Egg Harbor River data and used in conjunction with average discharge data to determine the volume of sediment discharged by each river.

79. The total volume of sediment discharged by these rivers is quite low when measured with respect to the areal extent of the study area. Assuming a length of 75 km and a width of 5 km, the study area is approximately 375 sq km. An even distribution of the approximately 1,850 cu m/year sediment contributed by rivers would yield an annual blanket of sediment 0.004 mm thick over the entire study area. This is a relatively insignificant quantity of sediment compared with other east coast estuaries, such as Chesapeake Bay with a nonuniform, bay-wide sedimentation rate of 0.8 mm/year (Schubel and Carter 1976).

Backbarrier infilling

80. To document progressive infilling of the backbarrier region, changes in the depths of undredged channels and lagoons were calculated (Table 3). In addition, grab samples were taken in both lagoons and tidal

channels to show systematic changes in grain size relative to distance from tidal inlets.

Table 3

Changes in Depth of Undredged Channels and Lagoons Between 1907 and 1983

Location	Depth in metres 1907	1983
Jarvis Sound	1.8	0.6
Ludlam Bay	1.1	0.6
Main Channel, south of Corson Inlet	4.1	2.6
Corson Sound	1.8	0.3
Golden Thorofare, west of Brigantine	3.7	2.0
Wading Thorofare, West of Brigantine	1.1	0.5

Note: In many cases, soundings have not been field checked since at least the 1949 edition of Chart 1219 (renumbered Chart 12316).
* Kummel 1909, NOAA Chart 12316, December 1983.

81. In 1907, bathymetric data were collected along the proposed route of the Inland Waterway, which is now the Intracoastal Waterway (Kummel 1908) (Figure 1). These soundings were compared with those that appear on a recent NOAA chart for the area (NOAA 1983), which were also taken at mean low water. It is important to note that 1983 depths in many of the lagoons did not differ markedly from a 1949 NOAA survey. This is due to the fact that depth of dredged channels and frequently navigated waters were updated, whereas depths of open lagoons were not field checked.

82. Calculations show that there is an average change in depth of approximately +1.2 m for undredged lagoons and channels between 1907 and 1983. Given the period of record of 76 years (using the 1983 date), the average sedimentation rate is 16 mm/year. If the 1949 survey is used, the period of record is 42 years, and the average sedimentation rate is 29 mm/year. Both of these calculated rates are excessive for regional extrapolation because channels and lagoons have locally higher sedimentation rates when compared with other backbarrier environments such as salt marshes. Conversely, these estimates may be conservative as they do not include the 30 cm of historical sea-level rise that has been documented for the region (Hicks, Debaugh, and Hickman 1983). Therefore, these data should be considered only as general

evidence of infilling through historical time, rather than as specific sedimentation rates.

83. A series of grab samples were taken in the lagoons and major tidal channels associated with several inlets in the study area (Figure 12). Analyses document a systematic decrease in grain size away from the inlets, through the channels and into the lagoons (Table 4). In a majority of cases, the proportion of sand in a sample decreases with increasing distance from the inlet and/or decreasing size of the channel. That is, some samples taken in relatively small channels proximal to the inlet resemble samples from the lagoons or more distal channels, in terms of their grain size characteristics.

84. Generally, the percentage of sand:silt:clay ratio changed systematically, whereas the percentage of coarse:medium:fine ratio of the sand fraction showed mixed results (Table 4). This was due to the moderate to high percentage of small shells and organics that occurred in the coarse fraction, as determined by visual examination. Shells were interpreted as in situ deposits, rather than sediments transported by tidal currents, due to their articulated and nonabraided conditions. Approximately 94 percent of the sand analyzed in these environments was very fine to fine grained. It should be noted that no samples were collected from the mouths of inlets.

85. Grab samples taken in the Great Egg Harbor River and Bay become progressively finer upstream (Table 4) (Figure 12). This trend resembles that shown for samples taken at increased distances from the tidal inlets. This indicates that hydraulic sorting is dominated by tidal, rather than fluvial, processes at the mouth of the river.

Historical Inlets

86. There are seven tidal inlets in the study area today, although historical data show the presence of several additional inlets (Figure 13). Examination of shoreline change maps for the period 1840 to 1955 (USACE 1956) provides evidence for the number of inlets and the amount of lateral migration of inlets. Lateral migration is bidirectional for many southern New Jersey inlets, defining a length of shoreline over which the inlet has existed historically. Quantitative data for the historical and active inlets are summarized in Table 5.

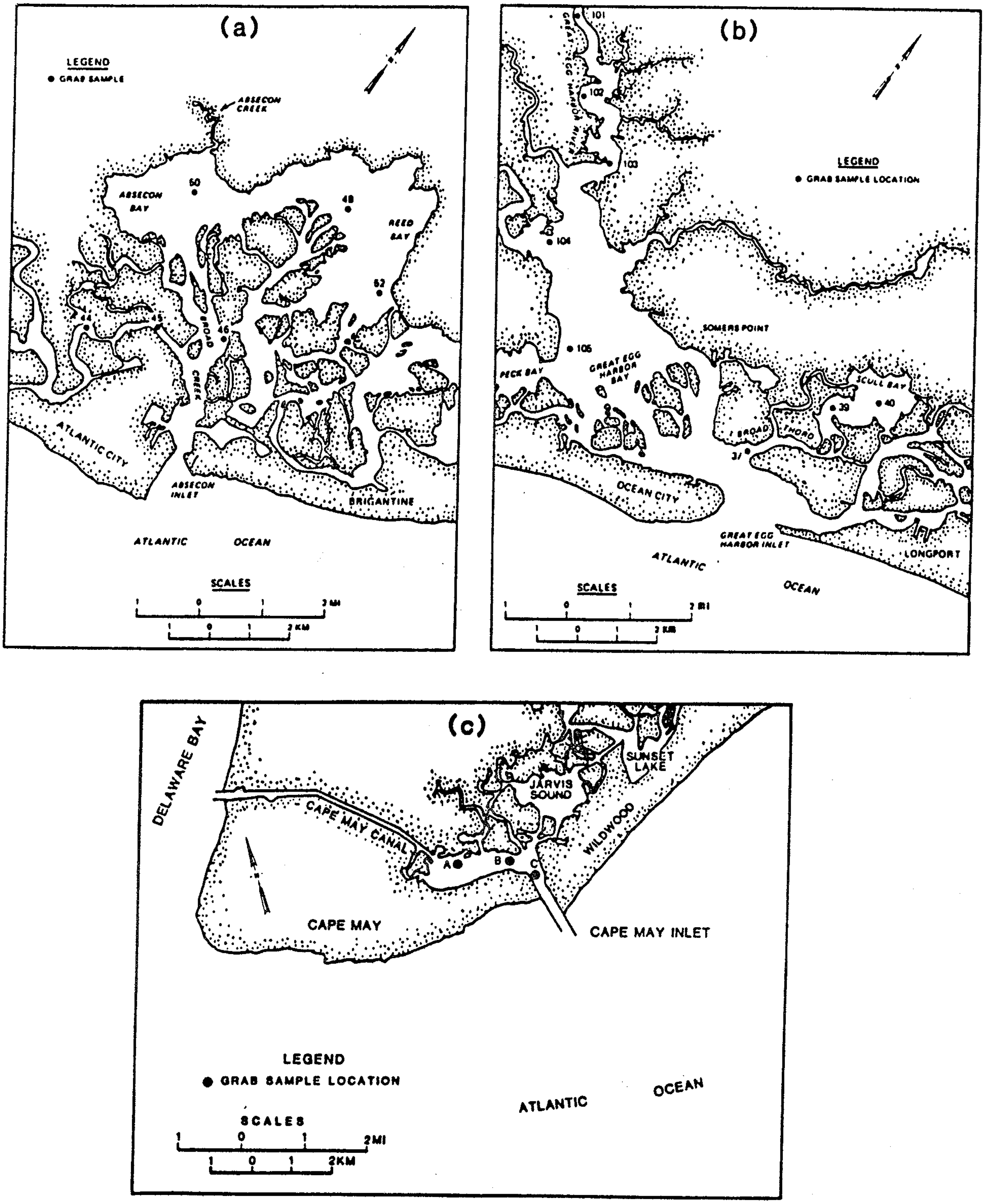

Figure 12. Locations of surface grab samples taken in the vicinity of (a) Absecon Inlet; (B) Great Egg Harbor, River and Bay; and (c) Cape May Inlet

Table 4

Results of Grain Size Analyses from Grab Samples Taken in Lagoons and Tidal Channels and the Great Egg Harbor River

Sample No.	% Sand:Silt:Clay	% Coarse:Medium:Fine
	Absecon Inlet and Vicinity (Figure 12a)	
44	32:29:39	0:0:100
45	68:16:16	5*:2:93
46	93:3:4	T**:T**:100
48	96:2:3	0:0:100
50	79:13:8	1:1:98
52	77:13:9	1:1:98
	Great Egg Harbor Inlet and Vicinity (Figure 12b)	
37	100:0:0	5:13:82
39	55:25:19	4:3:92
40	15:57:28	0:0:100
	Great Egg Harbor River and Bay (Figure 12b)	
105	92:4:4	3:35:61
104	73:20:8	T**:2:98
103	50:26:24	2:2:95
102	26:40:35	3:4:92
101	51:28:21	1:2:97
	Cape May Inlet and Vicinity (Figure 12c)	
C	100:0:0	1:1:98
B	81:12:7	1:1:98
A	11:48:42	0:0:100

* Mostly shell fragments.
** T = trace percent present in samples.

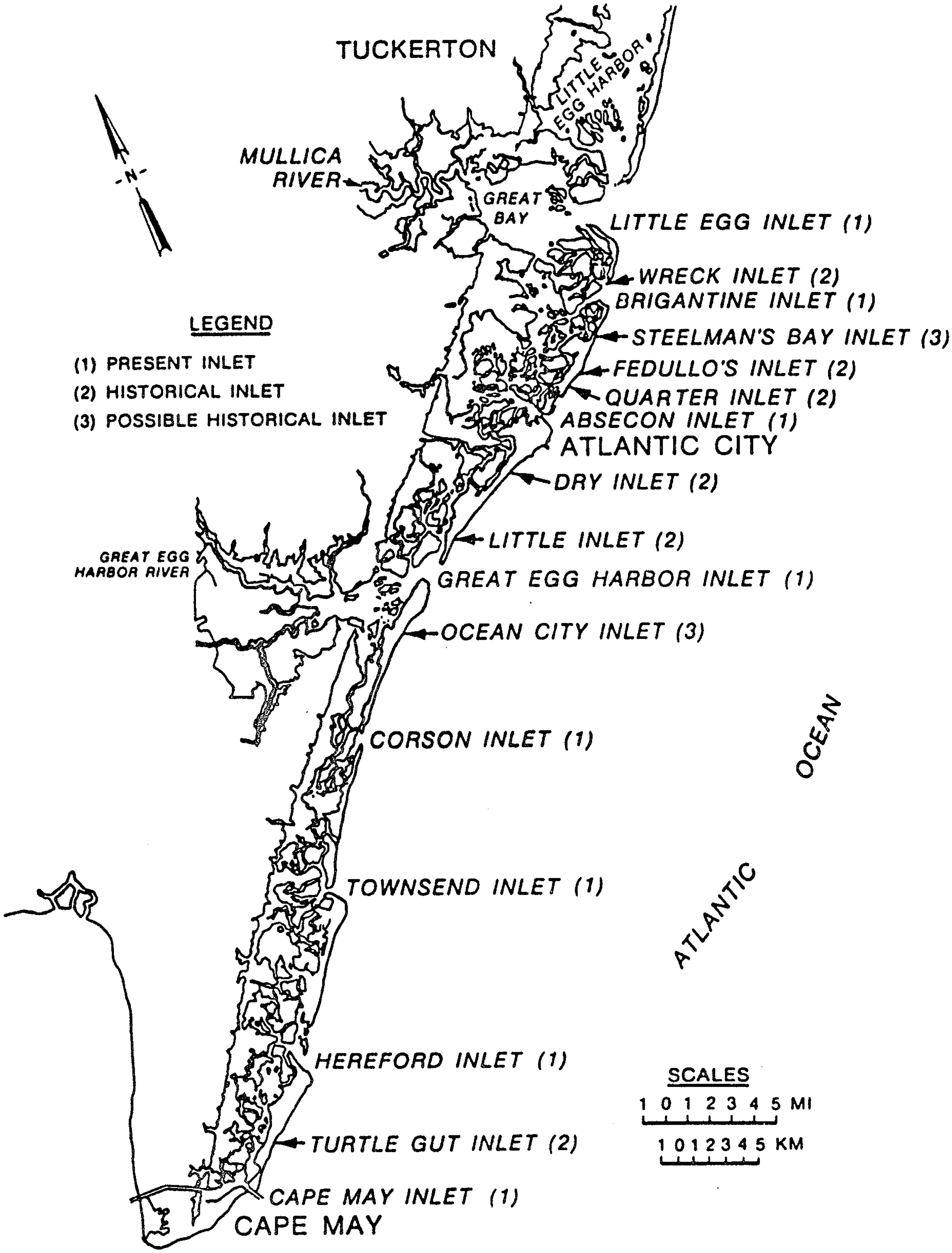

Figure 13. Present and historical inlet loctions

Table 5

Distance Over Which Bidirectional Inlet Migration Occurred and the Dominant Direction of Migration for Historical and Active Inlets*

Inlet Name	Status	Distance m	Migration Direction(s)
Wreck	?-1963	750	S
Brigantine	Open since 1840	2,440	N,S
Fedullo's	Open in 1869-71	300	N/A
Quarter	1744-1822	500	S
Absecon	Open since 1840	1,370	S
Dry	Prior to 1840-55	150	N/A
Little	Open in 1715, 1840	Unknown	N/A
Great Egg Harbor	Open since 1840	3,660	N,S
Corson	Open since 1840	1,980	N,S
Townsend	Open since 1840	915	N,S
Hereford	Open since 1840	2,440	N,S
Turtle Gut Inlet	Pre-1840 to 1920	1,220	S
Cape May	Open since 1840	550	S

Note: N = north; S = South; N,S = no dominant direction; N/A = inlet open during one survey only so that migration could not be determined.

87. Wreck Inlet once existed just north of Brigantine Inlet (Figure 13). A relatively deep channel is still evident within the marsh system. Sources differ as to the date, but Wreck Inlet seems to have merged with Brigantine Inlet in 1963 (New Jersey Department of Environmental Protection 1981).

88. Brigantine Inlet (Figure 13) has been open since at least 1840 when the first US Coast and Geodetic Survey (USCG) chart was produced for this area. It has migrated both northward and southward over a distance of approximately 2,400 m (Table 5). The inlet throat has been very wide at times, with a small island present in the central region of the inlet, around 1904.

89. An ephemeral inlet is shown on the 1869-78 survey line only, north of Absecon Inlet (Figure 13). The inlet has been named Fedullo's Inlet, after a pier that existed at approximately the same location. The 1840 survey showed a narrow island width of 180 m at this same location, a width that would be easily breached by high-water levels associated with a storm. Subsequent surveys (1886 to present) show an uninterrupted shoreline.

90. Quarter Inlet, located just north of Absecon Inlet, was open after 1744 and closed in approximately 1882 or 1883 (Haupt 1906, New Jersey Geological Survey 1885) (Figure 13). In 1825, Quarter Inlet was one of the five inlets open on Brigantine and Little Beach Islands (Haupt 1906). The number and location of ephemeral inlets open along this reach of coast has varied frequently. Hence, it is difficult to accurately determine the history of each particular inlet.

91. Absecon Inlet (Figure 13) has been open continuously since at least 1840. This inlet is relatively stable, showing maximum bidirectional migration of 1,370 m (Table 5). This inlet presently has pronounced downdrift offset to the south, and shoreline change data indicate a similar morphology has persisted for the period of record (1840 to 1955).

92. According to NOAA nautical charts (1984), there are several deep channels and a trifurcating channel-marsh system south of Atlantic City (Figure 13). This was the site of Dry Inlet, shown on Haupt's survey of the coast (1906). Although the area is highly developed now, a large relict flood delta can be delineated, with several major channels and lobes, now vegetated, evident in the backbarrier area. A narrow break in the shoreline several kilometres to the south is recorded on a map of the 1860 shoreline. This may represent the most southerly extent of migration for Dry Inlet, prior to closure; however, not enough data were available to determine historical changes.

93. Little Inlet was open in 1715 at the present site of Longport (Haupt 1906, New Jersey Geological Survey 1885) (Figure 13). The marsh islands and several bifurcating tidal channels behind the present barrier island provide geomorphic evidence for the inlet location. Longport Spit has accreted approximately 3 km to the south since the closure of Little Inlet sometime before 1840 (Haupt 1906).

94. Great Egg Harbor Inlet (Figure 13) has migrated north and south over a distance of 3,660 m (Table 5). In 1840, the inlet spanned this entire length with a small island/shoal located in the middle of the inlet throat. From 1840 to 1891, the northern spit (Longport) has generally migrated to the south, as the southern spit (Ocean City) has migrated to the north. A terminal groin constructed at Longport around 1920 prevented further migration of the spit to the south. From 1920, the inlet has migrated to the north as Ocean City has experienced various stages of shoreline change to the northern end of the island.

95. Corson Inlet (Figure 13) has migrated bidirectionally over a distance of approximately 1,980 m between 1840 and 1955 (Table 5). The northern and southern spits have each migrated about equal distances, maintaining an inlet throat width of 760 m.

96. Townsend Inlet (Figure 13) has been open continuously since at least 1840. This inlet is relatively stable, showing maximum bidirectional migration of 915 m (Table 5). This inlet also has a pronounced downdrift offset (to the south), and shoreline change data indicate a similar morphology has persisted for the period of record from 1840 to 1955.

97. Hereford Inlet (Figure 13) has migrated north and south over a distance of 2,440 m (Table 5). The downdrift offset morphology, which is apparent today, existed as early as 1940. In 1880, the shoreline of the northern spit was displaced in a seaward direction, but subsequent surveys show a more landward position, hence exaggerating the downdrift offset morphology. Intra-inlet shoals were found on the 1880 and 1920 surveys.

98. Turtle Gut Inlet (Figure 13) was open when the first USCGS map was produced in 1840 and artificially closed in either 1917 or 1920 (USACE sources differ). During that time, there was 1,220 m of migration to the south (Table 5). There is still a deep channel landward of the barrier island that represents the main inlet throat. Sunset Lake is the water body which fills that remnant channel. Extensive tidal channels leading landward from the inlet throat are also shown on the 1840 survey.

99. Cold Spring Inlet (now Cape May Inlet, Figure 13) has been open for the entire period of record, essentially maintaining its position and width of 550 m (Table 5). Downdrift erosion and updrift accretion occurred after emplacement of the twin parallel jetties in 1924.

100. There are well-documented examples of the stratigraphic significance of ephemeral inlet deposits (Fisher 1962, Kumar and Sanders 1974, Moslow and Heron 1978, Heron et al. 1984). Historically, inlets open during storms (Johnson 1919, Hite 1924, Fisher 1962) and remain open for varying lengths of time, depending on hydraulic efficiency, tidal prism, and sediment supplied through the longshore transport system. Large accumulations of sand can build quickly in shallow backbarrier lagoons. For example, the lagoon landward of Drum Inlet, North Carolina, was significantly filled after the inlet was artificially opened in 1970 (USACE 1977). After ephemeral inlets close, flood-tidal deltas frequently become vegetated and subsequently form a part of the

barrier island (Fisher 1962, Moslow and Heron 1978). These may become attached to the island as the hydraulic regime changes and old channels begin to fill with sediment. More likely, the abandoned channels will remain as regions of lower elevation, often still containing deep water, and hence are recognizable on maps and aerial photographs.

101. Relict flood deltas are common on many barrier island coastlines and appear as bulges on the landward side of the island (Hite 1924, Fisher 1962). Features indicating the location of a previous inlet include a deep shore-normal channel that ends abruptly against the landward shore of the barrier island, and large geomorphically recognizable lobes of marsh with radiating channels (Lucke 1934a, Fisher 1962). The shore-normal channel and associated lobate marsh deposits form a geomorphic unit that closely resembles active flood-tidal deltas. These two geomorphic features can be seen repeatedly at currently open inlets (Lucke 1934a, Hayes 1975) and at the site of inlets open at some time during the historical period. As such, several possible historical inlets are identified (Figure 13) and discussed below. There are no shoreline change data to conclusively show the existence of these inlets; however, geomorphic features do indicate that inlets may have been present at these locations prior to the earliest USCGS maps.

102. Steelman Bay, located on the landward shore of Brigantine Island (Figure 13), is a relatively deep (9 to 10 m) body of water that abuts the barrier island. This, in association with several lobes of marsh, provides evidence of a relict inlet channel and flood delta. Unfortunately, the area on the south side of the relict inlet is too highly developed for the entire marsh system to be recognized.

103. The area south of Ocean City (Figure 13) is also thought to have been the site of a tidal inlet (Ocean City Inlet, this study) before 1840. This is directly opposite the mouth of the Great Egg Harbor River and would be a likely location for an inlet, especially given the evidence for a paleo-fluvial channel located at this same location (McClennen 1973). There are several lobate marsh islands and associated tidal channels (3 m deep), although these are partially obscured by development. The USCGS charts for 1840 show these marsh islands to be in their present location, so inlet activity would predate 1840.

104. The shoreline between Brigantine and Cape May is approximately 75 km in length, of which 6.6 km is broken by active tidal inlets. Historical

data provide evidence that at least 14.6 km of coast has been occupied by tidal inlets at one time or another in the past (Table 5). Possible historical inlets (Steelman's Bay Inlet and Ocean City Inlet) add several kilometres to this figure; therefore, the length of coastline occupied by tidal inlets at any one time has decreased during the historical period.

105. Inlets are most likely to form when the backbarrier region is wide and open so that storm-elevated water levels can create breaches in the island (Johnson 1919, Hite 1924, Fisher 1962). As the proportion of backbarrier area occupied by relict flood-tidal deltas and salt marshes increases, the likelihood of new inlets opening decreases. These factors are responsible for the decrease in the number of inlets in southern New Jersey.

106. Shoreline change data for the period 1840 to 1955 indicate that areas adjacent to inlets are most subject to geomorphic change (USACE 1956). The central reach of each of the barrier islands is more stable by comparison, with longer term changes due to shoreface erosion and shorter term changes due to large storms or specific human activity.

Sources of Sediment

107. The trend of infilling of the backbarrier, noted in the subsurface, necessitates a source of sediment. Potential sources include the adjacent upland, the continental shelf, Delaware Bay, the headland coast to the north, and the adjacent beaches. Several possible transport mechanisms are identified for each sediment source, and these are discussed individually in the following paragraphs. It is important to keep in mind that sediment source may change through geological or historical time.

Upland

108. The upland provides a proximal source of sediment to the backbarrier. Rivers are potentially the major sediment transport mechanism from the upland to the marshes and lagoons. However, USGS data presented in Table 2 indicated the relatively insignificant amount of suspended sediment actually contributed at present by rivers discharging into the study area. The mean annual discharge of the Mullica River (Figure 12) is equal to about 0.1 percent of the mean tidal discharge of Little Egg Inlet (DeAlteris, McKinney, and Roney 1976). The lack of abundant sand-sized sediment on the floor of the Great Egg Harbor River (Table 3) strongly suggests that these rivers are not

now contributing significant proportions of sand to the backbarrier. These findings are not surprising given the shallow gradient of the coastal plain and the low-flow velocities of these rivers. Sediments that are carried by these rivers are most likely to be deposited directly into the adjacent bays (Great Bay and Great Egg Harbor Bay) (Figure 1) rather than transported throughout the backbarrier system.

109. On a regional scale, coastal fluvial systems, such as the Delaware River, do not carry high suspended loads of fine-grained sediment (Meade 1969). In addition, Hollister (1973) and Manheim, Meade, and Bond (1970) agree that very little sand is currently transported to the shelf by rivers. The fine-grained sediment that does escape from estuaries tends to be transported alongshore and, subsequently, is deposited in the nearshore zone. These studies further support the conclusion that the New Jersey coastal plain rivers and streams are not contributing significant proportions of sediment to the backbarrier marshes and lagoons.

110. Stratigraphic data presented earlier suggest that the upland was once a major source of sediment for the study area. Partially oxidized coarse sands and gravels are found as fining-upward sequences at depth in cores adjacent to the upland. Grain size decreases in a seaward direction within this facies, supporting a transport direction from west to east. Streams and rivers draining the upland during the late Pleistocene and early Holocene could have deposited these coarse sediments at the edge of the lagoon. Letzsch and Frey (1980) noted the ability of torrential rains to move Pleistocene sand from the terrestrial fringe to the adjacent marsh surface as a wash deposit. Basal core sediments resemble the pre-Holocene Cape May Formation sediments both texturally and mineralogically. The lack of any other potential source for the coarse sands and gravels is additional evidence that they were transported from the adjacent upland.

111. Paleodrainage patterns and topographic contours provide evidence of very small valleys oriented perpendicular to the strike of the Cape May Peninsula. MacClintock (1943) mapped contours of the Cape May Formation, both on the mainland and under the marshes, and documented that drainage channels extend under the marshes. These data provide sedimentologic, stratigraphic, and geomorphologic evidence to support the hypothesis of transport of sand and gravel from the upland during early development of the lagoon, similar to the findings of Halsey (1979) for the Delmarva Peninsula.

Continental shelf

112. The surface of the inner continental shelf of southern New Jersey is composed predominantly of fine to medium sand (Shepard and Cohee 1936; Donahue, Alba, and Heezen 1966; Milliman 1972; Milliman, Pilkey, and Ross 1972; Frank and Friedman 1973). Small deposits of granules and coarse sand are found in specific areas, most likely representative of relict stream deposits (Milliman 1972). Researchers have found relatively small percentages (1 to 2 percent) of silt and clay on the average, due to extensive reworking of the shelf sediments during the most recent transgression. Notable exceptions are the fine-grained sediments found locally at the mouths of large estuaries (Milliman 1972), adjacent to the 20- and 40-fathom contours (Frank and Friedman 1973), and in the troughs of large sand ridges (Stahl et al. 1974, Stubblefield and Swift 1976). In addition, 25 to 30 percent of the cores taken on the inner shelf off Cape May and central New Jersey contained silt and clay on silty sand in the upper 1 m of sediment (Meisburger and Williams 1980, 1982). However, the majority of cores contained clean medium to coarse sand, which occurs in 4- to 6-m-thick linear shoal deposits.

113. Early sedimentological studies indicated a similarity between beach and inner-shelf sands, which suggested that sand had been transported landward (Colony 1932, McMaster 1954). Additional research provided evidence that the shelf supplies a significant proportion of sediment to the New Jersey beaches (Frank and Friedman 1973; Sherif, Charlesworth, and Wilkand 1973; Cataldo 1980; Schroeder 1982). Pilkey and Field (1972) correlated textural and compositional parameters between the beach and shelf sediments for the southeastern Atlantic coast and deduced that storm-induced bottom currents actively transported sand onshore. Surface tidal currents are often unable to transport bottom sediment, whereas frequent winter storms induce wave surges near the seafloor that suspend and transport sediment shoreward (Stubblefield et al. 1975, Swift et al. 1977).

114. Recent process studies on the continental shelf indicate that sediments are actively transported along- and across-shelf, especially during storms (McClennen 1973, Stubblefield et al. 1975, Knebel 1981). The hydraulic conditions are frequently favorable to transport the predominantly fine sand and silty sediment that is presently exposed on the inner shelf. Photographs of the seafloor (Donahue, Allen, and Heezen 1966) and side-scan sonar profiles (McClennen 1973, 1983) indicate active reworking of the shelf surface as

evidence by bedforms of varying dimension. The reworked shelf sediments are contributed to the nearshore zone for subsequent transport (Hathaway 1972; Milliman, Pilkey, and Ross 1972; Meade et al. 1975). Milliman (1972) goes further to say that marshes of the mid-Atlantic Bight receive sediments from the continental shelf.

Delaware Bay

115. There is evidence to suggest that Delaware Bay may be a source for a portion of the sediment entering the backbarrier systems of southern New Jersey. Kelley (1980, 1983) gives evidence for resuspension of Delaware Bay bottom sediments and subsequent seaward transport during ebb tides. Suspended sediments are transported out of Delaware Bay and introduced to the inner-shelf waters, where they are carried to the north and may be transported through the inlets during flood tides. Hall et al. (1983) also present evidence of transport out of Delaware Bay and into the backbarrier systems.

116. There is probably only a small contribution of in-grained sediment from Delaware Bay to the backbarrier. Current meter observations (DeAlteris, McKinney, and Roney 1976) and Landsat data (Kelley 1983) for the region extend only as far north as Stone Harbor (Figure 1). Additional evidence is necessary before this hypothesis can be extended to the entire study area. To date, there is no evidence to suggest that sand-sized sediment is transported out of Delaware Bay and into the backbarrier region.

Headland erosion

117. The New Jersey coast is composed of several geomorphic units (Haupt 1906, Johnson 1919, Lucke 1934a, Fisher 1962) as discussed previously (Figure 3). The area near Manasquan Inlet was thought to be the source of sediment and a nodal point for sediment distribution along the New Jersey coast. The loosely consolidated nature of the headland is conducive to erosion by marine processes (MacCarthy 1931, Frank and Friedman 1973).

118. Geomorphologic evidence and the dominant littoral transport direction for the region both suggest erosion of sediment from the headland and subsequent transport to the south during both the historic and geologic past. However, contributions from the headland have decreased significantly through the historical period. Shore protection structures, such as groins and a nearly continuous sea wall, have essentially halted erosion of the headland. Thus, the subaerial headland does not contribute a significant quantity of sediment to the backbarrier region today.

Adjacent beaches and shoreface

119. Beaches of the barrier islands are ready sources of the fine sand predominantly seen in the vibracores. There are three major mechanisms for transporting sand from the beaches to the backbarrier. These are eolian activity, overwash, and tidal current-wave interactions at tidal inlets.

120. Eolian transport of sand necessitates the appropriate grain size and an exposed area of sand. It is difficult to hypothesize about environmental conditions existing throughout Holocene time, especially given the widely spaced core data. However, the lack of clean, cross-bedded, fine sand in the cores suggests that eolian sediment may represent a relatively small contribution to the backbarrier sediment budget.

121. Presently, the open ocean beaches represent the only environment with a sufficient source, to allow for sand entrainment, transport, and subsequent deposition. However, beaches are separated from the backbarrier region by at least 1 km of intense development. If any sand was transported across the developed zone, it would be deposited in the adjacent area only rather than spread throughout the backbarrier. In addition, there is no exposed source of silt and clay to be transported by wind, yet fine sediment constitutes a majority of the backbarrier sediment. Thus, eolian transport is not considered to be a significant process in present backbarrier infilling.

122. Overwash, a second possible transport mechanism, occurs only in selected locations along the southern New Jersey coast. Specifically, washover deposits are seen on the spits adjacent to tidal inlets and along several topographically low areas such as Whale Beach on Ludlam Island. The shore protection structures present along much of the New Jersey shore deter overwash except during the most extreme storm events.

123. Washover sediments were also not identifiable in the vibracores based on characteristics such as texture, sorting, and shell lag (Schwartz 1975). It may be that washover deposits were not seen due to the lack of cores in the region immediately landward of the barrier dune system.

124. Overwash processes may have been more active through the historical period or during the geologic evolution of the system. However, there is no evidence of extensive washover deposition in the subsurface. Thus, overwash probably has not been a quantitatively important process in late Holocene backbarrier infilling. The total width of the backbarrier and the presence of fine-grained marsh sediments at the surface indicate that washover deposits do

not constitute a significant portion of the sediment presently being deposited.

125. Littoral and inner-shelf sediments transported through the inlets have long been recognized as a source and a mechanism for backbarrier infilling (Haupt 1906, Johnson 1919, Lucke 1934b, Charlesworth 1968). MacCarthy (1931) and Caldwell (1958) discussed the fact that inlets act as sinks for sediment moving along the beach in the nearshore zone. More correctly, the inlets are the conduits, and the lagoons are the sediment sinks. Large sand shoals in lagoons and bays are evidence of the amount of sand trapped by inlets (Caldwell 1958). Flood-tidal currents are aided by wave action and can therefore be quite efficient in transporting sediment into an inlet. Ebb currents acting alone may be less effective at seaward sediment transport (Fisher 1961).

126. MacCarthy (1931) indicated that since there is a greater number of inlets in southern New Jersey, as compared with northern New Jersey, which are all trapping sediment, an offshore source of sand would be essential to replenish the beaches. Estimates of sediment losses from ocean beaches are in excess of the measured rate of littoral sediment transported alongshore (Caldwell 1958). Again, sediment transported onshore from the shoreface and inner shelf is suggested as a replacement for the sediment lost from the beaches. However, some sediment is permanently removed from the beaches and constitutes shoreface erosion.

127. In summary, there are two conclusions that follow from the discussion of sediment sources. Firstly, during late Pleistocene and early Holocene time, erosion of the upland and the coastal headland were significant sources of sediment to the landward portion of the backbarrier. Secondly, through the late Holocene and continuing to the present, sediment has been derived from the beach, shoreface, and inner shelf and transported through tidal inlets. This provides the major source of sediment for backbarrier infilling, which includes fine-grained suspended sediments that may have been transported out of large estuaries, such as Delaware Bay, to the continental shelf. Subsequently, the suspended sediment is also transported through tidal inlets to the backbarrier region.

PART IV: GEOLOGIC HISTORY

128. The patterns of facies distribution observed in the subsurface data and modern depositional environments have been combined to interpret the Holocene geologic history of the southern New Jersey backbarrier region. Specifically, changes in sea level, backbarrier stratigraphy, and the backbarrier infilling processes will be discussed in order to develop an evolutionary model of late Holocene deposition.

Sea-Level Changes

129. Changes in relative sea level can be viewed from two different time perspectives. Short-term variations are due to differences in meteorologic and oceanographic parameters, such as wind, atmospheric pressure, river discharge, currents, salinity, and temperature (Hicks 1972). Longer term variations result from sediment compaction, hydro- and glacioeustatic effects, and tectonic effects. Although the long-term changes will be emphasized in this discussion, there is a short-term sea-level rise curve based on tidal gage data from Atlantic City (Figure 14). The gage has recorded an annual rate of relative sea-level rise of 4.4 mm/year for the period of 1912 to 1980. This rate is higher than the average 2.5 mm/year for the northeast coast (Hicks, Debaugh, and Hickman 1983). The unusually high rate probably results from greater absolute subsidence in the mid-Atlantic Bight generally (Hicks 1972) and in New Jersey in particular. Preliminary evidence from radiocarbon dates indicates an increase in vertical accumulation for the recent geologic period; however, the data are inconclusive at this time.

130. Approximately 18,00 years B.P. marks the lowest position of Wisconsinan sea level, when marine processes were active in the vicinity of what now constitutes the shelf-slope break. During the last 18,000 years, sea level has risen approximately 100 to 130 m (Donn, Farrand, and Ewing 1962; Curray 1965; Bloom 1967; Emery and Garrison 1967; Morner 1971; Chappell 1974; Dillon and Oldale 1978). Since Late Pleistocene time, sea level has risen at a variable rate. A relatively rapid sea-level rise is hypothesized for the period 18,000 to 6,500 years B.P. (Emery and Garrison 1967, Belknap and Kraft 1977). Basal peats along the Delaware coast, for example, are dated at 6,680 to 7,725 years B.P. and are thought to mark the change in the rate of

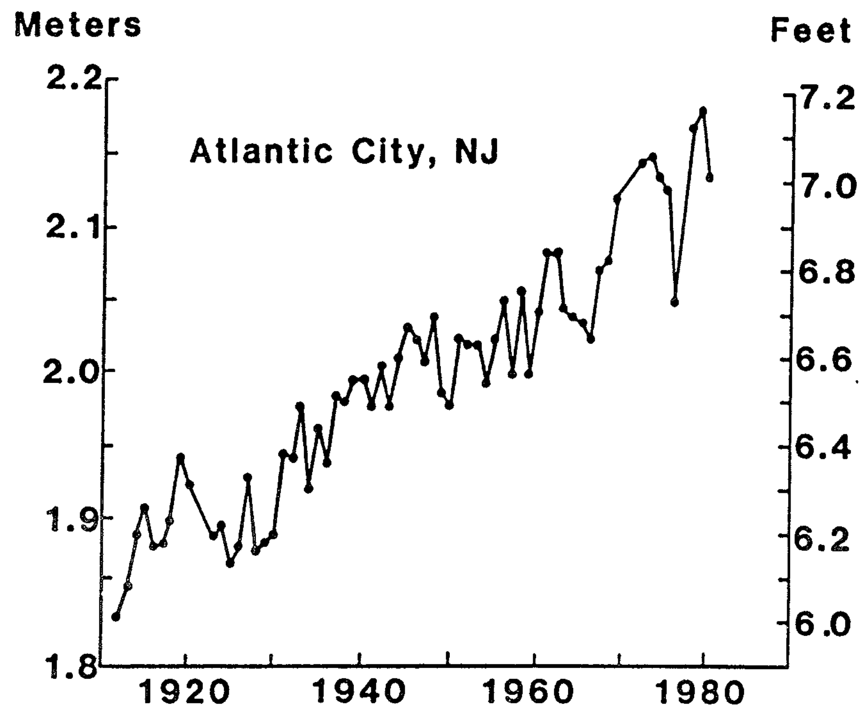

Figure 14. Sea-level rise curve based on tide gage from Atlantic City, NJ, 1912-1980 (Hicks et al. 1983)

sea-level rise (Belknap and Kraft 1977). A gradual decrease in the rate of rise persisted from 6,500 to 4,00 B.P. (Emery and Garrison 1967). A further decrease in the rate of rise is noted globally at 4,000 years B.P. (Emery and Garrison 1967, Redfield 1967, Bloom 1970), although some researchers consider the change in rate to have occurred at 2,000 years B.P. (Belknap and Kraft 1977). Data from North Carolina indicate that the rate of sea-level rise slowed at approximately 8,000 and 4,300 years B.P. and that sea level has gradually risen 3 m since 4,300 years B.P. (Heron et al. 1984). Since Late-Holocene time, eustatic sea level has risen less than 3 m according to Redfield (1967) and Bloom (1970) or as much as 5 m (Belknap and Kraft 1977).

131. Much of the literature regarding sea-level rise supports a variable but continuous rate of rise throughout the Holocene (Shepard 1963, Belknap and Kraft 1977). Some evidence has been presented that suggests fluctuations in the Holocene sea-level curve (Fairbridge 1961, 1976; Colquhoun et al. 1981). Meyerson (1972) presents evidence for sea-level fluctuations along Delaware Bay, where salt and freshwater peats interfinger at depth. Possible fluctuations in sea level are inferred from the presence of a subtidal lagoonal facies between two thick marsh sequences. However, in southern New Jersey,

there is no evidence to suggest that sea level was higher today than during Holocene time.

132. Increased submergence has been proposed for regions directly adjacent to continental glaciers (Bloom 1967; Emery and Garrison 1967; Clark, Farrell, and Peltier 1978; Clark 1981). It is difficult to accurately determine the effect of proximity to glacial ice on the regional topography. Some researchers have hypothesized an emergence of the coast due to isostatic adjustment as sea level rises and the relative weight of water on the shelf increases hydroisostasy (Bloom 1967, Morner 1971, Chappell 1974). Clark (1981) presents a scenario of discontinuous isostatic adjustment during the Late Pleistocene and Holocene periods. During times of maximum ice loading, southern New Jersey would have been located on the forefront bulge, and relative sea level would have been lowered. As the ice front receded, the study area would have undergone tectonic subsidence as well as eustatic sea-level rise. Continuous shorter term variations in the position of the ice front would have greatly affected the southern New Jersey coast.

133. Sea-level data for New Jersey are relatively sparse, especially dates on basal peats. Data from adjacent New Jersey marshes show an initiation of marsh growth at least by 6,000 years B.P. (Stuiver and Daddario 1973). Additional data from other mid-Atlantic marshes (Emery and Garrison 1967, Belknap and Kraft 1977) also indicate a change to a relatively gradual rate of sea-level rise at about 6,000 years B.P. Data accumulated up to this point indicate a gradual rise from 6,000 to 2,000 years B.P. (Daddario 1961, Stuiver and Daddario 1963, Psuty et al. 1983) and a slightly slower rate of rise since 2,000 years B.P. The oldest marsh peats from this study are dated at approximately 3,000 years B.P. and occur at depths of 4.5 to 6.5 m below the surface. Older basal peats may occur at depths of 10 to 15 m below present sea level, but they are separated from Late-Holocene marshes by a thick and extensive open lagoon-tidal-flat depositional sequence.

Radiocarbon-14 Age Dating

134. Organic material from vibracore samples were analyzed to obtain radiocarbon-14 age dates (Table 6). Material dated included marsh and peat samples, organic-rich mud, and one oyster shell in growth position.

135. The maximum and minimum ages were 2,880 years B.P. and 730 years B.P., respectively, not including the sample that was discounted due to unrealistic age. Gross vertical accumulation rates were calculated by dividing the depth of the sample by the radiometric age. The average rate of accumulation based on the eight samples is 1.85 mm/year. However, calculation of accumulation rates is problematic as accumulation varies through time. In addition, environments of deposition change and sediments undergo autocompaction at varying rates.

136. Radiocarbon dates were used to delineate an envelope that represents relative sea-level position during the Late Holocene (Figure 15). Due to the limited number of data points from this study, data from other studies were included. The composite sea-level envelope should be viewed as an approximation of the regional trend, which indicates a continual rise in relative sea level.

137. From the diagram, an average rate of sea-level rise of 2.0 mm/year is calculated. However, the data indicate a relatively faster rate of rise from 6,000 to 2,000 years B.P. and a more gradual rise from 2,000 years B.P. to the present. More data are needed to accurately complete the recent

Table 6

Radiocarbon-14 Age Dates

Core Number	Depth m	Lab Number*	Type of Material	Dates in Years B.P.
1-3-9	4.50	B-6081	Oyster shell	2110+/-80
3-3-8	2.65	B-6084	*S. alterniflora*	730+/-90
3-3-11	5.00	B-6083	*S. alterniflora*	2880+/-70
3-4-7	2.10	B-6086	*S. alterniflora*	1750+/-60
5-2-3	2.80	B-6090	Organic-rich mud	2460+/-150
5-4-8	4.30	B-6089	Shell fragments	3730+/-100**
5-4-13	6.55	B-6088	Sandy peat	2760+/-80
5-5-7	3.60	B-6087	Organic-rich mud	2210+/80
6-3-6	2.05	B-6085	*S. alterniflora*	2050+/-160

* Radiocarbon dating performed by Beta Analytic, Inc., Coral Gables, FL.
** This sample was unreasonably old compared with the stratigraphic relationships and may represent relict organic matter which was later transported into an active environment of deposition.

portion of the envelope (Figure 15). The envelope is in general agreement with regional curves produced for nearby Delaware (Belknap and Kraft 1977) and Virginia (Newman and Munsart 1968) (Figure 16). A more recent curve for Virginia developed by Finkelstein (1987) generally resembles the previous curve (Newman and Munsart 1968). Shepard's (1963) data are globally derived and not necessarily representative of local conditions in the mid-Atlantic Bight.

Stratigraphic Interpretation

138. The depositional regime of the southern New Jersey backbarrier region has changed during the Holocene during the last 10,000 years). The changes are evident in the subsurface sediments and the biota, rather than at the surface where salt marshes and tidal creeks dominate the landscape. Analyses of the subsurface deposits, in conjunction with data from similar depositional environments in adjacent states, permits an interpretation of the Late-Holocene stratigraphic record.

139. The late Pleistocene transgression is represented by a transgressive lag composed of clean marine sand or coarse fluvial gravelly sand that are both interpreted to be subdivisions of the Cape May formation (Gill 1962). Immediately above this formation is a basal peat or a silty lagoon deposit. This peat has been dated at approximately 6,000 years B.P. (Stuiver and Daddario 1963, Psuty et al. 1983). The peat and silt horizons were encountered at depths of -12 to -14 m in the northern half of the study area and at -10 m in the south (Craig Testing Laboratories 1979; New Jersey Department of Transportation 1967, 1972; New Jersey Highway Authority 1953, 1970).

140. Subsurface data also indicate a change in slope of the pre-Holocene to Holocene contact. The contact changes from moderately steeply dipping east of the backbarrier-mainland boundary to subhorizontal beneath the lagoons, salt marshes, and probably the barrier islands (MacClintock 1943, Daddario 1961, this study). This slope is thought to represent an erosional surface shaped by marine processes during a higher stand of sea level (Halsey et al. 1977, 1979). Since that time, the surface adjacent to the mainland has been dissected by small streams and rivers that resulted in an irregular topography (MacClintock 1943).

141. Overlying the basal silt or early transgressive lagoonal sequence

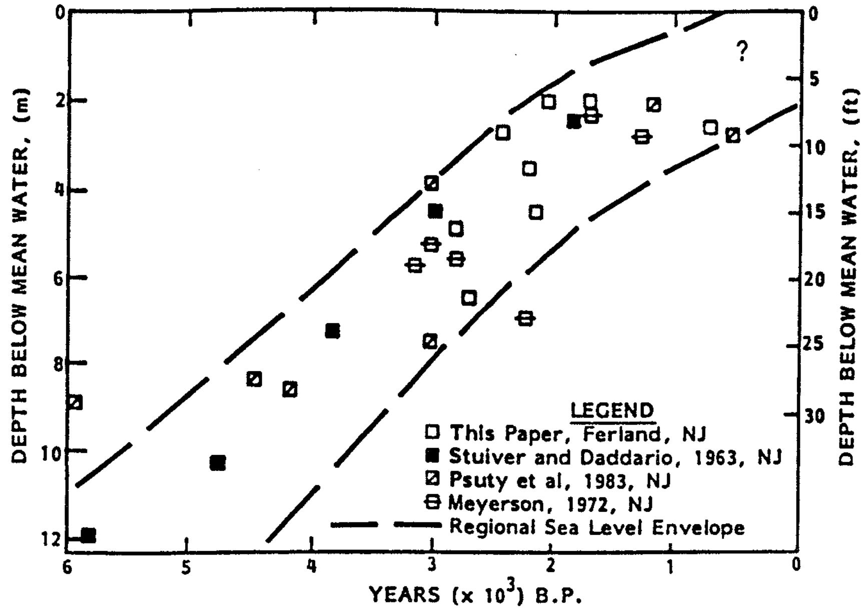

Figure 15. Regional relative sea-level envelope based on radiocarbon dates

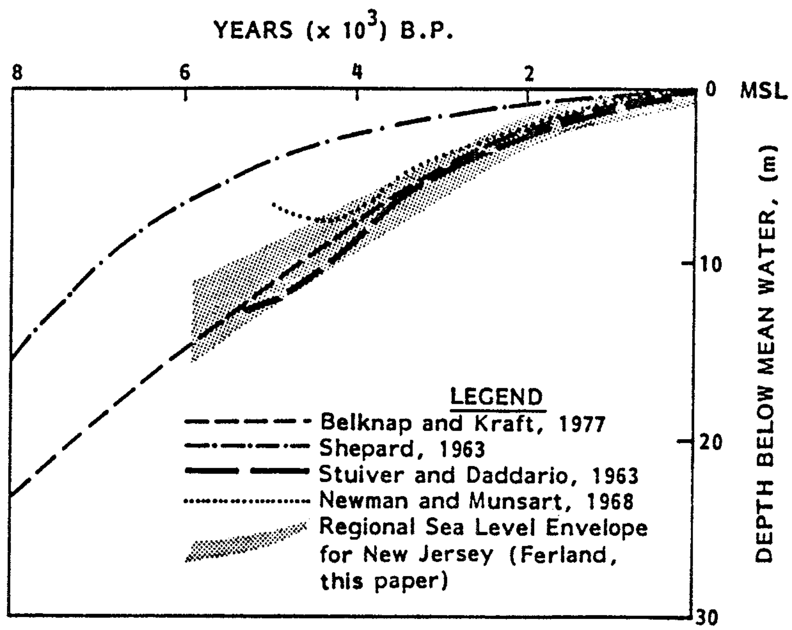

Figure 16. Lont-term sea-level curves for the mid-Atlantic coast

is a thick, homogeneous fine sand facies. This sand facies thins to the west and represents an amalgamation of sand flat, flood-tidal delta, and open lagoon deposition. The sand facies grades laterally and vertically into a mixed (sand and mud) flat deposit that represents an intermediate energy environment deposited as the average water depth shallowed (Figure 17).

142. The central to landward portion of the backbarrier contains relatively thick accumulations of mud flat and lagoonal deposits at depth and salt-marsh deposits near and at the surface. These environments are all indicative of relatively low-energy deposition, which persists throughout the modern backbarrier region. A well-developed network of tidal channels and creeks represents the only localized environment of potentially high-velocity sediment transport landward of the tidal inlets.

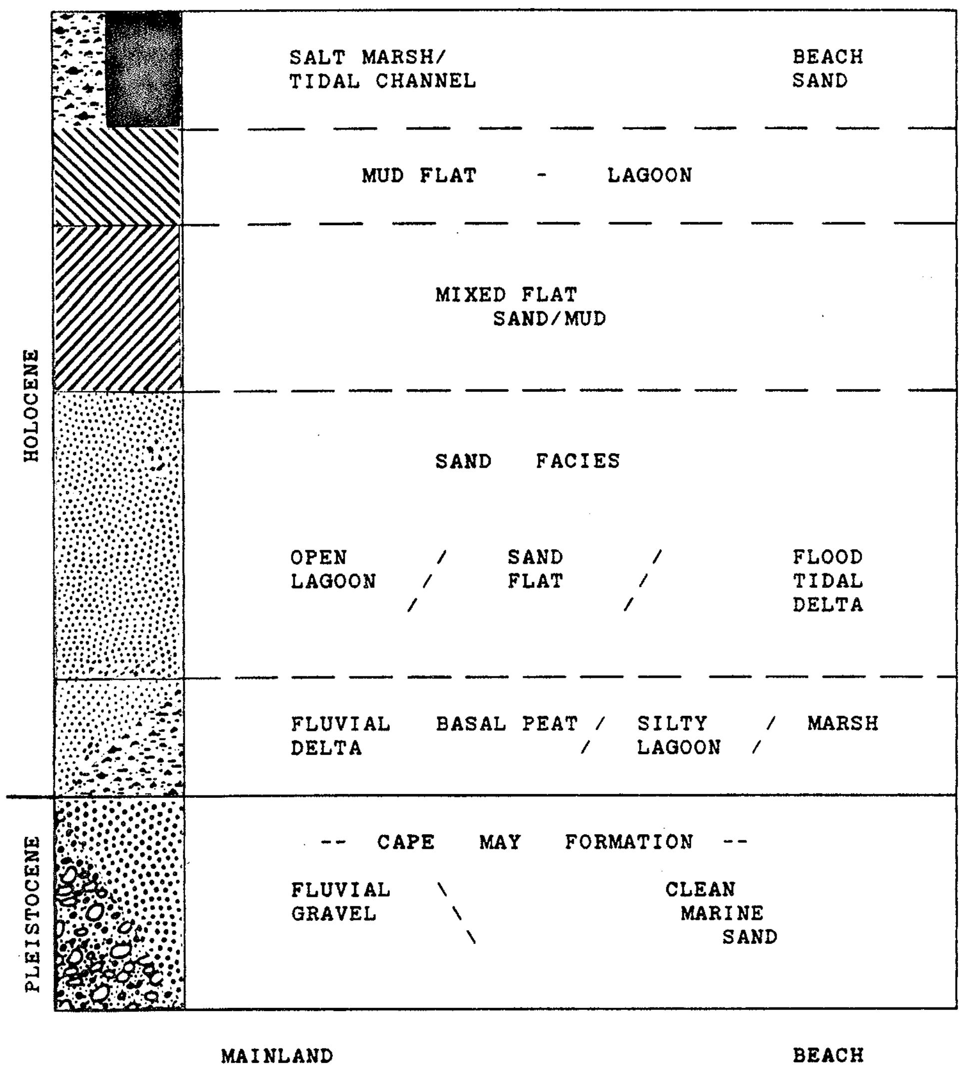

Figure 17. Generalized stratigraphic column

143. The stratigraphy can be described as an upward and landward fining sequence within the backbarrier sequences overall, but is not applicable for all cases. Textural changes in sediment reflect changes in the energy available during deposition. In addition, variations in the sources of sediment result in textural changes in the stratigraphic record.

144. Stratigraphic data presented in this study compare with data from similar research on the northeast and Mid-Atlantic coasts. Kraft (1971) and Kraft, Riggs, and Halsey (1973) have investigated the coastal Delaware Holocene stratigraphy and found that the Pleistocene-Holocene contact is overlain by a sequence of basal peat, lagoonal mud, and salt-marsh deposits. Belknap and Kraft (1977) concluded that an average of 5 m of sediment was deposited in the backbarriers of Delaware during the last 3,000 years. This is analogous with the thicknesses of Late-Holocene deposits in southern New Jersey.

145. Research conducted in the southern Delmarva backbarrier region (Finkelstein 1987) indicates similar sedimentation trends for the Late Holocene. Basal peats are overlain by a sand-mixed, mud-flat sequence and capped by salt marshes. The fining-upward sequence has been interpreted as a change to lower energy conditions in the backbarrier region (Finkelstein 1987).

146. Barrier and backbarrier systems in Rhode Island have been studied and found to have relatively thin (<4 m) Holocene depositional sequences (Boothroyd et al. 1981). Extensive glacial outwash deposits form the floors of the lagoons that began to form as sea level rose during the Holocene. Tidal-delta sedimentation began at 2,500 years B.P., and the lagoons are expected to continue infilling based on current rates of sedimentation and sea-level rise (Boothroyd et al. 1981).

147. In general, the stratigraphy of backbarrier regions along the mid-Atlantic coast is characterized by infilling as a fining-upward sequence and low-energy deposition. This trend will most likely continue as long as relative sea level continues to rise slowly and a supply of sediment is maintained.

Backbarrier Infilling Processes

148. The decrease in grain size within tidal channels and lagoons, with increasing distance form the inlet (Table 4) is indicative of transport from

the shelf through the inlets. Stratigraphic trends of a general fining toward the west, except adjacent to the upland, where fluvial deposits occur at depth, also support a seaward source for a significant proportion of the backbarrier sediment. The development of inlets and their associated flood deltas has been an important process in depositing large amounts of sediment landward of the barrier islands. Morton and Donaldson (1973) found that tidal-delta deposits associated with major inlets were the primary agents responsible for backbarrier infilling and marsh colonization. Results from this research support onshore and alongshore transport of marine sediment and subsequent transport through tidal inlets as the major mechanism of Late-Holocene backbarrier infilling in southern New Jersey.

149. Sedimentologic evidence indicates that sediment is transported from the inlets westward, throughout the backbarrier region. Results of process studies in large tidal channels leading from Townsend and Hereford Inlets show flood dominance of tidal current velocities (Ashley and Zeff, in preparation). Studies by Greaser and Wicker (1937) and Charlesworth (1968) indicate that tidal currents within several of the southern New Jersey inlets are best described as variable with no dominant ebb- or flood-flow velocity. Results of recent process studies have shown a relationship between the amount of open water in the backbarrier and the ebb- or flood-current dominance of the connecting inlet (Mota-Oliveria 1970, Nummedal et al. 1977, Nummedal and Humphries 1978, Boon and Byrne 1981, FitzGerald and Levin 1981, Ward 1981, FitzGerald and Nummedal 1983). These investigators have found that inlets connected to backbarriers that have large open-water lagoons tend to be flood dominant, whereas marsh-filled systems have ebb-dominant inlets. Examination of tidal current velocity data for marsh-filled backbarriers show greater average and maximum ebb velocity and shorter flow durations during the tidal cycle. Given the higher ebb velocities and the fact that sediment transport rate is proportional to the third power of velocity, greater ebb-directed sediment transport has been inferred. From these data, net export of sediment would be expected in marsh-filled systems.

150. The southern New Jersey backbarrier systems are considered to be marsh-filled (Fisher 1967, Belknap and Kraft 1985), and yet there is evidence that sedimentation is occurring in the lagoons and salt marshes today (Kelley 1983, Throbjarnarson et al. 1985). Although southern New Jersey has a morphology similar to that of the ebb-dominant systems of South Carolina and

Virginia (FitzGerald and Nummedal 1983, Boon and Byrne 1981), the infilling data indicate that true ebb dominance does not apply in New Jersey over the long term. The apparent discrepancy between data sets indicating flood or ebb dominance may be related to the type of deposition that is occurring. Most velocity and bed-form data are calculated for sand transport potential; however, fine-grained sediment (silt and clay) currently dominates deposition in the marshes. Fine-grained sediment is transported landward by flooding tides and deposited in the distal and quiet marsh areas, rather than being transported seaward during the ebbing tide. Studies of inlets along microtidal coasts indicate a net transport of sediment into a growing flood-tidal shoal even though the tidal hydraulics suggest an ebb dominance (Stauble et al. 1987). In that study, velocities on the ebb did not reach critical threshold until well into the inlet throat, precluding seaward transport of fine material deposited in the flood shoal on the previous flood-tidal cycle.

151. Southern New Jersey may also be in a transitional stage between truly open water or marsh-filled backbarrier conditions. Other data indicate that the study area is morphologically transitional between a micro- and mesotidal coast (Hayes 1975) having both well-developed ebb and flood deltas, numerous inlets, and extensive marshes. It is apparent that the New Jersey backbarrier represents an intermediate type between the large open sounds behind the Outer Banks and the entirely marsh-filled systems of South Carolina. Additional research needs to be carried out to answer the question of tidal dominance and sediment transport in southern New Jersey.

Model of Holocene Backbarrier Evolution

152. The author's model of backbarrier evolution in southern New Jersey is based on the sedimentary record that was deposited during conditions of changing sea level (Figure 18). The linear scarp, which forms the landward boundary of the backbarrier region, was created during the late Pleistocene by marine processes (MacClintock 1943; Halsey et al. 1977, 1979; Mixon, Szaso, and Owens 1983). During the subsequent global expansion of the ice sheets, sea level dropped approximately 100 to 130 m (Dillon and Oldale 1978). The regression occurred relatively rapidly, over approximately 2,000 years (Hoyt and Hails 1974), and caused rivers to deposit sediment on the adjacent continental shelf. The last transgression was also relatively rapid between

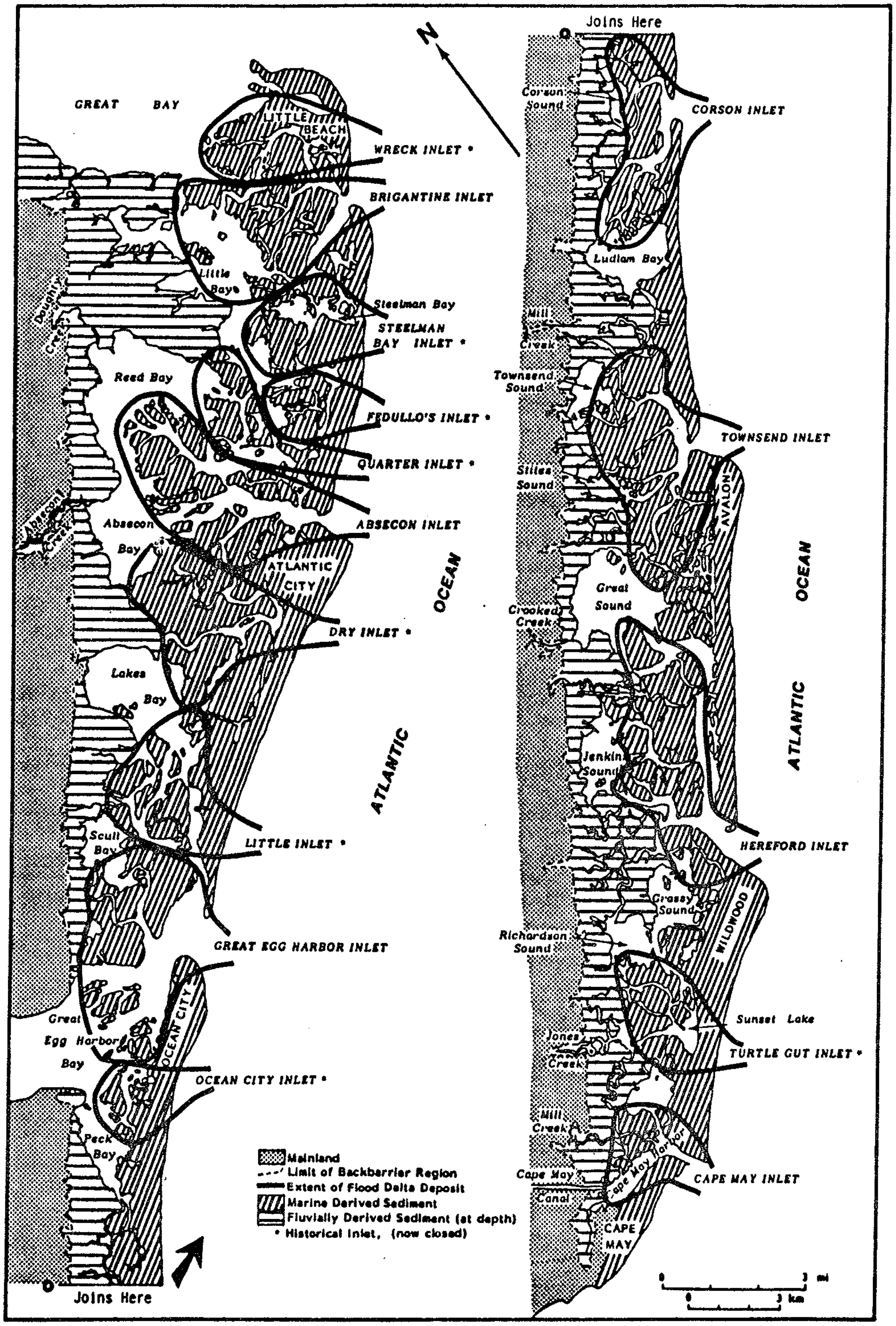

Figure 18. Model of backbarrier evolution for southern New Jersey with present and historical inlets identified

18,1000 and 6,500 years B.P. (Belknap and Kraft 1977), as glacial ice melted and water flowed back to the oceans. Subsequently, the rate of sea-level rise has decreased.

153. Approximately 18,000 years ago, southern New Jersey was less than 200 km from the edge of the ice sheet. As the ice sheet melted, fast-flowing water washed unconsolidated sediment from the Cape May Peninsula and deposited it seaward of the mainland scarp, under what is now the backbarrier region. Adjacent to the mainland, deposits of coarse sand and gravel are found at depths of 2 to 4 m below the present marsh surface. Several kilometres to the east, similar coarse-grained deposits are found at depths of 6 to 7 m, which indicates a change in slope of the coarse sand unit. There is a good correlation between the core samples and the surface samples taken from the Cape May Peninsula. This suggests transport of coarse sediment to the backbarrier region prior to present quiet water conditions.

154. As Holocene sea level continued to rise, the inner shelf was flooded with marine waters, and the barrier islands migrated landward. Initially, the barrier islands were probably long and narrow with relatively few inlets connecting the open backbarrier sounds. The lagoons would have been wide with a long fetch where wind-generated waves and tidal currents could transport large quantities of sediment. Core data suggest that relatively high-energy subtidal conditions existed in the central to seaward portion of the backbarrier region. Predominantly clean, fine sand occurs in the thick sand facies at the base of the cores. Some of this sand was deposited in flood-tidal deltas as inlets opened and closed, while some of the sand facies represents sand flat deposition.

155. In the landward portion of the backbarrier, coarse sand and gravel deposits were submerged as sea level rose and marshes developed in the intertidal zone. Samples taken from the deepest marshes indicate that the sea had transgressed this area before 2,000 years B.P. (Figures 5 and 9). In contrast, the seaward portion of the backbarrier contains thinner salt marsh deposits underlain by thick tidal flat deposits (Figure 7). The growth of the latter salt marsh probably resulted from a decrease in the rate of sea-level rise from 2,000 years B.P. to the present.

156. Through the late Holocene, the rate of rise of relative sea level slowed (Figure 15), but sedimentation continued in the backbarrier region. This caused subtidal sands to be overlain by tidal flat deposits. Lower

energy conditions fostered increased salt marsh growth that trapped more sediment and reinforced infilling of the backbarrier. Since the 1700's, a number of tidal inlets have closed as the tidal prism decreased and hydraulic efficiency was reduced because of sedimentation.

157. The stratigraphic data provide evidence for an evolutionary model with two fundamentally distinct foundations for the salt marshes in southern New Jersey (Figure 18). West of the present lagoons, the marshes are built upon fluvially derived sediments washed from the Cape May Peninsula before sea level reached the area. East of the lagoons, the marshes are built on more recent marine-derived sediments that were transported primarily through tidal inlets. The numerous small backbarrier lagoons represent a boundary between the two marsh environments (Figure 18). The lagoons are undergoing relatively slow deposition, although they are infilling continuously (Thorbjarnarson et al. 1985). The position of the flood-tidal deltas have been approximated based on the geomorphology of the tidal channels and marshes (Figure 18).

158. An earlier model of the evolution of New Jersey's lagoon, or backbarrier region, was developed by Lucke (1934b). Lucke's model was based largely on geomorphic evidence and his detailed study of Barnegat Inlet and depends on inlet-derived sediment (Figure 19). Lucke hypothesized that this sediment was deposited either as a flood-tidal delta, proximal to the inlet, or that it was carried by tidal currents to distal areas of the lagoon. He attributed extensive mainland fringing marshes to flood-delta deposits that had prograded across the lagoon to join the mainland. In Lucke's model, the mainland was essentially straight prior to the introduction of inlet-derived sediment. Protrusions from the landward side of the barrier islands were thought to be due to the redistribution of tidal sediments rather than the actual relict flood deltas (Lucke 1934b). There is now substantial evidence that these deposits represent the actual relict flood delta (Fisher 1962, Moslow and Heron 1978, this study).

159. The importance of paleo-drainage and mainland-derived sediment was determined largely by subsurface (MacClintock 1943) and stratigraphic data (Daddario 1961; Halsey, Farrell, and Johnson 1979; this study) that were not available to Lucke. In addition, radiocarbon dates indicate differences in the ages of formation of various marsh deposits within the backbarrier region. These data have been fundamental to the development of the author's model of backbarrier evolution. Another distinction between the model presented here

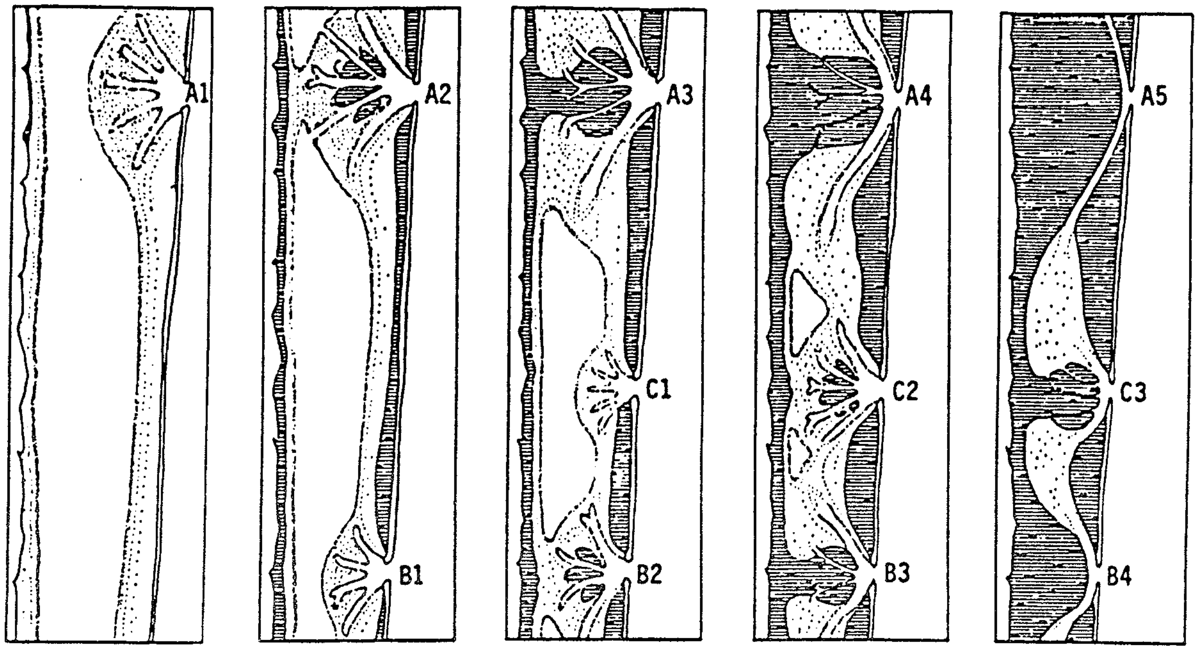

Figure 19. Lucke's (1934) model of backbarrier evolution in New Jersey

(Figure 18) and Lucke's model (Figure 19) is the origin of lagoons, or coastal bays, as he called them. Lucke considered lagoons to be evidence of the stability of tidal inlets and that lagoons would occur only if inlets did not migrate. However, New Jersey inlets do migrate (Table 5), and lagoons occur where inlets have migrated. For example, Scull Bay and Jenkins Sound have not been completely infilled (Figure 18) despite the fact that Great Egg Harbor Inlet and Hereford Inlet have each migrated more than 2 km during the last several hundred years (Table 5). The lagoons represent a zone that has not yet been filled with flood-delta sediments.

160. The New Jersey coast has been divided into several units (Figure 3) that each have different barrier island and inlet morphologies (Fisher 1967). Lucke (1934b) had previously recognized a subdivision of the southern barrier islands at Great Egg Harbor Bay. As discussed in Part I, the backbarrier region is wider, and the lagoons are larger north of this point. The subdivisions will be referred to as the northern segment (Little Egg Inlet to Great Egg Harbor Inlet) and the southern segment (Great Egg Harbor Inlet to Cape May Inlet).

161. Lucke (1934b) hypothesized that the southern segment was most mature, even though it was farthest from the source of sediment to the north.

He suggested that through the Holocene a smaller sediment supply had resulted in faster barrier island migration that narrowed the backbarrier to the point of an almost totally infilled system. If the Pleistocene scarp on the mainland were not present, of course the backbarrier region would continue to expand landward as relative sea level continues to rise. While Lucke's mechanism for narrowing the backbarrier region may not be correct, the southern segment certainly represents the most infilled, and thus mature, section of the New Jersey barrier coast.

162. In contrast, the northern segment has recently (1700 to present) undergone a period of pronounced inlet formation and flood-delta sedimentation. This has caused infilling, but still there remains significant areas of open-water lagoons of a larger size than those found in the south. This area also has two large river valleys (Mullica and Great Egg Harbor Rivers) entering the backbarrier region , which is absent in the marsh and creek environment to the south. Therefore, the northern segment is in an intermediate stage, based on its degree of infilling. The wide bays to the north of the study area, Little Egg Harbor Bay and Barnegat Bay (Figure 1), represent youth because they are still largely open-water lagoons with some flood-delta development.

163. Without overwash processes, the width of the barrier islands will decrease as the relative sea level continues to rise, resulting in shoreface erosion. The size of the backbarrier region will also decrease because the Pleistocene scarp prohibits landward encroachment of the marshes until sea level has risen by 2 to 3 m. As sediment is continually transported into the area, the backbarrier region is infilled. Thus, the likelihood of new inlets opening also decreases, since a partially marsh-filled system is relatively stable. In the future, the present number and configuration of inlets is likely to remain constant or to decrease. As sedimentation and infilling continue, the tidal prism will gradually decrease and inlet throats will narrow. Smaller inlets, such as Corson Inlet, may close entirely provided enough sediment continues to be supplied through the longshore and onshore transport systems. The post-1800 capture of sediment by updrift engineered structures decreases the sediment available to the system, which could slow the infilling process. Therefore, Long Beach Island to the north of the study area may progress to the next stage in the evolutionary model at a slower rate.

164. Geomorphic and stratigraphic evidence indicates the historical and geological significance of inlet-transported sediments for the southern New Jersey marshes and lagoons. However, it remains to be determined how much sediment is currently being transported through inlets and trapped in the backbarrier. This issue is fundamental to thoroughly understanding the future evolution of the study area.

PART V: CONCLUSIONS

165. Since the late Pleistocene and throughout the Holocene, rising sea level has stimulated the landward migration of barrier islands. Historically, sediment transport by rivers, by overwash, and most importantly, by tidal currents through inlets, has contributed large quantities of sediment to the backbarrier. Although the ocean shoreline has moved landward in historical time, the backbarrier-upland boundary has maintained a generally stable position. Antecedent topography and the marsh-filled backbarrier contribute to this stability.

166. The major conclusions of this research are as follow:

- a. The stratigraphic section fines upward from a dominantly sandy facies to tidal flats and marshes that are predominantly fine-grained mud.
- b. The rate of sea-level rise has decreased throughout the Holocene. A marked decrease in the rate of sea-level rise indicated at approximately 2,000 years B.P. allowed marshes to become established and thus promoted infilling of the system.
- c. Sources of sediment to the backbarrier have changed through time:
  - (1) Streams and rivers previously deposited fluvial-deltaic sediments into the backbarrier. These sediments have provided the foundation for intertidal sedimentation and subsequent marsh growth in the landward portion of the backbarrier region.
  - (2) The modern coastal plain rivers contribute very little sediment and seem to be tidally dominated in their lower reaches.
  - (3) Overwash into the backbarrier is not occurring extensively now and has not been a quantitatively important source of sediment for the backbarrier during late Holocene time.
  - (4) The inner continental shelf, shoreface, and adjacent beaches supply the majority of sediment to the backbarrier system. This sediment is transported through the inlets by flooding tides and is redistributed throughout the region by tidal currents.
- d. The backbarrier system of southern New Jersey has undergone dramatic geomorphic change throughout Holocene time.
  - (1) In the past, onshore barrier island migration contributed to the evolution from a wide and shallow open-water lagoon, to a predominantly marsh-filled system. The marshes nearest the mainland are built upon fluvially derived sediment deposited during lower sea-level conditions, whereas the marshes nearest the barrier islands

are built upon marine-derived sediment transported through tidal inlets.

(2) The modern lagoons represent a zone that was not affected by earlier fluvial-deltaic sedimentation and has not yet been filled with flood-tidal delta deposits. Although the position of these lagoons should remain constant through time, they will shoal and shrink as low-energy backbarrier sedimentation continues. Sedimentation will also continue in the marshes provided the supply of fine-grained sediment and the rate of sea-level rise are similar to that of the last 2,000 years.

167. Expected changes in the geomorphology of the southern New Jersey coast include continued narrowing of the subaerial portion of the barrier islands, rather than landward migration of the entire island. This is due to the lack of extensive overwash events and to the highly structured nature of the coast. If the islands become extremely narrow due to continued shoreface erosion, overwash could become a significant process in low dune areas, and landward migration of the barrier island could occur. As the subaqueous shoreface is eroded, significant quantities of fine beach sand and exposed ancient lagoonal mud will be available for transport and deposition along the coast and in the backbarrier areas.

168. In the future, the number of tidal inlets should decrease due to the continuous supply of sediment that reduces the tidal prism and hence diminishes the efficiency of existing inlets. New inlets are not likely to open along the southern New Jersey coast due to the relatively marsh-filled nature of the backbarrier region. Storms could potentially create ephemeral inlets in locations where the barrier islands are very narrow; however, these should close quickly due to the volume of longshore sediment transport and insufficient tidal sediment transport.

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APPENDIX A: VIBRACORE LOGS

1. Graphic and descriptive logs of the 24 vibracores are presented in this appendix. The location of each transect and a description of the core numbering system are found in the main report (Figure 4).

2. The core logs are labeled with a transect name and core number, total depth of penetration and total compaction. Each core log is annotated with a foot and metre scale to delineate depth below the marsh surface. A description of the physical characteristics, the sedimentary structures, and the macrofauna is given. The depths of specific sediment samples are shown with an arrowhead along the right side of the core and a sample number. Grain-size results for each sample are indicated by percent sand:silt:clay and by percent coarse:medium:fine sand. These results are also graphed to the right of the core. Radiocarbon dates are indicated at the appropriate depth of the organic material that was dated. Lastly, the depositional environment is shown at the left of the core and by symbol within the core.

Total Depth : 2.1 m
Total Compaction : none

Environment	Description	Sa:Si:Cl	Co:Me:Fi
Beach	Light grey, fine sand with small scattered shell fragments.		
		100:00:00	03:04:93
	Heavy mineral laminae at 0.3 and 0.9-1.2 m; increase in % heavy minerals with depth from 2 % at surface to 10-20 % at base.		
	Concentrated heavy minerals (30 %) in laminae.	100:00:00	01:04:95

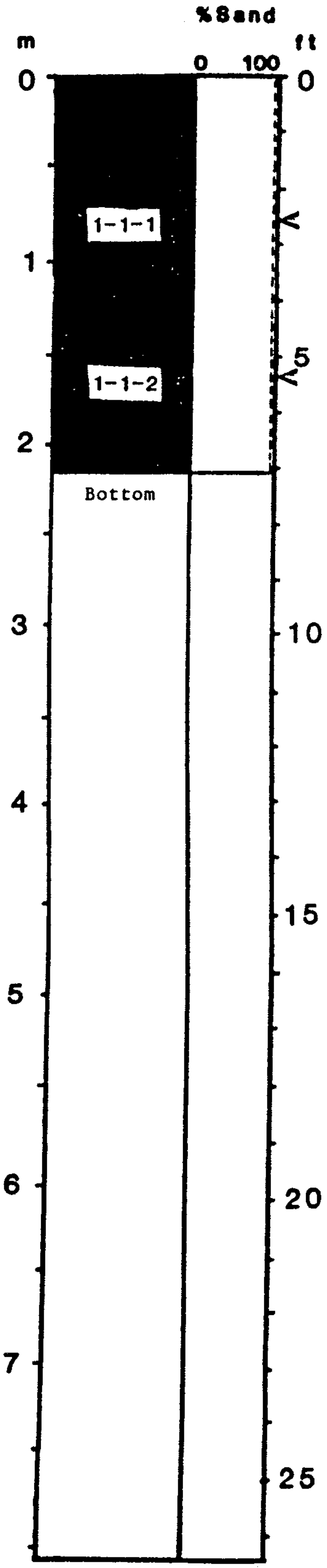


Figure A1. Wildwood transect core 1-1

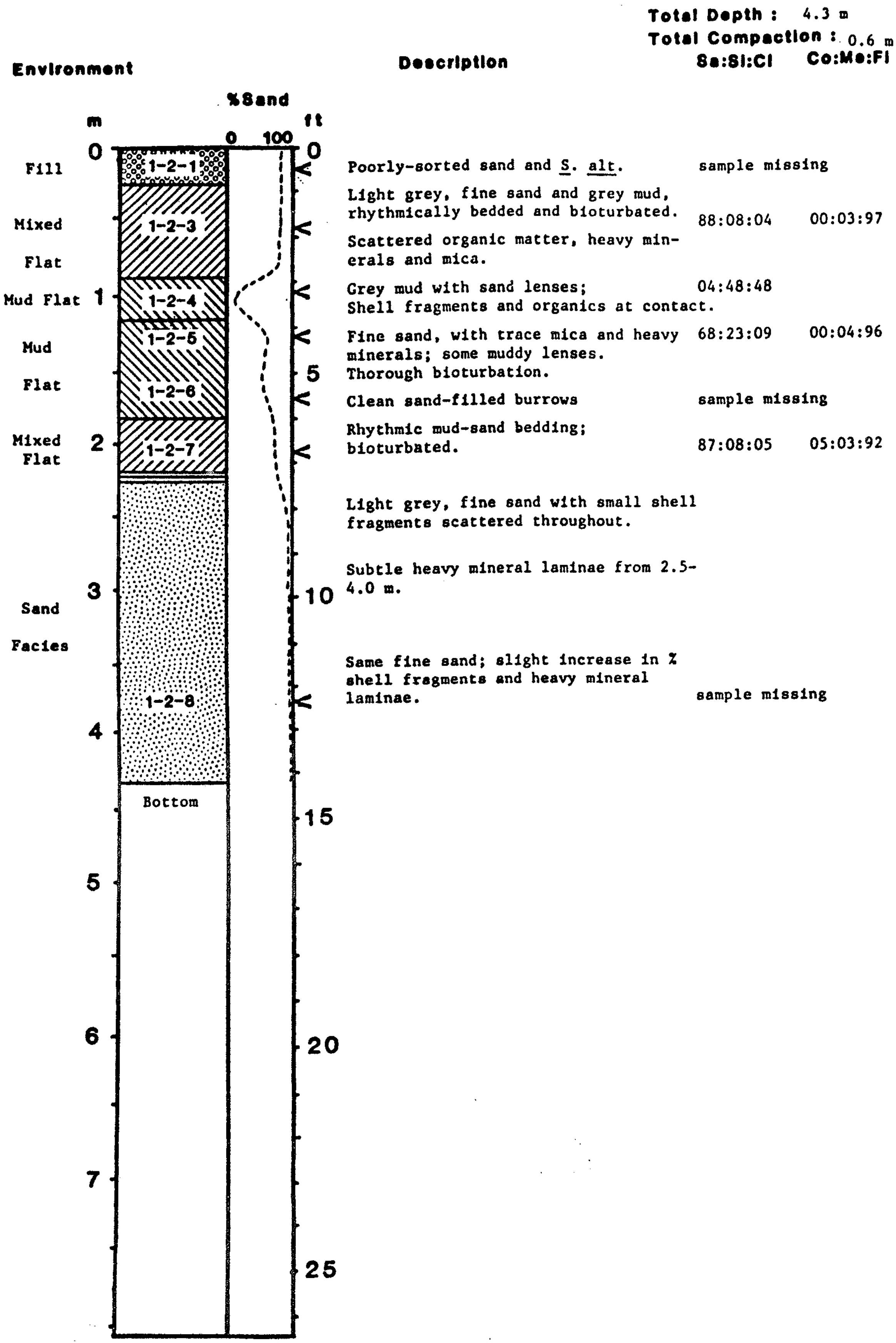
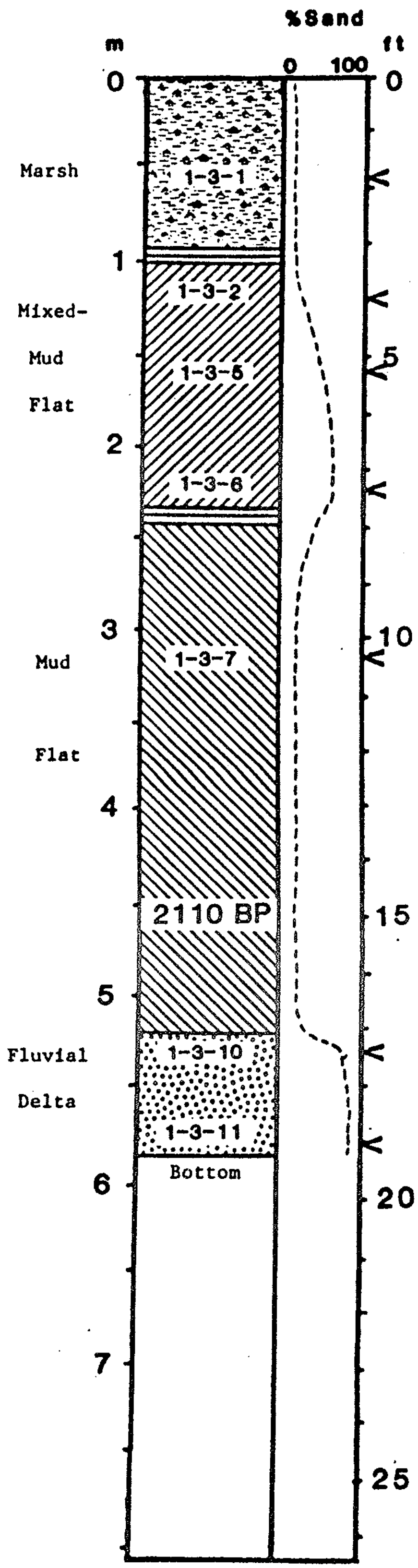


Figure A2. Wildwood transect core 1-2

Total Depth : 5.85 m
Total Compaction : 0.4 m



Description	Sa:Si:Cl	Co:Me:Fi
Dark grey mud and dense S. alt. stems, roots, and leaves; 5-10% fine sand.	10:50:40	
Shells in mud: Crassostrea virginica, Modiolus demissus, and Ilyanassa obsoleta at contact.	12:61:27	
Dark grey mud with thin, fine sand lenses disturbed by bioturbation. Sand-filled burrows scattered.	48:32:20	01:02:97
Scattered organics. Modiolus demissus and Ilyanassa obsoleta in sandier substrate.	57:28:15	01:02:97
Clayey mud with trace fine sand; sand fills burrows.		
Ensis directus, in situ.	08:51:41	
Scattered organic matter throughout.		
Subtle bioturbation throughout.		
Same clayey mud substrate.		
Crassostrea virginica zone of mostly fragmented shells.		
Crassostrea virginica zone with whole and fragmented shells.		
Dark brown sand with scattered pebbles and some mud.	78:14:08	11:31:58
Sand becomes cleaner with depth. Oxidized sand with micaceous mud laminae and pebbles.	84:11:05:	04:39:57

Figure A3. Wildwood transect core 1-3

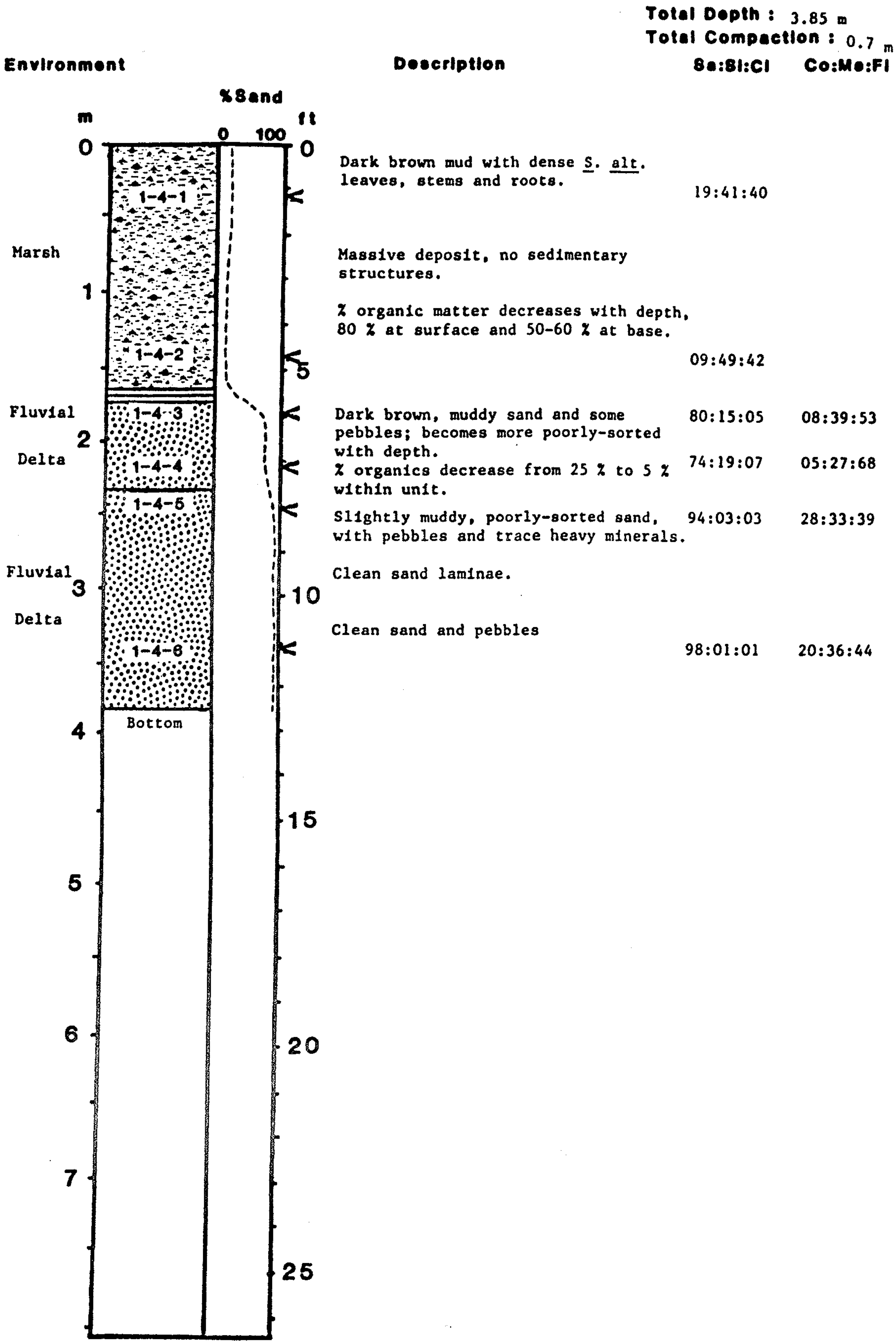


Figure A4. Wildwood transect core 1-4

Total Depth : 2.1 m
Total Compaction : none

Environment	Description	Sa:Si:Cl	Co:Me:Fi
	Light grey, fine sand; 2-3 % heavy minerals.	100:00:00	05:13:82
Beach	Heavy mineral laminae at 0.75 m.	100:00:00	01:05:94
	Heavy mineral laminae at 1.2 m.		
	Same light grey, fine sand	100:00:00	00:00:100
	Heavy mineral laminae at 2.0 m.		

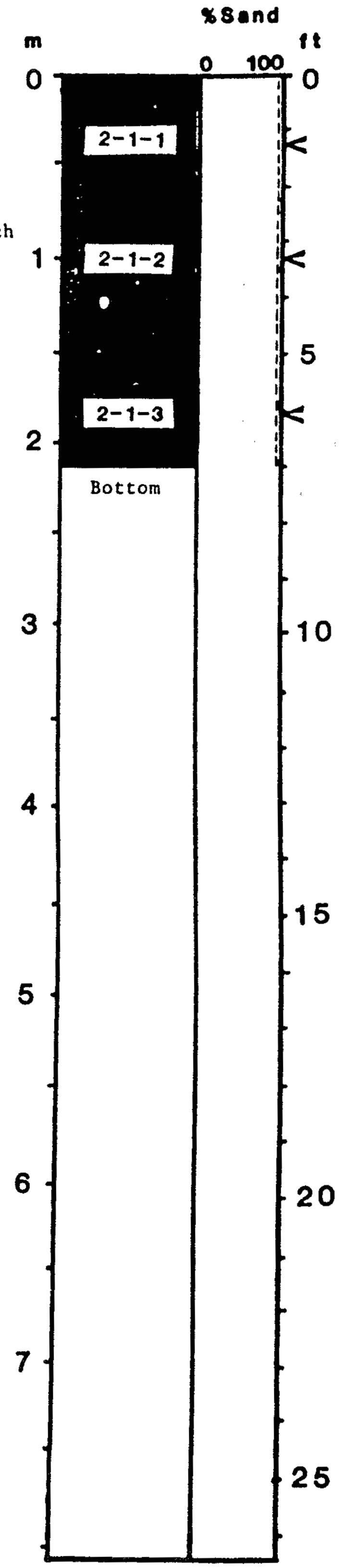


Figure A5. Stone Harbor transect core 2-1

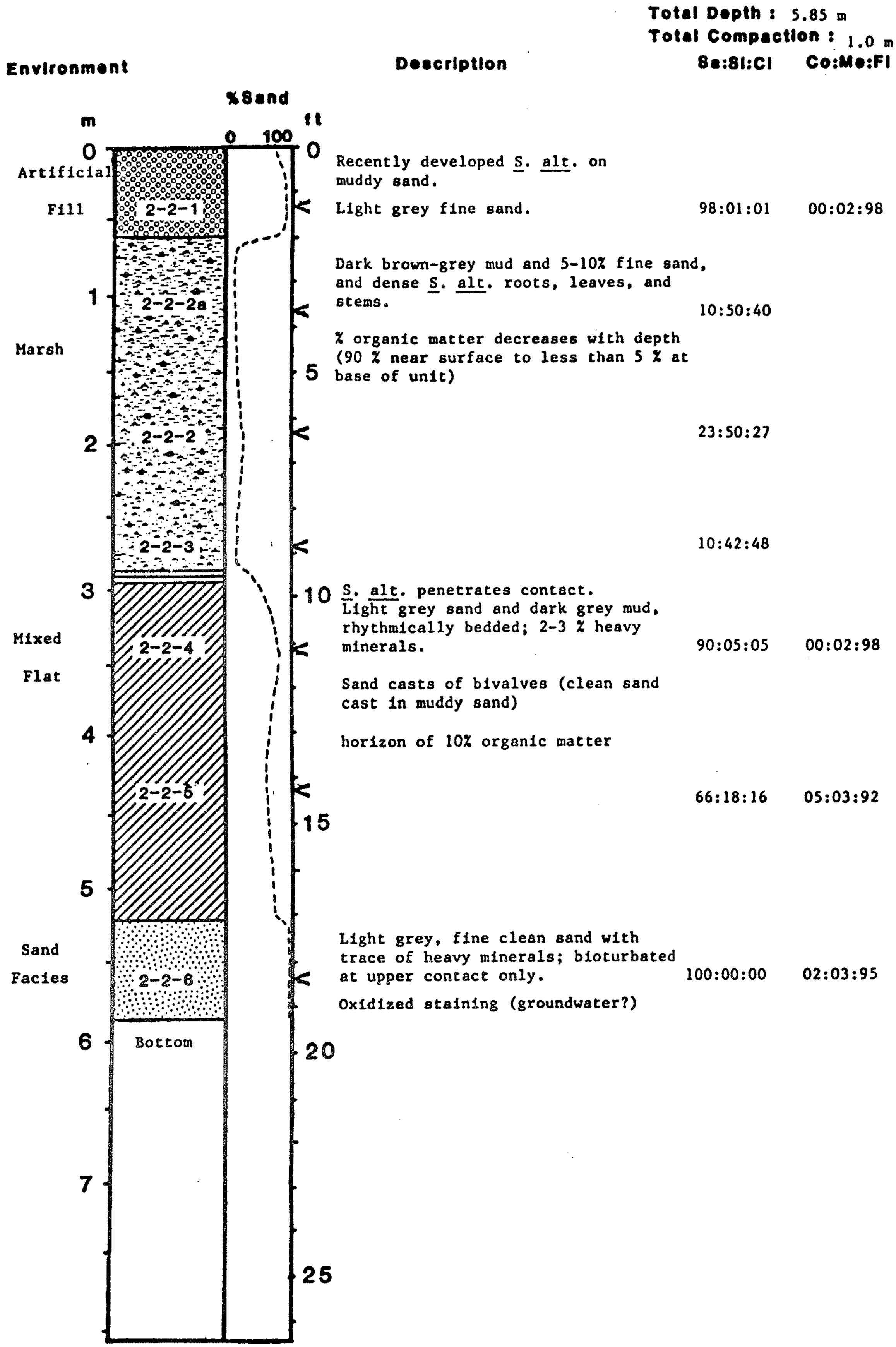
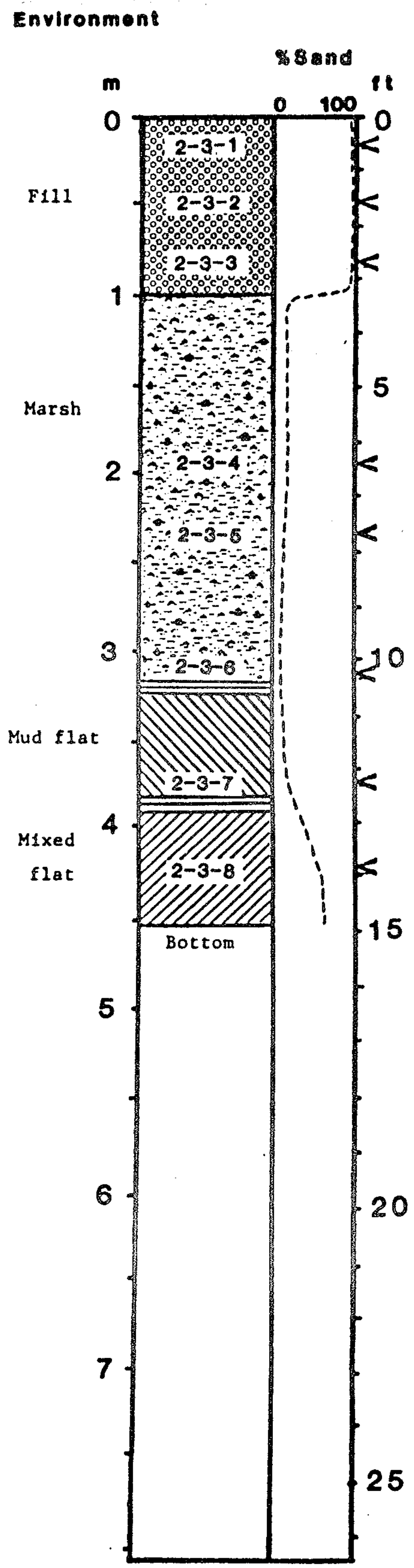


Figure A6. Stone Harbor transect core 2-2

Total Depth : 4.5 m

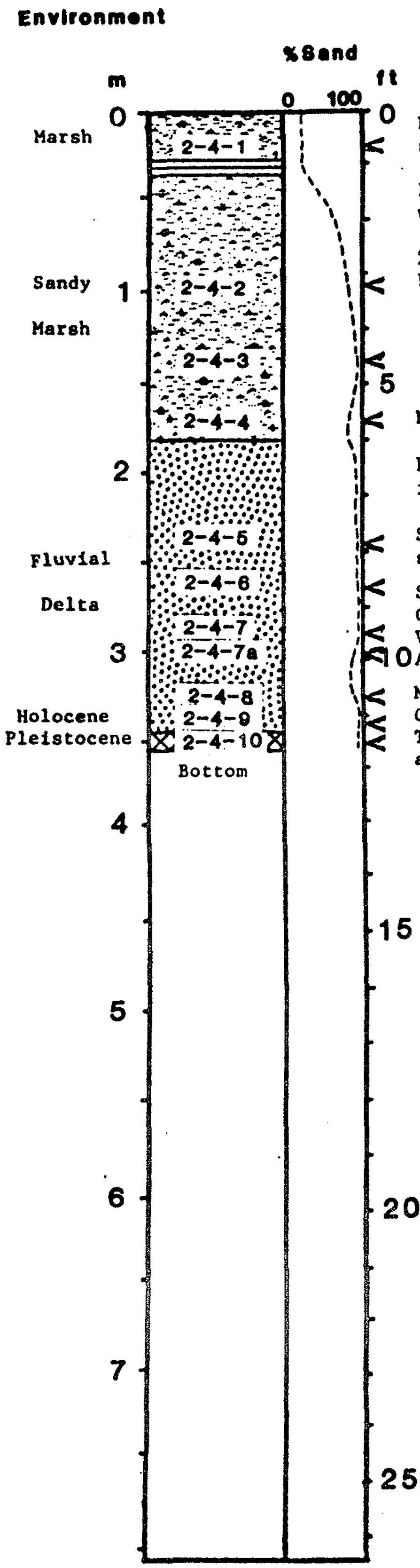
Total Compaction : none



Description	Sa:Si:Cl	Co:Me:Fi
Poorly sorted sand, mud and S. alt.	96:03:01	03:37:60
Medium-fine sand, mud and pebbles. Resembles Cape May Formation.	95:03:02	15:35:50
Poorly-sorted sand and pebbles	100:00:00	15:37:48
Grey mud and S. alt. vegetation; % organic matter decreases with depth.		
Ilyanassa obsoleta in situ.		
	14:47:39	
Barren zone: no organic matter in mud.		
	10:47:43	
30-40 % S. alt. in mud.		
Ilyanassa obsoleta	05:55:40	
Scattered organics only.		
Mud becomes sandy.	15:45:40	
Grey muddy, fine sand; 2-3 % heavy minerals and mica; scattered organics. Rhythmic bedding is moderately bioturbated.	60:21:19	01:02:97

Figure A7. Stone Harbor transect core 2-3

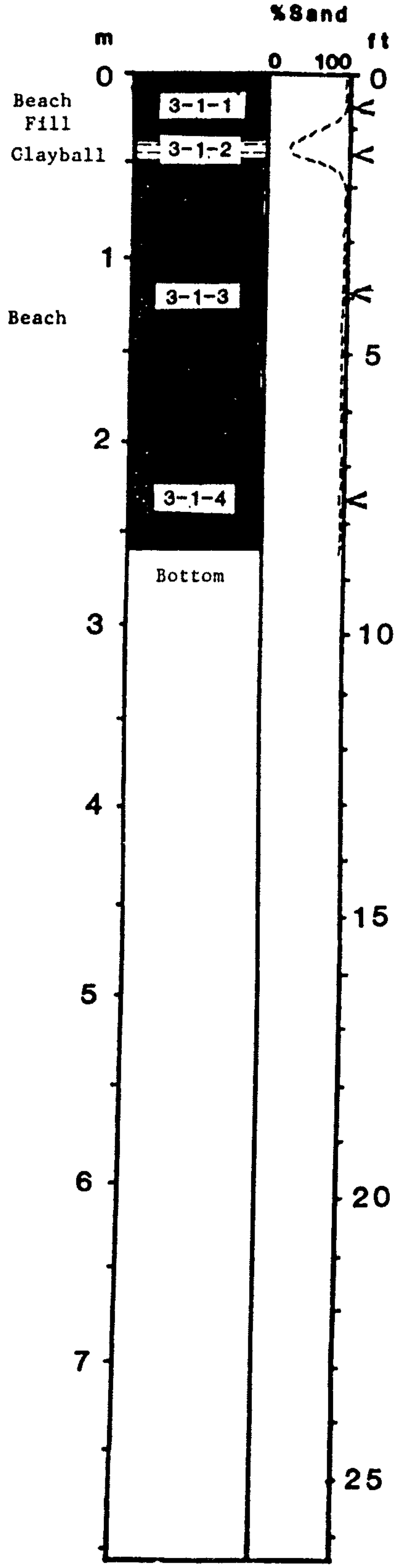
Total Depth : 3.55 m
Total Compaction : none



Description	Sa:Si:Cl	Co:Me:Fi
Dark brown mud and S. alt.; % organic matter decreases with depth.	12:42:46	
Brown-grey muddy sand; % mud decreases with depth.		
% organic matter decreases with depth; becomes S. patens (finer texture)	79:10:11	04:29:67
	96:02:02	08:49:44
Muddy, well-rounded gravel at contact	85:12:03	04:19:77
Light grey, fine sand to gravel; gravel is poorly-sorted and well-rounded.		
Several fining upward sequences with sharp contacts between sequences.	98:01:01	06:07:87
Slightly orange pebbles (reworked Cape May Formation)	100:00:00	33:16:52
V. fine micaceous sand laminae	100:00:00	01:06:93
Alternating silt and fine sand.	96:02:02	02:04:94
Medium-coarse sand and pebbles	100:00:00	27:26:46
Oxidized fine sand (thin lamina)	100:00:00	03:03:94
Thoroughly oxidized (orange) sand and gravel.	100:00:00	26:27:47

Figure A8. Stone Harbor transect core 2-4

Total Depth : 2.6 m
Total Compaction : 0.3 m



Description	Sa:Si:Cl	Co:Me:Fi
Light grey-tan, poorly-sorted sand and granules.	100:00:00	23:22:55
Grey mud and scattered organics	22:37:41	
Light grey, fine sand; 2-3 % heavy minerals.		
Interbedded mud and sand.	100:00:00	01:06:93
No shells, some scattered organics.		
Subtle heavy mineral laminae.	100:00:00	00:03:97

Figure A9. Sea Isle City transect core 3-1

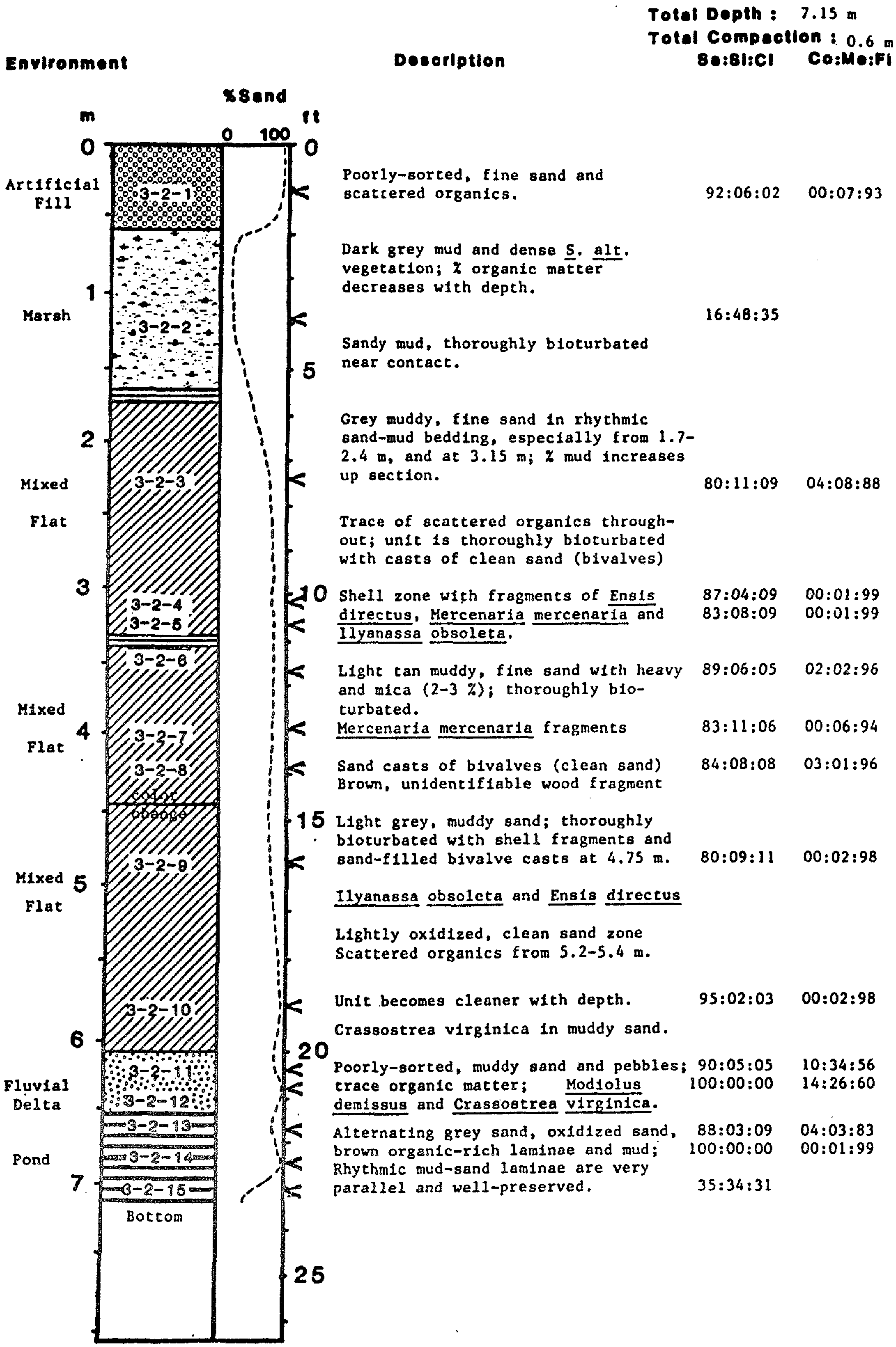
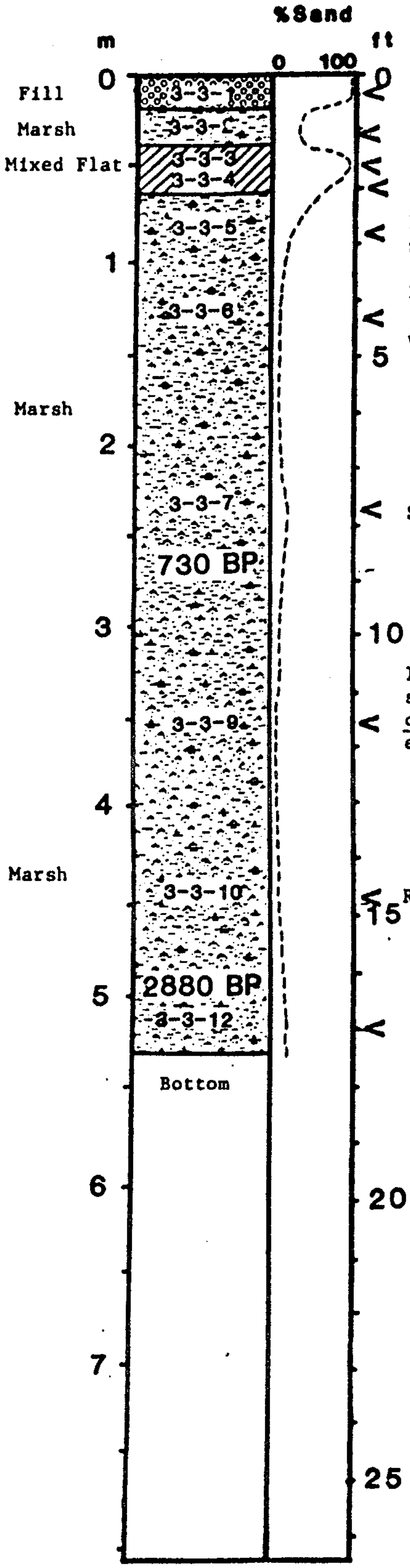


Figure A10. Sea Isle City transect core 3-2

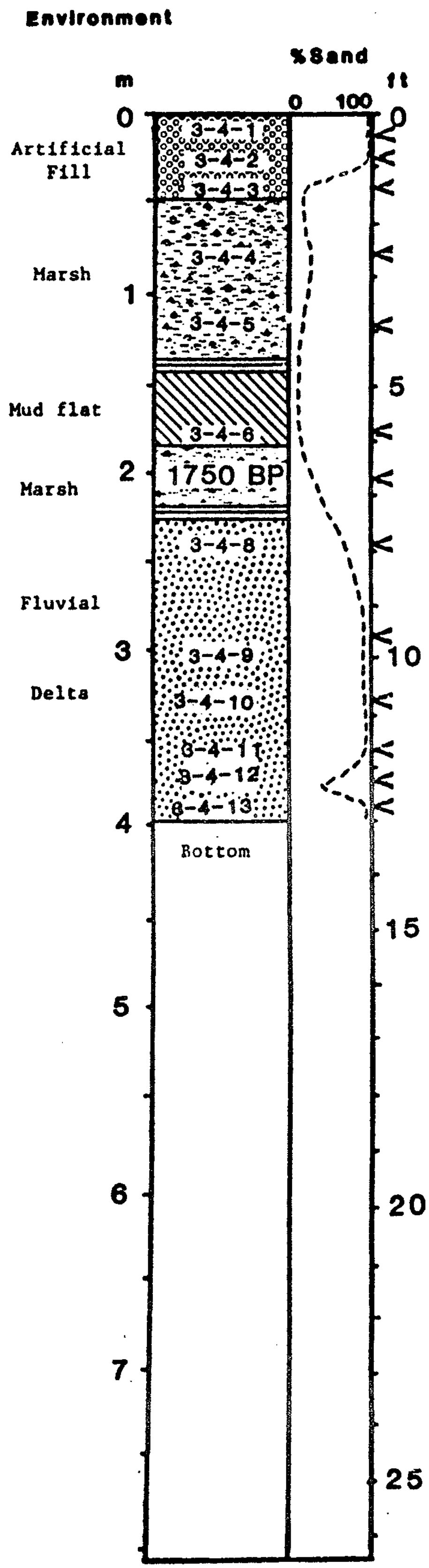
Total Depth : 5.3 m
Total Compaction : none



Description	Sa:Si:Cl	Co:Me:Fi
Oxidized sand and gravel; *S. alt.*	100:00:00	47:28:25
Brown gritty mud and dense *S. alt.*	32:40:28	
Light grey muddy, fine sand, pebbles.	100:00:00	02:39:59
Rhythmic sand/mud bedding and shell.	74:22:04	03:02:95
Laminae of v. fine, well-sorted, micaceous sand at 0.9-1.1 m.	19:36:45	
Brown-grey mud and dense *S. alt.* vegetation; % organic matter decreases with depth.	03:59:38	
Same brown-grey mud and organic matter.	14:65:21	
Increase in % mud and decrease in % organics; several *Ilyanassa obsoleta* and *Ensis directus* fragments; may represent ephemeral mud flat environment.	01:41:58	
Return to brown-grey mud and organic matter.	04:46:50	
	11:46:43	

Figure A11. Sea Isle City transect core 3-3

Total Depth : 4.0 m
Total Compaction : 0.3 m



Description	Sa:Sl:Cl	Co:Me:Fi
Poorly sorted sand and pebbles.	100:00:00	26:25:49
	100:00:00	00:19:81
Gritty mud and fine sand	12:67:21	
Brown-grey mud with dense S. alt. vegetation; % organic matter decreases with depth.	13:48:39	
Massive deposit: no shells or sedimentary strucures	05:45:50	
Grey, silty clay with some fine sand and scattered organics	03:52:45	
Dark brown-black sandy peat, somewhat dessicated.		
Grey-tan, muddy sand; sand is poorly-sorted with some pebbles and gravel. (reworked Cape May Formation)	67:23:10	17:35:48
	95:01:04	28:37:36
Several small unidentifiable shell fragments		
Clean sand and gravel	100:00:00	55:10:35
Poorly-sorted, oxidized coarse sand and pebbles.	100:00:00	38:18:44
Fine sand, mica and heavy minerals.	43:55:02	00:02:98
V. fine-fine oxidized sand.	100:00:00	01:01:98

Figure A12. Sea Isle City transect core-34

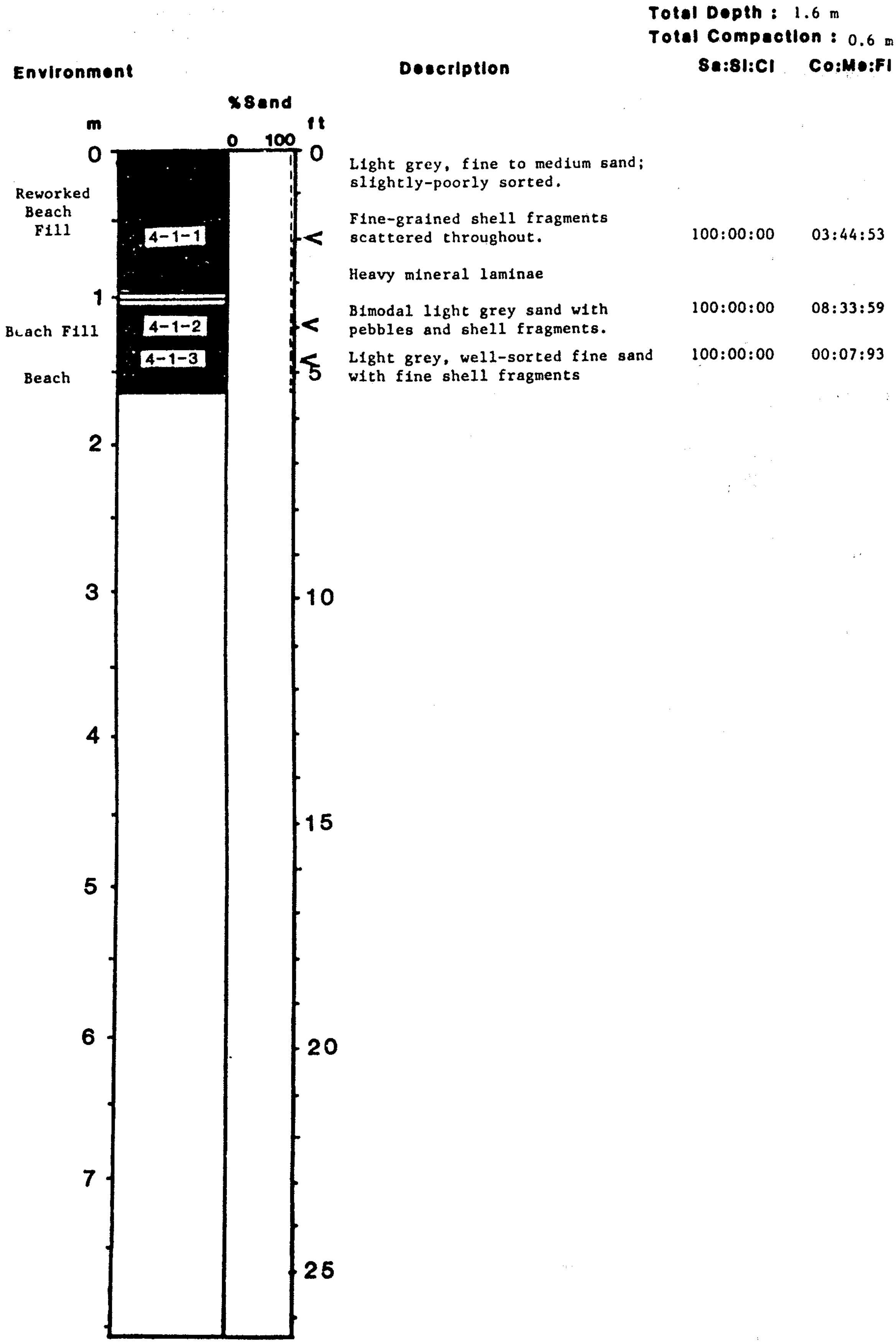
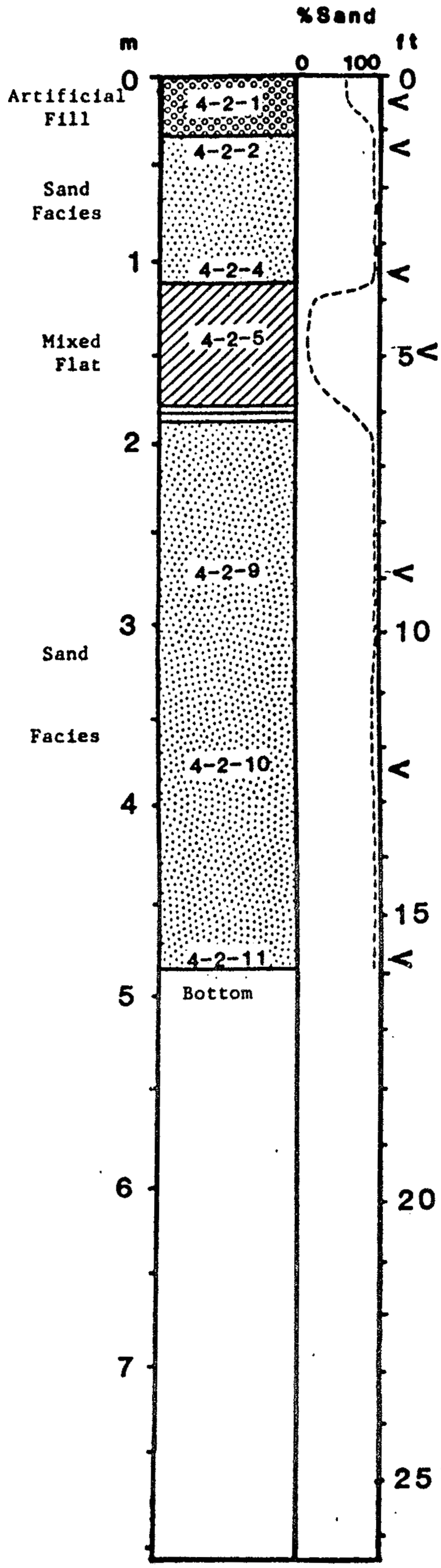


Figure A13. Ocean City transect core 4-1

Total Depth : 4.8 m
Total Compaction : 1.7 m
(core slipped)



Description	Sa:Si:Cl	Co:Me:Fi
Grey muddy sand and S. alt.	63:19:18	
Light grey-tan, fine sand with few mud lenses (0.45 and 0.93 m) Trace-2 % mica and heavy minerals, decreasing up section.	100:00:00	02:06:92
	100:00:00	02:05:93
Brown-grey, silty mud with light grey, well-sorted sand; 2 % mica. Intermittent sand and mud bedding. Moderate bioturbation throughout. Ilyanassa obsoleta, in situ (several)	16:51:34	
Light grey, slightly oxidized, fine sand. Sand is well-sorted with 2-3 % heavy minerals and mica. Ensis directus Unidentifiable wood fragment	100:00:00	03:03:94
Small shell fragments scattered throughout.		
Trace organic fragments in infrequent mud lenses (1 mm thick)		
	100:00:00	04:02:96
Same light grey sand.		
	100:00:00	00:01:99

Figure A14. Ocean City transect core 4-2

Total Depth : 5.1 m
Total Compaction : 1.0 m

Environment	Description	Sa:Sl:Cl	Co:Me:Fl
Marsh	Dark brown mud with S. alt. roots and stems; % organic content decreases with depth. Fine micaceous sand horizons, 0.7-0.9 m. Partially weathered, unidentifiable shell and Littorina irrorota in slightly bioturbated mud.	18:46:36	
Mud flat	Littorina irrorota in mud with scattered organics.	08:57:35	
Sand Facies	Light grey sand with mud lenses and oxidized (orange) zones at 1.9-2.3 and 3.2-3.4 m. Mud lenses are bioturbated. Scattered organic material, including small dark brown twig at 2.1 m.	100:00:00	00:01:99
	Discrete mud lenses from 2.1-3.0 m. % mud decreases with depth	100:00:00	03:02:95
	Heavy mineral laminae from 3.2-3.4 m. Shell hash and whole Ensis directus, Mercenaria mercenaria, Littorina irrorota, and Peticola pholodiformis	100:00:00	00:05:95
Mixed flat	Light grey, fine sand with dark grey mud; scattered organics throughout. Littorina irrorota and 25 cm long, mud-filled bivalve escape structure. Slightly bioturbated mud lenses	82:11:07	01:04:95
	Ensis directus fragments and Littorina irrorota (whole)	100:00:00	01:04:95
	Clean sand-filled casts in muddy sand. Modiolus demissus fragments	54:24:22	

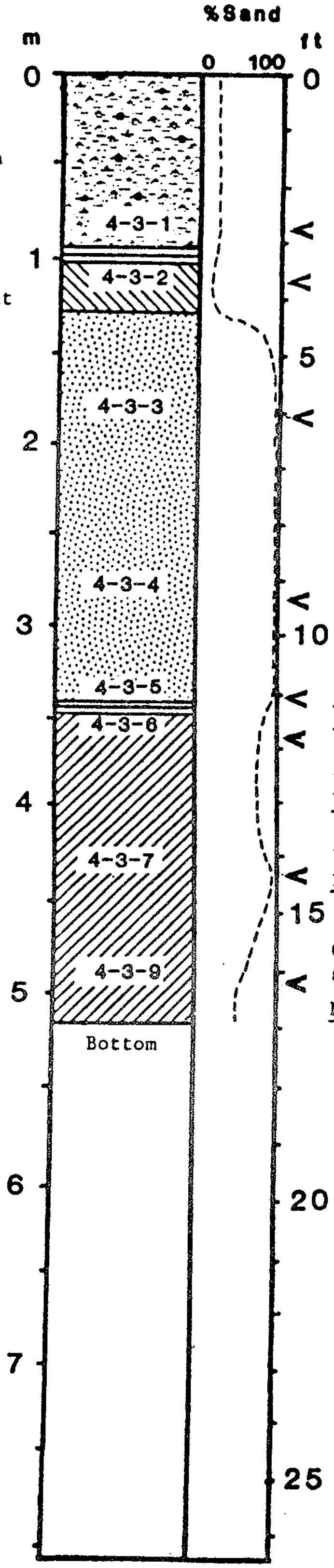


Figure A15. Ocean City transect core 4-3

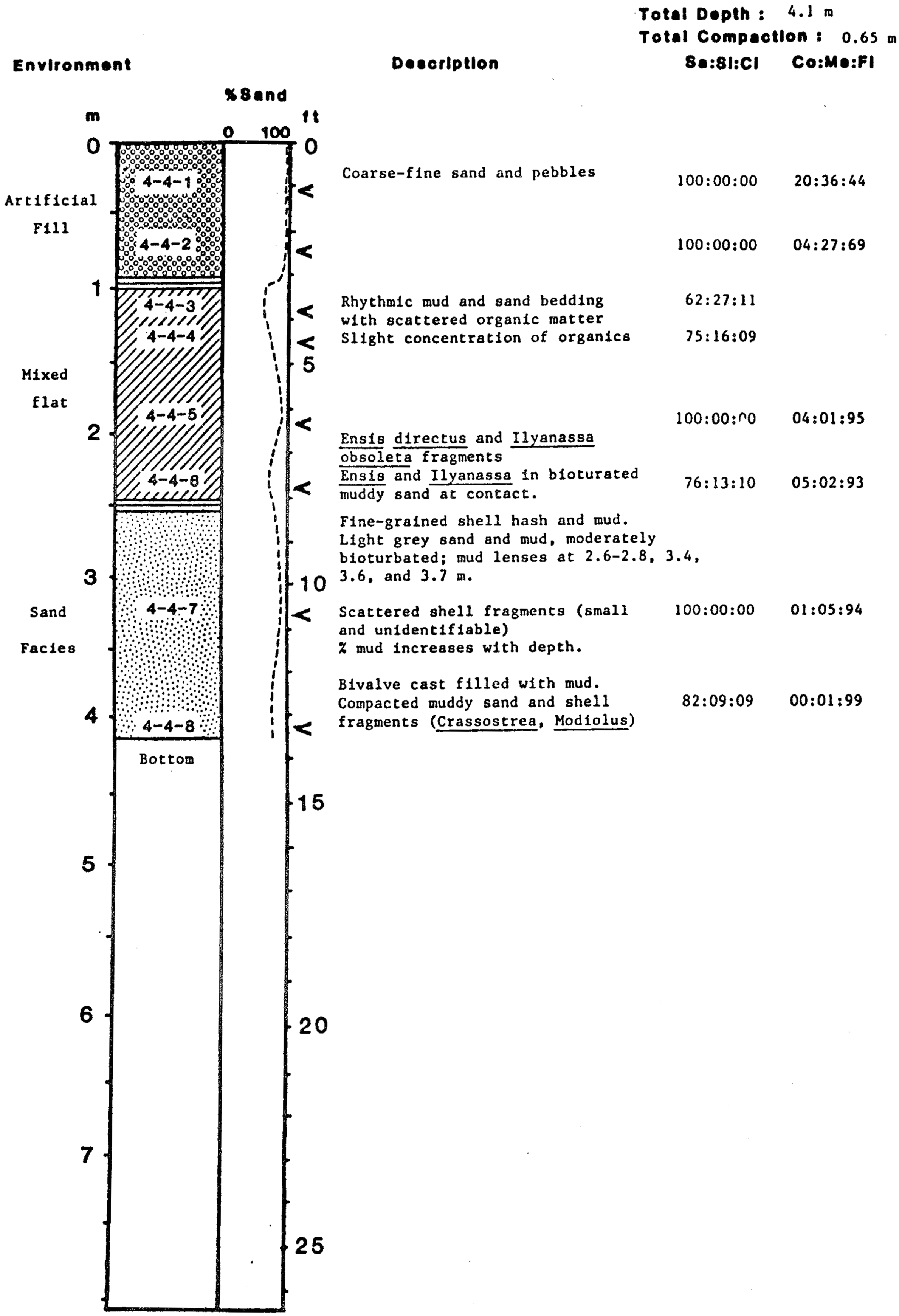
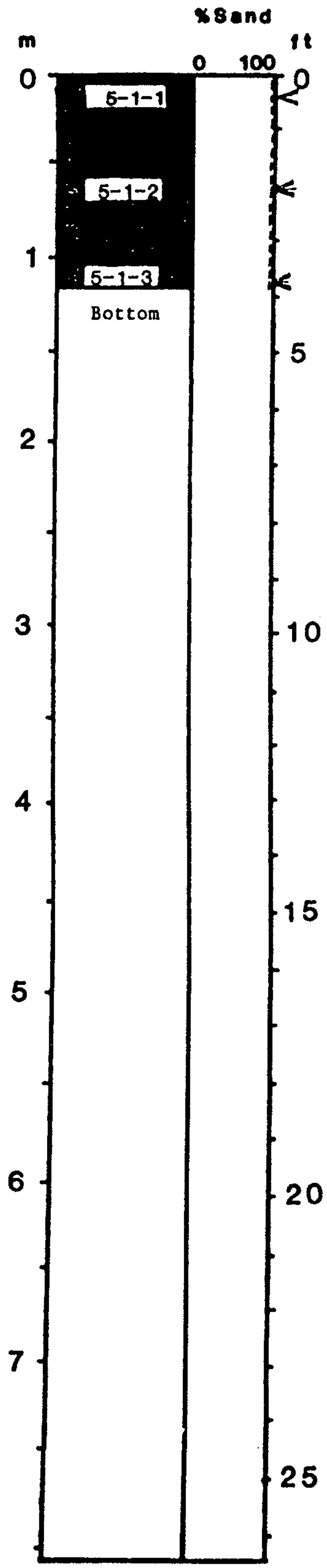


Figure A16. Ocean City transect core 4-4

Total Depth : 1.2 m
Total Compaction : none



Environment	Description	Sa:Si:Cl	Co:Me:Fl
Beach	Light tan, fine-medium sand with 1-2 % heavy minerals.	100:00:00	01:32:67
	Heavy mineral laminae at 0.5, 0.75, and 1.2 m.	100:00:00	01:41:58
	<u>Ensis directus</u>, <u>Anaderra odulus</u>, and <u>shell fragments</u>	100:00:00	00:02:98

Figure A17. Margate City transect core 5-1

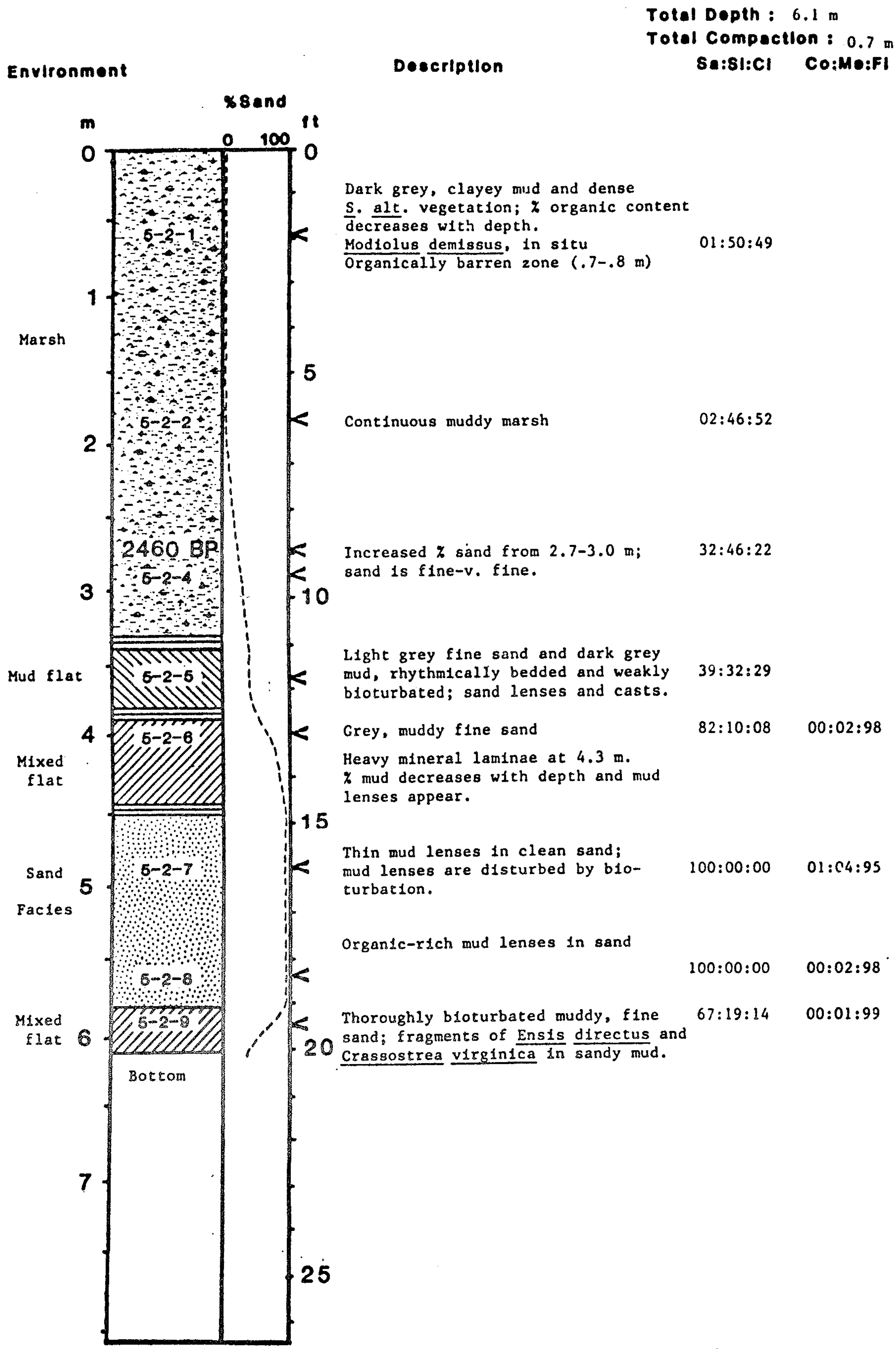


Figure A18. Margate City transect core 5-2

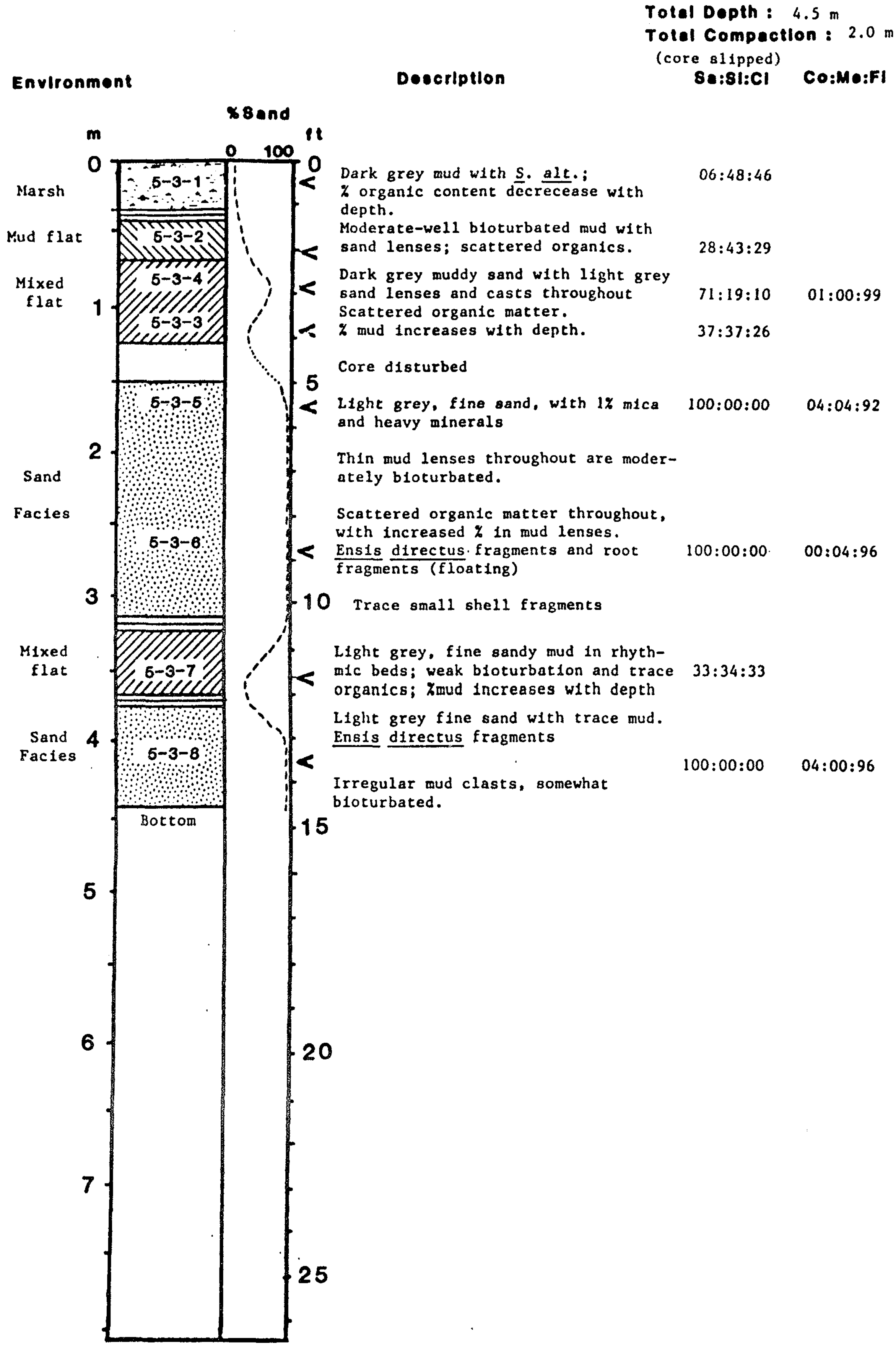


Figure A19. Margate City transect core 5-3

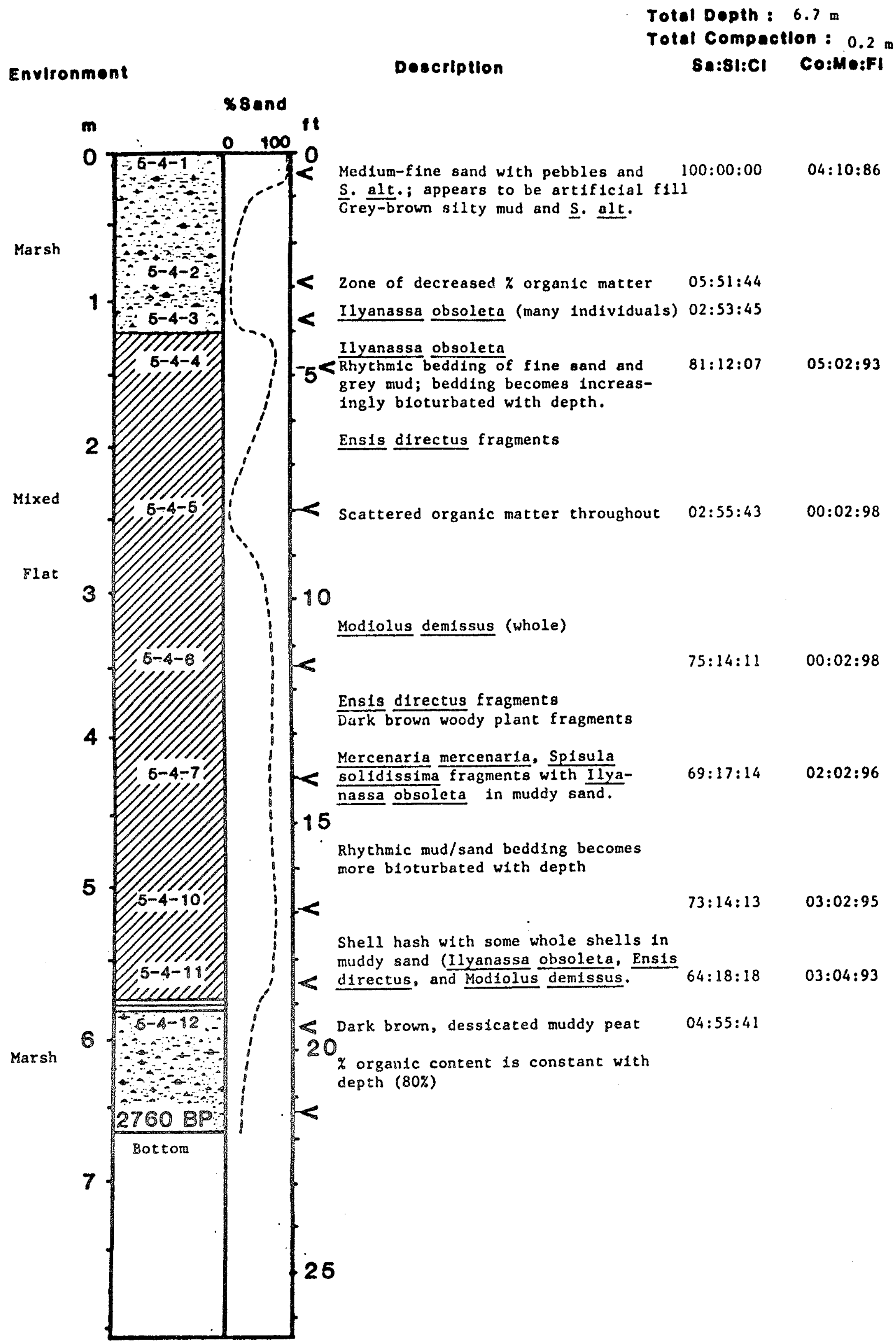


Figure A20. Margate City transect core 5-4

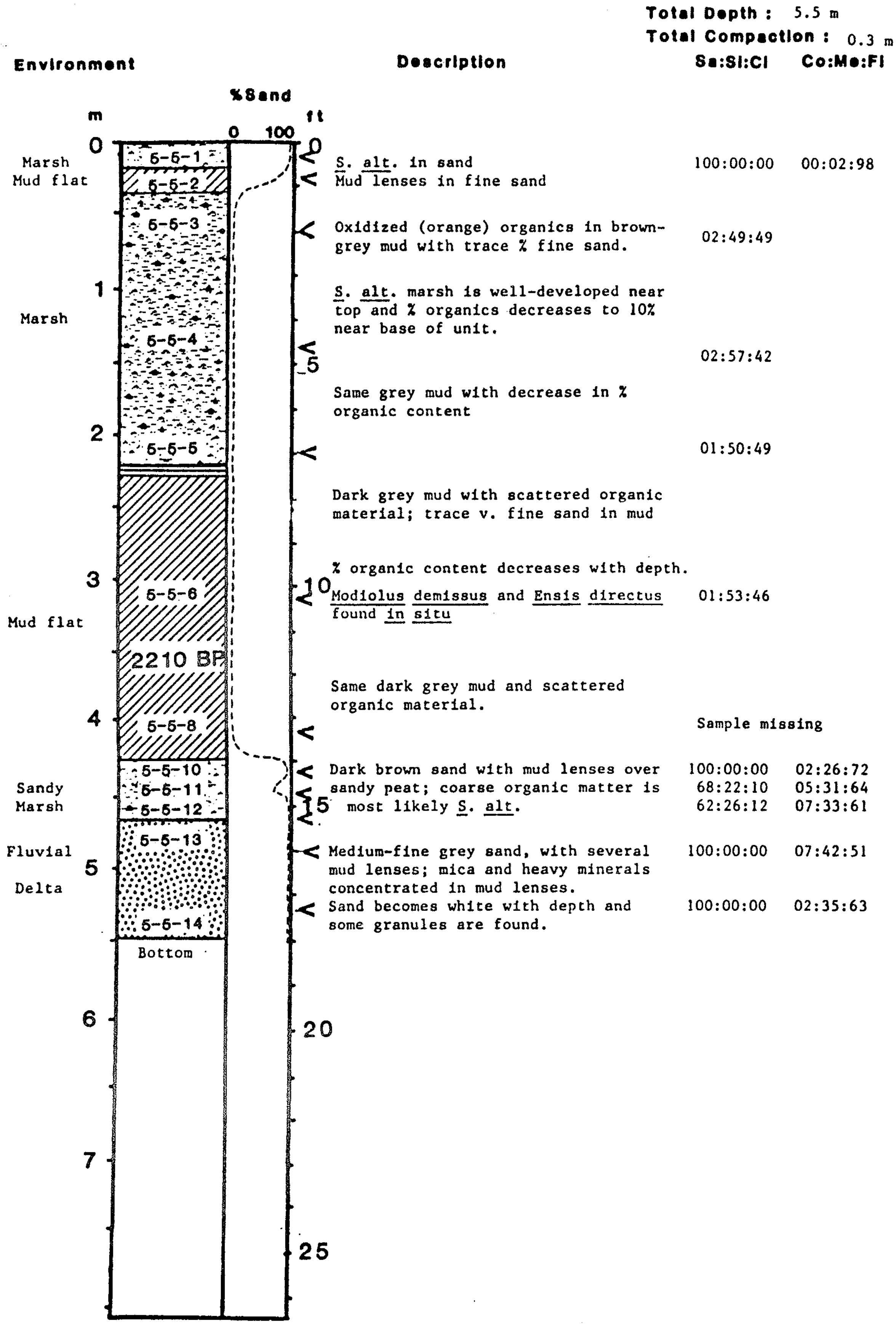


Figure A21. Margate City transect core 5-5

Total Depth : 1.6 m
Total Compaction : 0.2 m

Environment	Description	Sa:Si:Cl	Co:Me:Fi
	Light grey, fine sand with 3-4 % heavy minerals and mica.		
	Heavy mineral laminae at 0.1, 0.6, 0.7, 0.8, and 1.1 m.	100:00:00	02:15:83
	Unidentifiable shell fragments at 0.95 m; contact based on color change.		
	Light grey fine sand; heavy mineral laminae at 1.3 m; scattered shell fragments.	100:00:00 100:00:00	02:18:80 01:02:97

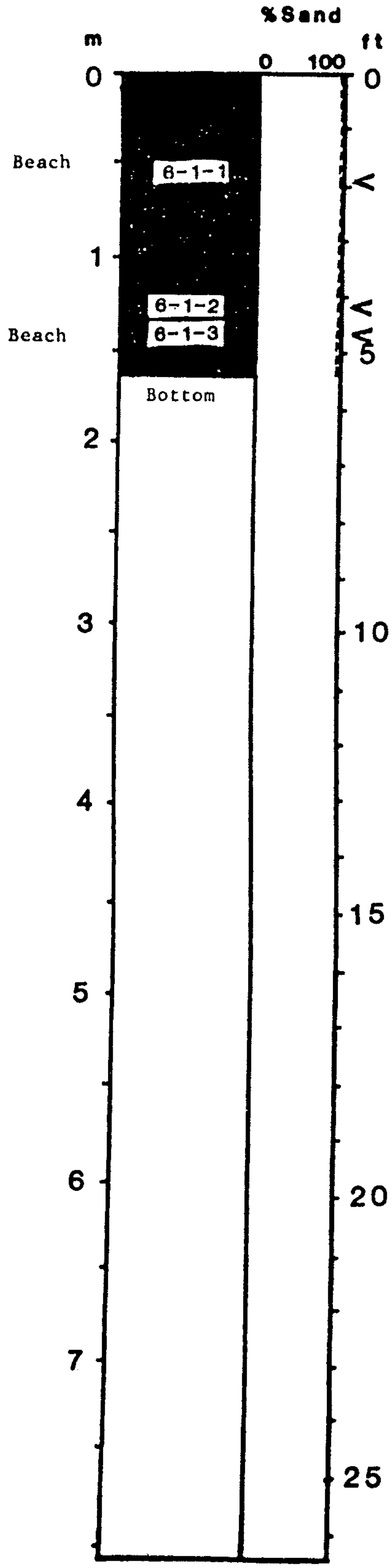
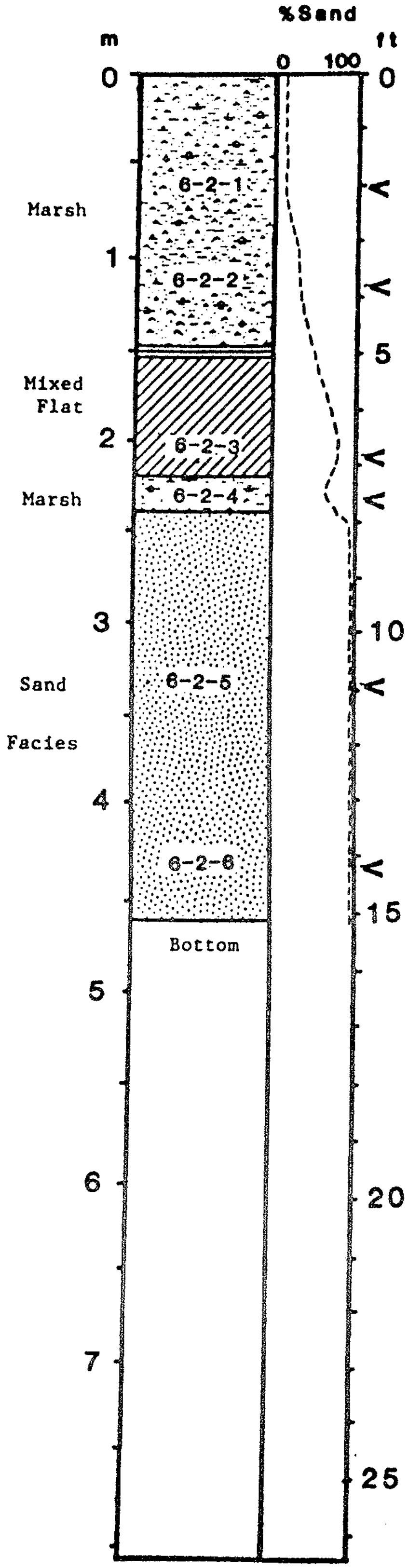


Figure A22. Brigantine transect core 6-1

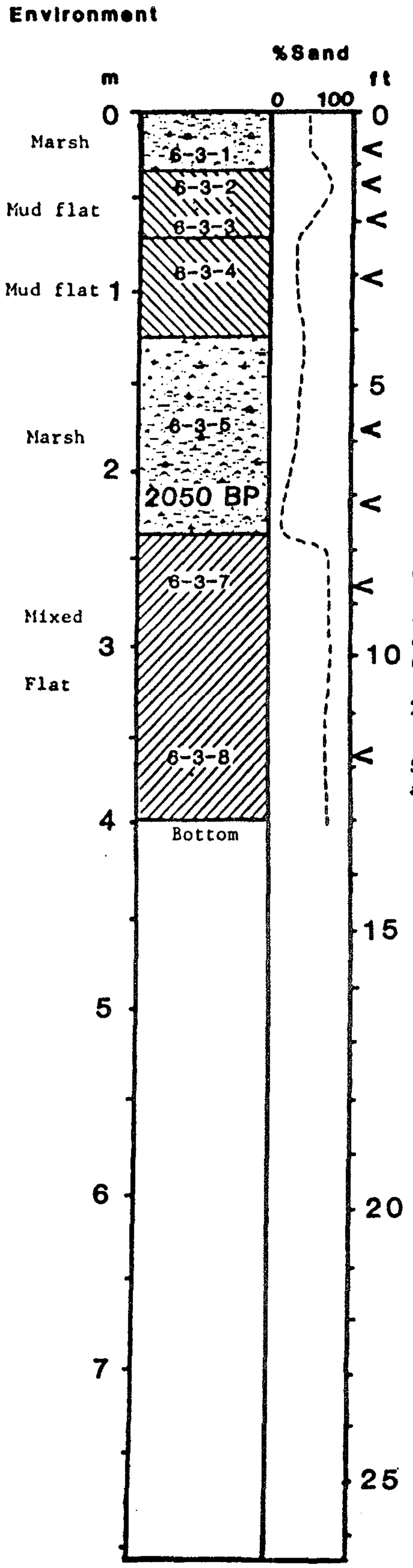
Total Depth : 4.9 m
Total Compaction : 1.4 m



Description	Sa:Si:Cl	Co:Me:Fi
Dark brown mud and dense S. alt. vegetation.		
% organic content decreases dramatically with depth.	07:57:36	
% sand (v.fine-fine) increases with depth, as does % mica (2-3%)	36:41:23	
Dark grey, rhythmically bedded, muddy sand. Weak bioturbation and scattered organics throughout.	86:08:06	01:03:97
Sandy peat with 20% organics	95:05:00	00:02:98
Light grey, fine sand and dark grey mud lenses; mud lenses contain 3% mica. Mud-filled bivalve cast.		
Thin, discrete mud laminae at 3.4-3.6 m.	100:00:00	00:02:98
Same as above.	100:00:00	00:03:97

Figure A23. Brigantine transect core 6-2

Total Depth : 4.1 m
Total Compaction : 3.1 m,
(core slipped)



Description	Sa:Si:Cl	Co:Me:Fi
Dark brown, silty mud and S. alt. organics decrease with depth	48:37:15	
Brown-grey, fine micaceous sand and mud as rhythmic bedding; sand lenses	78:17:05	01:01:98
disturbed by bioturbation	48:31:21	03:01:96
Dark grey, silty mud-v. fine sand; % sand increases with depth. Scattered organics throughout; Crassostrea virginica (whole shell and fragments)	32:42:27	
Thoroughly bioturbated medium-dark grey, muddy sand-sandy mud; scattered organics, increasing with depth. Fine, well-sorted sand decreases with depth.	39:54:07	00:03:97
Increase to 20% organic content		
Grey, muddy, fine sand; 3% mica in mud; rhythmic bedding is present but moderately bioturbated; scattered organics throughout. Core slightly disturbed from 2.6-3.4 m.	83:09:08	00:03:97
% mud increases slightly with depth		
Sand-filled bivalve cast in moderately bioturbated muddy sand.	70:19:11	02:01:97

Figure A24. Brigantine transect core 6-3