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Holocene Geology and Migration of a Low-Profile Barrier Island System, Metompkin Island, Virginia

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HOLOCENE GEOLOGY AND MIGRATION OF A LOW-PROFILE BARRIER ISLAND SYSTEM, METOMPKIN ISLAND, VIRGINIA

by

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ABSTRACT

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Analysis of historical shoreline position, cross-island profile change, and stratigraphic data has provided a shoreline response model for low-profile barrier island systems. Historical island shoreline data illustrates continuous, shore-parallel retreat between 1852 and 1957 at which time the island narrowed to a width of approximately 200 m. Between 1957 and 1981, ephemeral inlet breaching along southern Metompkin Island disrupted longshore sediment transport, increased the rate of shoreline recession, and resulted in differential rates of retreat associated with an abrupt break in backbarrier morphology. By 1981, a 400 m offset had formed at a position midway along the Metompkin Island shoreline. Therefore, inlet processes provided the primary mechanism for accelerated migration rates along the southern island shoreline segment.

Sediment budget data from a two-year island profiling study (November 1983 to November 1985) were used to evaluate the consistency of historical trends on a shorter time scale. Significant deficits of sand along northern Metompkin Island and small additions along the southern island segment were recorded. Washover was the primary sand source to landward profile segments during recession. This supports the concept of barrier rollover as a primary mechanism for mass transfer of sand during island retreat. The island was continuous throughout the study until

elevated waves and tides associated with Hurricane Gloria created an inlet along southern Metompkin Island.

Sediment of the barrier island system includes thick sequences of fine-grained, highly bioturbated lagoonal material that are capped by 0.6- to 2-m thick marsh deposits along northern Metompkin Island and by finely laminated sand to bioturbated silty sand units associated with inlet sedimentation in Metompkin Bay along the southern island segment. Configuration of the pre-Holocene surface appeared to affect the distribution of major coastal lithosomes. Lagoonal deposits thicken eastward and to the south towards a prominent antecedent valley associated with Folly Creek while marsh deposits are well-developed in the northern back-barrier region and an open-water bay is associated with sedimentation along southern Metompkin Island. This pattern of deposition may have provided a secondary influence on the mode and rate of island retreat.

A model describing the late Holocene depositional history of the Metompkin Island system began with a period of relative shoreline stability when fine-grained deposition was dominant throughout the back-barrier system. Between 1859 and 1887, the formation of Fishing Point significantly reduced the magnitude of longshore transport to the beach along Metompkin Island. Consequently, the rate of shoreline migration increased and the island narrowed. When island width decreased to approximately 200 m, inlet breaching was frequent along bay-backed southern Metompkin Island, increasing the rate of shoreline retreat. Conversely, the primary mechanism by which the northern marsh-backed shoreline segment migrated landward was washover. Assuming that present trends in island recession continue, predicted future adjustments suggest that Metompkin Island would be at the mainland shoreline around the year 2150.

Experience is not what happens to you;
it is what you do with what happens to you.

Aldous Huxley

ACKNOWLEDGEMENTS

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INTRODUCTION

General Statement of Problem and Objectives

A major goal of coastal geologists is understanding the relationship among changes in adjacent sedimentary environments to the response of an entire coastal system. Early work on barrier islands mainly addressed the question of origin or dealt almost exclusively with individual environmental components. Recent investigations (Oertel and Leatherman, 1985), emphasizing a system-oriented approach, have provided coastal researchers a focus for further comprehensive investigations of the interactive nature of barrier island systems.

A barrier island system consists of six major environmental components: 1) mainland, 2) backbarrier lagoon-marsh complex, 3) barrier island, 4) barrier island platform, 5) inlet and inlet shoals, and 6) shoreface (Oertel, 1985). The interactive nature of these elements during transgression controls barrier island morphodynamics. Recognition of a dominant component depends on the influence of any one element upon the entire system. For instance, lateral changes in mainland slope and lithology affect the rate of island recession, but barrier platform characteristics, barrier island width and height, shoreface slope and wave and current dynamics, and lagoonal lithology and hydrodynamics may also influence the rate of island retreat. Therefore, depending on the variability of each component, some may be relatively unimportant while others dominate.

It is generally accepted that barrier migration proceeds in response to a relative rise in sea level. However, varying rates of shoreward migration are observed along most barrier shorelines. This variable response may be the result of regional geologic characteristics or wave and current dynamics, as well as sea level rise. The main purpose of this study is to examine how lateral facies changes in the backbarrier environment affect the migration and evolution of highly transgressive, low-profile barrier island systems. Metompkin Island, Virginia provided an excellent setting for examining historic morphologic changes as well as Holocene facies relationships for this type of environment. System feedback mechanisms responsible for island morphologic variations were evaluated to develop a depositional model for this low-profile barrier island complex.

A time-integrated approach was adopted to analyze variations in backbarrier depositional patterns and associated island response by utilizing short-term sediment budget data, historical shoreline movement data, and Holocene stratigraphic data. This design permitted an evaluation of temporal and spatial responses to a myriad of processes (waves, storms, tides), towards a comprehensive understanding of the factors affecting low-profile island mobility. To this end, four major objectives were proposed:

1) to determine the importance of inlet and overwash processes, including event magnitude and duration, to island evolution;
2) to quantify sediment mobility along two sections of barrier shoreline with contrasting backbarrier morphologic characteristics;

3) to determine lateral and vertical facies relationships of the backbarrier lagoon-marsh complex; and

4) to derive a general depositional model for the Metompkin barrier island system.

A study of this kind provides an understanding of the integral relationship among components of a coastal system, the associated fluid dynamics, and resultant sedimentation patterns in the entire system.

Regional Setting

Geology

The Delmarva Peninsula is that part of the Atlantic Coastal Plain lying between the Delaware and Chesapeake Bays (Figure 1). It is part of an Amero-trailing edge coast, being actively modified by depositional products and erosional affects from upland sources (Inman and Nordstrom, 1971). The peninsula includes most of the state of Delaware and extensive areas of eastern Maryland and Virginia, being part of a topographic basin called the Chesapeake-Delaware lowland (Mixon, 1985). The gently rolling surface of this area ranges in altitude from about 24 m above sea level in the north-central portion of the Delmarva Peninsula to a minimum of about 9 m below present sea level over most of the submerged portion of the lowland.

In general, this region is underlain by poorly consolidated to unconsolidated deposits ranging in age from late Holocene to pre-Cretaceous (Sinnott and Tibbitts, 1968). Overlying the crystalline metamorphic and igneous basement complex is a thick (500 m) sequence of Cretaceous clay, sand, and minor gravel deposits. Above this unit are

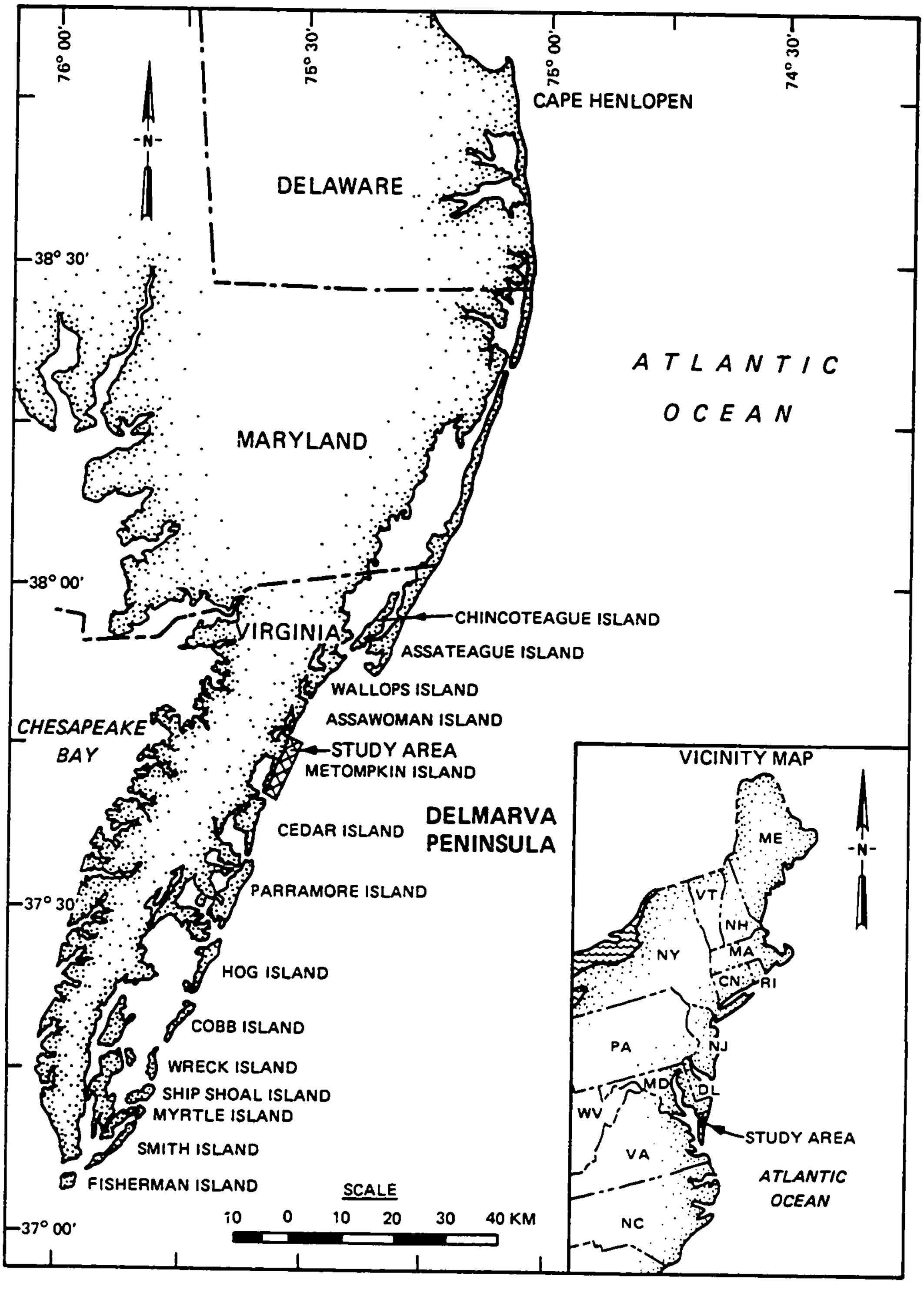

Figure 1. Index map of Delmarva Peninsula showing study area.

Eocene interbedded sand and clay and similar Miocene/Pliocene deposits of variable thicknesses. The uppermost sedimentary units are composed of Pleistocene clay, sand, and gravel and Holocene silts and sands (Figure 2). The distributions of individual sand, clay, and gravel deposits appear very discontinuous. A complete review of the Pleistocene geology of the Virginia portion of the Delmarva Peninsula, including descriptions of lithology and sedimentary structures, identification of sedimentary facies, and interpretation of depositional environment and characteristic lateral and vertical facies successions, can be found in Mixon (1985) and Mixon and Powars (1985).

Tectonic influences on the southern Delmarva Peninsula have been noted as contributing factors to coastal geologic change. Harrison et al. (1965) used evidence from buried and submerged channels in Chesapeake Bay to obtain data suggesting an uplift of 52 m during the past 18,000 years. This magnitude of change is approximately half that of the accompanying rate of sea level rise (≃120 m), implying a slower than average rate of submergence in this region. Sabet (1973), using gravity and magnetic investigations, proposed a series of highs and lows trending roughly northwest-southeast across the southern Delmarva Peninsula. He suggested that these features represented variations in the topography of the crystalline basement. This appears to have exerted considerable influence on subsequent depositional patterns as evidenced by similar erosional surface features on the top of the Tertiary beds in this region (Mixon, 1985). Recent vertical crustal movements, obtained from precise leveling surveys, have also been indicated along the entire length of the Delmarva Peninsula (Holdahl and Morrison, 1974; Brown, 1978). Differen-

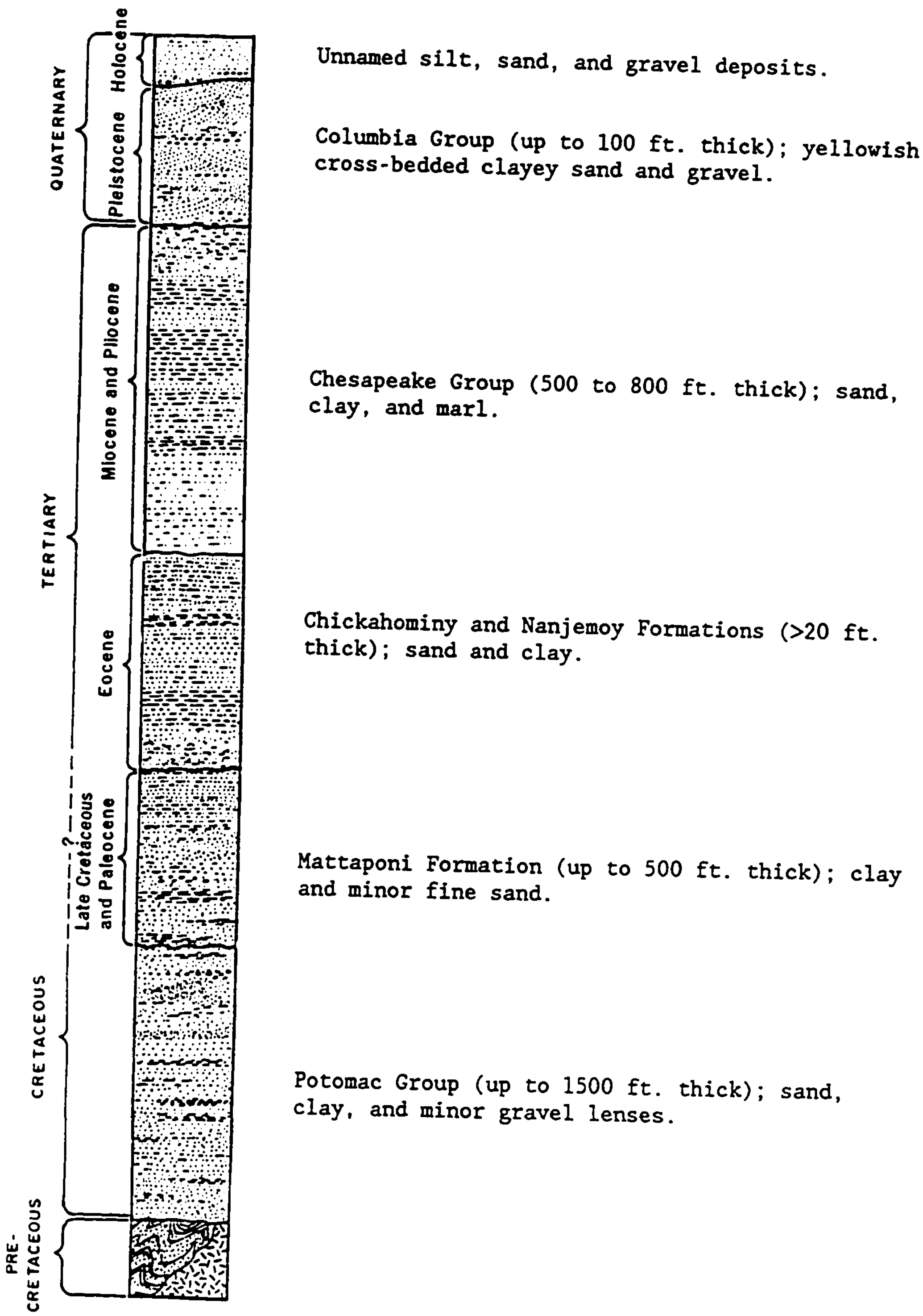

Figure 2. General stratigraphic section from the southern Delmarva Peninsula (from Sinnott and Tibbitts, 1968).

tial subsidence from north (2.0 mm/yr) to south (1.2 mm/yr) suggests an apparent sea level rise rate of 0.8 mm/yr in the north. Rice and Leatherman (1983) provide geomorphic evidence supporting these findings. However, neotectonic influences appear suspect considering the uniform patterns of correlatable coastal plain deposits along the entire Delmarva (Mixon, 1985).

Coastal Geomorphology

Virginia's barrier islands lie in the southern sector of the Delmarva coastal compartment (Fisher, 1967). Fisher's model called attention to coastwise similarities in form along five coastal segments of the Mid-Atlantic Bight (Long Island, New Jersey, Delmarva, and Virginia-North Carolina) separated by estuaries (Block Island Sound, New York Harbor, Delaware Bay, and Chesapeake Bay) (Figure 3). Due to the prevailing easterly wind and wave direction, each compartment tends to follow the same geomorphic pattern, starting with a cuspate spit extending northeast of an eroding headland and a second spit developing southwest from the headland (Swift, 1969). The southernmost compartmental sector is represented by a chain of barrier islands. Fisher (1967) suggested that these compartments are classic examples of barrier island formation by spit progradation. However, subsequent stratigraphic studies have illustrated a much more complex evolution (Pierce and Colquhoun, 1970a, b; Schwartz, 1971).

Harrison (1971) recognized three distinct geomorphic subdivisions for the Delmarva Peninsula. From Ocean City Inlet to Cape Henlopen, barrier beaches exist along the mainland and in places separate estuaries associated with drowned fluvial systems from the ocean. Assateague

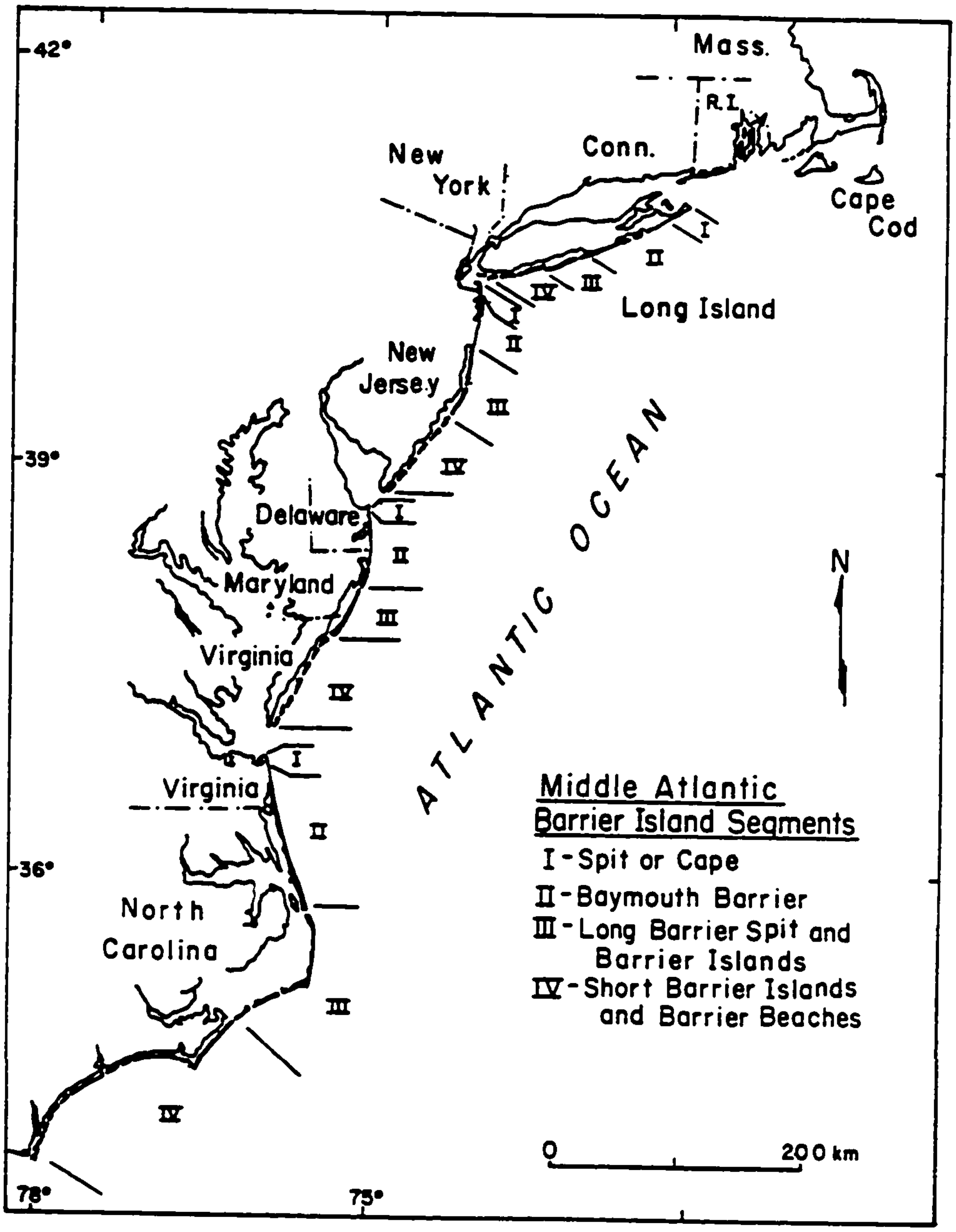

Figure 3. Fisher (1982) diagram delineating the geomorphic similarity of coastal compartments along the Mid-Atlantic Bight.

Island, a continuous barrier system, from Ocean City to Chincoteague Inlet, comprises the second subdivision and is separated from the Pleistocene mainland by Chincoteague Bay. Fishing Point, a recently formed hook-like compound spit (Halsey, 1978; Goettle, 1981), dominates southern deposits in the region. The southern group of barrier islands along the Delmarva exhibit a distinctly different geomorphic pattern than either northern subdivision (Harrison, 1971). A backbarrier lagoon-marsh complex, consisting of numerous shallow bays, marshes, and connecting tidal channels, extends approximately 100 km form Chincoteague Inlet to Fisherman Island. Extensive geomorphic variability characterizes this region, as seen in historic rates of change in island mobility (Rice et al., 1976; Leatherman et al., 1982). These subdivisions appear nearly congruent with Fisher's (1967) model.

Ingram (1975) divided Virginia's barrier coastline into three distinct geomorphic subdivisions: 1) Assateague Island, 2) Central Inlet-Marsh, and 3) Southern Inlet-Marsh. Assateague Island, the northern sub-region, consists of a mostly continuous barrier island backed by a large, shallow-water lagoon. The Central Inlet-Marsh subregion is characterized by numerous inlets and narrow marshes, extending from Chincoteague to Wachapreague Inlet. Based on quartzite cobble samples found on Metompkin Island, diagnostic of formations from the Blue Ridge and Ridge and Valley Provinces, Harrison (1971) suggested that this embayment may be the former course of the Potomac and Susquehanna Rivers. The Southern Inlet-Marsh subregion is characterized by numerous inlets and wide lagoonal complexes. Slow uplift may characterize this region (Harrison et al., 1965; Holdahl and Morrison, 1974; Rice and Leatherman, 1983).

Finally, Leatherman et al. (1982) subdivided the barriers of the Delmarva Peninsula into three groups based on historical shoreline change. The northern group, which is identical to Ingram's Central Inlet-Marsh subregion, is characterized by parallel beach retreat during historic times (sediment-starved). The middle group, from Wachapreague Inlet to New Inlet, exhibits rotational instability retreat due to the effects of erosion and deposition in changing the shape and orientation of an island. The southern group of islands (Ship Shoal, Myrtle, Smith, and Fisherman) is characterized by non-parallel beach retreat due to varied rates of shoreline change during historic times. These patterns may be related to varied topographic changes in the pre-Holocene surface (Shideler et al., 1984).

No major streams drain the eastern Delmarva Peninsula to supply sand-size sediment to modern coastal environments. Erosion of headlands and onshore transport of exhumed shoreface sediment (Holocene and pre-Holocene) provide the only sources of sand for the beaches (Kraft et al., 1973; Swift, 1975; Belknap and Kraft, 1985). The lack of an adequate supply of sediment from outside the coastal compartment has resulted in net recession of the modern day shoreline (Rice et al., 1976; Dolan et al., 1979; Leatherman et al., 1982). Consequently, the average rate of recession along this coast is relatively high. Barrier beaches north of Chincoteague Inlet exhibit an historic retreat rate of about 60 cm/yr while islands to the south average 4 m/yr (NOS-CERC, 1984). This 6.5 fold increase in migration rate is related to distance from headland source and geologic variability in the complex island systems.

Variations in mainland coastal morphology are also apparent. Small estuaries dominate Delaware's landward shoreline (Kraft and John, 1979) suggesting that portions of the mainland have been shaped primarily by fluvial processes (Halsey, 1978). South of Fenwick Island the mainland shoreline becomes straighter and the presence of several sandy, elongate, coast-parallel necks (Hog, Upshur, Bradford, Brick House) suggest that this region is composed of transitional-marine sediments, possibly analogous to modern barrier beaches.

Area of Investigation

The outer coast of the Virginia portion of the Delmarva Peninsula is composed of 14 barrier islands, each separated by permanent tidal inlets (Figure 1). Island height and width ranges from greater than 10 m and 2 km (Parramore Island) to less than 4 m and 200 m (Metompkin Island). Average tidal range varies from 0.9 m at Fisherman Island to 1.2 m at Wachapreague Inlet. Considerable variation in seasonal wave height and direction exist in direct relation to wind patterns.

Wind data, summarized for the period 1945-1957, were used by Slingerland (1977) to construct a composite wind rose (Figure 4) showing two preferred wind azimuths, N60^{o}W and S10^{o}W. Winds from the NW have speeds greater than 20 knots (10 m/s) for between 40 and 60 hr/yr while those from the SSW have speeds greater than 20 knots (10 m/s) for approximately 20 hr/yr; however, winds blow more frequently from the SSW. Consequently, prevailing winds are from the SSW and predominant winds are from the NW. Monthly wind roses for this same period of time show preferred orientation as a function of time (Slingerland, 1977). The

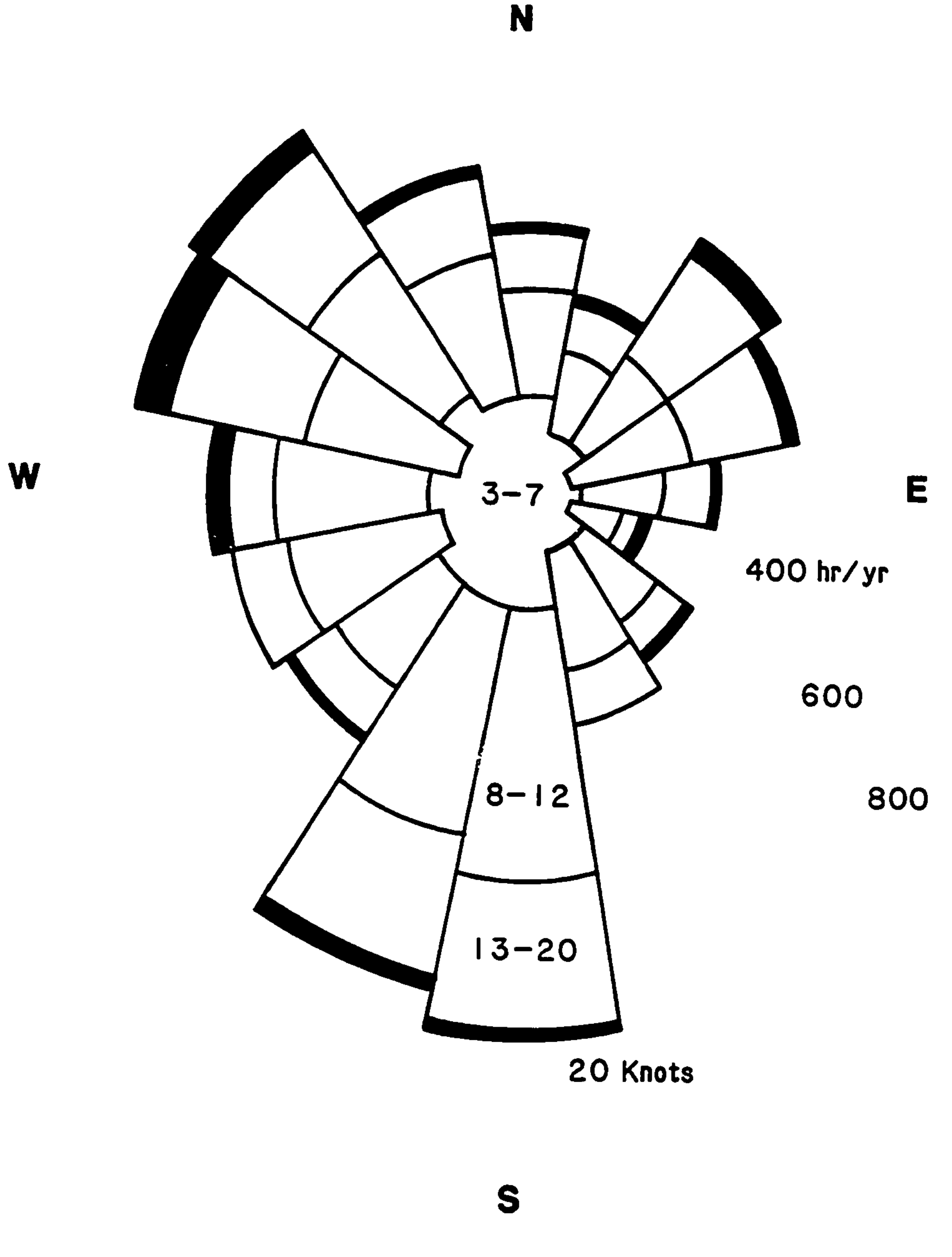

Figure 4. Summary of wind data from 1945-1957 for the lower Delmarva Peninsula. Wind speed, direction, and duration are indicated (from Slingerland, 1977).

most frequent direction for November to March is NW and for April to August is SSW. Thus, winter winds generally blow offshore and alongshore to the south while summer winds push water onshore and alongshore to the north. In addition, wave height will be greater in the winter and slightly smaller during summer months (Slingerland, 1977). Average wave height and period are about 0.7 m and 7.8 sec for this region.

The Metompkin barrier island system was chosen for intensive study for three reasons: 1) its character mimics that of typical low-profile barriers (Nummedal, 1983; Penland and Suter, 1984a, b, c; Schwartz and Anderson, 1986); 2) historic and recent island migration rates provide ample evidence for the evaluation of process-controlled mechanisms on rate of retreat (Rice et al., 1976); and 3) the backbarrier complex affords an ideal natural laboratory to study contrasting lagoonal characteristics.

Metompkin Island trends north-northeast from Metompkin Inlet to Gargathy Inlet and lies in Ingram's (1975) Central Inlet-Marsh subregion and the northern group of Leatherman et al. (1982). The northern half of Metompkin is characterized by a narrow, linear barrier backed by extensive marsh, while the southern portion is backed by a shallow, open-water lagoon (Figure 5). The entire island (10.8 km long) has an average width of 200 m and a maximum relief of 4 m above mean low water (MLW), with no extensive dune development. Major portions of the island are dominated by washover fans and terraces.

A 300-400 m shoreline offset exists midway down Metompkin Island at the abrupt change in the lagoon-marsh complex. This change in shoreline orientation appears to be the result of numerous inlet breaches in

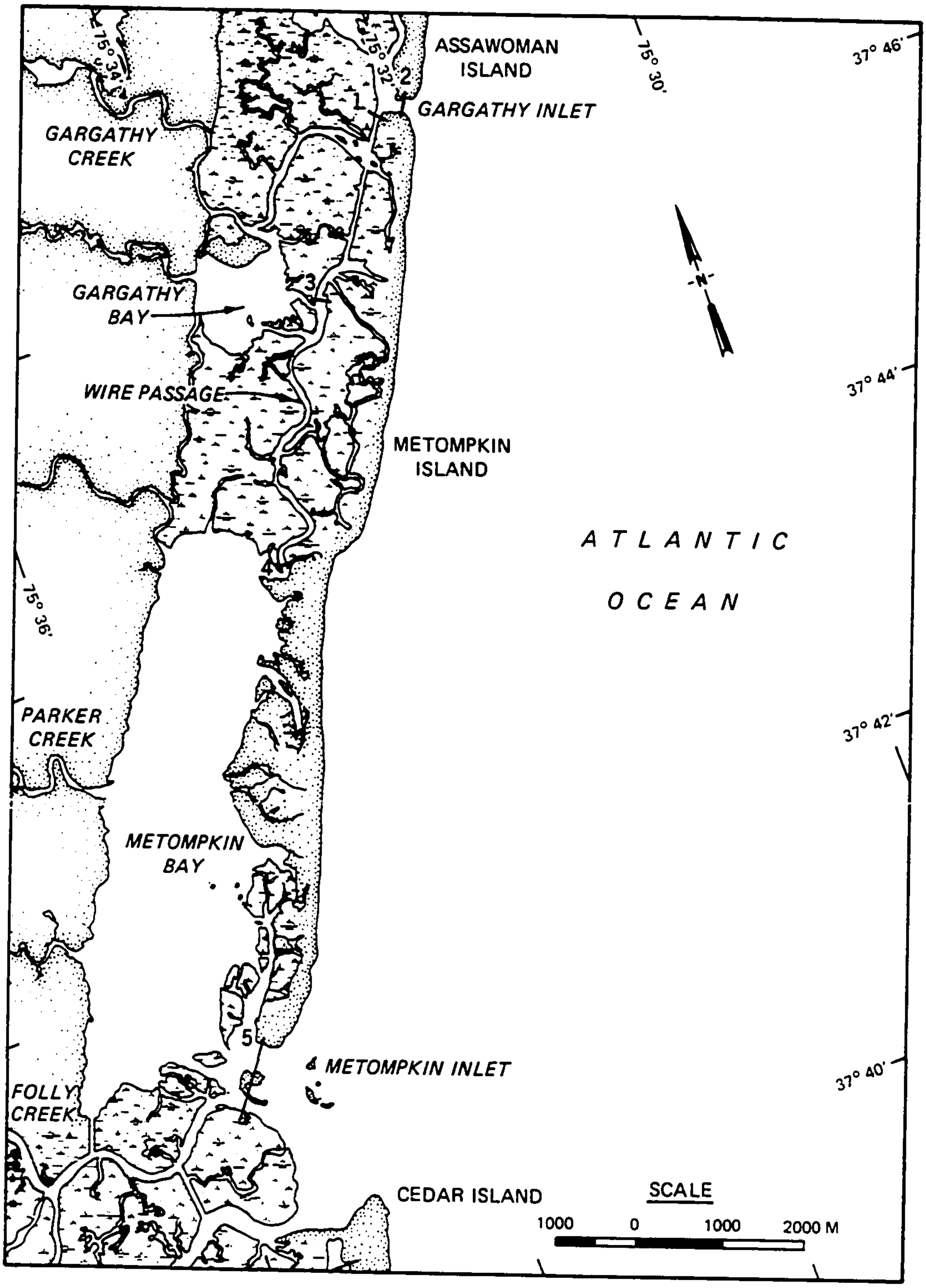

Figure 5. Location map of Metompkin Island showing open-water lagoon along the southern half and marsh-filled backbarrier to the north. Tidal stations of Galvin (1982) marked 1 - 5.

response to storm events over the past three decades (Kemerer, 1972; Rice et al., 1976; Byrnes and Gingerich, 1987). Extensive marsh deposits outcrop in the surf zone along northern Metompkin Island, indicating the transgressive nature of this region.

Metompkin Inlet tidal ranges vary from 0.85 m (neap) to 1.3 m (spring) with a mean of 1.1 m (NOAA Tide Tables, 1985). This is slightly less than the average mean range for 12 localities listed for Virginia's outer coast. Backbarrier tides were measured at three positions along Wire Passage and at Metompkin and Gargathy Inlets (Figure 5) in an effort to gauge the reliability of predicted values (Galvin, 1982). The measured time difference of high water from northern Wire Passage to Metompkin Inlet was equivalent to the predicted value (30 min), while measured water surface elevations were slightly higher (0.2 m) than those predicted. Tide range was also found to increase slightly from north to south, as is predicted. Associated currents range from 0.9 to 1.0 m/s. The shallow open-water conditions in Metompkin Bay provide adequate surface area for local wind wave formation. Typically, 30 to 60 cm waves are present, adding to the dynamic nature of this area.

Dominant littoral transport along the Delmarva barrier island chain is to the south. At Ocean City, MD, Johnson (1956) calculated a net southerly drift rate of 115,000 m^3/yr. A Corps of Engineers survey report (1973) suggested 460,000 m^3/yr reaches the southern end of Assateague Island where 300,000 m^3/yr is stored indefinitely in the growth of Fishing Point. Consequently, 160,000 m^3/yr is available for potential sand transport along Metompkin Island.

Methodology

In an effort to examine how lateral backbarrier facies changes affect the evolution of low-profile barrier islands, it is important to consider recent sedimentation patterns and processes as well as preserved coastal lithosomes. The causes, mechanics, and rates of sedimentation are all related to variations in wind, waves, longshore currents, and sediment source and supply rate. Coastal storms may be the most critical factor affecting system development (Nummedal, 1983; Dott, 1983). If so, rapid sedimentation associated with storm events should be recognized stratigraphically as indicators of intense coastal change. By investigating the characteristics of time-dependent processes, a more complete understanding of barrier island component responses can be achieved.

Field Techniques

Beach Profiling. A short-term (two year) sediment budget study along Metompkin Island was initiated in November 1983 to determine the results of sediment movement in the cross-shore and longshore directions. Initially, 38 base stations were established by leveling with reference to five National Ocean Survey (NOS) tidal datums, positioned along the southern end of Wire Passage (NOS 0705 A-E). The markers were established in 1981 and referenced to mean lower low water. All island base station elevations were corrected to MLW for the purpose of this study. Ten stations were eventually utilized to produce cross-island profiles normal to the shoreline for two stretches of straight beach along the northern and southern portions of the island (Figure 6).

At each station, a 2.4 m galvanized steel rod was driven to resistance and used as the station marker. Secondary reference stakes were

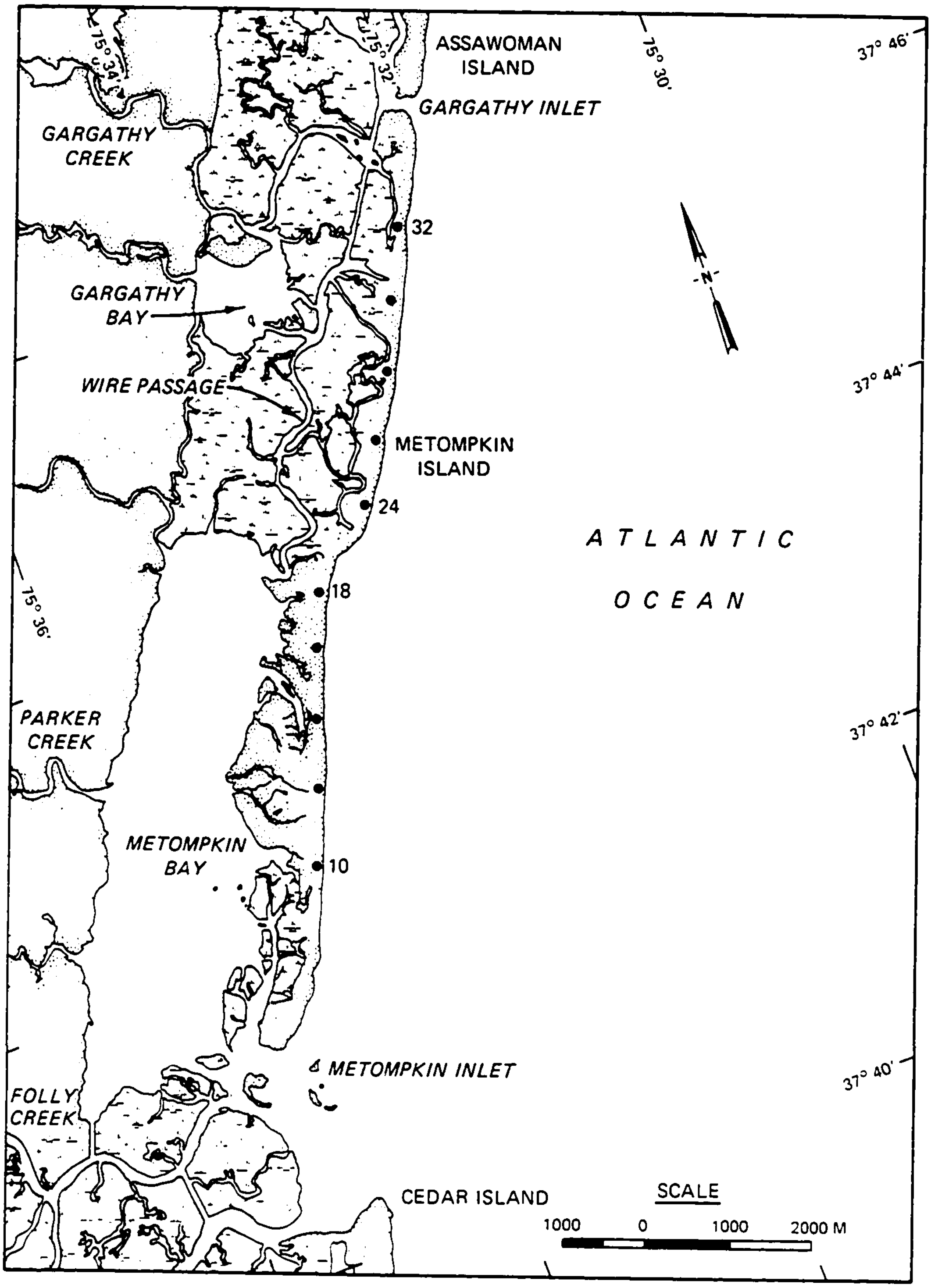

Figure 6. Map of Metompkin Island showing benchmark positions for cross-island profiles.

placed landward of the primary markers to insure accurate profile reoccupation. Profiles were constructed by means of the Shor-J method (Oertel et al., 1979). This method employs an elevation staff 1.8 m long and graduated in 2 cm intervals, and a sighting staff connected by a 6 m chain. The sighting staff is constructed so that the optic axis of a hand level (2X magnification) corresponds to zero on the elevation staff (Figure 7). A measurement of vertical elevation change is made by sighting through the hand level to the elevation staff. Consecutive elevation changes from the station marker to the MLW shoreline produced the seaward profile. In order to assess the effect of seaward profile adjustments on the landward side of the island, landward profiles were constructed in a similar manner referencing a common bayshore vertical datum for each transect.

Tests of precision and accuracy were performed along profiles of varying topography and length to evaluate the usefulness of this technique in assessing changes in sand volume. All readings were made to ± 1 cm for the Shor-J method and ± 1 mm for a standard engineering rod and level technique at a length interval of 6 m between readings. Test profile lengths varied between 42 and 138 m. As expected, accuracy and precision decreased as profile length increased, producing a maximum repeatability error of ± 1.0 m^2 and a maximum 3.06% difference between techniques.

Between November 1983 and November 1985, cross-island transects were reoccupied at six time periods. Data collection coincided with spring low tide and took two days to complete. Most profiles were 800 m apart and parallel to each other (Table 1).

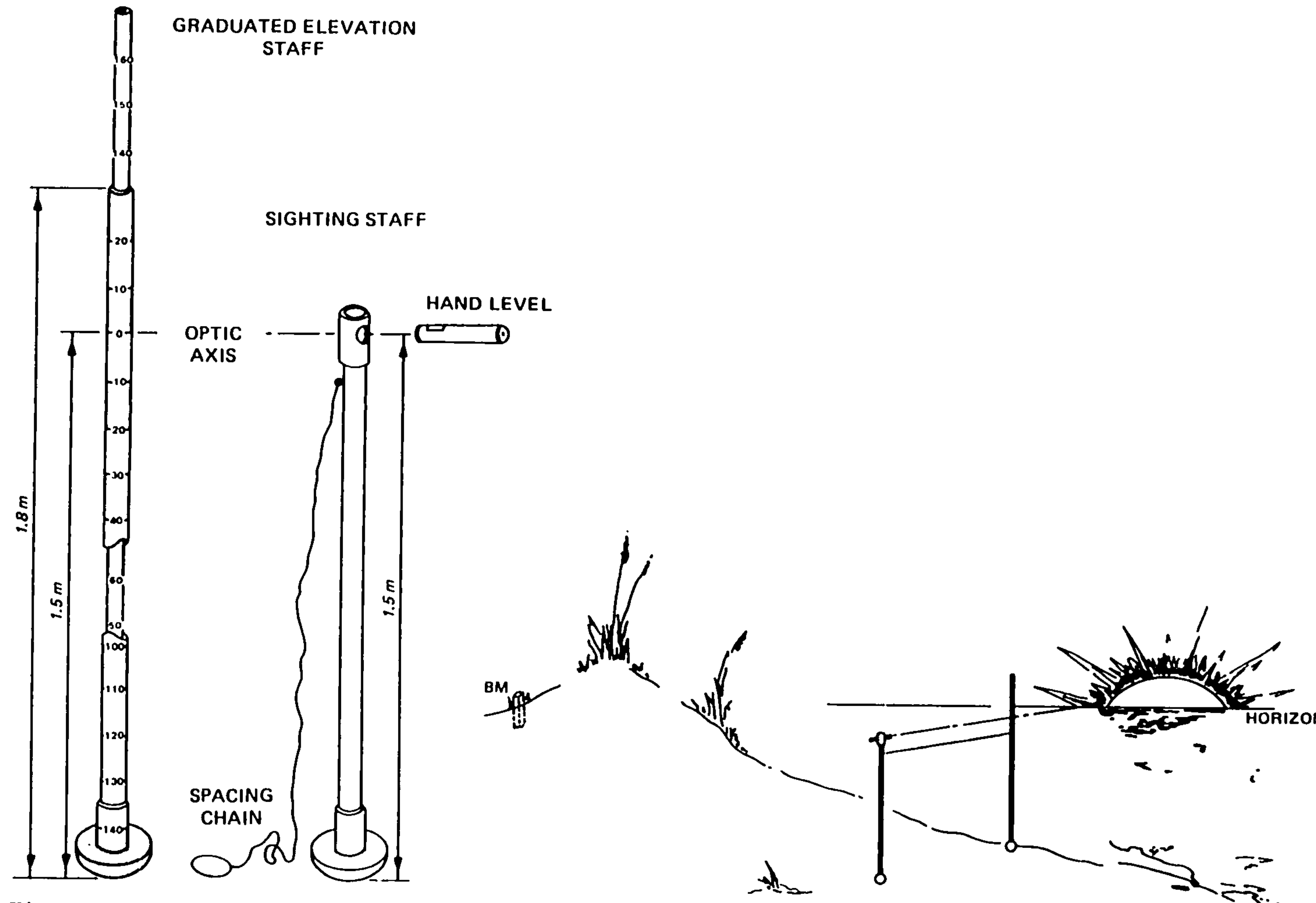

Figure 7. Sketch of instrumentation employed with Shor-J method of beach profiling (from Oertel et al., 1979).

TABLE 1

PROFILE MARKER ELEVATIONS AND SPACING

Marker Number	Elevation Above MLW (m)	Profile Spacing (m)
10	2.72	
		800
12	2.98	
		800
14	3.25	
		800
16	2.70	
		600
18	2.68	
24	2.47	
		800
26	2.67	
		800
28	2.90	
		800
30	2.90	
		800
32	2.71	

Vibracoring. Subsurface facies analyses of the study area were conducted by initially taking 16 cores utilizing a portable vibracoring system. All core positions were accessible only by small boat at predicted high water. Elevations of sampling sites were leveled to NOS tidal datums (NOS 0705 A-E) while exact locations were determined using aerial photographs, maps, and Loran-C (Table 2). Mean sea level (MSL) was used as a datum for construction of all cross-sections. A Briggs and Stratton 5-horsepower engine, designed for use as a concrete vibrator, was used as the power source for the coring system. The engine powered the vibrating head through an 8-m length of flexible cable. The vibrator head set up a low amplitude (0.1-1.0 mm) standing wave which fluidized and displaced sediment adjacent to the core tube allowing it to pass through unconsolidated sediment (Lanesky et al., 1979). Core liners were 9.15 m sections of 7.6 cm diameter aluminum irrigation tubing. Further details concerning this coring method are discussed by Lanesky et al. (1979) and Finkelstein and Prins (1981).

After the core liner ceased penetration into the sediment or the tube was filled, the engine was shut off and the vibrating head was removed. If necessary, excess core tubing was cut off, and the amount of sediment compaction was measured. The tube was then filled to the top with water and capped with a gas main plug, creating a vacuum-type suction that kept the core from sliding out of the tube upon extraction. A 4.5 m aluminum tripod and 3-ton come-along were used to extract the core from the ground. Each core was cut into manageable sections (approximately 2 m lengths) and capped with aluminum foil and duct tape before transporting back to the lab. This technique provided a

TABLE 2

VIBRACORE LOCATIONS AND ELEVATIONS

Core Number	Latitude (N)	Longitude (W)	Elevation Above MSL (m)
M1	37°41'40"	75°35'00"	1.40
M2	37°41'44"	75°35'11"	.29
M3	37°41'52"	75°35'43"	.15
M4	37°46'26"	75°32'31"	.78
M5	37°46'33"	75°33'13"	.82
M6	37°46'44"	75°33'40"	.56
M7	37°42'04"	75°36'27"	-.23
M8	37°46'18"	75°32'20"	.29
M9	37°45'05"	75°33'27"	.72
M10	37°45'13"	75°33'55"	.73
M11	37°45'02"	75°33'05"	.67
M12	37°45'26"	75°34'18"	.73
M13	37°43'27"	75°34'12"	.85
M14	37°43'30"	75°34'12"	.85
M15	37°43'51"	75°35'23"	.18
M16	37°43'34"	75°34'48"	.15

relatively undisturbed core for observation and analysis of primary sedimentary structures.

Four transects were drilled perpendicular to the shoreline for observation of backbarrier facies relationships along dip section. The position of each transect was designed to obtain maximum coverage of the three-dimensional geometry of characteristic sedimentary environments (Figure 8). A total of 96.74 m of unconsolidated sediment was recovered. Core lengths ranged from 8.73 m to 3.02 m, with an average of 6.05 m. Core liner penetration varied considerably, as did thickness of core recovered, due to changes in sediment texture. Sandy sediment generally exhibited greater compaction than mud due to an increase in available pore space. Percent core recovery averaged 91, ranging from 78 to 100 (Table 3).

Laboratory Techniques

Analysis of Sand Volume Adjustments and Shoreline Movement. Quantitative evaluations of short-term and historic rates of change in shoreline movement were implemented to assess the importance of varying meteorological effects on subaerial beach sediment mobility. An Apple II+ microcomputer and a Houston Instruments HIPLOT digital plotter were used to reduce individual profile elevation changes to shoreline recession or progradation rates, volume changes, and plotted profiles. Four programs were employed in data reduction.

Profiles were generated both landward and seaward of the temporary markers. Seaward profiles were determined by plotting elevation changes from a station marker (benchmark) to MLW. Landward profiles were constructed from the station marker landward to a position of constant

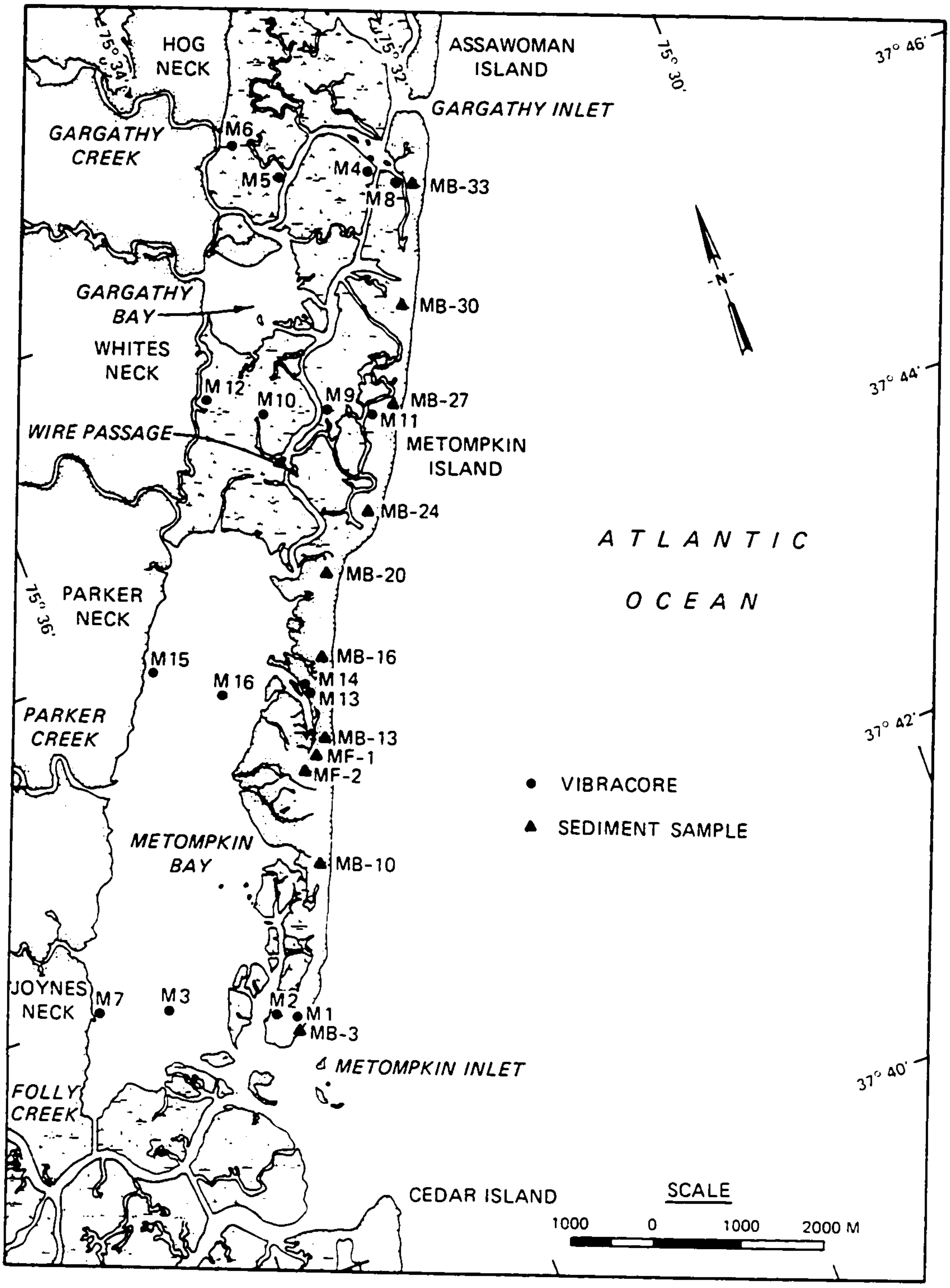

Figure 8. Map of Metompkin Island showing vibracore and beach sediment sample locations.

TABLE 3

VIBRACORE CHARACTERISTICS

Core Number	Total Length (m)	Compaction (m)	Core Recovery (%)
M1	7.30	1.08	87
M2	4.38	1.00	81
M3	8.40	.03	100
M4	7.31	.71	91
M5	5.09	.16	97
M6	3.71	.98	79
M7	4.21	.86	83
M8	8.73	0	100
M9	8.32	0	100
M10	8.21	.14	98
M11	7.74	.78	91
M12	6.58	.92	88
M13	3.70	.83	82
M14	3.02	.83	78
M15	3.16	.55	85
M16	6.88	1.00	87
AVERAGE	6.05	.62	91

elevation below the calculated high water line (HWL). Wave runup for average wave conditions was included in this calculation, producing an average elevation for the HWL of 1.45 m. The area under the profile was then calculated analytically.

Temporal and spatial analyses of cross-island profiles were implemented by comparing consecutive surveys. Longshore and cross-shore variations in erosion and accretion were compiled and examined for trend along northern (profiles 24-32) and southern (profiles 10-18) Metompkin Island. Landward profiles were monitored to examine the influence of overwash as a mechanism for rollover during transgression. This data base was used to analyze the subaerial sediment budget during the two year study.

While short-term shoreline movements were monitored utilizing high water line recession or progradation rates, historical shoreline surveys (past 129 years) were employed to examine the long-term trends in position of the mean high water (MHW) shoreline. Maps, charts, and aerial photographs were used by the National Ocean Survey, Army Corps of Engineers, and Rice et al. (1976) to generate a sequence of shoreline position change maps from 1852 to 1981.

Core Preparation and Sampling. Lateral and vertical facies relationships were documented utilizing the following techniques in an effort to extract a maximum amount of information from available subsurface data. Aluminum core liners were split using a 1-1/2 horsepower router with a 6.4 mm carbide steel tipped bit (Meisburger et al., 1980). The cores were halved using piano wire and spatulas, providing an undisturbed surface prior to further examination. One half of the core was cut into 0.38 m sections, double wrapped with 0.10 mm (4 mil) sheet plastic to ensure minimal moisture loss, and archived in D-tubes until radiography could be performed. The other half was photographed, described in detail, and sampled for textural and micropaleontological analysis.

Prior to photography, cores were dried under normal room conditions for 24 hours to increase the visibility of bedding structures and textural contrasts. Cores were photographed, at 15% overlap, using Kodak 5247 film with tungsten light. An advantage to using this type of film was that prints, slides, and negatives could be obtained from the same roll.

A detailed written description of each core was made, including color, lithology, texture, primary sedimentary structures, and organics. Samples for textural analysis and micropaleontological identification were selected based on changes in lithology. A 0.03-m thick, semi-circular wafer, with all sides scraped clean of contamination, was extracted at each sample location. A total of 134 samples were obtained for an average of one sample every 0.70 m. Twenty nine of these samples were selected for foraminiferal analysis; two to three samples from each lithosome.

Sample Analysis. Sediment textural analysis was performed utilizing standard sieving and pipette techniques (Royse, 1970; Folk, 1980). Sample weights ranged from 60-70 g for sandy samples and 15-20 g for muddy samples. Size determinations were made from -1 to 10 ϕ using a class interval of quarter phi, half phi, and full phi for sand, medium silt, and fine silt and clay, respectively. The purpose of this interval scheme was to minimize grain interference errors and to maximize data usefulness. Only 4 and 8 ϕ withdrawals were taken for samples with a mud fraction < 5% of the total weight. A computer program was written to calculate moment and Folk inclusive graphic statistics.

Identification of foraminifera was performed on 29 samples. Each sample (approximately 35 cm^3 of material) was soap-floated to produce a concentrate that was dried and picked. Where possible, 300 or more specimens were counted and identified for each sample (Culver and Banner, 1978). In most cases, all specimens were picked from the concentrate. Five sample concentrates had to be split prior to picking due to very high numbers of foraminifera. The residue (sample remaining after floating) was split using a microsplitter and picked for remaining specimens. The number of individuals counted in the split was multiplied by the ratio of the residue weight to the split weight. The total number of foraminifera in the residue was then added to the total number of foraminifera in the float concentrate to determine the number of individuals in the entire sample. Counts were standardized to # of foraminifera/100 g dry weight of sediment. Identification to species was accomplished utilizing selected references on Holocene coastal and nearshore environments (Phleger and Parker, 1951; Parker, 1952a, b; Miller, 1953; Phleger, 1954; Todd and Low, 1961; Grossman and Benson, 1967; Akers, 1971; Feyling-Hanssen et al., 1971; Haynes, 1973; Poag, 1978; Scott and Medioli, 1980; Mechler and Grady, 1984; Buzas et al., 1985.

X-ray Radiography. One hundred and thirty two sections of core, 0.25-0.38 m long, were analyzed in detail for internal sedimentary structure utilizing a Hewlett-Packard Faxitron Series x-ray oven. Radiograph sections were chosen to correspond with sediment samples. Core sections were exposed on Kodak Industrex AA film at 60 to 75 kVp at 3 mA for 2.5 to 5 minutes, depending on sediment core bulk density. The film was developed, fixed, rinsed, and dried prior to examination on a light table.

Optical density differences on radiographs were analyzed for primary sedimentary structures, texture, percent bioturbation, and biota. Recognition of these features allowed for an interpretation of depositional and post-depositional processes.

Multivariate Statistics. Various methods of multivariate statistics are recognized as valuable analytic tools and have become increasingly popular in geology due to their ability to handle many variables which are independent and show simultaneous variation (Davis, 1986). In this study, cluster analysis was employed to quantitatively compare and analyze samples in a nonarbitrary manner to extract information from grain size frequency distributions without *a priori* knowledge of geographic position. Individual weight percentages for each sample were used to formulate a 149 x 30 data matrix to be classified.

Cluster analysis provides a means whereby samples (Q-mode) or variables (R-mode) can be divided into homogeneous groups on the basis of some measure of similarity. The Bonham-Carter (1967) cluster analysis program was used to eliminate attribute redundancy and classify samples to evaluate simultaneous variation in variables. The program utilizes an iterative procedure to obtain a hierarchical classification. Meaningful aggregates consist of samples that were clustered at fairly high levels of similarity and were associated with other groups at relatively low similarity levels (McCammon, 1975). Discrete clusters were assumed to represent environmentally similar samples (Ali et al., 1976; Chambers and

Upchurch, 1979). An IBM 4381 computer was used in classifying this large data matrix.

Scope

This dissertation presents the results of a study on the evolution of the Metompkin barrier island system. Chapter 2 provides a detailed review of basic concepts referenced in any study of barrier island development. In addition, topics specific to this study were reviewed to provide background information useful for interpretation of the results. Chapter 3 describes the results of experiments designed to address the objectives of the study, including: 1) a subaerial sediment budget analysis; 2) a description of sedimentary facies encountered in Holocene and pre-Holocene deposits; 3) an analysis of variations in antecedent topography; 4) a summary of grain size sample classification using cluster analysis; and 5) a description of foraminiferal abundance and occurrence related to characteristic sedimentary facies. Chapter 4 synthesizes these results by providing an environmental interpretation of sedimentary facies and a discussion of island response to the interaction between dynamic coastal processes and changing backbarrier characteristics. A conceptual model is presented describing the evolution of the Metompkin barrier island system and predicted future adjustments. Chapter 5 summarizes the findings of the study.

RELATED STUDIES AND CONCEPTS

Barrier Island Formation

The origin of barrier islands has been debated for more than a century. By 1890, four basic theories had been developed. Elie de Beaumont (1845) provided the first explanation for the origin of barrier islands through the emergence of longshore sand bars far from the shoreline on a gently sloping inner continental shelf. Applying a dynamic equilibrium approach, he reasoned that as waves transported offshore sand and gravel shoreward, it would eventually be deposited in response to the interaction between wave energy and sediment size (Figure 9). Based on relict shorelines of Lake Bonneville, Utah, G.K. Gilbert (1885, 1890) proposed that barrier islands developed from the successive elongation of coastal sand spits through longshore transport of sediment. He argued that sediment transported by longshore currents would be deposited as a succession of sediment layers; their extent and magnitude being a function of sediment supply. Eventually the sand spit becomes so long that it is breached during storm activity, forming an inlet as well as a downdrift barrier island (Figure 10). Changes in the position of sea level were introduced by McGee (1890) and Merrill (1890) as causative factors in barrier formation. McGee stated that sea level rise led to the submergence of elevated shore ridges on a gently sloping coastal plain while Merrill suggested that relative sea level fall (or coastal

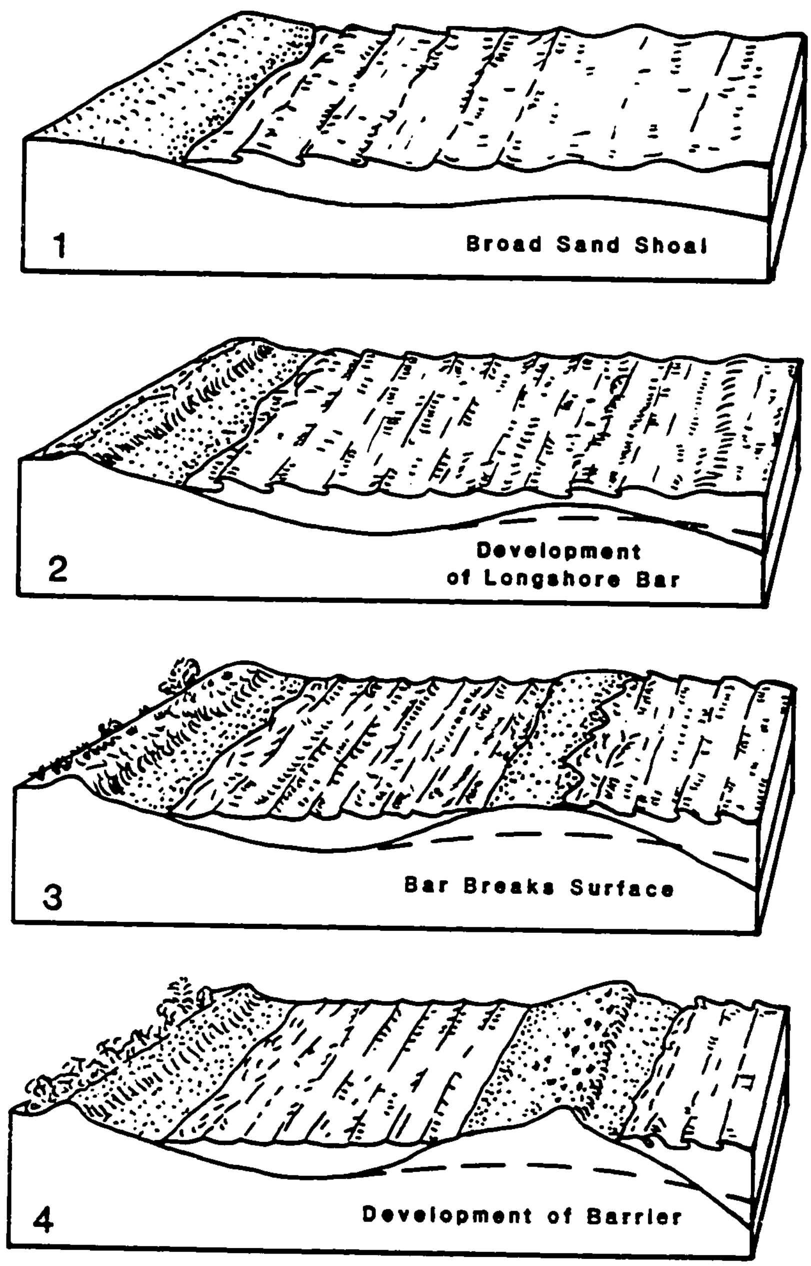

Figure 9. Idealized cross-sections showing barrier island formation from an offshore bar (from Leatherman, 1982).

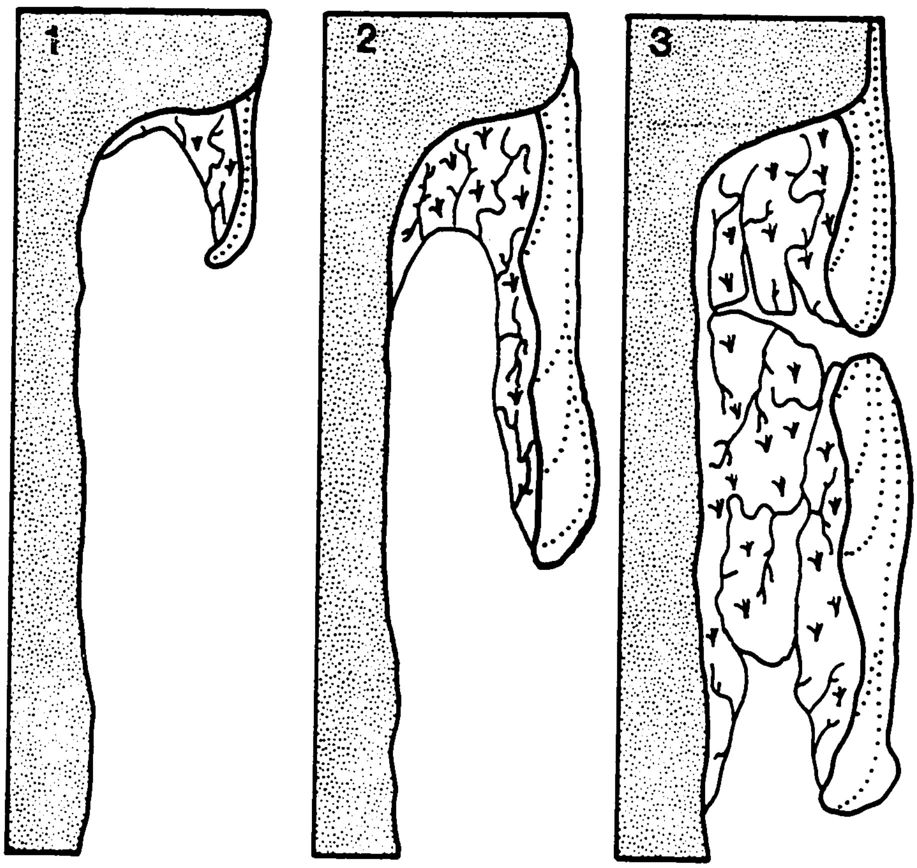

Figure 10. Idealized diagram showing barrier island formation from a spit (from Leatherman, 1982).

uplift) brought submarine bars above sea level, forming barrier islands (Figure 11). Throughout the twentieth century, these concepts would be applied to explain barrier island origin.

For decades, de Beaumont's theory was widely accepted due to the strong support of D.W. Johnson (1919). Johnson originally considered two hypotheses for the origin of barrier islands: 1) in response to wave energy establishing a new profile of equilibrium on an emerging shoreline and 2) in response to longshore movement of sand along a stable shoreline. A worldwide analysis of 18 offshore projected profiles indicated to him that wave action on a shallow bottom produced a ridge of sand in readjusting the submarine slope to a profile of equilibrium (Johnson, 1919). He also proposed that wind-transported sand would develop sand dunes on newly emerged islands, giving them additional height and width. It was further indicated that this would allow the barrier to migrate landward in the presence of a slow rise in sea level. Otvos (1970a) supported this premise, providing data from Gulf coast barriers. However, Fisher (1973) showed this analysis to be flawed by comparing profile measurements from barrier and non-barrier emergent coastal areas having similar geomorphic controls. No significant differences were found, discounting the relevance of this analysis for supporting the emergence hypothesis.

In the 1950's and 1960's, several Russian geologists and geomorphologists (Yegorov, 1951, 1956; Leont'yev, 1965; Leont'yev and Nikiforov, 1965) provided evidence contradicting the de Beaumont-Johnson emergent bar hypothesis. It was demonstrated that an offshore bar could only become emergent to form a barrier under conditions of lowered sea level. With a constant slow rise in sea level, wave dynamics would not allow an

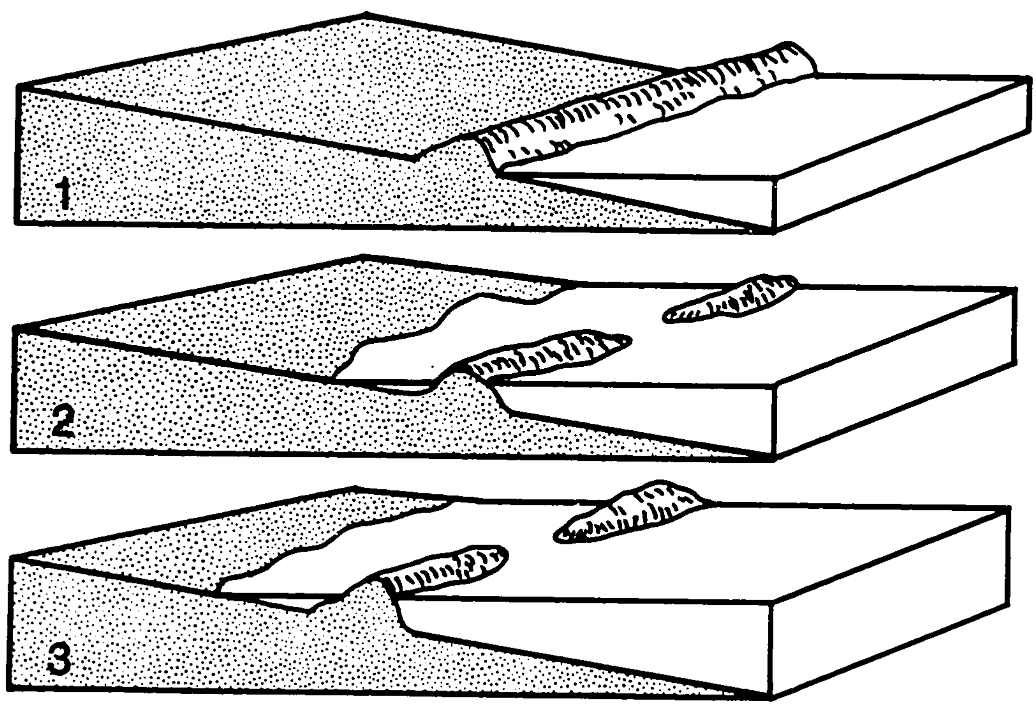

Figure 11. Barrier island formation by submergence (from Leatherman, 1982).

offshore bar to emerge (Leont'yev and Nikiforov, 1965; Leont'yev, 1969). Evans (1942) presented this concept years earlier, observing that bars in Michigan lakes were limited by wave action from building above the water surface, suggesting instead that barriers perhaps developed as spits. Shepard (1950) presented similar evidence suggesting that the growth of offshore bars was limited by the depth at which waves will begin to plunge. Using Gulf coast barriers as examples, Shepard (1960) also rejected the emergence hypothesis suggesting that these features developed with rising sea level (submergence).

Support for Gilbert's spit hypothesis was presented by Fisher (1967, 1968). Using geomorphic evidence from the mid-Atlantic coast, present day processes of spit development were considered to be analogous to past barrier island formation. Fisher proposed that barriers accrete in the predominant direction of longshore sediment transport while each successive beach deposit builds the barrier seaward. However, Steers (1946) indicated that several shingle barrier beaches developed as spits along the English East Anglican coast, although he later suggested an initial offshore bar had formed the spit (Steers, 1969). This clearly illustrates the interactive nature of differing concepts.

Few studies have referenced Merrill's emergent offshore bar hypothesis. It is subtly different than de Beaumont's emergent bar concept in that relative sea level fall was the impetus of formation rather than strictly sediment accumulation. Leont'yev (1965) and Leont'yev and Nikiforov (1965) made use of this idea in explaining the worldwide occurrence of barrier beaches. Data on the distribution and height of postglacial (Flandrian) marine terraces (from tectonically active regions) were used to propose a relative rise (3-5 m above present mean sea level) and subsequent fall in sea level approximately 5000 to 6000 years BP. This would enable the tops of submarine bars to become subaerial barrier islands that have since transgressed landward under slow sea level rise. However, evidence for the worldwide occurrence of a Holocene higher sea level stand is inconclusive. More likely, differential rates of coastal uplift and subsidence became the dominant process affecting coastal development as sea level rise slowed considerably around 4000 to 4500 years BP (Belknap and Kraft, 1977; Kraft et al., 1979; Bloom, 1983). Boyd (1985) used Sable Island, Nova Scotia, as an example of an offshore emergent feature. This area has acted as a depocenter, forming a subaerial island in response to glacial rebound. However, its distance from the mainland and nature of the "backbarrier" complex pose a serious question as to its classification as a barrier island.

Among the strongest proponents of McGee's ridge submergence hypothesis of island formation were McIntire and Morgan (1963) and Hoyt (1967, 1968c). McIntire and Morgan's stratigraphic study of Plum Island, Massachusetts led them to conclude that the island originated offshore (approximately 10,000 years BP), migrated landward in response to sea level rise, and eventually grew by longshore transport as the rate of sea level rise decreased (approximately 4000 years BP) (Jones, 1977). This model of formation is similar in concept to that of Hoyt but lacked considerable information pertaining to finer details supporting the model. Hoyt cited the absence of open marine sediments behind the Georgia, Texas, and Netherlands barriers, suggesting that these features originated from embayed beach and dune deposits as a result of marine transgression. Slow submergence would flood the area landward of the ridge, forming a barrier island and lagoon. In addition, straight mainland beaches (wave-cut shorelines) were not observed along the landward side of lagoons. Zenkovitch (1962, 1964, 1969) provided similar evidence for this hypothesis from Black Sea transgressive barriers.

Finally, after a series of lengthy discussions and replies [Cooke (1968) - emergence of offshore shoals migrating landward; Fisher (1968) - formation by complex segmented spits; Otvos (1970b) - nearshore aggradation; Hoyt (1968a, b, 1970) - mainland beach detachment], it was agreed that landward migration (sea level rise) or seaward progradation (increased sediment supply) of a barrier could eliminate the true subsurface record of any origin hypothesis. Slowly rising sea level enables islands to migrate continuously landward (Dillon, 1970), subsurface deposits being reworked through shoreface erosion (Swift, 1975, 1976; Swift et al., 1985), while inlet migration continually erodes earlier subsurface deposits that may help explain origin (Moslow and Heron, 1978; Susman and Heron, 1979; Heron et al., 1984). In addition, Jones and Cameron (1977) and Byrnes and Gingerich (1987) have shown that landward island migration may occur in response to storm events, irrespective of eustatic sea level rise, further exposing backbarrier deposits to nearshore erosional processes.

Most studies since 1970 have adopted a multiple mode of formation approach in explaining barrier evolution. Based on stratigraphic evidence, Pierce and Colquhoun (1970a, b) proposed that the North Carolina barrier system originated as a primary barrier through submergence. These features rested on subaerially weathered and eroded

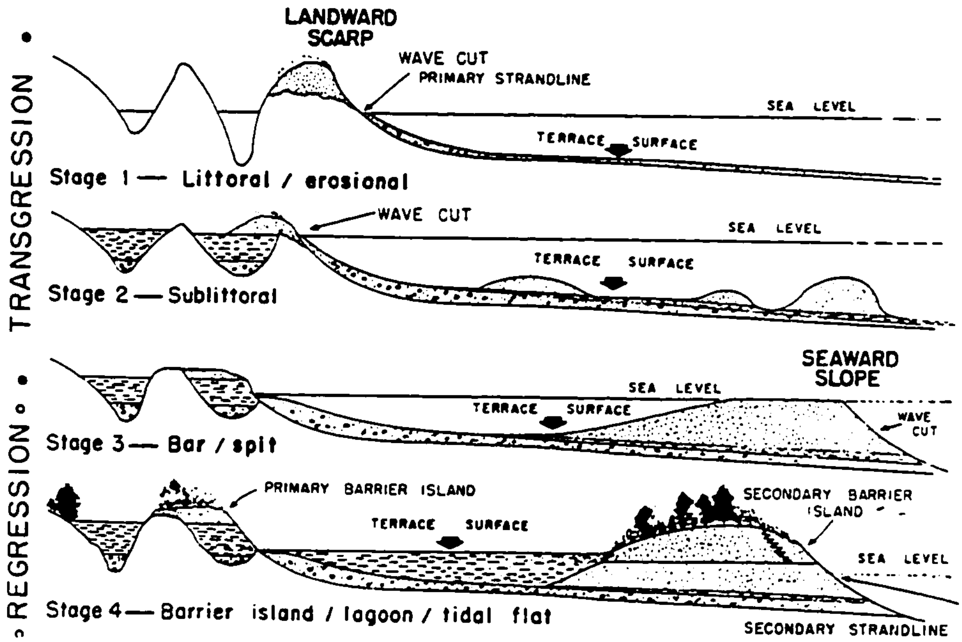

Figure 12. Cross-section showing evolutionary development of primary and secondary barriers. Initial submergence of the terminal geomorphic surface produces a wave cut, primary strandline. Continued relative sea level rise results in further coastal inundation and deposition on the shoreface. A increase in sediment supply produces a bar or spit deposit seaward of the primary shoreline, creating a secondary barrier island (from Colquhoun, 1969).

surfaces. Secondary barriers, formed as spits extending from deltas, headlands, or primary barriers, rested on shoreface facies (Figure 12). Schwartz (1971), after reviewing this work and many others (see Schwartz, 1973), suggested that the global occurrence and formation of barrier islands could best be explained utilizing polymorphic events rather than one specific process. Applications of this "multiple causality" approach are illustrated in Orme's (1973) study on South African barriers and Wilkinson's (1975) and Wilkinson and Basse's (1978) stratigraphic studies of Matagorda Island along the Texas coast. In addition, Halsey (1976, 1978, 1979) proposed a linking between new and old (pre-Holocene) topography, combined with varying rates of sediment supply, in presenting a multiple cause model (Nexus) to explain coastwise similarities in form for barriers along the Delmarva Peninsula.

However, due to the complex nature of these coastal systems and the need to fit new evidence into an overall evolutionary model, the debate has and will continue. Swift (1975) and Field and Duane (1976) found evidence on the mid-Atlantic continental shelf to support the notion that barriers formed in response to the onset of coastal submergence after the late Wisconsinan lowstand. Swift (1975) stated "the relative roles of coastwise spit progradation and mainland-beach detachment depend on coastal relief and slope, with steep, rugged coasts favoring progradation at the expense of mainland-beach detachment". Field and Duane (1976) found stratigraphic evidence for the existence of barriers on the inner shelf and thus supported the idea of continual landward migration in response to sea level rise. Jones (1977) studied geomorphic and sedimentologic parameters along Plum Island, Massachusetts, and proposed that high-energy storm transport of sediment and spit development were the mechanisms responsible for barrier migration rather than sea level rise. On the other hand, Sanders and Kumar (1975) and Rampino and Sanders (1980, 1981, 1983) found preserved backbarrier facies on the Long Island, New York shoreface and proposed in-place "drowning" of the barrier and rapid landward translation of the surf zone as a means of island formation. Swift and Moslow (1982) refuted these findings on the basis of well-accepted shoreface dynamics models, opting for continual erosional retreat of barriers versus catastrophic "overstepping". Panageotou and Leatherman (1986) supported these ideas by re-evaluating pre-existing shoreface data off Long Island and providing new seismic and sedimentologic evidence suggesting continuous shoreface retreat during the Holocene Epoch. Finally, Otvos (1979, 1981, 1985a, b) cited considerable stratigraphic, sedimentologic, and micropaleontologic evidence to support formation through nearshore aggradation for some northeastern Gulf coast barriers.

The Barrier Island System

It generally has been accepted that barrier coasts represent 10-13% of the combined continental coastline (Leont'yev, 1965; Zenkovitch, 1967; Cromwell, 1971). Glaeser (1978), using McGill's (1958) map of coastal landforms of the world and Inman and Nordstrom's (1971) tectonic classification of coasts, provided an excellent summary of the distribution of barrier islands in relation to trailing and collision margins, and marginal seas. He found the presence of a broad, low gradient coastal plain (as well as a gradual shelf slope and sufficient sediment supply) to be decisive in determining the extent to which barrier islands line the coastal margin. In one of the earliest efforts to define the terminology of coastal deposits, Price (1951) utilized a series of fundamental elements for describing barrier islands versus bars. These included elongate, permanently subaerial, sand or sand and gravel deposits, lying offshore on a gently sloping bottom, and separated from the shore by a coastal lagoon or "sound". Shepard (1952, 1960) included size as an important characteristic stating that barriers may be "as much as 20 miles across and 100 miles or more in length, and may have hills 100 feet or more in height". Berryhill et al. (1969) imposed an island width to length ratio of 10:1 while Cromwell (1971) used an elevation limit of "less than 10 m above sea level" in identifying barrier coastlines.

Three primary geomorphic characteristics of a barrier island system evolve from the preceding discussion: 1) the sandy barrier deposit; 2) the lagoon or estuary landward of the barrier; and 3) the tidal inlet channels connecting the lagoon and open ocean. Provided this geomorphic framework, Reinson (1979) proposed that barrier island systems are composed of three major depositional environments: 1) the subtidal to subaerial barrier beach complex; 2) the backbarrier subtidal-intertidal lagoon complex; and 3) the subtidal-intertidal delta and inlet channel complex (Figure 13). More recently, Oertel (1985) included the dissected subaerial and submerged pre-Holocene surface in proposing six major elements needed to impose the designation barrier island to a littoral sand body (Figure 14). It was suggested that the absence of any coastal element should prohibit the use of the term barrier island. The following discussion summarizes the varying characteristics of each element with special reference to the Delmarva barrier coastline.

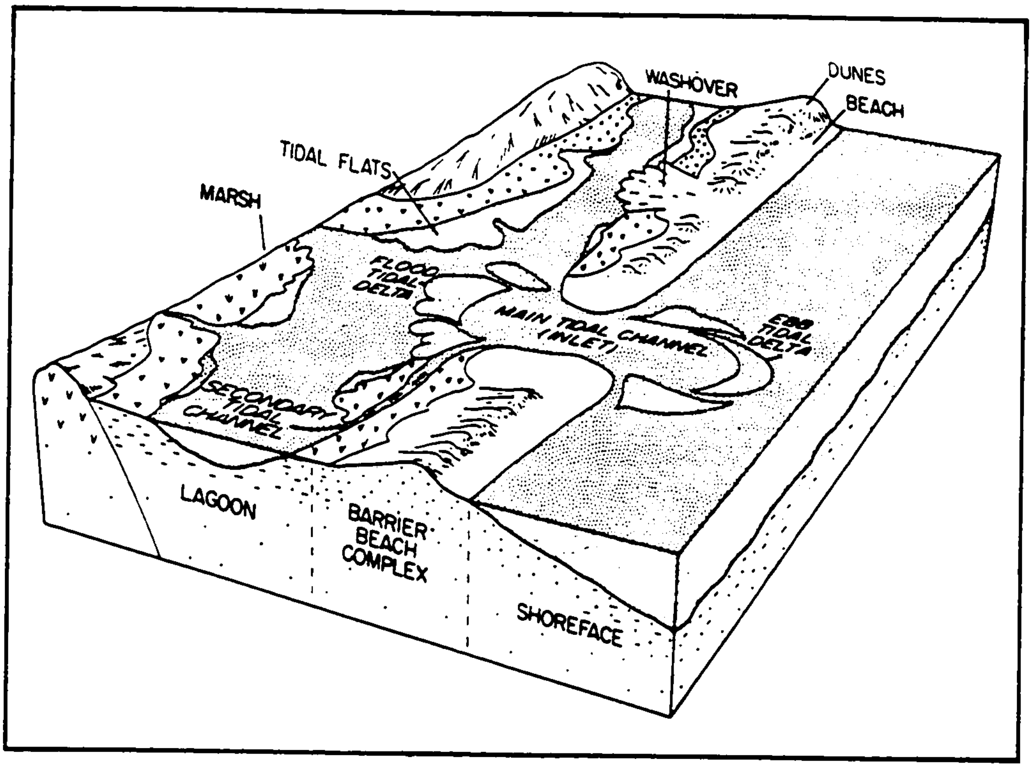

Figure 13. Schematic diagram of major depositional environments for barrier island systems (from Reinson, 1979).

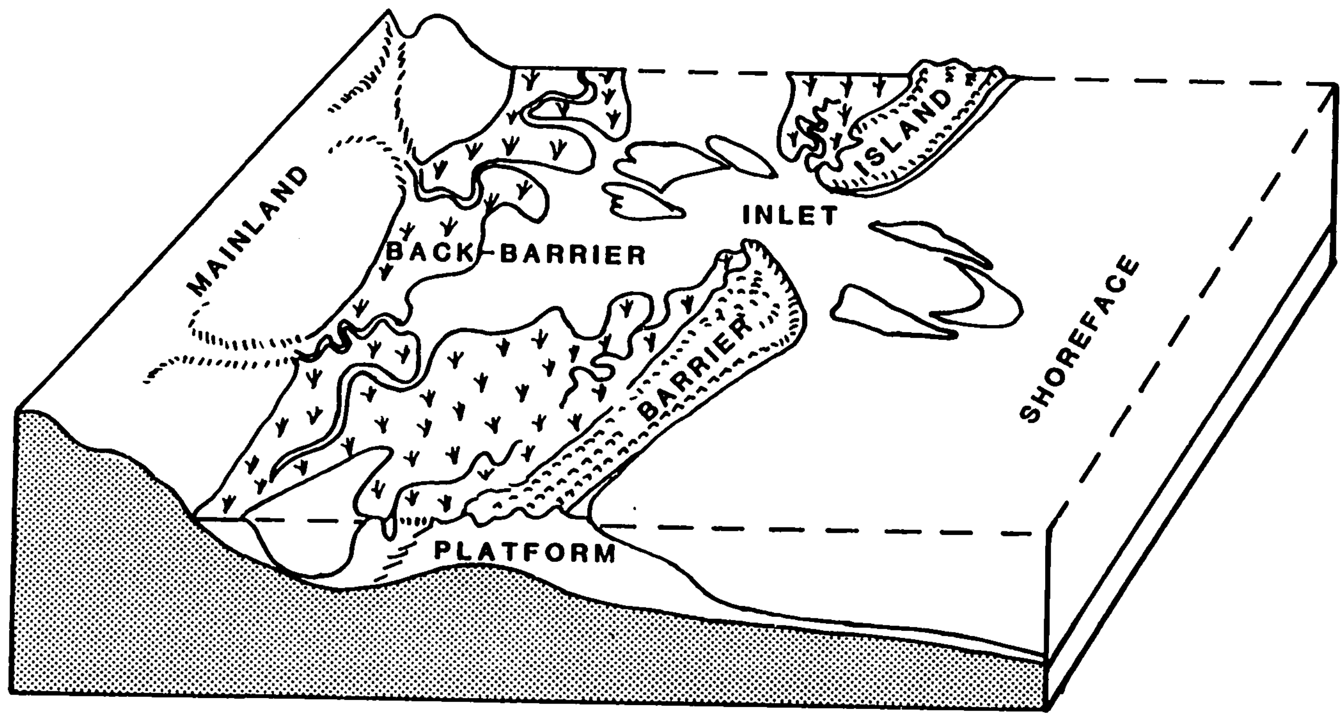

Figure 14. Schematic diagram of a barrier island system illustrating the six interactive sedimentary environments (from Oertel, 1985).

Mainland

During the Holocene, pre-existing topography has played an important role in the development of transgressive barriers and backbarrier lagoons (Melville, 1984; Demarest and Leatherman, 1985). Two elemental characteristics have contributed significantly: 1) drainage patterns associated with dissection of the weathered pre-Holocene surface and 2) variations in slope of the pre-Holocene surface. These effects can be manifested in two different ways; those related primarily to subaerial mainland drainage networks, and those related to submerged relict shoreface deposits seaward of the relict Pleistocene shorelines (Demarest and Leatherman, 1985). Both have profound influences on the configuration of Holocene barrier systems.

Distinct changes in mainland drainage are quite evident along the entire Delmarva coast. North of Ocean City, Maryland, large dendritic drainage basins influence major portions of coastal uplands. Sea level rise has created major drowned river estuaries (Indian River, St. Martins River) that provide considerable amounts of sediment to adjacent coastal environments (Kraft and Margules, 1971; Kraft et al., 1979). Baymouth barrier systems dominate this region where modern shorelines intersect Pleistocene headlands that supply sediment to downdrift beaches (Kraft, 1971a; Kraft and John, 1979; Halsey, 1979; Kraft et al., 1981; Demarest and Leatherman, 1985). Along Virginia's seaward coastline of the Delmarva Peninsula, the drainage divide is much closer to the present coast and is occasionally characterized by trellis-type drainage networks (eg. Machipongo River)(see Demarest and Leatherman, 1985, p. 27). Consequently, well-developed barrier complexes may evolve during submergence of relict, shore-parallel coastal features. In addition, numerous secondary streams drain smaller areas and have narrower channels, supplying very little sediment to coastal environments (Harrison, 1971). These geomorphic differences correlate well with relative age differences between surfaces being transgressed by Holocene barrier systems; the greater the degree of fluvial dissection, the older the deposit being transgressed (Demarest and Leatherman, 1985).

Longshore variation in slope of pre-existing topography has also produced major differences in barrier configuration. Baymouth barriers along the northern Delmarva outer coast are attached at either end to eroding headlands. Shore stability is at a maximum, and mainland submergence is at a minimum (relatively steep slope) except in regions of fluvial incision (Demarest and Leatherman, 1985). Consequently, pre-Holocene headlands outcrop along the coast and subcrop on the shoreface, regionally nourishing coastal deposits. Barrier beaches in this region have well-developed dune systems and are rarely overwashed by storm waves. On the other hand, barriers along Virginia's outer coast are perched at varying distances (2-10 km) from the mainland shoreline on a gently sloping, pre-existing Pleistocene shoreface (Demarest and Leatherman, 1985). Island migration rate is quite variable and of greater magnitude compared to northern Delmarva barriers (Dolan et al., 1979; Leatherman et al., 1982). Overwash and inlet breaching are frequent responses to storm events. However, mainland submergence is relatively slow due to the presence of a scarp at the landward edge of the Pleistocene shoreface (Mixon, 1985), thus creating a continually shrinking backbarrier complex.

Although lithologic variations in mainland deposits may be a contributing factor (Oertel, 1985), submergence of mainland topography, rather than differential rates of shoreline erosion, is probably the dominant mechanism affecting coastal response.

Backbarrier Lagoon-Marsh Complex

The general shape of a coastal lagoon is relatively narrow with the long axis parallel to the coast (Figure 5). Lagoonal length depends in part upon the regularity of coastal trend and upon the configuration of the subaerial and submerged mainland surface (Phleger, 1969). Backbarrier sedimentation patterns are governed by four important variables: 1) tidal range and frequency; 2) tidal prism; 3) wind and wave energy impacting the barrier; and 4) type and amount of sediment supply (Boothroyd et al., 1985). Geomorphic variation in lagoons and associated marshes along the Delmarva ranges from relatively narrow, marsh-filled lagoons (northern Metompkin Island, Assawoman Island) to wide, shallow-water lagoons with mostly fringing marsh (Assateague Island, Hog Island) (Rice et al., 1976). Essentially all environmental components of the barrier island system influence, or are influenced by, backbarrier characteristics (Oertel, 1985).

As a consequence of tidal range, three distinct sedimentation zones may be defined: 1) permanently exposed high marsh deposits; 2) intertidal sand and mud flats; and 3) permanently subaqueous bays. Lagoonal dynamics and sedimentation patterns evolve in response to variations in each zone. Depending on the relative importance of each sub-environment, Oertel and Dunstan (1981) proposed two endpoints based on surface area changes related to tidal fluctuations. Open-water lagoons have a relatively constant surface area from mainland to barrier, regardless of tide, whereas expandable tidal lagoons exhibit a change in surface area of greater than 15% between low and high water (Figure 15) (Oertel, 1985).

The magnitude of tidal change affects backbarrier hydrodynamics (Zimmerman, 1981; Isaji et al., 1985). By definition, open-water lagoons are typically more stable than expanding lagoons. Intertidal sediment dispersal patterns change rapidly in response to marsh and tidal flat runoff (Boon, 1975; Frey and Basan, 1978; Bayliss-Smith et al., 1979; Oertel and Dunstan, 1981) as well as external additions (mainland, washover, inlet). An evolutionary sequence from open-water to marsh-filled lagoon was presented by Lucke (1934) for New Jersey barrier complexes. Assuming that sediment source and lagoonal hydrodynamics controlled deposition, closure would be governed by shoal deposition around inlets and by the growth of fringing marsh. Most studies support this model except in cases of significant fluvial input (Shepard and Moore, 1955; Newman and Munsart, 1968; Phleger, 1969; Frey and Basan, 1978; Oertel, 1979; Wojtal and Moslow, 1980; Nichols and Allen, 1981; Howard and Frey, 1985; Thorbjarnarson et al., 1985).

Transfer of beach and nearshore sediment to the backbarrier region is accomplished through washover (storm waves), inlet sedimentation (waves and currents), and aeolian transport. Baymouth barriers along Delaware's coast typically have well-developed dune systems, rarely affected by storm overwash. Therefore, littoral sediment contributions to backbarrier environments are mainly associated with inlet and aeolian activity (Kraft, 1971a, b; Kraft and Allen, 1975; Halsey, 1978). Since dominant wind direction is NW along the NNE-SSW trending Virginia

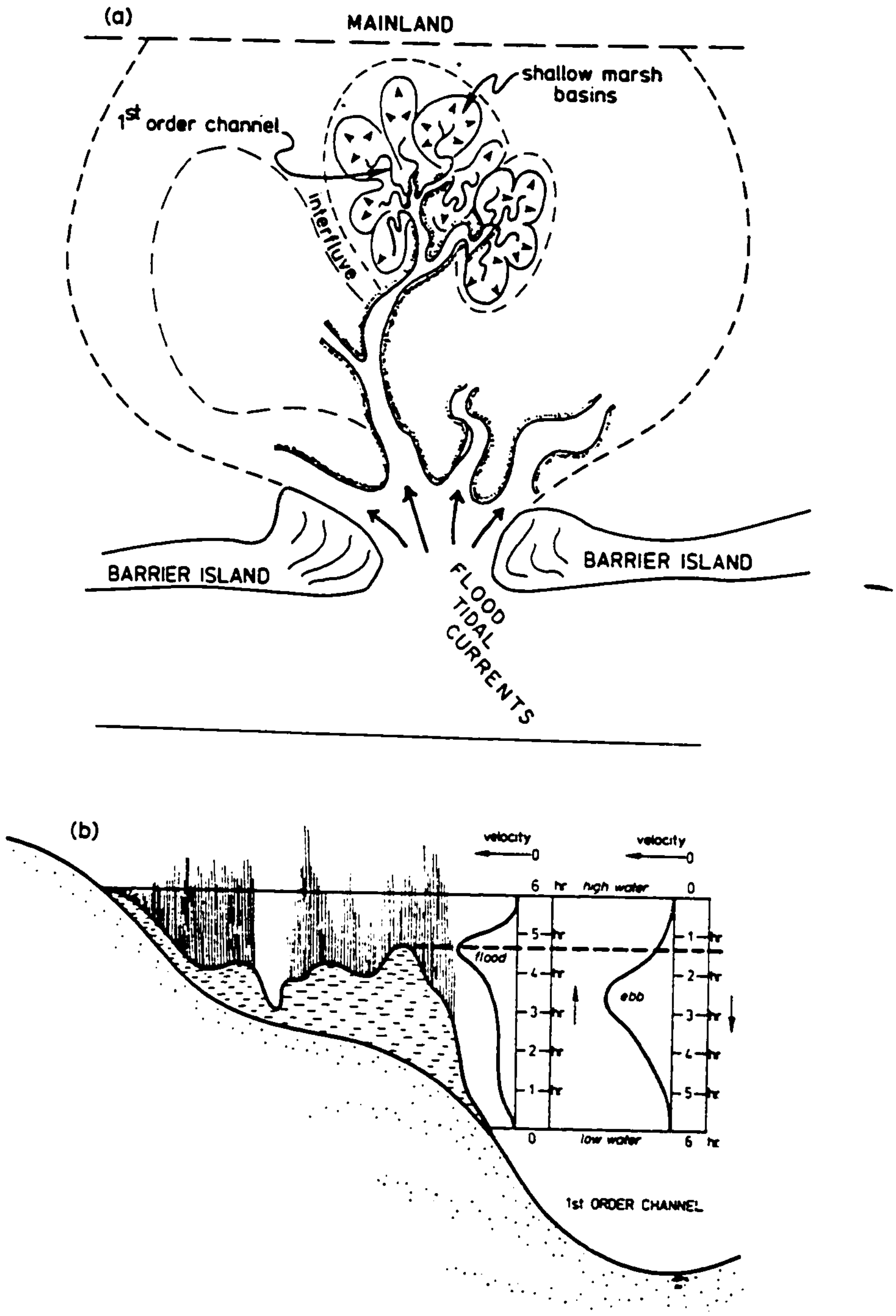

Figure 15. a) Schematic showing characteristics of expandable tidal lagoons. b) Cross-section of tidal channel and marsh for expandable backbarrier lagoon complex (from Oertel and Dunstan, 1981).

barrier chain (Slingerland, 1977), aeolian activity can safely be eliminated as a significant transfer mechanism. However, many of Virginia's coastal lagoons are dramatically influenced by washover sedimentation and inlet breaching, effecting both subaerial beach and subaqueous lagoonal deposits (Rice et al., 1976; Rice and Leatherman, 1983; Byrnes and Gingerich, 1987). Large washover deltas (Shepard and Wanless, 1971; Kumar and Sanders, 1974) and storm surge platforms (Boothroyd et al., 1985) rest on top of lagoonal silts, often providing an ideal region for marsh grass colonization (Godfrey and Godfrey, 1973, 1974; Leatherman, 1979c) while extensive washover aprons or terraces become perched upon large expanses of permanently subaerial marsh (Fisk, 1959; Hayes, 1967; Hosier and Cleary, 1977; Deery and Howard, 1977; Byrnes and Gingerich, 1987). Landward island migration is relatively rapid, often exposing backbarrier deposits in the surf zone.

The type and amount of backbarrier sediment accumulation are a result of fluvial deposition and mainland erosion, longshore and cross-shore transport, and shoreface erosion. Backbarrier lagoons or estuaries act as fine-grained sediment sinks (scour lag-settling lag; Postma, 1967; Thorbjarnarson et al., 1985) while sand is supplied through washover, inlet shoal deposition, and higher energy event transport through permanent inlets (Fischer, 1961; Bartberger, 1976; Leatherman, 1979c, 1985; Nichols and Allen, 1981). Consequently, depositional units range from highly bioturbated muds to interlaminated sands and muds to ripple laminated sands.

Barrier Island

The barrier island element is recognized as the subaerial accumulation of sand-sized sediment, situated between the backbarrier complex and shoreface environment, unaffected by backbarrier depositional processes. Inlet environments often separate similar adjacent deposits (see Figure 1). Morphologic variations are a result of various coastal characteristics, including climate, winds, waves, type and amount of vegetation, and type and abundance of sediment available for nourishment (Phleger, 1969). Depositional sub-environments of a barrier-beach complex include: 1) the seaward facing intertidal zone (foreshore); 2) the subaerial zone or backshore dune complex landward of the berm crest; and 3) the supratidal to subaerial wave-formed and wind-modified washover flats which extend across the barrier to the lagoonal fringe (Figure 16) (Reinson, 1979).

Foreshore deposits are confined to the intertidal zone, where a sharp change in slope is recognized at the base and top of the beachface (Figure 17; Reinson, 1979). The swash-backwash mechanism is mainly responsible for distinct sub-parallel to low-angle, seaward dipping, planar laminations (Clifton et al., 1971; Moiola and Spencer, 1973; Komar, 1976), generally recognized as distinct wedge-shaped units (truncated and non-truncated) resulting from depositional and erosional events. Consequently, sediment mobility is at a maximum, with occasional sand transport to backshore environments during storms.

The backshore environment is characterized by wind- and wave-generated depositional processes. Berm construction is the result of landward sediment transport over the berm crest during spring high tides and storms. Overwash and aeolian activity distribute and redistribute littoral sand across the backshore, producing a subdued landward-sloping berm, primary and secondary dunes, and washover deposits (Andrews, 1970;

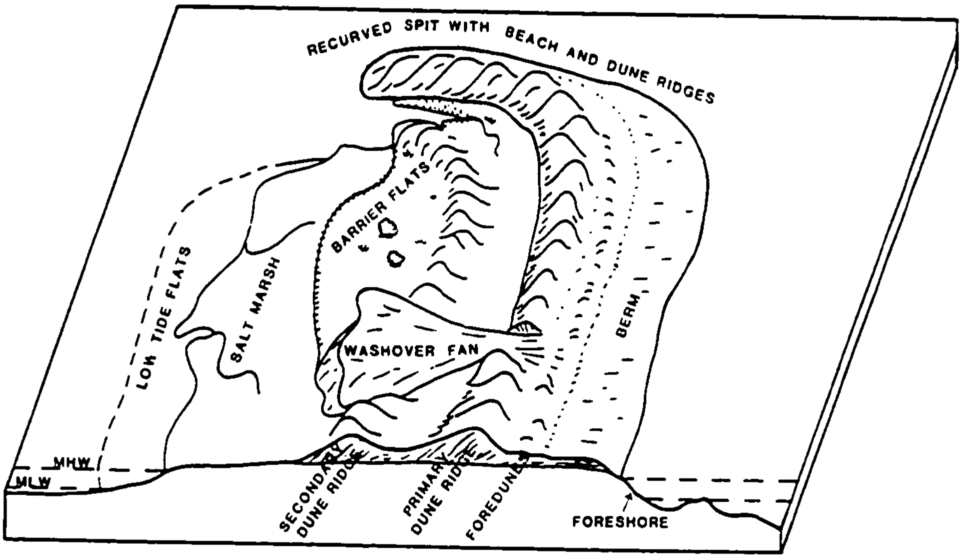

Figure 16. Schematic illustrating the relationship among major sedimentary environments and landforms (from Oertel, 1985).

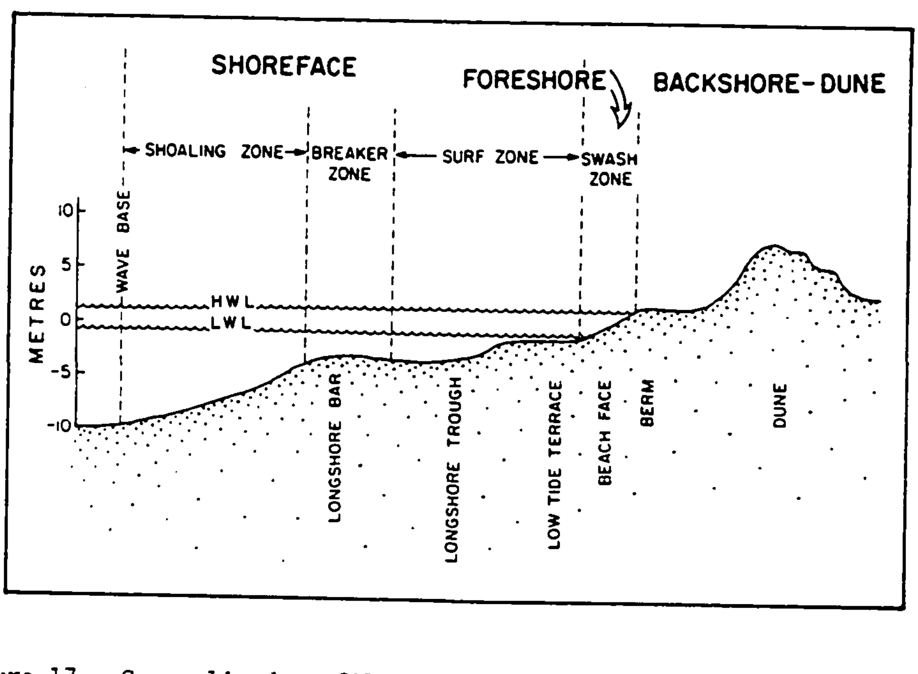

Figure 17. Generalized profile of the barrier beach and shoreface environments (from Reinson, 1979).

Fisher et al., 1974; Schwartz, 1975; Leatherman, 1976, 1977, 1979a, b, 1983, 1985; Armon and McCann, 1979; Leatherman and Zaremba, 1987). Sub-horizontal to landward-dipping planar beds characterize berm and washover deposits while trough to planar cross-stratified sets are typical of dune deposits (Goldsmith, 1973; Godfrey and Godfrey, 1973; Hayes and Kana, 1976; Leatherman and Williams, 1977, 1983). Much of the vertical growth of barrier islands is controlled by dune formation. Their size and height is a result of prevailing winds and wind velocities, the amount of sand available from adjacent sub-environments, and the rate at which vegetation becomes established. The type and degree of vegetation is a function of climate and can act rapidly to stabilize berm and dune features. Less humid, sparsely vegetated regions will generally exhibit more intense aeolian activity, creating larger dune systems (Phleger, 1969).

Many of Virginia's barrier islands are greatly affected by washover resulting from wind-generated storm surges that have overtopped and cut across the islands, creating lobate or sheet deposits of sand often extending to the lagoonal shoreline (Figure 18). Overwash channels subsequently provide corridors for wind-transported sand across the backshore, nourishing the backbarrier sand flats. These sand flats provide environments favorable for marsh colonization as well as relatively stable platforms for migrating barriers. However, active reworking by lagoonal processes operationally classifies them as backbarrier sub-environments. Individual washover deposits are generally thin, although vertically sequential units dominate barrier sedimentation patterns along rapidly transgressing coastlines (Leatherman and Williams, 1983; Leatherman, 1985). The mechanism of continued overwash is one of

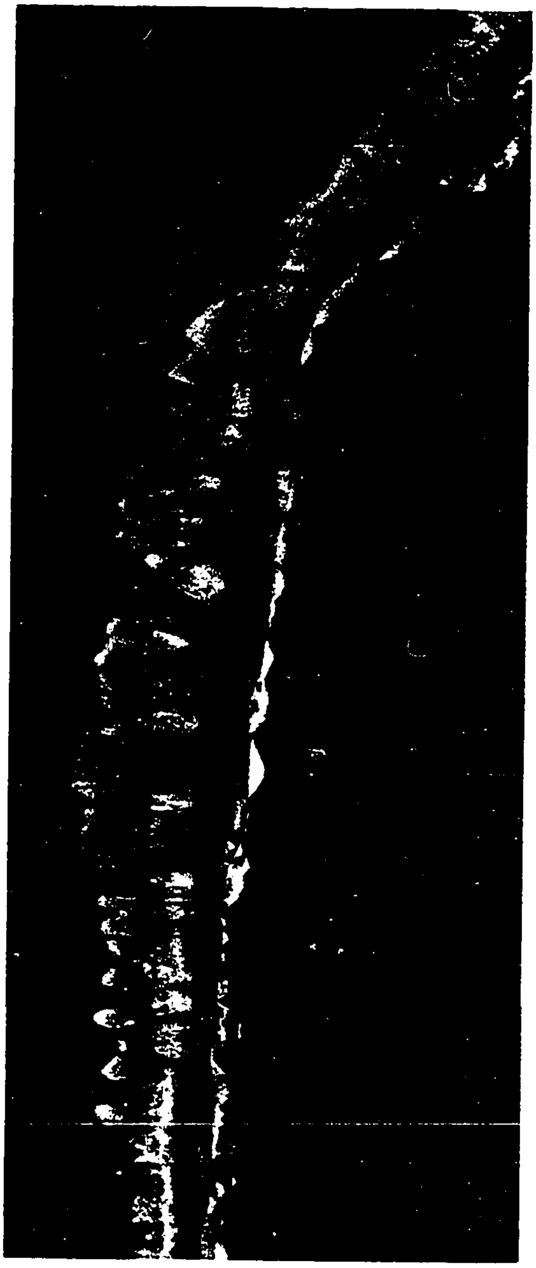

Figure 18. Photograph of extensive washover fans and flats on Metompkin Island resulting from wind-generated storm activity.

the main processes by which these barriers migrate landward and is often responsible for the initiation of new tidal inlets (Dillon, 1970; Leatherman, 1979c, 1985).

Barrier Platform

Oertel (1985) refers to the barrier platform as the stratigraphic substructure of a barrier island. Due to a wide variety of geologic settings along barrier coastlines, the configuration of island migration often reflects the importance of substructure control. Four types of platform substrate can be recognized: 1) pre-Holocene deposits; 2) transgressed backbarrier deposits; 3) spit or inlet facies; and 4) shoreface deposits.

Pre-Holocene topographic highs on submerged mainland surfaces have been recognized as important factors controlling the origin and evolution of barrier island systems. As sea level rises, the rate of horizontal position change will be governed by mainland slope characteristics. Topographic irregularities (ridges) represent an increase in slope, effectively altering the local rate of shoreline displacement. This provides a source of unconsolidated sediment as well as a platform for island development (Oertel, 1985). Hoyt (1967) used this idea to further develop the model of McGee (1890) on barrier island formation. Oertel (1975a, 1979) supported this hypothesis of coast-parallel topographic control by Pleistocene barrier ridges. In addition, antecedent topographic influence has been utilized by several other authors to develop evolutionary models. Kraft (1971b) and Belknap and Kraft (1981, 1985) examined coast-perpendicular topographic control on barrier island initiation and anchoring along the Delaware coast, and attributed pre-

Holocene relief to paleo-fluvial drainage. Morton and Donaldson (1973) and Wilkinson (1975) described similar findings for Virginia barriers and Matagorda Island, Texas. Other studies noting antecedent topographic influences include Pierce and Colquhoun (1970a, b) and Moslow and Heron (1978) for the Outer Banks of North Carolina, Halsey (1979) for the Delmarva Peninsula, McCann (1979) for Nova Scotia, Rampino and Sanders (1980) for Long Island, Otvos (1982) for Santa Rosa Island, Florida, and Evans et al. (1985) for the west-central Florida coast.

Transgressive stratigraphic models (John, 1977; Kraft and John, 1979) illustrate the contribution of Holocene backbarrier facies to island substructure. Subaerial and submerged lagoonal deposits (including washover deltas, relict flood deltas, and fluvial deltaic deposits) provide relatively unstable platforms. Local subsidence, associated with overburden on marsh and lagoon surfaces, may account for a considerable reduction in island elevation (Guber and Slingerland, 1981), accelerating recession. Transgressed lagoonal materials are subsequently reworked by upper shoreface processes (Swift, 1975, 1976; Swift et al., 1985), often being redeposited in backbarrier environments. Platform characteristics along the Virginia barrier chain are typically of this type. In areas of rapid subsidence, islands may eventually become shoreface shoals (Suter et al., 1985).

Where the lateral rate of island migration is greater than the landward component of motion, inlet-related facies become important platform materials. This specifically refers to barrier systems where a relative balance between sediment supply, coastal hydrodynamics, and changes in sea level have resulted in an essentially stable shoreline.

Using core data, Hoyt and Henry (1967) illustrated the contribution of spit deposition to the substructure of southern Sapelo Island, Georgia while Pierce (1970), Moslow and Heron (1978, 1979), and Heron et al. (1984) documented the importance of inlet fill deposits as barrier platform material along North Carolina's Outer Banks. Kumar and Sanders (1974, 1975) have presented similar results for Fire Island, New York. In addition, where inlet migration is restricted by paleofluvial drainage patterns in the submerged pre-Holocene surface, inlet fill deposits may still contribute significantly as platform material, although not as extensively as in migrating circumstances. The existence of these deposits provides a more stable barrier platform and sand-sized material to nourish downdrift beaches.

Finally, regressive barrier islands respond to an excess in sediment supply by prograding seaward over shoreface deposits. LeBlanc and Hodgson (1959) documented the Holocene development of Galveston Island, Texas as it migrated seaward over the Gulf of Mexico shoreface in response to a surplus of sediment. Van Straaten (1965) showed that barriers of the Dutch Wadden Sea prograded seaward, under rising sea level, over shoreface deposits reworked by nearshore processes. More recently, Moslow (1980) and Moslow and Colquhoun (1981) have documented the depositional history of Kiawah Island, South Carolina in response to fluctuations in sea level, illustrating a net prograding barrier beach-ridge complex perched on upper shoreface deposits. Although island progradation is the most likely means of attaining shoreface platform characteristics, Otvos (1985a), using Horn Island, Mississippi as an example, stated that nearshore aggradation of barriers would produce the same result.

Inlet and Inlet Shoals

Inlet features associated with barrier island complexes separate adjacent island sub-environments and act as conduits for exchange of water and sediment between the backbarrier element and nearshore environment. The number and size of inlets connecting coastal lagoons with the open ocean are dependent upon the volume of water flowing through the orifice (Bruun et al., 1978). The source of water flow is from rivers and tidal exchange; if tidal range is small, river flow may be the principal factor maintaining the inlet. For example, the Mississippi Sound barrier chain has four wide inlets in a distance of 90 km (Figure 19), due to a surplus of river water from the Pascagoula and other streams. Conversely, Padre Island, Texas is approximately 200 km long with small inlets at each end, owing to a very low tidal range and no fluvial influence (Figure 20) (Phleger, 1969; Nichols and Allen, 1981).

Brown (1928), and later Escoffier (1940, 1977), examined the stability of tidal inlets by balancing tidal currents and littoral drift. Assuming a constant tidal prism, inlet geometry and mean inlet throat velocity could be used to predict inlet fate. In addition, O'Brien (1969), Johnson (1973), and Jarrett (1976) established linear relationships between inlet cross-sectional area and backbarrier tidal prism for stable inlets. Maintenance of this relationship (thus stability) requires an equilibrium response to a change in either parameter.

Inspection of barrier island morphology and geology along North American barrier coastlines reveals that as much as 30-50% of sediment deposited may be related to tidal inlet sedimentation (Kumar and Sanders, 1974; Hayes, 1976; Moslow and Tye, 1985). Characteristic shoal deposits

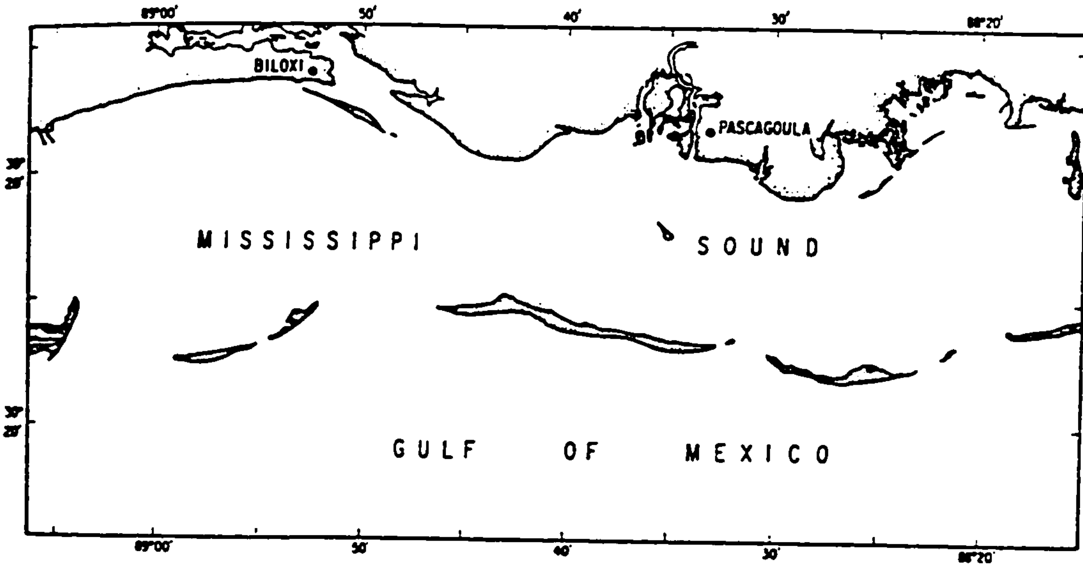

Figure 19. An example of large, closely spaced inlets separating the barriers fronting Mississippi Sound (from Phleger, 1969).

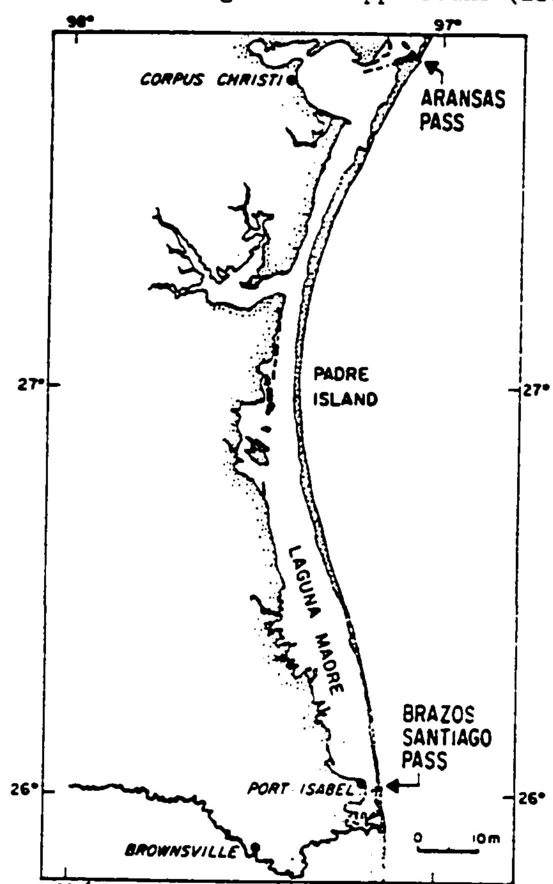

Figure 20. Laguna Madre, Texas, an example of a lagoon with small, widely-spaced inlets (from Phleger, 1969).

result as a function of tidal range and frequency, sediment supply, and nearshore energy sources (Hayes and Kana, 1976; Hubbard et al., 1979). From the standpoint of process influence, it is possible to identify three types of coasts related to the position and magnitude of inlet deposits: 1) wave-dominated; 2) tide-dominated; and 3) those with a balance between waves and tides (Davis and Hayes, 1984). It is reasonable to assume that the dominant physical processes affecting inlet sand body geometry would also influence adjacent system components. Consequently, inlet dynamics exert considerable control on the evolution of barrier island systems.

Wave-dominated inlets are present where wave action causes significant sediment transport and dominates tidal effects (Heward, 1981). Under these circumstances, a majority of the sand is transported into the lagoon producing large flood-tide delta deposits, or is bypassed around the inlet. Tidal inlets along the Outer Banks of North Carolina are typically wave-dominated (Nummedal et al., 1977). Due to the predominance of wave energy, wave-tidal current interaction occurs close to shore producing small seaward shoals that are mainly utilized to bypass sand around the inlet (Figure 21) (Bruun et al., 1978; Sexton and Hayes, 1982; Silvester, 1985). The ebb-tide delta is often segmented by numerous shallow tidal channels and ephemeral wave-generated swash features such as small scale megaripples (Hubbard et al., 1979). By contrast, the flood-tide delta is generally large and multi-lobate, dominated by landward-oriented bedforms in a varied sequence of planar and trough cross-beds, and consists of a flood ramp, flood channels, ebb shields, ebb spits, and spillover lobes (Figure 22) (Hayes, 1975;

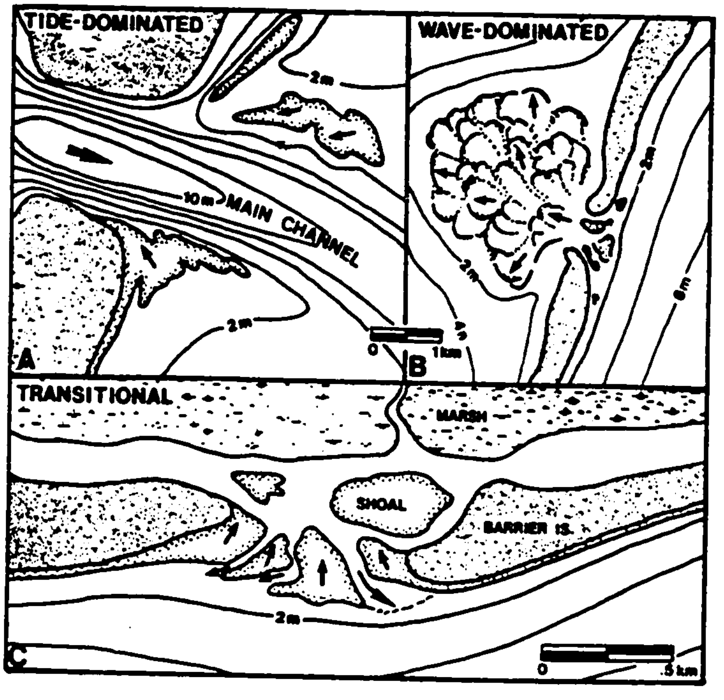

Figure 21. Tidal inlet types: A) tide-dominated - characterized by a deep channel flanked by extensive channel-margin bars. B) wave-dominated - generally dominated by landward transport; ebb-tidal delta is small and often breached by numerous shallow channels. C) transitional - characterized by shoals contained in the inlet throat (from Hubbard et al., 1979).

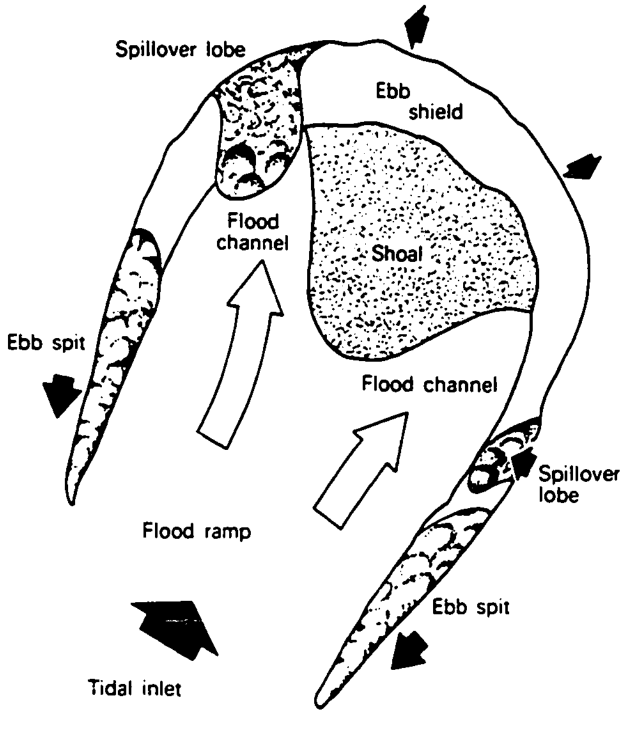

Figure 22. Typical morphology of a flood-tidal delta (from Hayes, 1975).

Boothroyd and Hubbard, 1975; Boothroyd, 1978). Consequently, resultant sedimentation patterns strongly influence development of the backbarrier complex. In addition, since inlet migration rates associated with these features are at a maximum (Moslow and Tye, 1985), sediment contribution to barrier substructure is significant.

Tide-dominated inlets exemplify regions where sediment transport associated with tidal currents dominates wave effects. Portions of coast in the central Georgia Embayment illustrate this characteristic, possessing inlets with extensive ebb-tide deltas (Oertel, 1972, 1975b, 1977; Hubbard et al., 1979). DeAlteris and Byrne (1975) and Goldsmith et al. (1975) provided similar descriptions of inlets along the Virginia barrier islands. The morphology of ebb-tidal deltas is generally controlled by tidal current segregation during different phases of the tidal cycle. However, Todd (1968) has shown that shoal formation is affected by the hydraulic interaction between tidal flow and wave-generated, sediment-bearing longshore currents. Oertel (1975b) utilized this concept to model ebb delta configuration as a function of the relative magnitude of "dynamic diversion" forces (Figure 23). Flood-tide shoal deposits are poorly developed or absent and exert little influence on lagoonal sedimentation at tide-dominated inlets since marsh development is generally extensive (Hayes, 1979). The frequency of inlet occurrence is increased over that of wave-dominated barrier coastlines, thus increasing their effect on the barrier island component. In addition, the bulbous updrift ends of barriers along the Virginia outer coast (Goldsmith et al., 1975) often represent a point of attachment for a portion of the ebb-tidal delta, subsequently nourishing downdrift island environments (FitzGerald, 1984; FitzGerald et al., 1984).

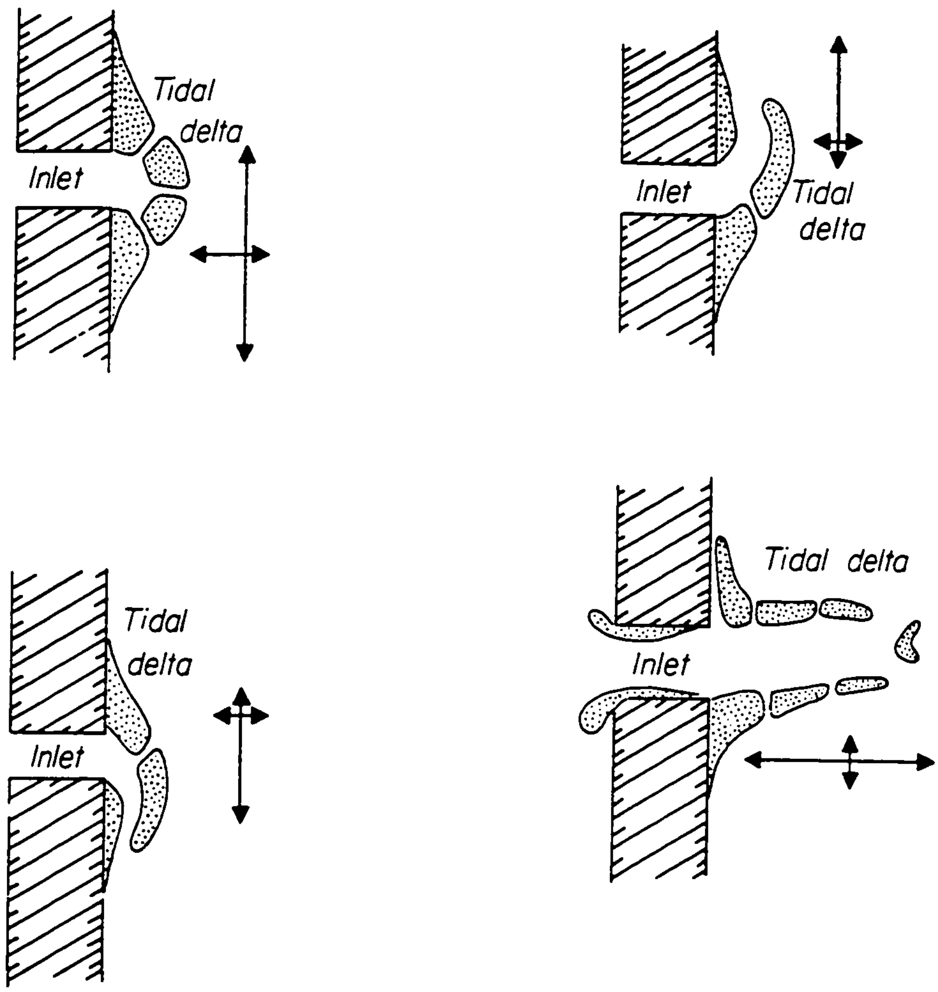

Figure 23. Classification of ebb-tidal deltas. Vectors are relative forces of onshore, offshore, and longshore currents (from Oertel, 1975b).

Transitional inlet environments exhibit a high degree of shoal morphologic variability between inlets (Hubbard et al., 1979). Large sand prisms landward and seaward of the inlet are uncommon and inlet maintenance is controlled by shoal separation. Dominant bedforms are megaripples with a variety of orientations and wave-generated planar laminations (Hubbard et al., 1979). In addition, these inlets typically have one main channel and a number of secondary channels, often covering a considerable distance between barriers (eg. Stono Inlet, South Carolina).

Shoreface

Swift et al. (1985) define the shoreface element as the relatively steeply dipping subtidal portion of the inner continental shelf, commencing at mean low tide level and terminating at depths of 15-20 m; the depth being greater as wave and current energy increases (Figure 24). Regional and local scale variations in coastal dynamic regimes and resultant morphologies reflect the complex mutual interactions between energy inputs and boundary configurations (Wright, 1976). Swift (1969) introduced a simple process-response model that can be used to illustrate sediment-water interactions on the shoreface (Figure 25). Throughout time, this model generates the three-dimensional shoreface configuration characteristic of local and long-term material and energy fluctuations.

In physical terms, the shoreface is an area of transition between offshore and shelf processes, and nearshore processes such as the breaking of waves. This region can be divided into two broad process sub-regimes, the upper shoreface and the lower shoreface. The upper shoreface regime is generally dominated by wave-driven flow associated with shoaling waves whereas the lower shoreface may also be influenced by

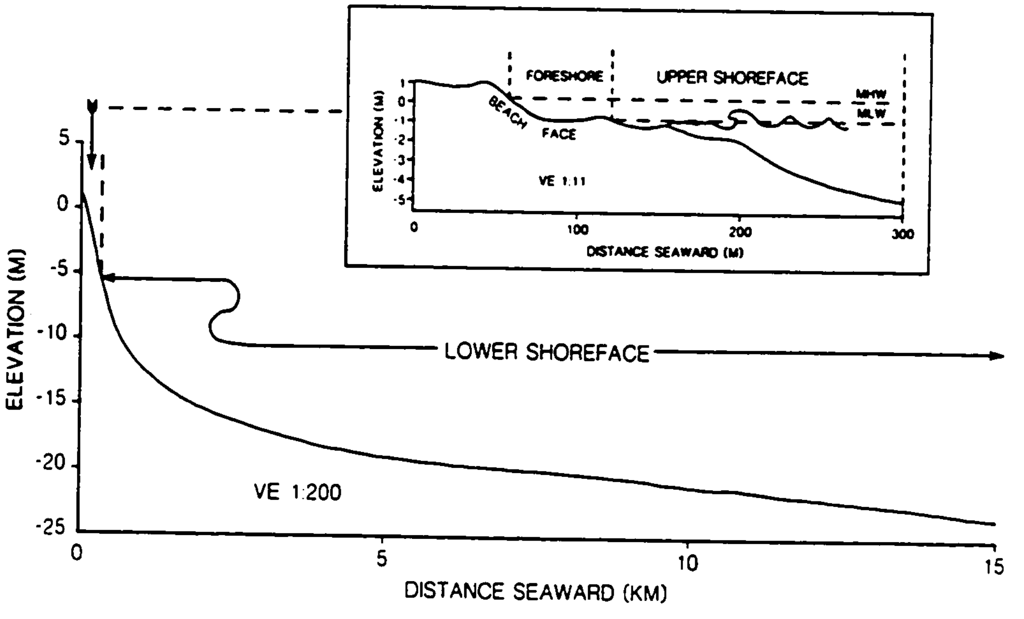

Figure 24. Generalized diagram of the shoreface illustrating the major sub-environments (from Oertel, 1985).

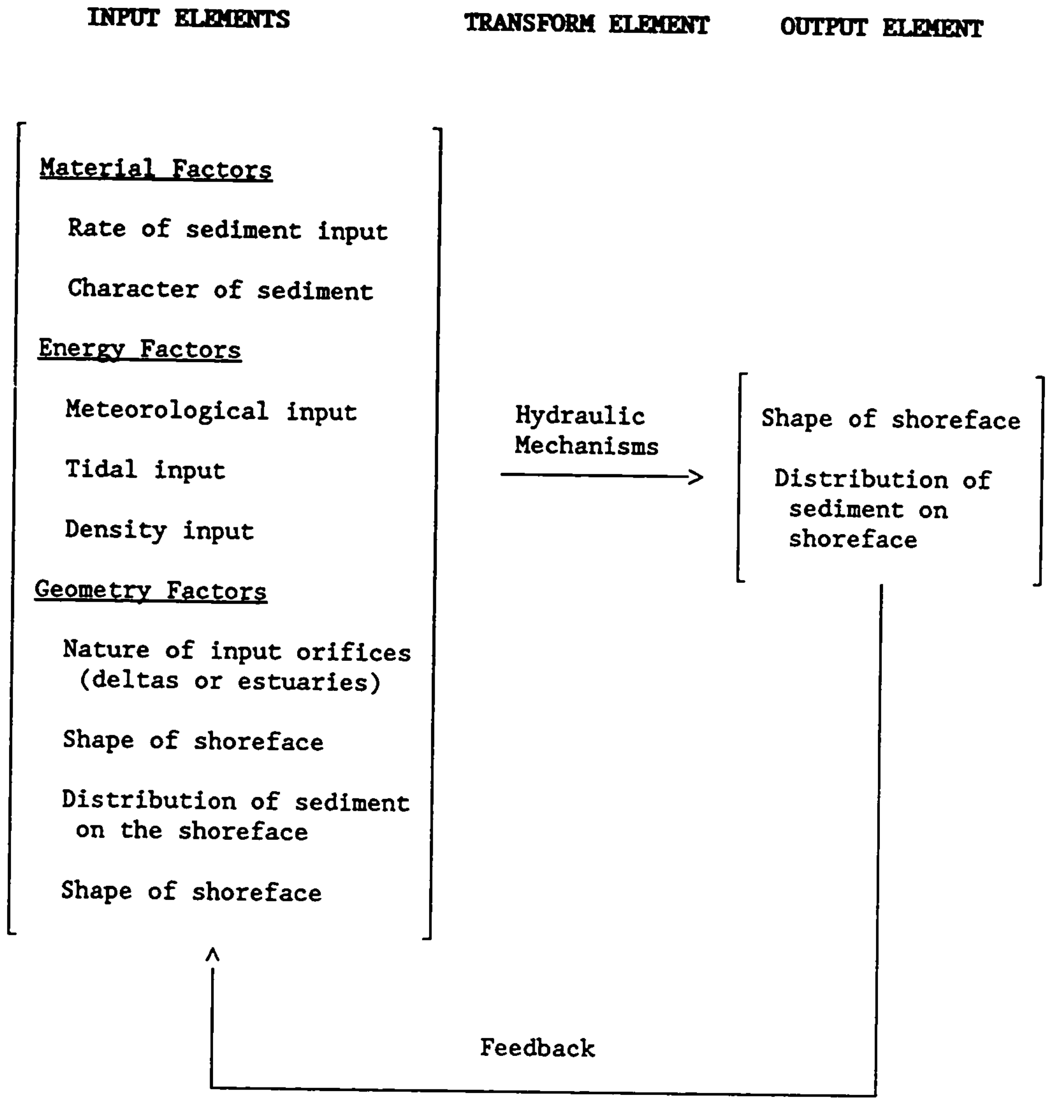

Figure 25. Process-response model for the water-sediment system of the shoreface (from Swift, 1969).

tidal currents and storm-induced flows (Swift, 1975, 1976; Niedoroda et al., 1984; Swift et al., 1985). Although coastal currents tend to be more intense over the lower shoreface, horizontal wave orbital motion is an important mechanism for initiating sediment movement for transport by a steady or slow-varying flow (Bagnold, 1963; Swift et al., 1985). The boundary between the upper and lower shoreface is dependent upon the intensity of the wave and current climate, and therefore not absolute.

Bruun (1962, 1983) noted a characteristic curve to the shoreface and assumed that it constituted an equilibrium response to the hydraulic climate. Utilizing a closed material balance model along a coast-normal shoreface profile, it was demonstrated that the geometry of profile translation, related to sea level rise, requires shoreface erosion and corresponding aggradation on the adjacent sea floor (Figure 26). Although the validity of this two dimensional concept has been supported by field data (Schwartz, 1967; DuBois, 1976; Rosen, 1978), some researchers suggest that the "Bruun Rule" is inappropriate along barrier coastlines (McCormick and Toscano, 1981; Wolfe, 1982) or needs modification to support cross-island sediment transfer (Dean and Maurmeyer, 1983).

Wright and Coleman (1972, 1973) and Wright (1976) applied a nearshore wave-power dissipation model to explain nearshore profile characteristics worldwide. Deep-water ocean wave height is determined by the strength, duration, and fetch of wind blowing over the sea surface. However, the height of waves near the coast is further influenced by wave attenuation and refraction across the shoreface. Short and Hesp (1982) found that within high energy environments where shoreface slopes were steepest, more than 75% of the deep-water wave energy reached the shore,

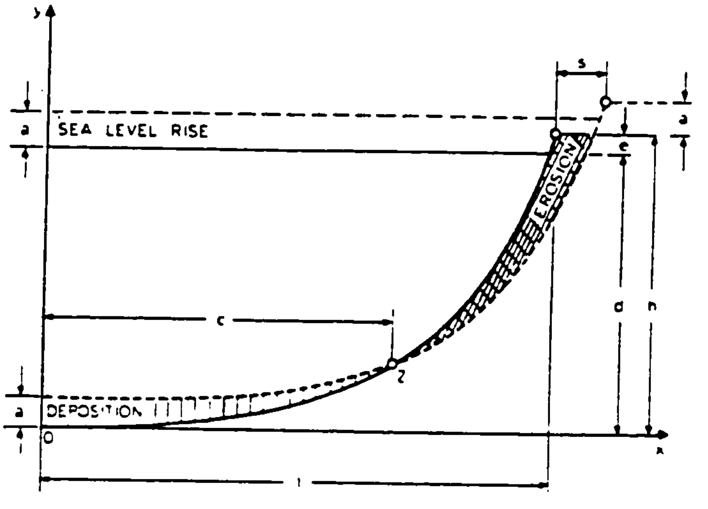

Figure 26. The Bruun Rule - translation of the beach profile, resulting in shore erosion and deposition of sediment offshore (from Bruun, 1983).

resulting in high energy, dissipative or intermediate beaches. Conversely, low energy, reflective beaches, with shallow shoreface slopes, received only 25-40% of the deep-water wave power. Although wave power loss by friction is only one of many complex factors influencing dynamics of barrier shorelines, it is an important process through which varying combinations of wave climate and subaqueous boundary conditions may yield pronounced coastal geomorphic contrast.

Coastal transport of sand by wave orbital and wind driven currents strongly influences shoreface geometry, grain textural variability, and barrier island configuration. Shoreface response to changes in hydraulic regime is instantaneous with respect to long-term sea level fluctuations. Dynamic interaction patterns of the upper and lower shoreface may give rise to long-term cyclic patterns of advance and retreat of the coast profile. On coasts experiencing a positive net littoral drift, fair weather progradation is more effective than storm erosion, and the profile translates seaward. On coasts experiencing a net sediment deficit, storms control the onshore-offshore sand budget, and the shoreface profile undergoes landward and upward translation.

Shoreface geometry along the Delmarva Peninsula appears to exhibit considerable influence on the rate of barrier system development (Field and Duane, 1976). Upper shoreface slope, calculated using depths from NOAA charts 12214 and 12221, varies from 1.0° at Fenwick Island, Maryland to 0.2° at Smith Island, Virginia. Consequently, barriers south of Parramore Island, Virginia (see Figure 1) are situated farther seaward of the mainland than those to the north. This potentially provides southern Delmarva barriers a wider buffer zone for frictional dissipation of incoming wave energy as well as a more extensive offshore source of sand for barrier nourishment. Conversely, northern Delmarva barriers are mainly nourished by longshore transport of sediment from eroding headlands (Kraft, 1971a; Kraft and John, 1979).

Transgressive Barrier Stratigraphy

Patterns of sedimentation at barrier island complexes are greatly influenced by sea level fluctuations. Sea level changes are the consequence of a considerable number of factors including global glacial volume changes due to global climate changes, ocean basin volume changes due to earth movements, ocean level distribution changes due to geoid variations (Moerner, 1976), and volume expansion of sea water due to temperature change (Roemmich, 1985). In addition, regional meteorologic and hydrographic factors such as atmospheric pressure, wind, and water density may exert considerable effect on sea level (Lisitzin, 1974). Therefore, the response of coastal environments often results in complex depositional sequences. The rate of shore level displacement reflects the combined effect of eustatic and crustal movements. Belknap and Kraft (1977) combined a number of Holocene sea level curves illustrating the controversy over interpretation (Figure 27). However, most researchers support a steadily rising sea level during the early Holocene Epoch (until 3600 to 5000 years BP) followed by an asymptotic decrease in rate to the present. Recent tide gauge data support continued eustatic coastal submergence, although mean annual fluctuations do exist (Stapor, 1982; Nummedal, 1983; Hicks et al., 1983; Braatz and Aubrey, 1987).

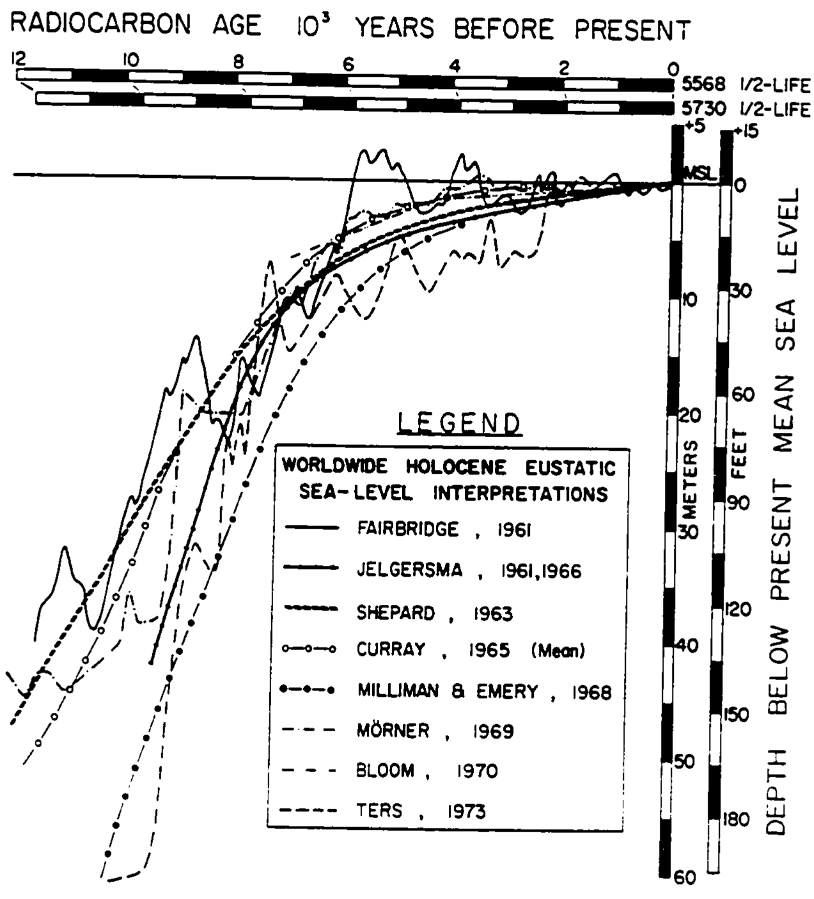

Figure 27. Depth vs. time plot of published sea level curves (from Belknap and Kraft, 1977).

The products of transgressions and regressions depend on many factors including the rate and nature of sediment supply, the intensity of oceanographic processes, the width and configuration of the pre-Holocene transgressed surface, and the rate and direction of sea level change. Kraft (1972) presented several potential elements of a marine transgression or regression that affect coastal stability in a sedimentary continental shelf-coastal plain setting (Figure 28). Clifton and Hunter (1982) schematically illustrated the interrelation of various environmental influences determining the character of coastal sedimentary facies (Figure 29). It is clear that a shift in shoreline position could be triggered by an extremely complex set of events. However, Curray (1964) suggested that relative sea level fluctuations and the rate of net deposition were the two main factors controlling coastal evolution and proposed a conceptual model illustrating this concomitant relationship to explain shoreline migration perpendicular to the shoreline (Figure 30). If the rate of sedimentation is less than the rate of sea level rise, shoreline transgression occurs. Conversely, shoreline regression results when the rate of vertical sediment accumulation exceeds the rate of sea level rise. Therefore, it is imperative to recognize that coastal development is not determined directly by the absolute rates of sea level rise and fall, but by the relative rates of sedimentation and sea level change (Nummedal, 1983).

In addition to controlling shoreline location, the rate with which sea level has been fluctuating relative to local sedimentation or erosion rates determines the stratigraphic signature of coastal deposits as well as the topographic profile of the barrier island surface. Sloss (1962)

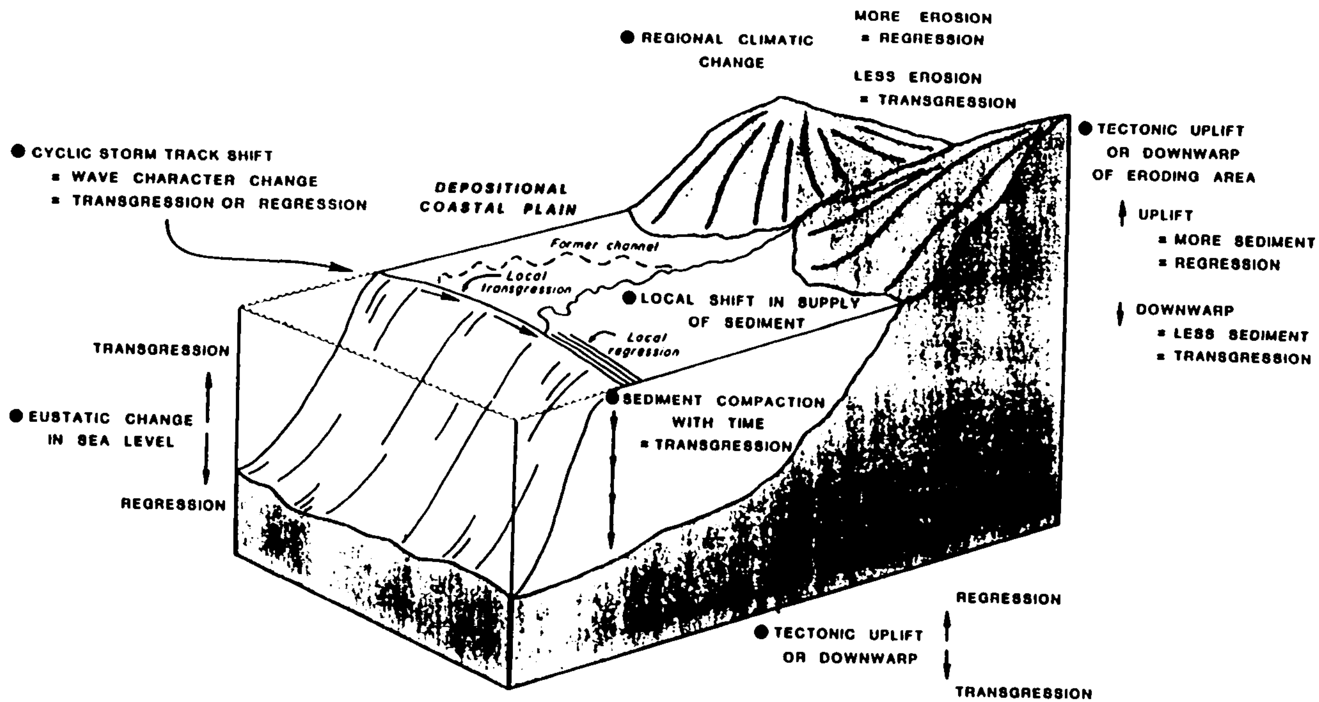

Figure 28. Potential elements of a marine transgression or regression (from Kraft, 1972).

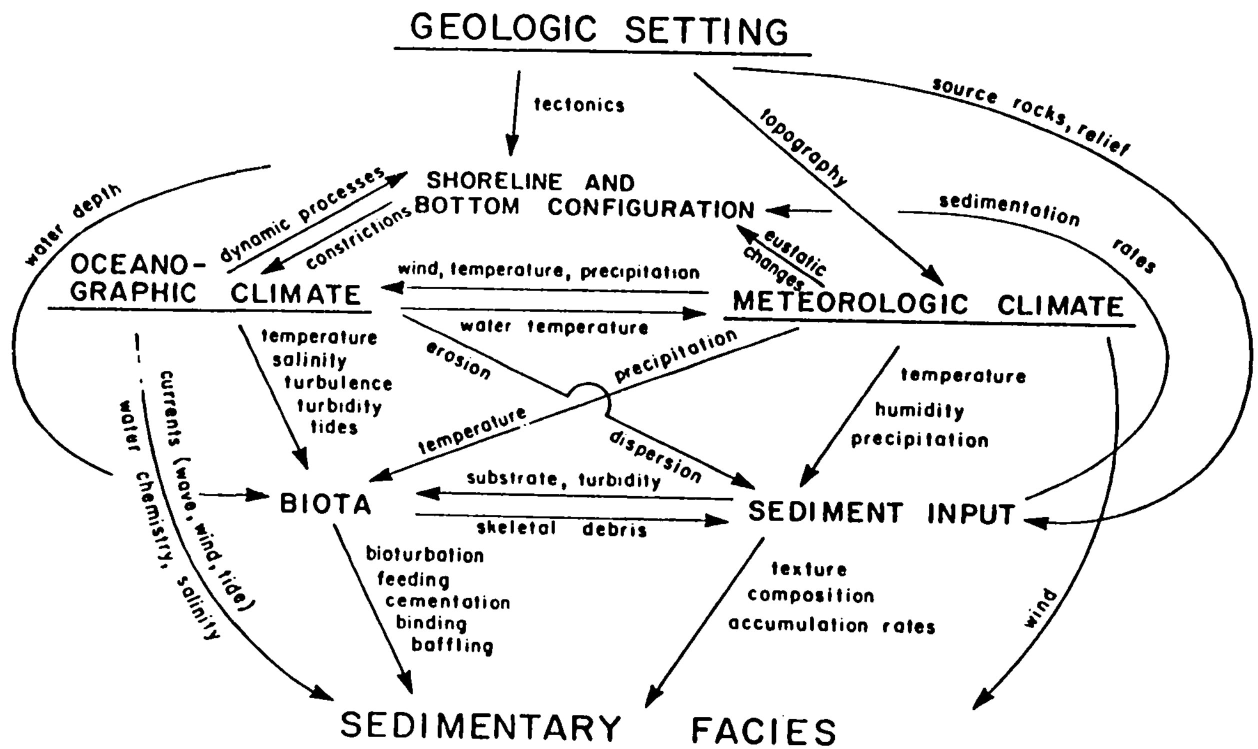

Figure 29. Schematic showing interrelation of environmental factors and their control on coastal sedimentary facies (from Clifton and Hunter, 1982).

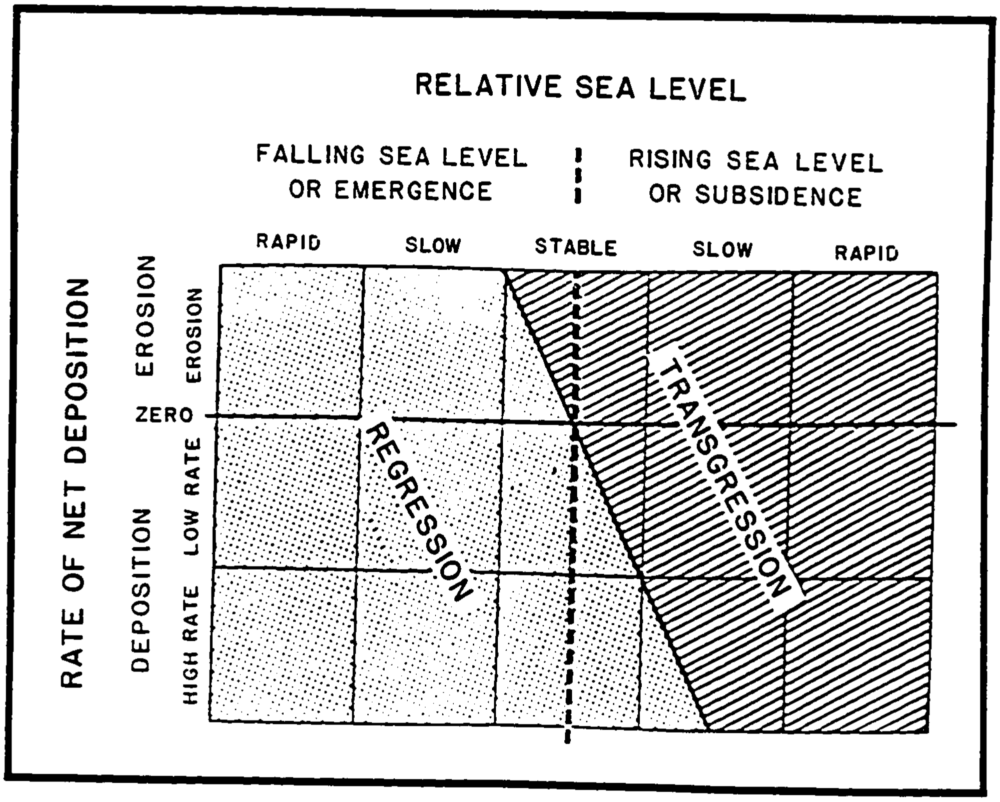

Figure 30. Diagram showing the effects of the rate of change of relative sea level and local net rate of deposition on shoreline migration (from Curray, 1964).

and Allen (1964) discussed the variables which determine the nature of coastal sedimentary sequences. Swift et al. (1972) presented a semi-quantitative expression relating these variables;

$$K = (S/E)_G - R \qquad (1)$$

where S is the rate of sediment input, E is the energy input, G is the character of the sediment, R is the rate of relative sea level rise, and K is the rate and direction of shoreline movement. This expression states that for a given grain size, the ratio between the rate of sediment supply and the energy available to disperse it, must equal the rate of relative sea level change; otherwise, the coastline will advance or retreat.

Modern barrier island stratigraphic studies have been utilized to investigate the past history of transgressions and regressions. Most of the earlier studies were concerned with facies relationships and time-stratigraphic position for the purposes of developing models of barrier island deposition (Shepard and Moore, 1955; Fisk, 1959; LeBlanc and Hodgson, 1959; Shepard, 1960; Bernard et al., 1962). For years, the Galveston (prograding seaward) and Padre Island (vertical aggradation) stratigraphic models were widely accepted as representative examples of modern barrier shorelines and were used extensively for the interpretation of ancient barrier shorelines (Davies et al., 1971; Dickinson et al., 1972; Reinson, 1979). Although many coastal plains of the world do contain stable or regressive shorelines, initial transgressions of the sea were needed prior to recent barrier evolution. A closer examination of "regressive" barrier complexes has revealed transgressive phases as well (Wilkinson and Basse, 1978; Kraft and John, 1979; Moslow, 1980).

Subsurface investigations on east coast barrier systems confirmed two important findings briefly addressed in previous Gulf coast studies: 1) the transgressive nature of many barriers (Kraft, 1971a, b; Kraft and John, 1979; Heron et al., 1984) and 2) the reworking effects of laterally migrating tidal inlets (Hoyt and Henry, 1967; Moslow and Heron, 1978; Moslow and Tye, 1985). Continued study has shown that most modern barrier island systems are migrating landward in response to rising sea level (McIntire and Morgan, 1963; Hoyt, 1967; Dillon, 1970; Otvos, 1970a; Pierce and Colquhoun, 1970a, b; Kraft et al., 1979; Moslow and Heron, 1979; Heron et al., 1984; Niedoroda et al., 1985; Otvos, 1985a, b). Transgressive sequences associated with retrograding barriers have been described by Fischer (1961), Oomkens (1967), Swift (1968), Kraft et al. (1973), Bridges (1976), Kraft and John (1979), Otvos (1979), and Thom (1983).

The Atlantic coast of the Delmarva Peninsula is composed of a transgressive barrier island system characterized by tidal delta deposits, medium relief to low relief barriers, and extensive washover fan morphology. Detailed stratigraphic studies along the Delaware coastline form the most extensive data base for retrograding Holocene barriers in the world. Analysis of geomorphology, subsurface geology, coastal processes, and paleogeographic reconstructions enabled Kraft et al. (1979) to suggest that the Delaware Atlantic coastal zone could be represented by three models: 1) an Atlantic coastal lagoon transgressive barrier system dominated by tidal inlets; 2) an Atlantic coastal lagoon-linear baymouth barrier and eroding pre-Holocene headland; and 3) a complex spit evolving at the southern margin of the mouth of Delaware Bay. Local relative sea level rise serves as an important driving mechanism for coastal evolution. Sea level rise at the Delaware coastal compartment was smooth and continuous until present, with a decrease in rate over the past 7000 years (Figure 31). However, fluctuating sedimentation rates in accordance with supply have produced both transgressive and regressive events (Kraft and John, 1979).

Atlantic barrier island systems are dominated by the development of flood-tidal deltas in lower energy lagoon environments. Tidal inlet breaching in response to storm processes causes the accumulation of extensive backbarrier sand deposits through wave activity and longshore transport (Kraft et al., 1979). Eventual closure and subsequent transgression recycles sediment through the system by longshore transport and storm overwash deposition in backbarrier environments. Surface geomorphic expression includes narrow coast-parallel dunes, washover fans, and flood-tide deltas. Consequently, vertical sedimentary sequences tend to coarsen upward and are often comprised of interbedded sands and muds (Figure 32). Baymouth barrier systems are similar to the previous model but develop mainly by longshore transport and storm overwash processes. Tidal inlets and associated deltas are absent and pre-existing topography determines the thickness and shape of sedimentary environmental sequences during transgression (Belknap and Kraft, 1985). Incident wave energy is a major cause of net landward migration, providing frequent exposure of backbarrier marsh in the surf zone. Subsurface borings frequently encounter marsh lenses within the sand (Kraft et al., 1979; Figure 33).

From the data presented above, a generalized cross-section for transgressive barrier sequences can be constructed (Figure 34). This provides an illustration of Walther's law of succession of facies which

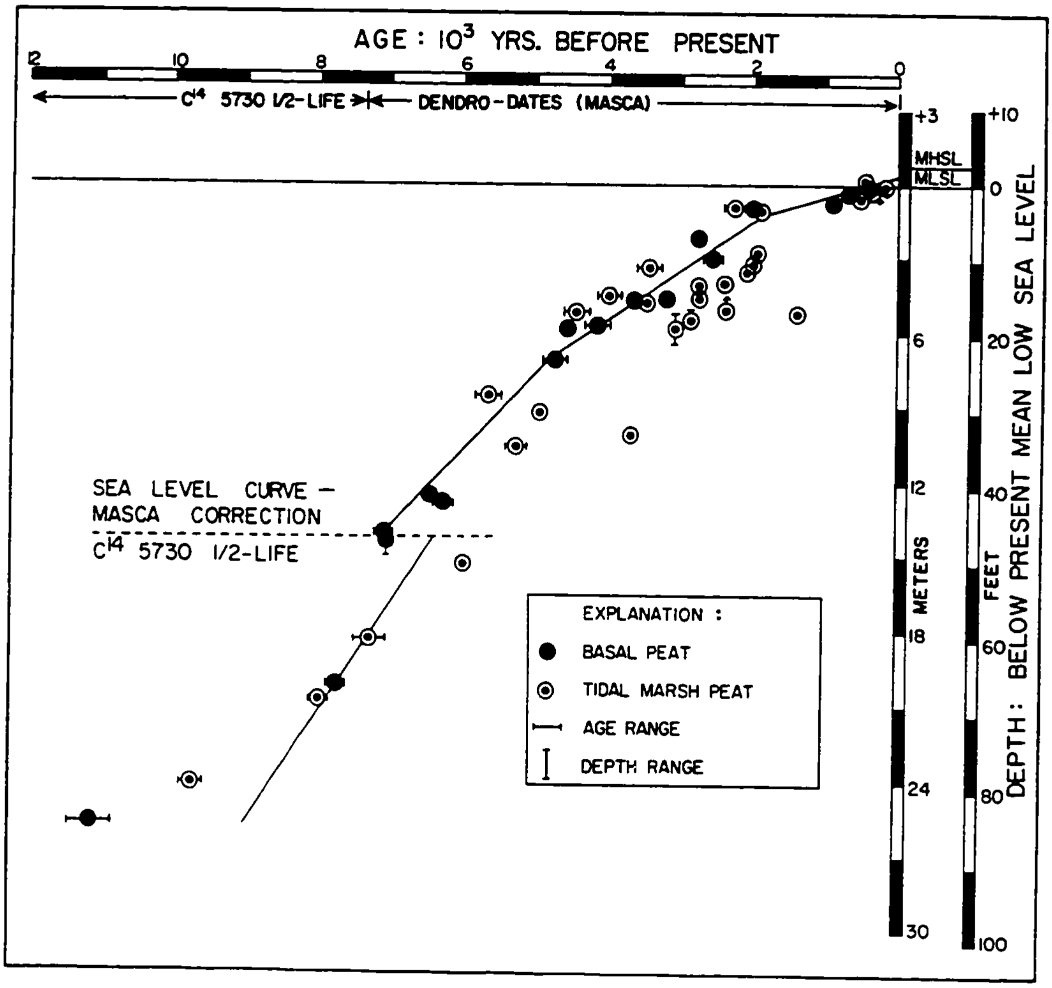

Figure 31. Local relative sea level rise curve for the coastal Delaware region. The age in years before present has been corrected to 5730 1/2-life or the dendro-date correction (MASCA) of the University of Pennsylvania Museum, Applied Science Center for Archeology, as appropriate (from Kraft, 1976).

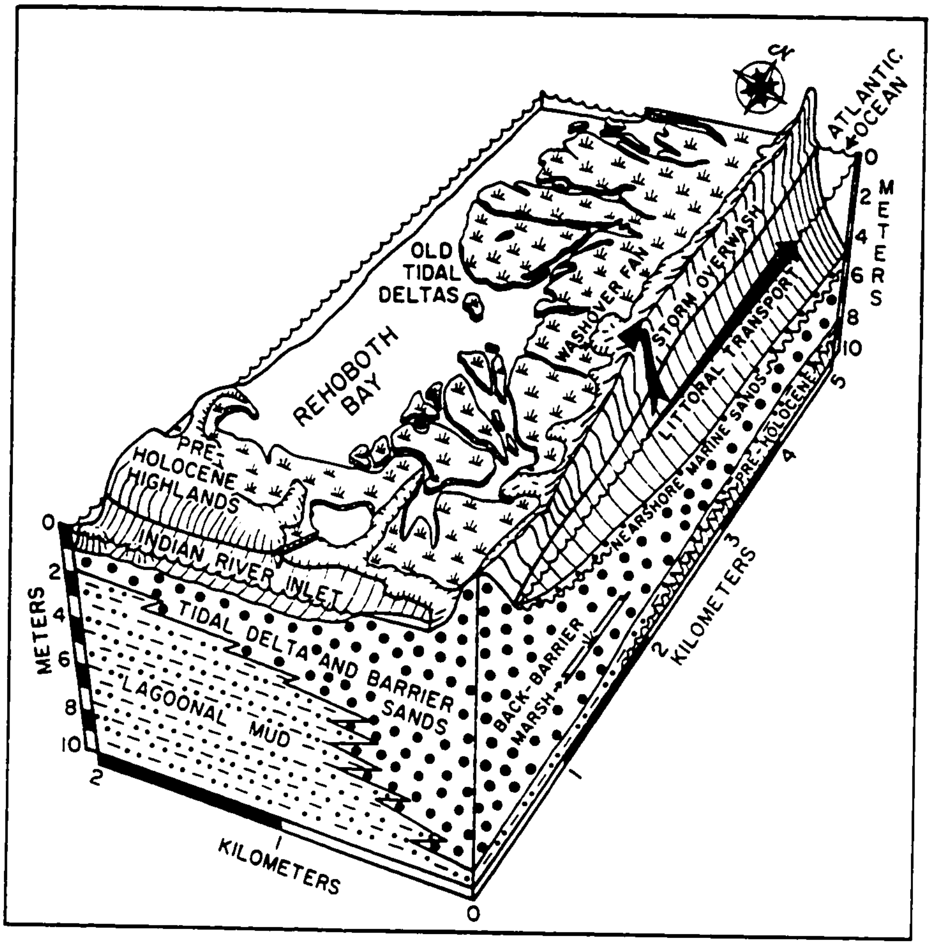

Figure 32. Schematic showing geomorphic and stratigraphic elements of an Atlantic coast barrier in the vicinity of tidal deltas (from Kraft et al., 1979).

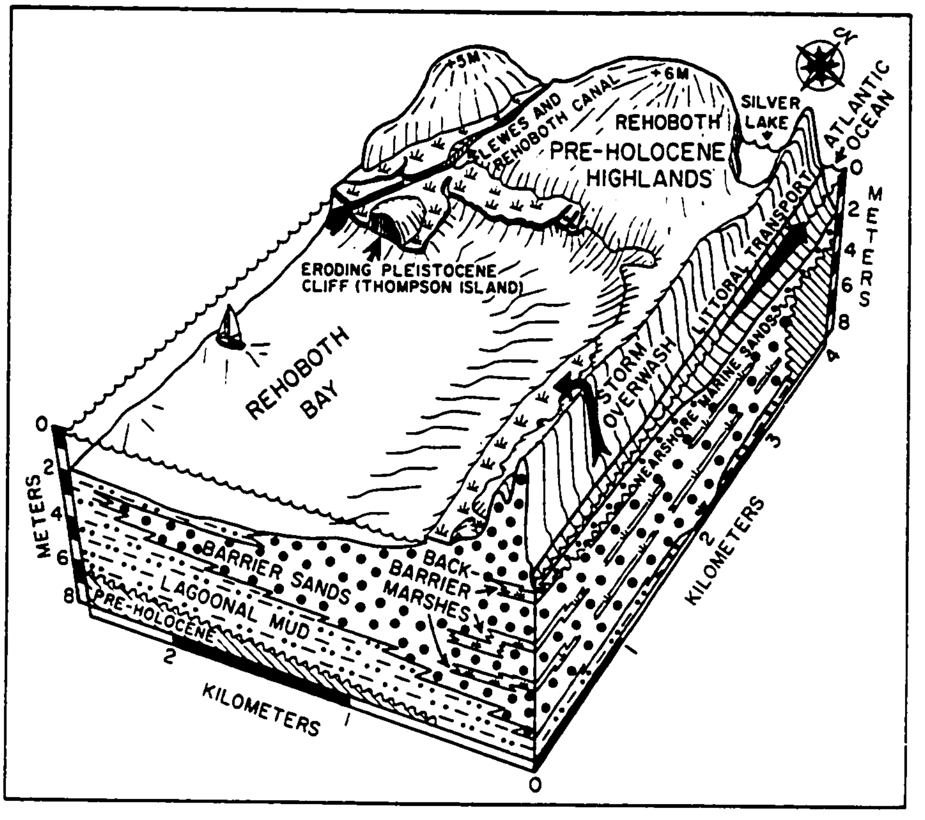

Figure 33. Schematic of a linear Atlantic baymouth barrier and headland showing geomorphic features and sub-surface sedimentary units (from Kraft et al., 1979).

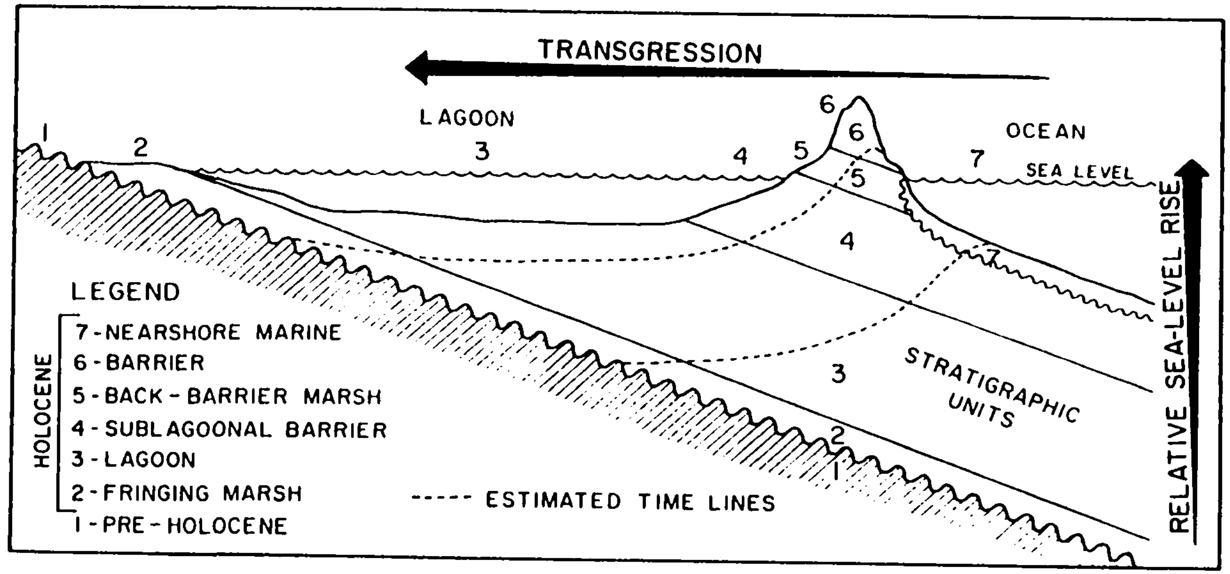

Figure 34. Idealized depositional environment sequence for transgressive barrier island systems (from Kraft and John, 1979).

Selley (1982) briefly stated as "a conformable vertical sequence of facies generated by a lateral sequence of environments". Clearly local stratigraphic relationships will depart from this model depending on sources of sediment, tectonics, eustacy, geomorphology, and hydrodynamic conditions.

Most stratigraphic studies associated with Virginia barrier islands have dealt with backbarrier sedimentation patterns (Newman and Munsart, 1968; Harrison, 1971; Kemerer, 1972; Morton and Donaldson, 1973). Recent work by Shideler et al. (1984) and Finkelstein (1986) illustrate transgressive sequences similar to those of Kraft and John (1979) and Kraft et al. (1979). However, barrier sands appear to be less significant (often less than 4 m thick) and the variation in lagoonal sediment texture more apparent. The variability in backbarrier sediment texture is due to a decrease in sediment supply and subsequent increase in washover deposition, as well as an increase in the number of stable inlets in this coastal region.

Recognition of ancient strandline deposits depends on the preservation potential of transgressive coastal lithosomes. Belknap and Kraft (1981, 1985) address this issue using seismic and stratigraphic evidence from the Delaware-Maryland continental shelf. Preservation of all or part of the transgressive sequence of sedimentary units depends on the depth of erosion. The magnitude of erosion is a function of sediment supply, impinging wave and current energy, tidal range, resistance to erosion, pre-existing topography, and rate of relative sea level change (Belknap and Kraft, 1981). Fischer (1961) postulated the concept of fractional preservation of the stratigraphic record in a continuing transgression as a function of the depth of shoreface erosion (Figure 35).

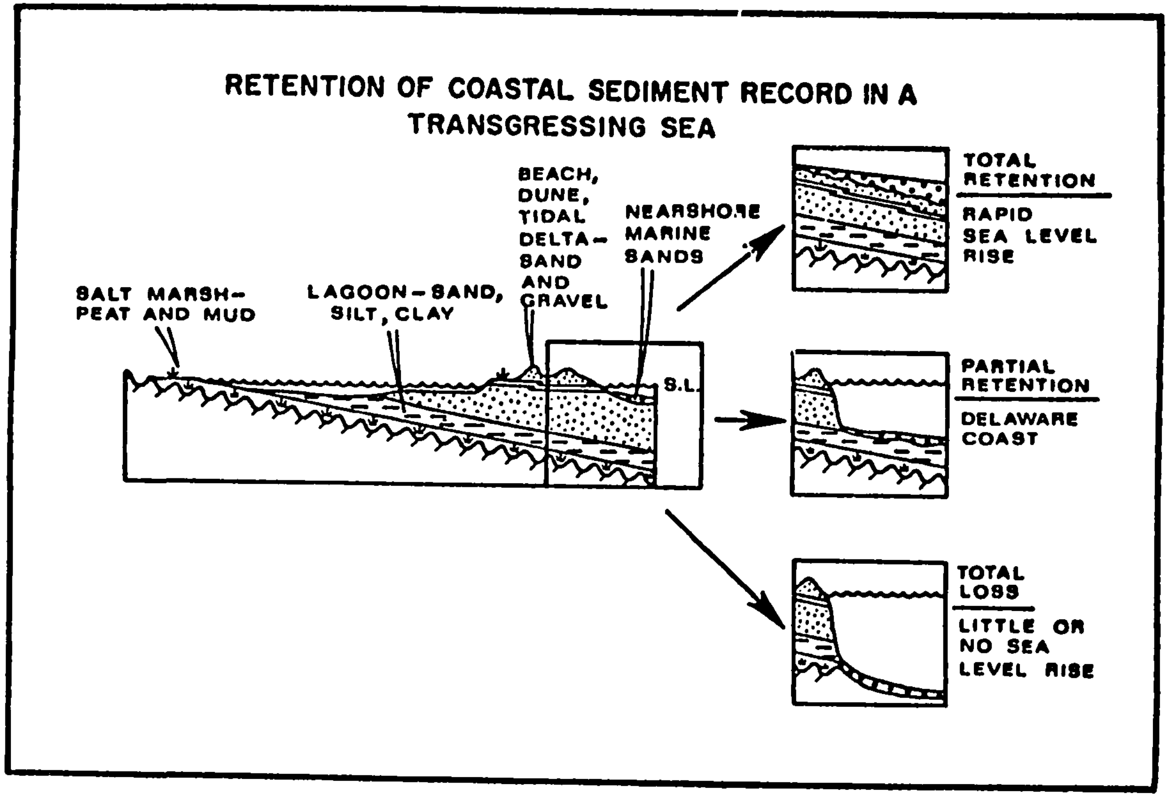

Figure 35. Diagram of retention of the coastal sediment record in a transgressing sea (from Fischer, 1961).

This, as well as the Bruun quantitative model of shore erosion in response to sea level rise (Bruun, 1962, 1983) and evidence for a non-uniform rise in Holocene sea level (Belknap and Kraft, 1977), provided the basis for a conceptual model of preservation potential (Belknap and Kraft, 1981). It was hypothesized that the preservation of coastal lithosomes varied in space and time, from a highly preserved record on the outer shelf to an almost completely reworked upper shoreface. In addition, the spatial relationship between the basal unconformity (hiatus at the pre-Holocene boundary) and the ravinement surface (zone of shoreface erosion) is influenced by antecedent topography. Therefore, on pre-Holocene interfluves, destruction of the Holocene record is complete, while in the adjacent ancient valley preservation may be complete (Belknap and Kraft, 1985).

Depositional Sedimentary Environments

Depositional sedimentary environments are three-dimensional units in which deposition is characterized by a unique set of physical, biological, and chemical processes operating at a specific rate and intensity. Physical processes are most important since they provide the most basic information for geomorphic interpretation (Reineck and Singh, 1980). Grain size and primary sedimentary structures have the highest preservation potential, often providing useful details about hydrodynamic conditions associated with deposition. In addition, environmentally sensitive biological components may provide considerable ecologic information necessary to delineate spatial and depositional patterns.

In this study, environmental reconstruction of coastal sedimentary sequences has been accomplished utilizing several criteria including grain textural analysis, primary sedimentary structures, and microfossil assemblages. Since most individual characteristics occur separately in several different environments, a spectrum of sedimentary structures and textures and their presence in certain combinations were used to provide direct information for environmental interpretation.

Grain Size Distribution

Sedimentologic models often use concepts based on fundamental relationships between grain textural parameters and depositional environments. The grain size of clastic sediment is a measure of the energy of the depositing medium and is therefore thought to be environmentally sensitive. Various factors related to grain size distributions, such as shape of cumulative curves, frequency curves, histograms, and various other statistical parameters, have been used to differentiate depositional environments, delineate transport paths, and to suggest transport mechanisms (Inman, 1952; Folk and Ward, 1957; Passega, 1957, 1964; Sahu, 1964; Klovan, 1966; Friedman, 1967, 1979; Doeglas, 1968; Greenwood, 1969; Visher, 1969; Upchurch, 1970; Allen, 1971; Glaister and Nelson, 1974; Granat, 1976; Moussa, 1977; Chambers and Upchurch, 1979; Tucker and Vacher, 1980; Bridge, 1981; Sly et al., 1983; Brown, 1985; El-Ella and Coleman, 1985; Williams and Scott, 1985). An important assumption for many of these studies was that particle sizes encompassing distributions are log-normally distributed. Although recent studies have argued rather convincingly against the use of the Gaussian curve (LeRoy, 1981) and pointed out the existence of other more naturally occurring distributions such as the log-hyperbolic or hyperbolic curve (Bagnold and Barndorf-Nielsen, 1980), deeply entrenched traditional concepts of log-normality have generally prevailed. The following discussion summarizes the most widely used techniques for grain size studies.

The most common method of classifying sediments is based on descriptive measures of their distribution as determined by graphical techniques (Folk, 1966) or by the method of moments (Friedman, 1967). Commonly calculated statistical parameters, including mean, standard deviation, skewness, and kurtosis, are often analyzed on bivariate scatter diagrams. Mason and Folk (1958) and Martins (1965) effectively differentiated beach and dune environments by plotting skewness versus kurtosis. However, Moiola and Weiser (1968) found this plot to be useful only in limited cases and agreed with Friedman (1961, 1967) in stating that mean grain size versus skewness provided a more effective method of discriminating the same two environments. On the other hand, Shideler (1974) found that plotting standard deviation against kurtosis most effectively differentiated beach and dune environments. Individual statistical parameters have also been used for environmental differentiation (Duane, 1964; Hails and Hoyt, 1969; Valia and Cameron, 1977). However, many geologists including Shepard (1964), Schlee et al. (1964), Gees (1965), Sevon (1966), and Moiola and Spencer (1973), felt that grain size parameters provided limited if any success in differentiating sedimentary environments. Regardless, LeRoy (1981) demonstrated that moment method statistics were most applicable for this or any type of analysis since no particular physical theory of distribution rules had to be assumed.

Passega (1957, 1964) considered the two most important parameters for characterizing a sediment sample to be the coarsest one-percentile particle size (C) and the mean grain size (M). A plot of C versus M was assumed to reflect the processes of sediment transport and thus used to discriminate environments of deposition. Spencer (1963) and later Visher (1969) utilized a highly controversial technique of graphically analyzing textural patterns and stated that log-normal subpopulations on a probability cumulative frequency curve could be recognized as distinct line segments. These straight line subpopulations were said to indicate various possible transport mechanisms such as traction, saltation, and suspension. Glaister and Nelson (1974) found this approach most reliable in identifying log-normal segments of the entire size distribution thought to vary systematically in relation to sedimentary process, provenance, and sedimentary dynamics. However, recent work by LeRoy (1981) has clearly shown that line segments on cumulative curves can be understood as mathematical artifacts, implying no necessary relation to grain subpopulations.

With the advent of high speed computers, the ability for one to analyze sample covariation in large multi-dimensional data sets has increased. Therefore, the individual weight percentages in each size category can be used to characterize a sample, rather than summary statistics containing an inevitable loss in information. Numerous multivariate statistical techniques, including factor analysis, principal components analysis, discriminant function analysis, cluster analysis, and others, have been successfully employed in classifying sediment samples. Sahu (1964) established four discriminant functions based on summary statistics from various known depositional environments for use in classifying samples of unknown environmental origin. Klovan (1966) used Q-mode factor analysis (the relationship between n sample vectors based on p components) on Krumbein and Aberdeen's (1937) Barataria Bay sediment samples to discriminate environments of deposition. Using individual weight percentages of the entire sediment size distribution, three factors were determined to account for 97.5% of the original information (10 variates). Klovan then deduced the geologic and environmental significance of these mathematically derived variates by examining the grain-size distribution of the highest loading for each of the three factors. This method allowed for a categorization of geologically and geographically intact groups and trends without relying on *a priori* knowledge of the spatial positions of the samples and the significance of any grain-size measures, providing a new and objective approach towards examining multi-dimensional sediment size data sets. In addition, Solohub and Klovan (1970) showed that the techniques of Passega, Mason and Folk, Friedman, and Sahu were not as reliable in identifying depositional environments because the entire distribution was not utilized.

Davis (1970), using the same data as Klovan (1966), found principal components analysis to be extremely useful in characterizing sediments since it extracts the most significant linear combinations of original variates. Two principal components accounted for approximately 88% of sample variability and supported the findings of Krumbein and Aberdeen (1937) and Klovan (1966). However, it was also indicated that most information from the Barataria Bay sediments could have been recovered by recording the percent material retained on the 63 μ sieve.

Feldhausen (1970) used the ordination multivariate method to analyze gradational relationships among sediment samples from the Cape Hatteras continental margin without previous knowledge of sample environment or geographic position. The entire grain-size distribution was used to suggest six sedimentary facies that could be qualitatively related to environmental processes.

Several researchers have employed multivariate analytical techniques in an optimal sequence to extract information from environmental data (Block, 1972; Granat, 1976; Ali et al., 1976; Chambers and Upchurch, 1979; Doyle and Feldhausen, 1981). This typically involves eliminating redundant data, classifying samples into discrete classes, and verifying interpretations. Undoubtedly this is the most thorough and objective means of classifying environmentally sensitive data matrices.

Primary Sedimentary Structures

Primary sedimentary structures can be separated on the basis of energy conditions. Inorganic structures are those formed at the time of deposition as a result of interactions between gravity, physical and chemical characteristics of the sediment and fluid, as well as the hydraulic environment (Brush, 1965). Biogenic structures are the result of post-depositional reworking within the sediment or on the sediment surface by organisms inhabiting specific environments according to salinity, energy levels, substrate characteristics, and food supply (Howard and Frey, 1985). Although patterns of biogenic activity are not necessarily predictable, an increase in the amount of bioturbation generally accompanies a decrease in energy intensity (i.e. from barrier beach to lagoon-marsh complex).

Inorganic sedimentary structures develop as a result of sorting of sediment with respect to size, shape, and density. This is, in turn, the result of variable settling rates of grains, turbulent diffusion, gravitational avalanching, and the time- and space-distributions of boundary shear stress. Consequently, these structural features provide useful information about hydrodynamic conditions of the environment of deposition (Reineck and Singh, 1980). The generation of biogenic structures often causes partial destruction or reformation of inorganic structures. Recognition of organic activity is generally associated with the absence of well-developed bedding. Stratified layers are disrupted or broken and mottled structures such as sand pockets provide evidence of biogenic reworking. Lithology influences the visibility and preservation of sedimentary structures. Visual identification of sedimentation horizons in core sections or trench and pit exposures is often aided by relief peels (sands), thin sections (muds), and x-ray radiographs (all sediment types) (Bouma, 1969).

In order for sedimentary structures to be useful in environmental interpretation, it is necessary to develop a working classification of distinctive structure types and to establish the conditions under which formation occurred (Coleman and Gagliano, 1965). Detailed discussions on the occurrence and significance of sedimentary structures are included in Pettijohn and Potter (1964), Conybeare and Crook (1968), Reineck and Singh (1980), and Allen (1984); the latter two being most up-to-date and comprehensive for all modern depositional sedimentary environments. Many studies pertinent to structures found within barrier island systems are summarized in Table 4. Furthermore, two excellent collections of papers edited by Middleton (1965, 1977) provide valuable information on the concepts of flow regime, bed configuration, and resulting sedimentary sequence characteristics under unidirectional flow.

TABLE 4

SEDIMENTARY CHARACTERISTICS OF BARRIER ISLAND SYSTEM SUB-ENVIRONMENTS

Beach-Barrier Island

Foreshore: more or less flat, without many morphologic features; 1 to 10° (increases with grain size) seaward-dipping parallel laminations with low-angle discontinuities (1 to 15 cm thick bedsets); high-angle landward-dipping longshore bar, storm berm, and ridge and runnel cross-stratification, including planar festoon-shaped cross-bedding, antidunes, symmetrical and asymmetrical wave ripples, megaripples, and small-scale current ripples; reactivation surfaces common; limited faunal bioturbation.

(Thompson, 1937; McKee, 1957; Hoyt, 1962; Hoyt and Weimer, 1963; Russell and McIntire, 1965; Clifton, 1969; Frey and Howard, 1969; Clifton et al., 1971; Davis et al., 1972; Wunderlich, 1972; Harms et al., 1975; Davidson-Arnott and Greenwood, 1976; Davis and Ethington, 1976; Hayes, 1976; van den Berg, 1977; Hine, 1979; Hawley, 1982; Moore et al., 1984)

Backshore: generally molded by aeolian activity except during storm overwash; dominated by horizontally laminated sand; small-scale current ripple cross-bedding; irregular and scoured low angle cross-laminations; some faunal bioturbation.

(Russell and McIntire, 1965; Andrews and van der Lingen, 1969; Frey and Howard, 1969; Hill and Hunter, 1976; Shideler and Smith, 1984)

Coastal dunes: variably developed in areas of sufficient sediment supply; generally absent in areas of predominant offshore winds; high and low angle cross-bedding (10-40°) with abundant erosional unconformities; disturbed and slumped laminations; plant rootlet bioturbation.

(McKee, 1957; McBride and Hayes, 1962; Land, 1964; Frey and Howard, 1969; McKee and Bigarella, 1972; Goldsmith, 1973, 1978; Oertel and Larsen, 1976; Kocurek and Dott, 1981)

Beach ridges: features of prograding shorelines; relatively coarse, water-lain storm deposits; horizontal to seaward dipping parallel laminations with low angle discontinuities near base of ridge to steeply landward dipping cross-bedded units with washover deposition; faunal bioturbation; subaerial modification.

(Psuty, 1965, 1967; Curray et al., 1969; Stapor, 1975; Barwis, 1976, 1978; Hine, 1979; Moslow, 1980)

TABLE 4 (cont.)

Washover: storm deposits related to landward transfer of sediment; thin landward dipping parallel laminations predominate; landward oriented tabular to trough cross-stratification; small ripple bedding to megaripples to antidunes are common in washover channel; inverse and normally graded bedding; faunal and plant rootlet bioturbation.

(Hayes, 1967; Andrews, 1970; Pierce, 1970; Schwartz, 1975, 1982; Deery and Howard, 1977; Leatherman and Williams, 1977, 1983; Morton, 1978; Barwis and Hayes, 1985)

Backbarrier

Marsh: horizontal finely laminated silts and clays with extensive floral and faunal bioturbation.

Lagoon-estuary: deposition of fine-grained suspended particulates produces finely laminated muds, highly churned by the locomotion and feeding of organisms.

Tidal channels: current ripple to megaripple bedding and cross-stratification as a result of hydrodynamic conditions and sediment source; convolute bedding.

Tidal flats: parallel laminae and small scale cross-bedding of current ripples (sand flat) to flaser, wavy, and lenticular bedding (mixed flat) to thick finely laminated mud layers with thin sandy intercalations (mud flat); faunal disturbance decreases with an increase in energy although organic structures often dominate sequences

(Reineck and Wunderlich, 1968; Frey and Howard, 1969; Reineck, 1972; Hayes and Kana, 1976; de Jong, 1977; Frey and Basan, 1978; Reineck and Singh, 1980; Bartsch-Winkler and Schmoll, 1984; Gerdes et al., 1985; Howard and Frey, 1985)

Tidal Inlets and Deltas

Shoals: tabular and trough cross-stratification with ripples, megaripples, and sand waves abundant; reactivation surfaces; channel cut and fill and accretionary bedding; some faunal bioturbation.

TABLE 4 (cont.)

Channels: tabular and cross-stratification with unidirectional bedforms common; transverse, lingoid, and rhomboid megaripples present; scale of cross-stratification generally decreases upward; minor bioturbation.

(Hoyt and Henry, 1967; Kumar and Sanders, 1974; Greer, 1975; Oertel, 1973, 1975b, 1977; Hayes and Kana, 1976; Hubbard and Barwis, 1976; Hubbard et al., 1979; Moslow and Heron, 1978; Tye, 1984; Moslow and Tye, 1985)

Shoreface

Upper shoreface: predominant depositional structures are multi-directional trough cross-stratified beds produced by the complex interaction of waves and wind-generated currents; low angle bi-directional planar cross-bedded sets and subhorizontal plane beds also present; ripples, megaripples, and sandwaves; erosional surfaces; some bioturbation - vertical dwelling burrows.

Middle shoreface: low angle wedge-shaped sets of planar laminae; ripple laminae and trough cross-laminations common; graded bedding; ripples, megaripples, sandwaves; storm-generated hummocky cross-stratification; frequent faunal bioturbation.

Lower shoreface: mostly parallel laminations with some ripple cross-laminations; graded bedding; most structures completely obliterated by faunal bioturbation - horizontal deposit-feeding burrows.

(Clifton et al., 1971; Howard and Reineck, 1972; Harms et al., 1975; Davidson-Arnott and Greenwood, 1976; Chowdhuri and Reineck, 1978; Reinson, 1979; Swift et al., 1979; Reineck and Singh, 1980; Howard and Reineck, 1981; Swift et al., 1983; Greenwood and Mittler, 1985; Niedoroda et al., 1985)

Foraminifera

Benthic foraminiferida are widely distributed in nearly all estuarine and marine environments. They are useful indicators of modern environments and their fossils offer an important means of interpreting ancient depositional environments. To determine the applicability of foraminiferida to the recognition of past environments, it is first necessary to examine the environmental and geographic boundaries associated with living species. The areal distribution of different species of modern foraminiferida can be attributed to a number of ecological factors including temperature, salinity, food supply, turbidity, substrate type, turbulence, water chemistry, and depth (Ellison, 1951; Phleger, 1954). Qualitative and quantitative studies on modern foraminiferida have shown them acutely responsive to their environment (Miller, 1953; Phleger, 1954; Parker and Athearn, 1959; Todd and Low, 1961; Lidz, 1965; Grossman and Benson, 1967; Kane, 1967; Bradshaw, 1968; Phleger, 1970; Kraft and Margules, 1971; Lamb, 1972; Murray, 1973; Seiglie, 1975; Poag, 1978; Scott and Medioli, 1980; Albani et al., 1984; Hart and Kaesler, 1986). However, Murray (1973) has shown that living and dead populations from the same surface samples often reveal different assemblages as the result of differential shell production, postmortem transportation, and selective preservation.

Death assemblages in marginal marine environments are a function of post-depositional energy fluctuations as well as biogeochemical factors (Parker and Athearn, 1959; Phleger, 1960; Kraft and Margules, 1971; Murray, 1973; Culver and Banner, 1978). If a species is represented by well-preserved individuals of all growth stages, it is assumed that the specimens developed *in situ* (autochthonous) and are paleoenvironmentally indigenous (Culver and Banner, 1978). However, if the individuals of a particular species show an anomalous size distribution with signs of abrasion, etching, or breakage, post-depositional transportation was likely (allochthonous) regardless of their established ecological characteristics. Consequently, changes in particle dispersal patterns could be identified to explain anomalous distributions.

The spatial patterns of living benthic foraminiferida along Atlantic coastal regions of the United States have been investigated both north and south of Virginia's Eastern Shore. Early work focused on shallow-water species off the New England coast (Cushman, 1944). Phleger and Walton (1950) studied the marsh and bay fauna in Barnstable Bay, Massachusetts, where little variation in salinity and temperature suggested that the main factors determining distribution were the movements of bottom material by tidal action and organic productivity. Said (1951) found that the distribution of some species in Narragansett Bay varied with salinity while others did not. Parker (1952a) and Phleger (1952) dealt with distributions in the Gulf of Maine, suggesting that there was a close association between species and sediment type. However, Parker (1952b) found salinity to be the controlling factor from river to bay environments while temperature dictated species distribution from bay to open-ocean for Buzzards Bay and Long Island Sound. Parker and Athearn (1959) reported that marsh species differed in their response to salinity for the Poponesset Bay area while Scott and Medioli (1980) found marsh forams to be highly sensitive to salinity and elevation (exposure). Todd and Low (1961) investigated various microenvironments of Martha's Vineyard Island and found that abundant foraminiferida populations were associated with seaweed and algae and organic-rich sediments. Clean sand beaches were virtually barren. Lidz (1965), working in Nantucket Bay, found maximal populations associated with fine-grained organic-rich sediments. Contrary to previous findings, Buzas (1965) found no relationship between foraminiferal species and sediment size, depth, temperature, salinity, pH, or Eh in a distribution survey of Long Island Sound.

Investigations along the Mid-Atlantic Bight include a description of species found in New York Harbor by Shupack (1934) and surveys of foraminiferida along the southeastern coast of the United States by Cushman (1947) and Wilcoxon (1964). Ronai (1955) suggested that the controlling factors for brackish water species in the New York Bight are salinity, sediment type, organic content, and currents affecting the distribution of sediments. Acknowledging a lack of accurate environmental data, Miller (1953) stated that substrate characteristics apparently controlled the abundance of forams at Mason Inlet, North Carolina. Clean, loose, fine sand, uncontaminated by organic debris provided the maximum number of specimens while anaerobic conditions associated with organic clays made substrate unsuitable. Working in the Rappahanock River Estuary, Virginia, Ellison et al. (1965) found that foraminiferal populations were distributed according to depth as well as bottom type. On the other hand, Grossman and Benson (1967) found that salinity, vegetation, and tidal currents have the most effect on distribution of microfauna in southern Pamlico Sound, North Carolina. However, Kraft and Margules (1971) showed no significant correlation between patterns of foraminiferal abundance and the distribution of sediment types for Indian River Bay, Delaware. In addition, with the exception of one assemblage, there was no significant correlation between species occurrence and observed physical parameters.

Numerous studies on the ecology and distribution of foraminiferida along the Gulf coast have also provided valuable information pertinent to patterns associated with the Virginia barrier system. Phleger and Parker (1951) first published a memoir on the ecology of foraminifera in the northwest Gulf of Mexico. Subsequent work, under sponsorship of API Project 51, yielded significant results throughout the northern Gulf. Parker et al. (1953) found large numbers of calcareous tests in San Antonio Bay, Texas, and related their occurrence to the encroachment of Gulf water masses through narrow inlet openings. However, Phleger (1954) found marked differences between open-Gulf (greater than 90% calcareous) and Sound (entirely arenaceous) biofacies for the Mississippi Sound area. This apparent anomaly was related to variations in climate and therefore river runoff. Although large inlet openings provided adequate exchange channels between Gulf and Sound environments, low tidal range and high river runoff into Mississippi Sound suppressed the invasion of open-Gulf water masses. This was not the case in San Antonio Bay where low runoff was dominated by intrusion of open-Gulf water. This indicates the influence of salinity variations on distribution. Parker (1954), working in northeastern Gulf of Mexico, found lateral variations in species distribution from Louisiana to Florida. This was related to outflow from the Mississippi River and associated changes in turbidity, food supply, and water chemistry. Kane (1967) suggested that salinity was the major ecologic factor controlling distribution in Sabine Lake, Texas and Louisiana. Lamb (1972) presented similar results for Mobile Bay, Alabama while Poag (1978) described a direct correlation between the distribution of each member of a phenotype pair and the distribution of salinity and temperature for San Antonio Bay. In addition, Mechler and Grady (1984) found similar results for St. Andrews Bay, Florida, and included depth as an influential parameter. However, no significant correlation with sediment size was recorded.

Most studies on the effects of environmental factors on benthic foraminiferida provided insufficient data to determine the true cause of distribution patterns. It is apparent from the preceding paragraphs that population structure is affected not only by magnitude of environmental change but also by rate. Bradshaw (1968) demonstrated that changes are often large and fast in coastal marine environments. Consequently, distribution trends many times become blurred as the result of continuous fluctuations among a wide variety of local environmental parameters. Clearly all variables must exert some influence on distribution, creating seasonal and long-term shifts in faunal patterns. These time-dependent relationships have rarely been considered in ecological studies, undoubtedly producing tenuous, if not erroneous, results (Bradshaw, 1968).

Regardless, enough study has been done on the distribution of marginal marine foraminiferida to recognize general patterns of occurrence. Four studies (Newman and Munsart, 1968; Halsey, 1978; Shideler et al., 1984; Finkelstein, 1986) have briefly mentioned the existence of certain environmentally sensitive species at Virginia barriers. These were used as paleoenvironmental indicators in support of lithostratigraphic interpretations. This study represents an initial attempt at qualitatively and quantitatively examining systematic variations in taxonomic composition associated with environments in the Virginia barrier system. Since no ecologic studies of foraminifera have been done in this area, results of Ellison et al. (1965), Grossman and Benson (1967), Kraft and Margules (1971), and Ellison and Nichols (1976) were mainly utilized in associating environmental significance with postmortem assemblages. However, such interpretations must be affected by post-depositional biogeochemical and hydrodynamic processes (Bradshaw, 1968; Murray, 1973; Culver and Banner, 1978). Consequently, the qualitative interpretation of paleoecological significance associated with occurrence was re-evaluated as to autochthoneity or allochthoneity in each assemblage.

DYNAMICS AND DEPOSITIONAL HISTORY OF THE METOMPKIN BARRIER ISLAND SYSTEM

Modern sedimentary environments are sites of net erosion, dynamic equilibrium, or net deposition. Consequently, the processes and products associated with depositional sequences can be recognized as unique successions resulting from varying physical, chemical, and biological influences. Since the product of a depositional environment is a sedimentary facies (Selley, 1978), patterns of sediment accumulation associated with late-Quaternary deposition within the highly transgressive, low-profile Metompkin barrier island system were initially classified as facies. After examining various characteristics (primary sedimentary structures, sediment texture, paleontology) of individual stratigraphic units and their position within the depositional sequence, an environmental interpretation was established.

The temporal and spatial variability of sediment accumulation was assessed utilizing a tripartite approach: 1) historical shoreline position changes to assess island response to physical input; 2) a short-term sediment budget analysis of subaerial island sand volume changes in relation to transgression; and 3) vibracores to document late-Quaternary three-dimensional sedimentary relationships. The following discussion addresses the results of this study.

Barrier Island Dynamics

Understanding the magnitude and direction of island movement through time is important in discerning the occurrence of Holocene sedimentary deposits within a barrier island complex. Classic transgressive sequences often are interrupted by storm-related sand deposits that can be related to recorded changes in island morphology. Metompkin Island shoreline changes document these phenomena, providing support for event sequence stratigraphic interpretation along portions of the complex.

Since Metompkin Island has migrated so rapidly during recorded time, a short-term island profiling study (two years) was established to evaluate changes in island sand volume in relation to changes in shoreline position. Consequently, the washover process could be tested as a potential mechanism for island maintenance during landward migration. In addition, specific storm-related or seasonal effects could be evaluated as potential dominant mechanisms for landward retreat versus average, long-term conditions. Since a wide variety of meteorologic events occurred during the short-term profiling study (including Hurricane Gloria), shoreline change data are believed to accurately represent historical trends. Therefore, emphasis was placed on profiling data, allowing a comprehensive and quantitative evaluation of temporal and spatial changes. However, a synopsis of historical shoreline trends is provided as background to this more detailed assessment of barrier dynamics.

Historic Changes in Shoreline Position

Eleven historic shorelines were used to assess changes in position of the MHW shoreline between 1852 and 1981 (129 years). During this time, Metompkin Island migrated north-northwest over a variety of sedimentary deposits. Figure 36 compares four shorelines between 1852 and 1980. The 1852 shoreline was approximately 750 m (north end) to 1100 m (south end) seaward of the 1980 position. Island width was fairly constant at about 750 m. Extensive aeolian deposits likely covered the landward portion of the island. The seaward edge of Metompkin Island moved an average of 200 m landward over the next 58 years. The 1959/1962 shoreline shows a considerably narrower feature that had been dissected in two places along southern Metompkin Island due to the 1962 Ash Wednesday Storm (Rice et al., 1976). Aerial photographs illustrated a subdued morphologic feature as the result of storm activity. The island maintained these characteristics through 1980, but the large ephemeral inlet breaches had closed. The entire island was nearly one continuous unit although an offset was created midway along its length as a result of historic inlet breaching along the southern, bay-backed island segment. In addition, a small inlet was present at mid-Metompkin Island associated with an abrupt break in backbarrier lagoon characteristics.

Figure 37 compares four shoreline positions from 1888 and 1963. For the 36-year period prior to the earliest survey (1852-1888), the entire shoreline migrated landward approximately 35 m, resulting in the slowest retreat rate during historic times (Table 5). However, as the island narrowed between 1888 and 1928, the rate of retreat increased dramatically to 8.3 m/yr. Island recession slowed slightly between 1928 and 1963 to about 7 m/yr but island width reached its narrowest point in 1955 (250 m) and extensive inlet breaching dominated shoreline response along the southern end of Metompkin Island by 1963.

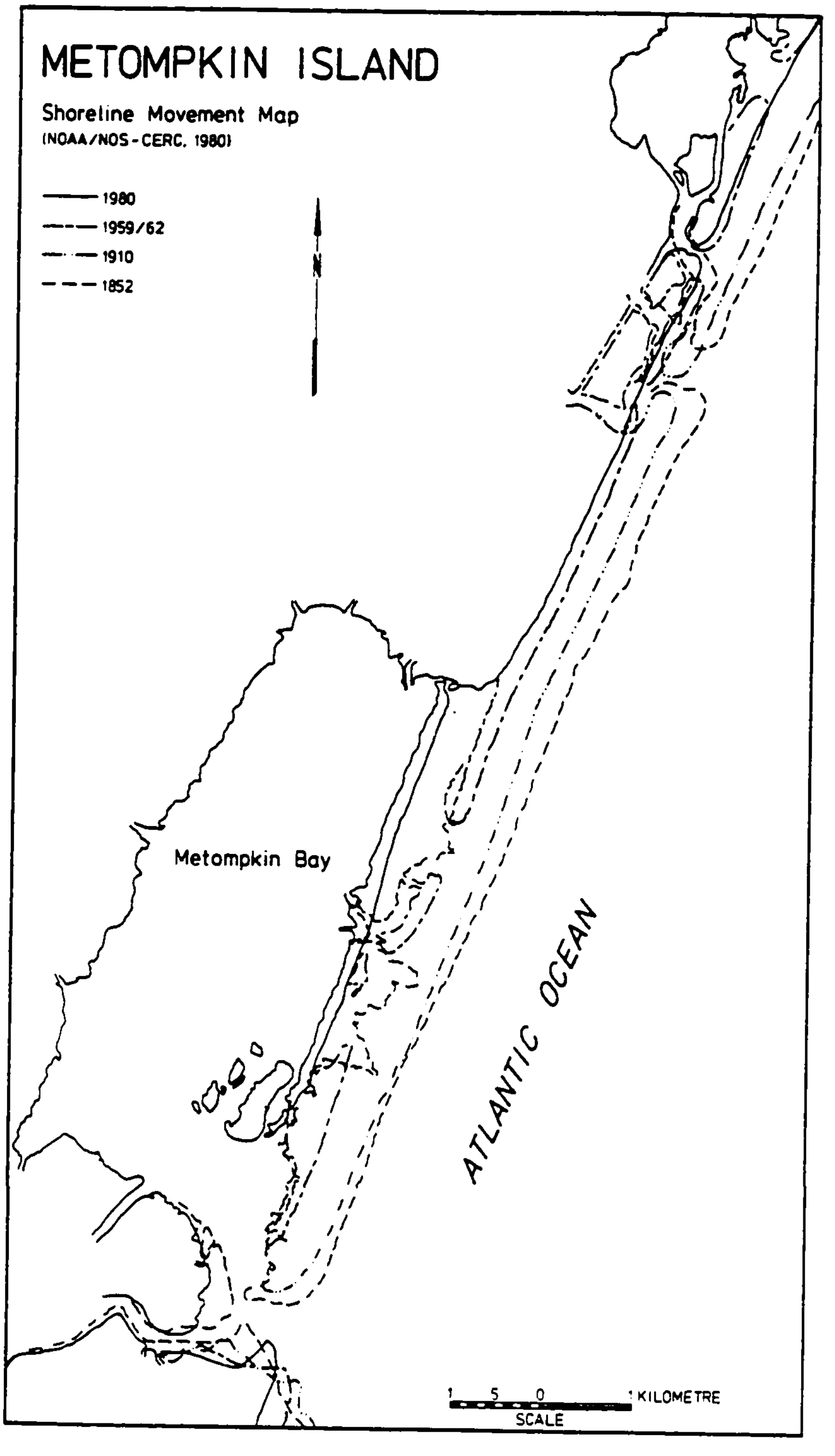

Figure 36. Historic shoreline change along Metompkin Island, 1852-1980 (NOS-CERC, 1980).

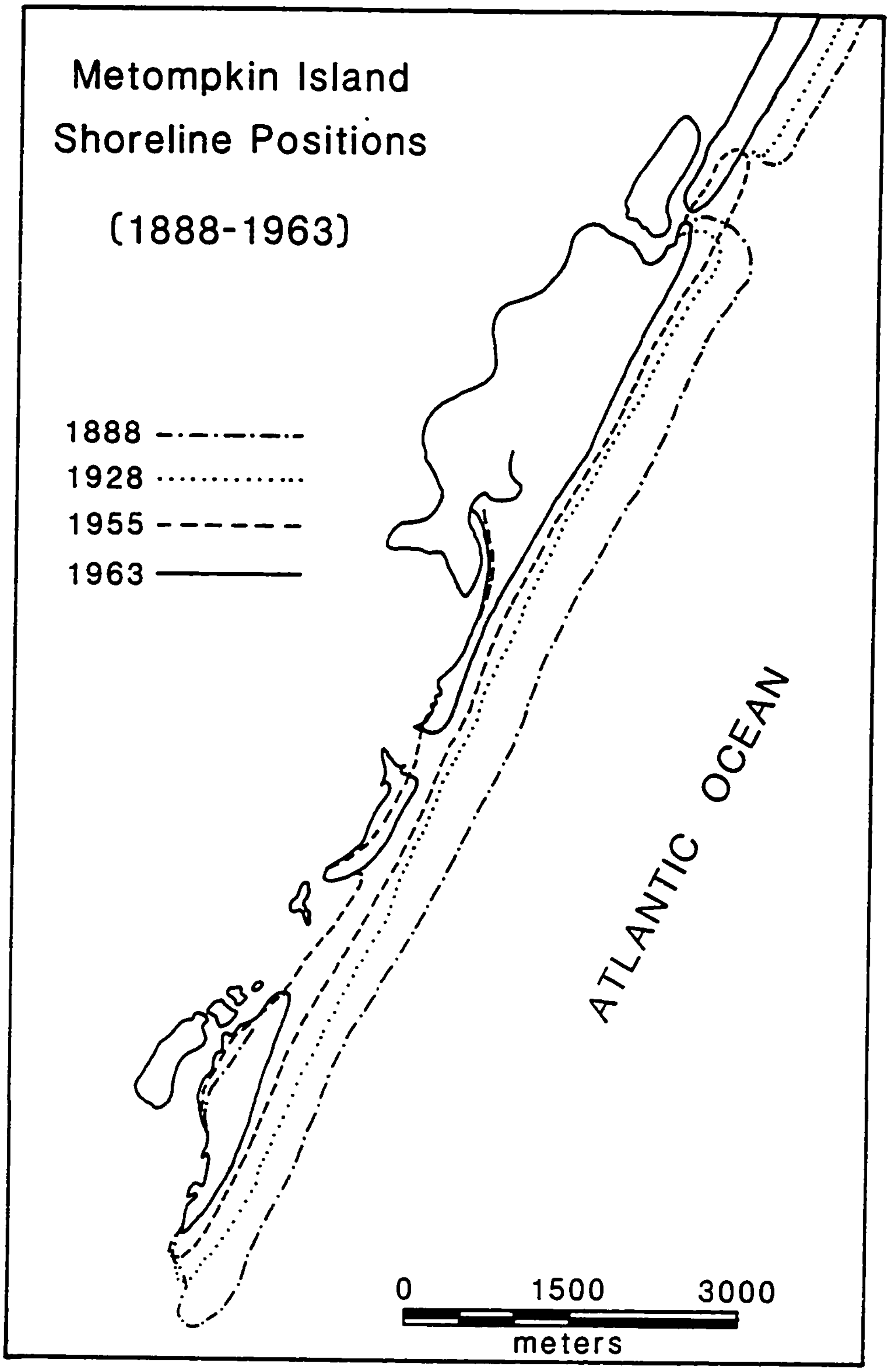

Figure 37. Historic changes in shoreline position along Metompkin Island, 1888-1963 (from Rice et al., 1976).

TABLE 5

METOMPKIN ISLAND SHORELINE MOVEMENT RATES
1852 TO 1985

PRIOR TO HISTORIC INLET BREACHING

1852 to 1955	-4.7 m/yr[a]	(-484 m)[b]
1888 to 1955	-6.7 m/yr	(-447 m)

POST-INLET BREACHING

	North End	South End	South End/ North End [c]
1957 to 1981	-11.1 m/yr (266 m)	-28.4 m/yr (682 m)	2.6
1967 to 1981	-14.0 m/yr (196 m)	-39.4 m/yr (552 m)	2.8
1983 to 1985[d]	-16.12 m/yr (-32.25 m)	-4.15 m/yr (-8.29 m)	0.26
5/85 to 11/85	-36.60 m/yr (-18.30 m)	-3.58 m/yr[e] (-1.79 m)	0.10

a - a negative value represents landward migration

b - numbers in parentheses represent the absolute change in shoreline position for the given time interval

c - values represent a ratio of island retreat rate between the southern, bay-backed shoreline segment and the northern, marsh-backed shoreline segment

d - data from the two-year island profiling study

e - includes profiles 10-16

Shoreline sketches in Figure 38 overlap time periods covered in the previous two figures. The 1934 shoreline illustrated a consistent retreat rate along the entire length of Metompkin Island and the 1957 shoreline indicated the first occurrence of historic inlet breaching. Shoreline position changes shown in Figure 39 depict the importance of historic inlet activity on the rate of island migration. Between 1949 and 1974, southern Metompkin Island had receded approximately two to three times farther than the northern island segment, initiating the development of an island offset coincident with an abrupt change in backbarrier characteristics.

Examination of sequential shoreline position changes along the southern island segment provided a means of comparing the effects of morphologic variability on the rate of island recession. Figure 40 illustrates changes in inlet development between 1955 and 1974. Initial inlet breaching was recorded in 1957 as a result of intense storm activity (Rice et al., 1976). The location of this feature directly corresponded with the narrowest position along the 1852 shoreline (Figure 36). It was maintained through 1961 and eventually expanded to two independent features in response to the 1962 Ash Wednesday Storm (Rice et al., 1976). Although maintained through 1974, hydraulic conditions apparently were not sufficient to maintain inlet width. Consequently, slow but continuous sediment deposition sealed these ephemeral features, creating a narrow, uninterrupted island shoreline (Figure 41). The rate of shoreline retreat between 1957 and 1981 was not uniform along the entire island; in fact, southern Metompkin Island retrograded at a rate 2.6 times that of the northern island segment (Table 5). This differen-

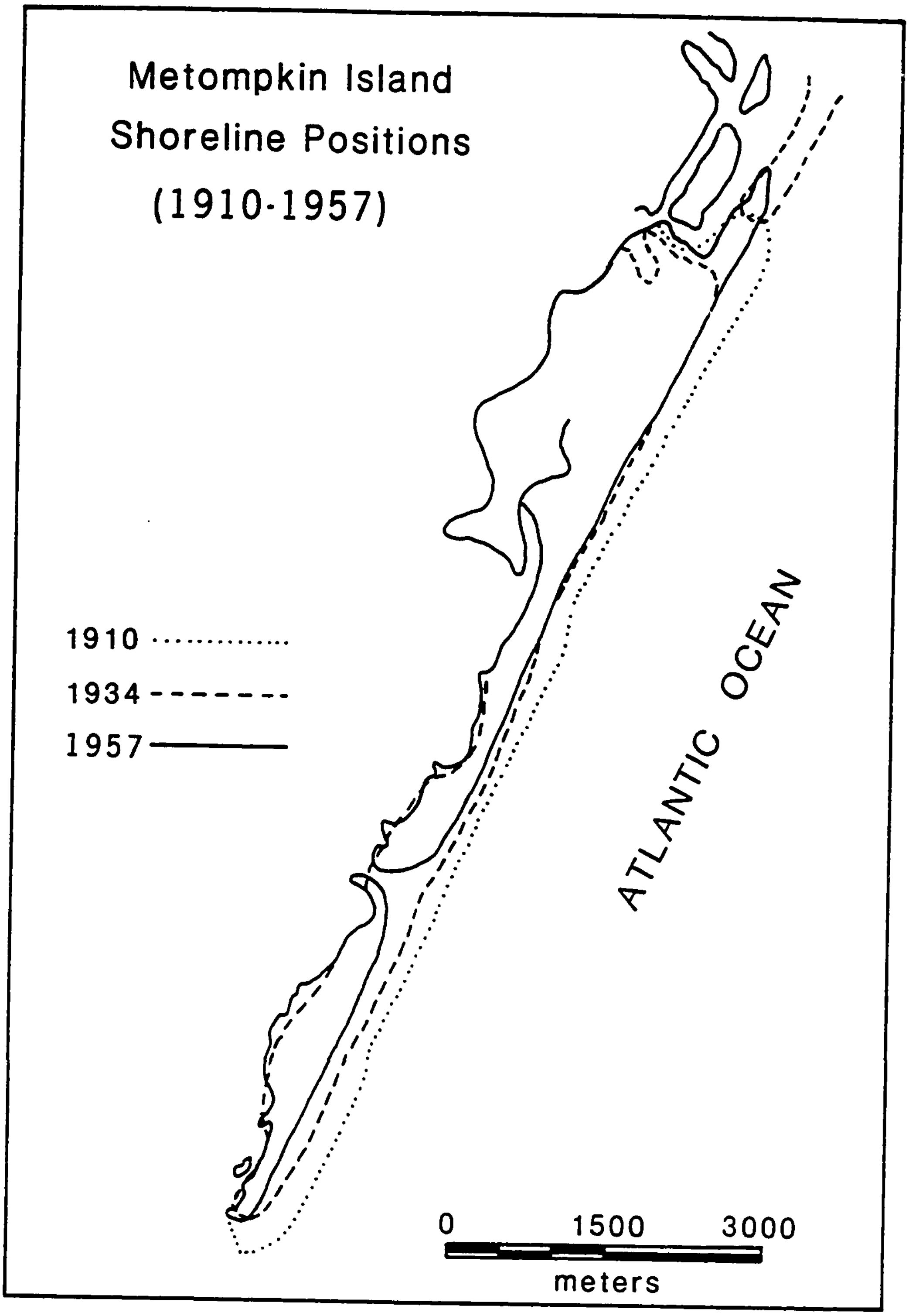

Figure 38. Historic change in shoreline position along Metompkin Island, 1910-1957 (from Rice et al., 1976).

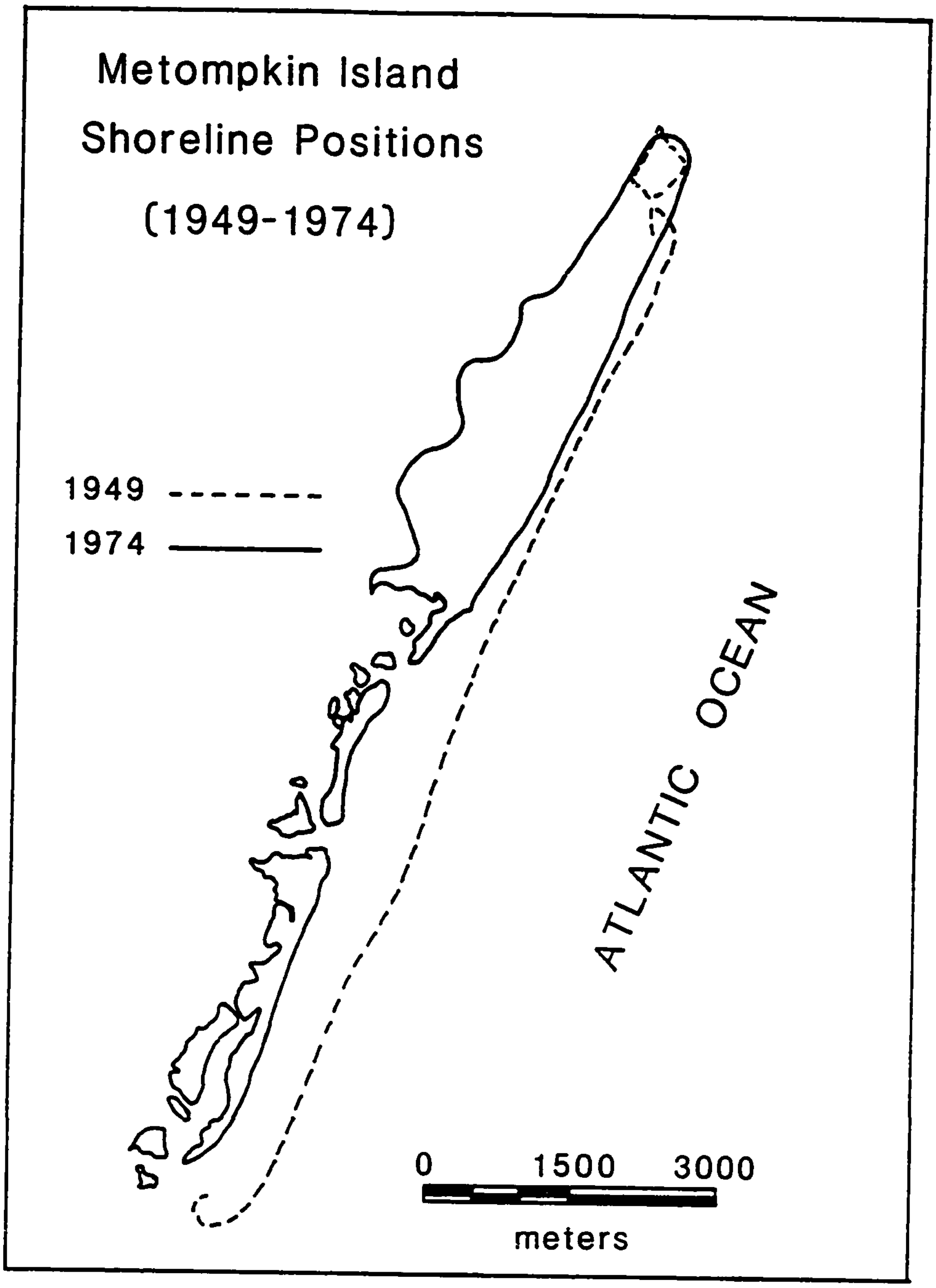

Figure 39. Historic shoreline change between 1949 and 1974 showing dramatic recession along southern Metompkin Island (from Rice et al., 1976).

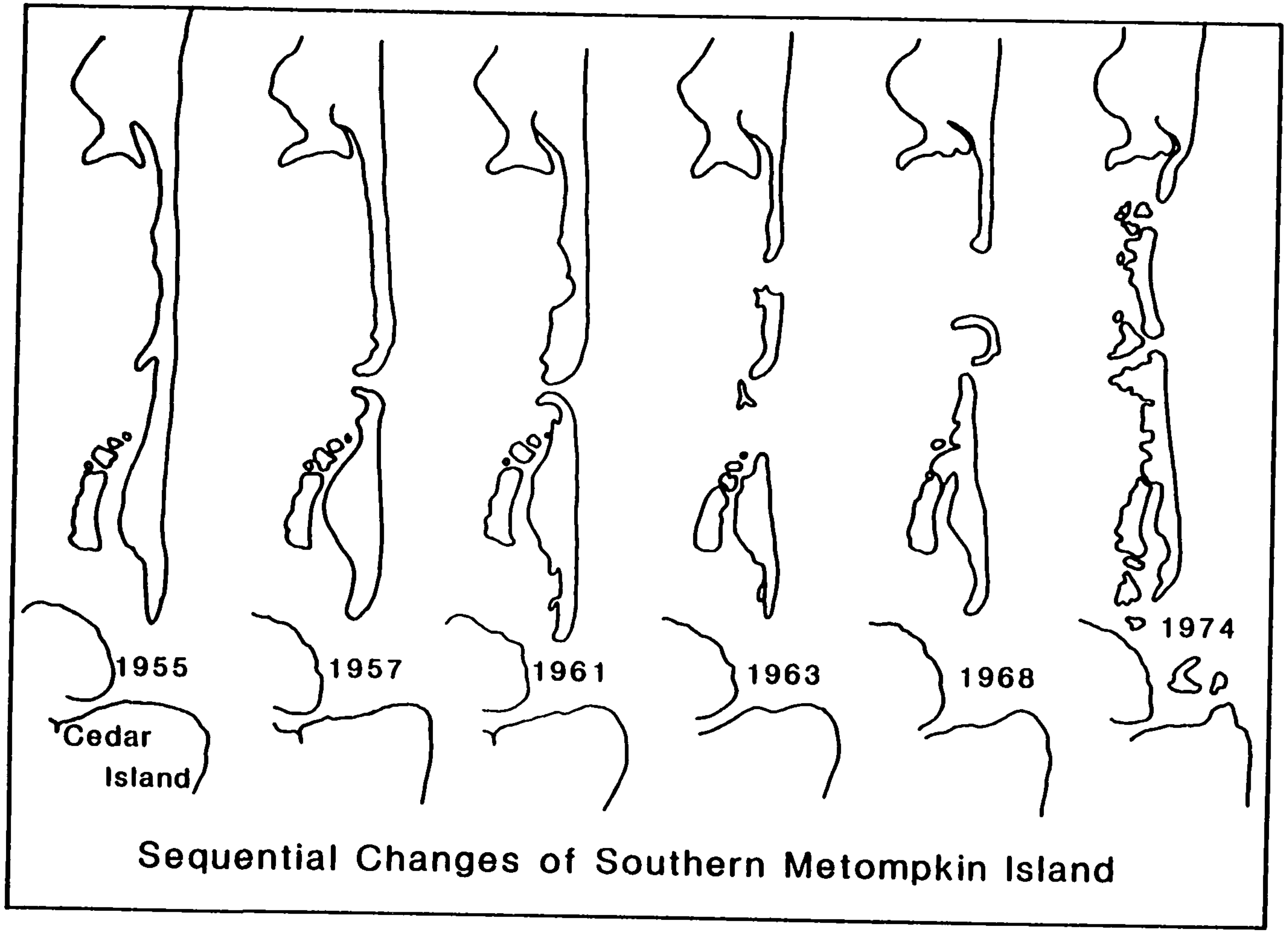

Figure 40. Sequential changes in barrier island morphology along southern Metompkin Island, 1955-1974 (from Rice et al., 1976).

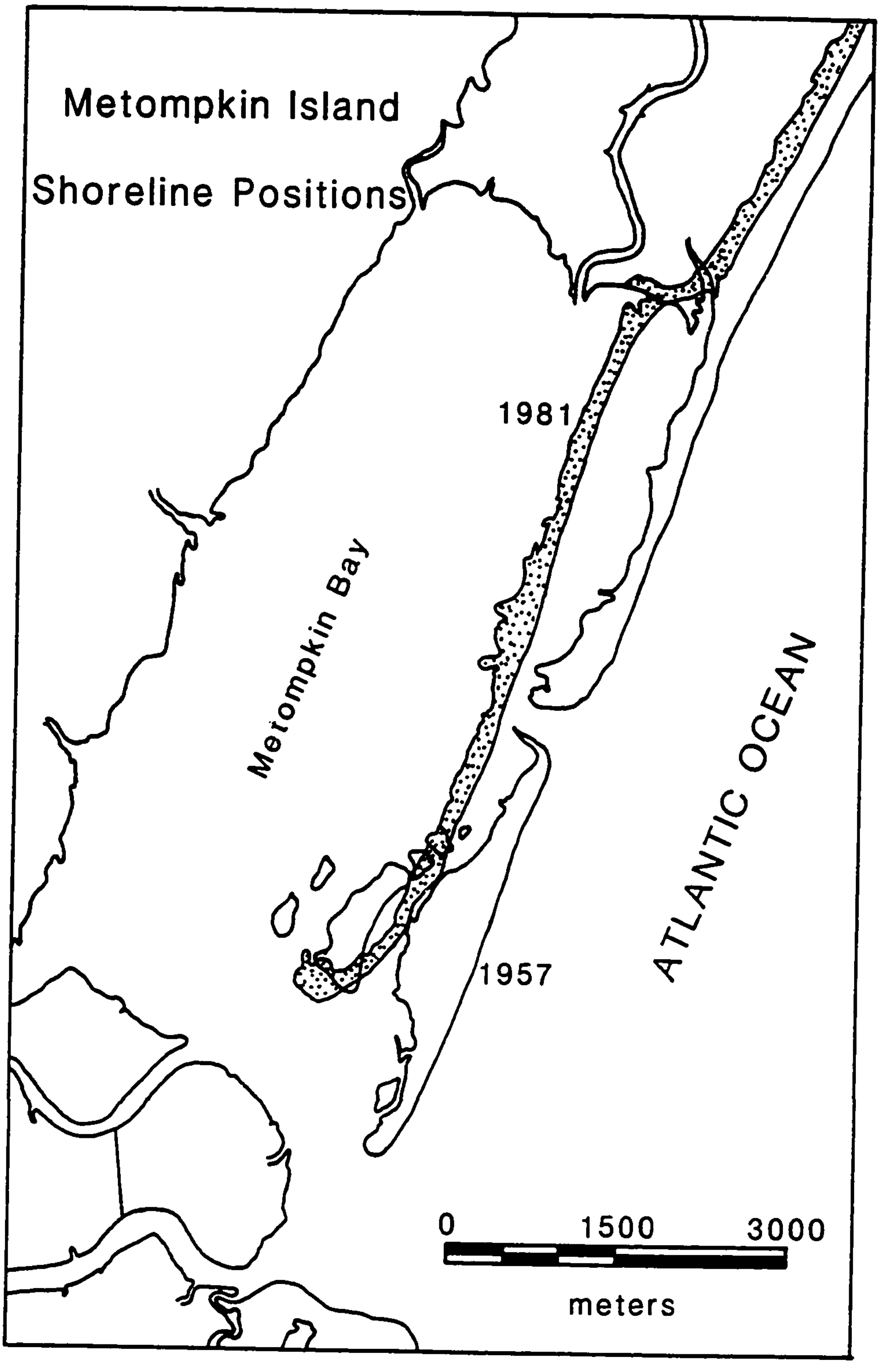

Figure 41. Cumulative change in shoreline position along southern Metompkin Island, 1957-1981 (from Galvin, 1982).

tial rate of retreat created a 400 m island offset midway along Metompkin in association with a change in backbarrier characteristics.

Between 1981 and 1985, the seaward shoreline along Metompkin Island responded as one continuous unit to a variety of meteorological events. Although the trend of differential retreat continued, the magnitude of response was radically altered. The northern island shoreline segment migrated at a rate four times greater than southern Metompkin Island from November 1983 to November 1985. In addition, at least half the magnitude of retreat along northern Metompkin Island was due to Hurricane Gloria (Table 5). Furthermore, a post-hurricane survey revealed inlet breaching along the northernmost section of south Metompkin Island. This was the first occurrence of breaching since 1981.

Subaerial Sediment Budget Analysis

The following discussion provides a quantitative evaluation of shoreline response and associated profile volume change (cubic meters of sand per meter length of shoreline) at ten cross-island transects from November 1983 through November 1985. A high water shoreline vertical datum (HWL) was used as a reference for measuring changes in shoreline position. Wave runup was incorporated in this datum by using average nearshore wave characteristics and average beach slope for Metompkin Island. This value was then added to the mean high water datum producing a HWL reference elevation of 1.45 m above MLW. Unless otherwise indicated, all references to HWL or high water shoreline refer to seaward profiles.

Since historical trends and geomorphic evidence exhibited differential rates of retreat, northern and southern island shoreline segments were analyzed separately to evaluate the consistency of these historical trends over a shorter period of time. Seaward profile changes refer to positions seaward of the reference benchmark while landward profiles occupied positions landward of the reference benchmark on the back side of the island where washover sedimentation and aeolian processes were dominant. Plots of sequential and cumulative profile changes are provided in Appendix A.

Southern Metompkin Island. Five cross-island profiles were measured at six time periods between November 1983 and November 1985 for a 3 km straight segment of shoreline along southern Metompkin Island (Figure 6). Sequential changes in seaward and landward profile shape were quantitatively evaluated for comparison with high water shoreline position changes. In addition, changes in sand volume above the high water line were measured to assess the maintenance of island shape during landward retreat.

February 1984. Very little change in profile volume and shape occurred at profile 10 between November 1983 and February 1984 (Table 6). Although the high water shoreline moved 0.83 m landward of its original position, ocean wave and current processes caused insignificant adjustments in net sand volume on the seaward side of the transect while aeolian processes resulted in equally small changes on the landward portion of the profile.

Just 800 m to the north, profile 12 exhibited significantly different trends for most measured parameters where large amounts of sand accumulated across most of the entire profile (see Appendix A). Foreshore accretion was 9.53 m^3/m while additions on the landward side of

TABLE 6 - SOUTHERN METOMPKIN ISLAND PROFILE CHANGES - FEBRUARY 1984

November 1983 - February 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	-0.65	1.49	-0.83	0.66	-1.80	-0.74	0.01	-0.31
12	9.53	0.83	1.31	25.25	19.65	25.80	34.78	20.48
14	12.07	6.16	6.01	7.11	6.09	0.46	19.18	12.25
16	------	------	------	------	------	------	------	------
18	------	------	------	------	------	------	------	------
AVERAGE	7.62	2.33	1.95	14.57	10.90	12.83	22.19	13.23

the island exceeded 2.6 times this quantity, creating a net gain of 34.78 m^3/m (Table 6). Additions to the landward side of the profile were influenced by aeolian activity over the winter months. Change in distance to the seaward high water line was 1.31 m.

The beach at profile 14 showed net positive volume changes across the entire island transect (19.18 m^3/m). The foreshore prograded and sand deposition associated with aeolian activity nourished the back side of the island (Figure 42). The high water shoreline moved 6.01 m landward of its original position in response to these adjustments.

Due to logistical difficulties in November 1983, only profiles 10 through 14 were surveyed. Net changes in island volume averaged 22.19 m^3/m for the 2.4 km stretch of shoreline. An average increase in seaward profile volume resulted in a relatively small average change in distance to the high water shoreline (1.95 m). Approximately twice the amount of accretion occurred on the landward side of the island.

June 1984. Between February and June 1984, net seaward volume change at profile 10 was nearly conserved but profile shape was altered dramatically due to erosion on the lower foreshore and deposition on the upper foreshore (Figure 43). This caused a 9.36 m seaward shift in position of the high water line. Aeolian processes (noted from field observations) produced a net loss in sand volume across the landward profile, resulting in a total island volume change of -3.23 m^3/m width of shoreline (Table 7). Cumulative changes from November 1983 governed profile adjustments during this 4 month interval.

At profile 12, sand movement on the seaward side of the island produced a small amount of net erosion, although profile adjustments were

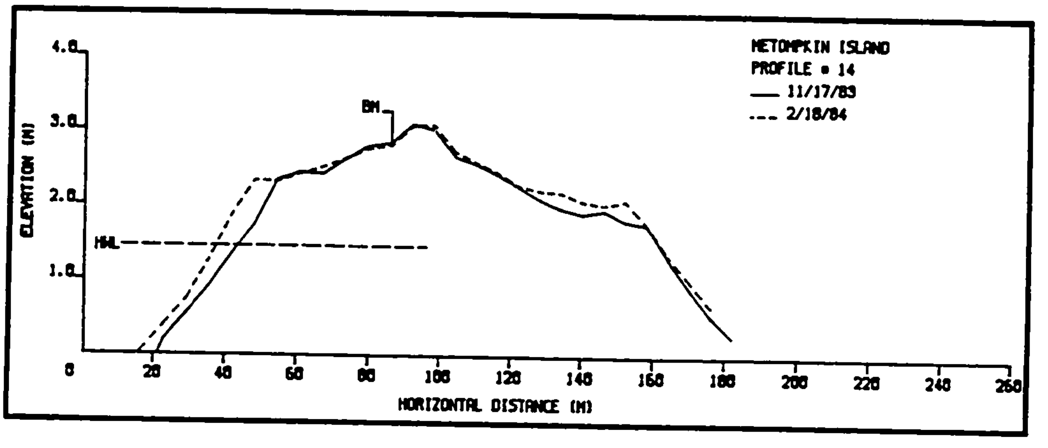

Figure 42. Plot of profile changes at transect 14 showing foreshore progradation and sand deposition on the landward profile.

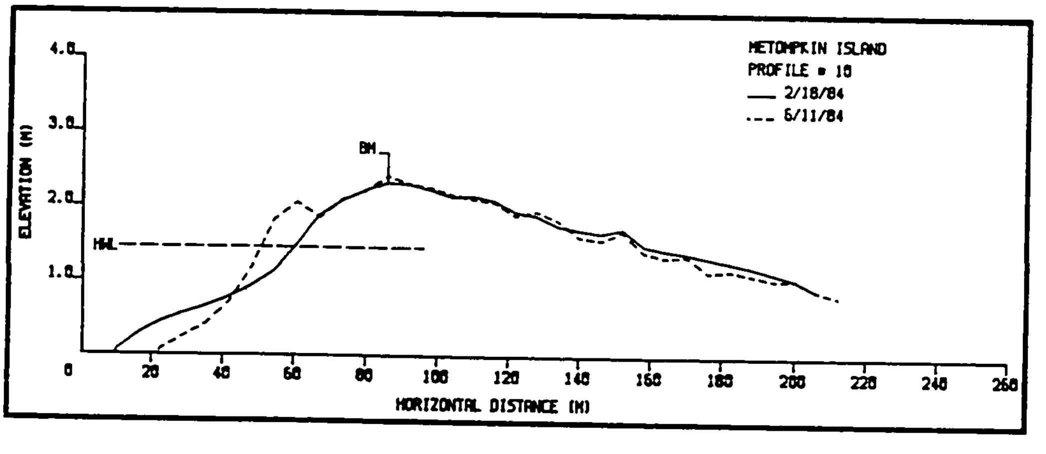

Figure 43. Plot showing erosion on the lower foreshore and deposition on the upper foreshore at profile 10.

TABLE 7 - SOUTHERN METOMPKIN ISLAND PROFILE CHANGES - JUNE 1984

February 1984 - June 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	1.24	5.55	9.36	-4.47	-0.80	-5.67	-3.23	4.75
12	-4.52	-11.05	-3.62	-19.63	-14.01	-22.27	-24.15	-25.06
14	-10.75	-2.60	-7.78	-13.27	-8.90	-4.18	-24.02	-11.50
16	24.21	5.92	9.48	7.09	5.33	2.10	31.30	11.25
18	8.77	4.58	15.94	-3.96	-0.29	-4.33	4.81	4.29
AVERAGE	2.62	-1.03	2.01	-8.11	-5.00	-7.75	-5.49	-6.03

November 1983 - June 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	0.59	7.04	8.53	-3.81	-2.60	-6.41	-3.22	4.44
12	5.01	-10.22	-2.31	5.62	5.64	3.53	10.63	-4.58
14	1.32	3.56	-1.77	-6.16	-2.81	-3.72	-4.84	0.75
16[a]	24.21	5.92	9.48	7.09	5.33	2.10	31.30	11.25
18[a]	8.77	4.58	15.94	-3.96	-0.29	-4.33	4.81	4.29
AVERAGE	8.29	1.00	3.86	0.61	1.62	-0.85	8.90	2.62

(a = cumulative from February 1984)

significant. Foreshore profile shape changed as sand was eroded from the upper foreshore and deposited below the high water line, creating a reduction in slope (Figure 44). The position of the high water line shifted landward 3.62 m while net sand movement for the entire profile was -24.15 m^3/m. Net profile accretion between November 1983 and February 1984 dominated profile adjustments to June 1984. A net loss in sand volume on the foreshore at profile 14 produced a 7.78 m landward shift of the HWL. However, cumulative changes in profile characteristics from November 1983 exhibited insignificant changes (Appendix A; Table 7).

Data collection at profiles 16 and 18 was initialized in February 1984. Sand deposition across the seaward side of transect 16 produced a 9.48 m progradation of the high water shoreline. Washover deposition was the dominant process contributing to changes just landward of the island crest (see Appendix A). Since the direction of volume change was consistent along the entire profile, the magnitude of net sediment accumulation was large (31.30 m^3/m).

Cumulative changes at profile 18 exhibited trends in island response similar to those at profile 16. Deposition on the middle to upper foreshore and minor erosion on the lower foreshore and at the island crest produced a net increase in seaward profile volume (8.77 m^3/m). This resulted in a steeper foreshore and subsequent progradation of the high water shoreline. In addition, island profile changes were net depositional (4.81 m^3/m) although profile adjustments on the landward side of the island exhibited erosion (Table 7).

Average changes in island profile response between February 1984 and June 1984 showed net erosion (-5.49 m^3/m). Sand losses on the landward

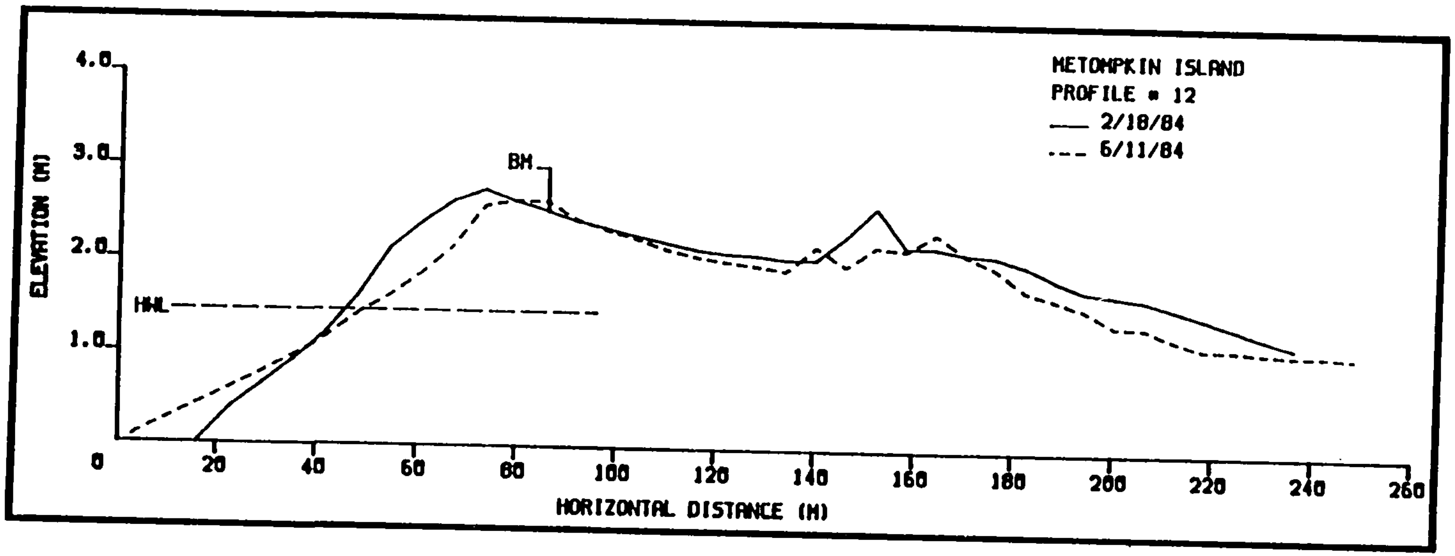

Figure 44. Beach adjustments at profile 12 illustrating upper foreshore erosion and lower foreshore deposition, producing a net reduction in beach slope.

side of the island, due to aeolian processes, governed net volume change along the southern island segment. However, the high water shoreline prograded 2.01 m in response to a small amount of net foreshore accretion (Table 7). Cumulative adjustments in profile shape since November 1983 were controlled instead by sand additions on the seaward side of the island, creating a net accretional southern island segment.

September 1984. Cumulative and sequential changes in island profile volume at transect 10 to September 1984 were relatively consistent in magnitude and direction (Table 8). Net deposition along the landward profile was less than erosion incurred on the seaward side of the island. Consequently, a 4.01 m^3/m deficit of sand was recorded across the island and the high water shoreline moved 6.26 m landward of its position in June 1984. Between June 1984 and September 1984, profile 12 illustrated a similar trend. However, significant deposition along the landward profile produced a net surplus of sand since November 1983.

Profiles 14, 16, and 18 were net depositional for sequential and cumulative changes. The magnitude of change was greatest along profiles 16 and 18 where sand deposition on the foreshore was dominant (Figure 45), producing a more steeply sloping beach and net progradation of the high water shoreline. Cumulative changes in island sand volume at profiles 16 and 18 were greater than the three profiles to the south (Table 8). Therefore, the magnitude and direction of change along the southern island segment reflected additions at these island profiles.

Average seaward profile adjustment along the 3 km long southern island segment between June and September 1984 was very small. Since net accretion on the landward side of the island was relatively consistent

TABLE 8 - SOUTHERN METOMPKIN ISLAND PROFILE CHANGES - SEPTEMBER 1984

June 1984 - September 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	-9.45	-2.40	-6.26	5.44	0.16	4.67	-4.01	-2.24
12	-8.00	1.67	-1.24	5.09	-0.57	21.14	-2.91	1.10
14	1.38	-1.65	-1.28	4.66	1.12	3.24	6.04	-0.54
16	9.94	10.41	9.83	4.87	2.27	22.31	14.81	12.68
18	7.83	4.92	-1.28	3.66	1.47	-2.67	11.49	6.39
AVERAGE	0.08	2.61	0.65	4.82	0.83	12.06	4.90	3.44

November 1983 - September 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	-8.86	4.64	2.27	1.63	-2.44	-1.74	-7.23	2.20
12	-2.99	-8.55	-3.55	10.71	5.07	24.67	7.72	-3.48
14	2.70	1.91	-3.05	-1.50	-1.69	-0.48	1.20	0.22
16[a]	34.15	16.33	19.31	11.96	7.60	24.41	46.11	23.93
18[a]	16.60	9.50	14.66	-0.30	1.18	-7.00	16.30	10.68
AVERAGE	8.37	3.61	4.51	5.43	2.45	11.21	13.80	6.06

(a = cumulative from February 1984)

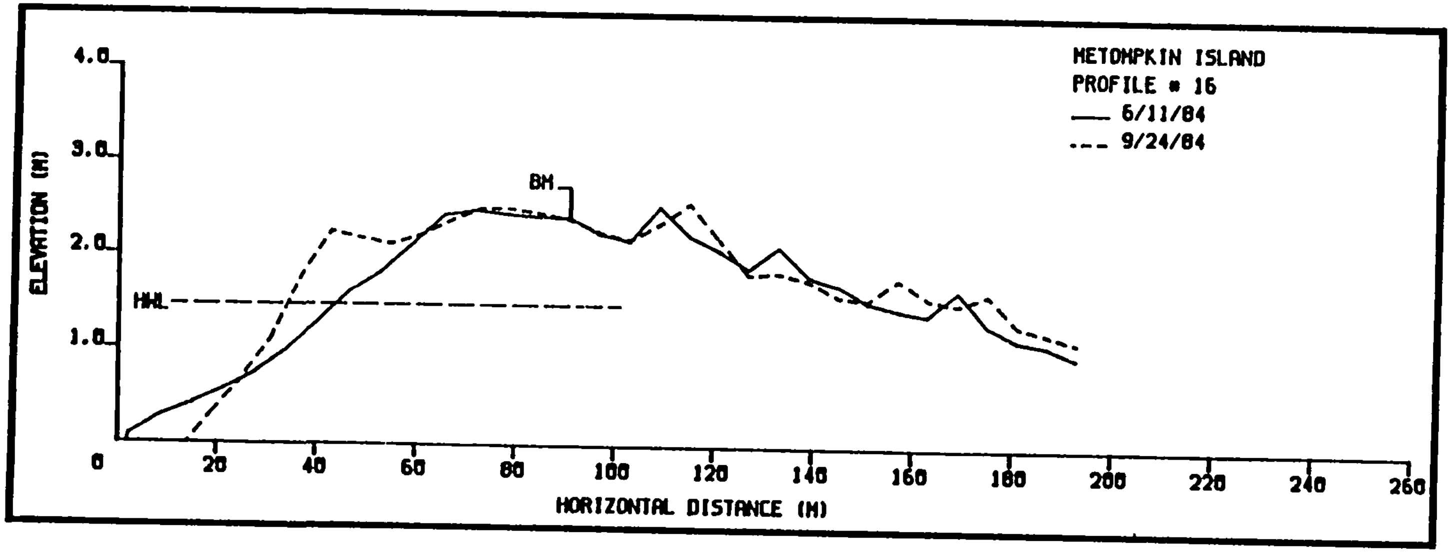

Figure 45. Changes at profile 16 showing a significant amount of deposition on the middle and upper foreshore, resulting in a steeper beach profile and progradation of the HWL.

for all profiles, aeolian activity and washover governed average total volume changes from June to September 1984. However, cumulative change from November 1983 to September 1984 exhibited significant seaward profile accretion (8.37 m^3/m) and progradation of the HWL. Therefore, average cumulative total volume change was governed by net deposition on the foreshore.

May 1985. Significant changes in shoreline position and volume occurred between September 1984 and May 1985. All profiles but #14 exhibited net erosion across the island profile. Furthermore, volume changes above the HWL showed a deficit for all island profiles (Table 9). As a result, the high water shoreline was displaced landward an average of 8.80 m in response to an average loss of 7.73 m^3/m of sand from the seaward side of the island. A relatively small amount of sand was transferred over the island crest by overwash but a near equal amount of sediment was transported by aeolian processes near the lagoon shoreline, resulting in an insignificant average change in total landward profile volume (Figure 46).

Between November 1983 and May 1985, profiles 10 and 12 illustrated similar changes in net shoreline response. Erosion on the upper foreshore dominated lower foreshore deposition (Figure 47). At profile 12, the berm crest moved 12 m landward while its elevation decreased by 0.15 m. Landward profile deposition by aeolian activity was not sufficient to counterbalance foreshore erosion, thus producing a change of -6.06 m^3/m across the island (Table 9).

Conversely, cumulative changes in profile shape to May 1985 at

TABLE 9 - SOUTHERN METOMPKIN ISLAND PROFILE CHANGES - MAY 1985

September 1984 - May 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	-3.78	-10.30	-11.84	-2.25	3.55	-1.00	-6.03	-6.75
12	-12.39	-7.67	-8.60	-1.39	-2.30	-4.10	-13.78	-9.97
14	1.13	-9.00	-3.63	4.40	5.04	-0.10	5.53	-3.96
16	-12.26	-11.66	-11.09	3.03	4.97	-12.81	-9.23	-6.69
18	-13.64	-11.55	-13.59	0.30	-1.10	5.71	-13.34	-12.65
AVERAGE	-7.73	-9.70	-8.80	1.24	2.27	-3.67	-6.49	-7.43

November 1983 - May 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	-12.64	-5.66	-9.57	-0.62	1.11	-2.74	-13.26	-4.55
12	-15.38	-16.22	-12.15	9.32	2.77	20.57	-6.06	-13.45
14	3.83	-7.09	-6.68	2.90	3.35	-0.58	6.73	-3.74
16[a]	21.89	4.67	8.22	14.99	12.57	11.60	36.88	17.24
18[a]	2.96	-2.05	1.01	0.00	0.08	-1.29	2.96	-1.97
AVERAGE	0.64	-6.09	-4.29	6.67	4.72	7.54	7.31	-1.37

(a = cumulative from February 1984)

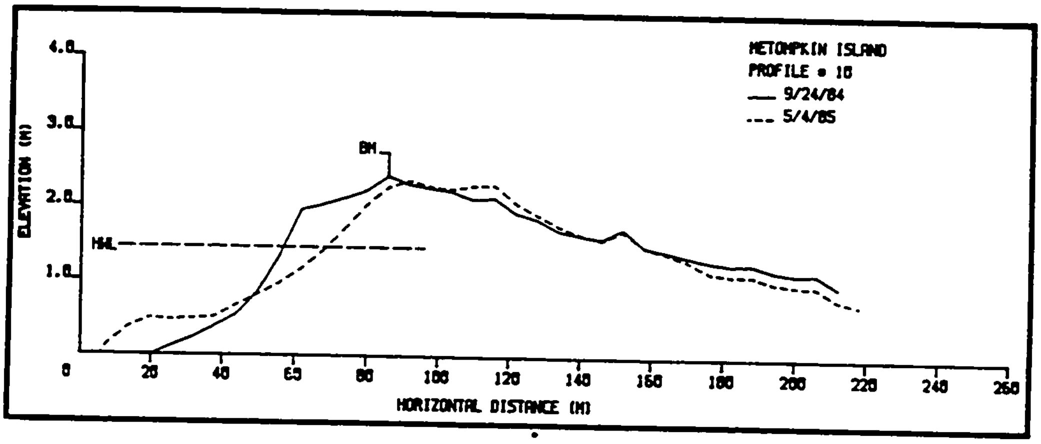

Figure 46. Changes in landward profile shape at transect 10 showing a near-balance between wind induced erosion near the lagoon shoreline and washover deposition just landward of the benchmark.

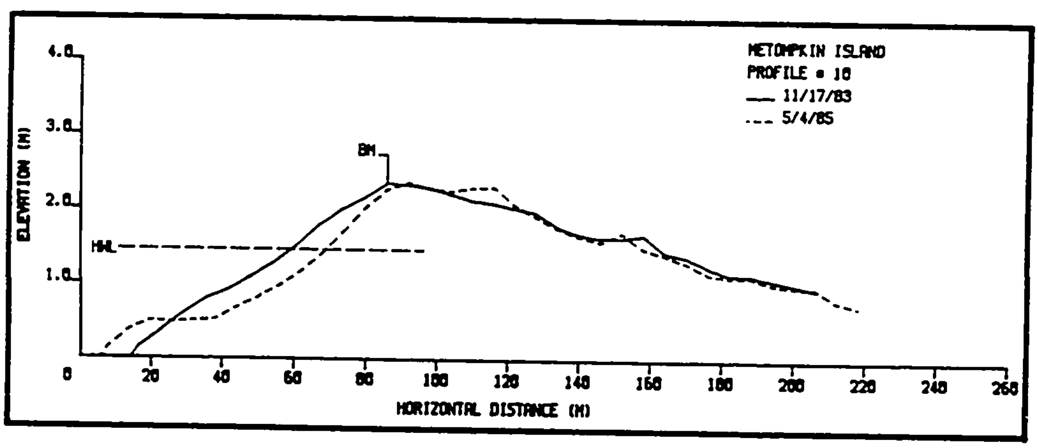

Figure 47. Plot of shoreline response at cross-island profile 10 showing significant erosion along most of the foreshore.

profiles 14, 16, and 18 showed lower foreshore deposition dominating erosion above the mid-foreshore. Landward profile changes were also net depositional. Consequently, net changes in sand volume along each transect exhibited deposition. At profiles 16 and 18, the high water shoreline prograded to a point seaward of its original position, however, a net reduction in foreshore slope at profile 14 produced a -6.68 m translation of the HWL (Table 9).

Resultant changes in island morphology between November 1983 and May 1985 illustrated a significant amount of net deposition (7.31 m^3/m), primarily associated with deposition along landward profiles. Although the magnitude of volume adjustment was greater for seaward profiles, the direction of change varied, producing an average total volume change of only 0.64 m^3/m. The average change in distance to the HWL was -4.29 m.

November 1985. Between May and November 1985, high energy storm processes significantly affected profile change. Hurricane Gloria impacted Metompkin Island on September 27, 1985. Processes related to the storm transported a considerable quantity of sand landward across the island. At profile 10, the position of the island crest was translated approximately 24 m landward of its May 1985 position but profile shape remained relatively constant during transgression (Figure 48). In addition, a sheet of sand, approximately 0.10-0.15 m thick, blanketed the entire landward portion of the island, graphically illustrating the rollover concept. Thus, total volume change across the island profile showed a net increase of 16.72 m^3/m (Table 10). Profile 12 exhibited similar characteristics although the magnitude of volume adjustment was

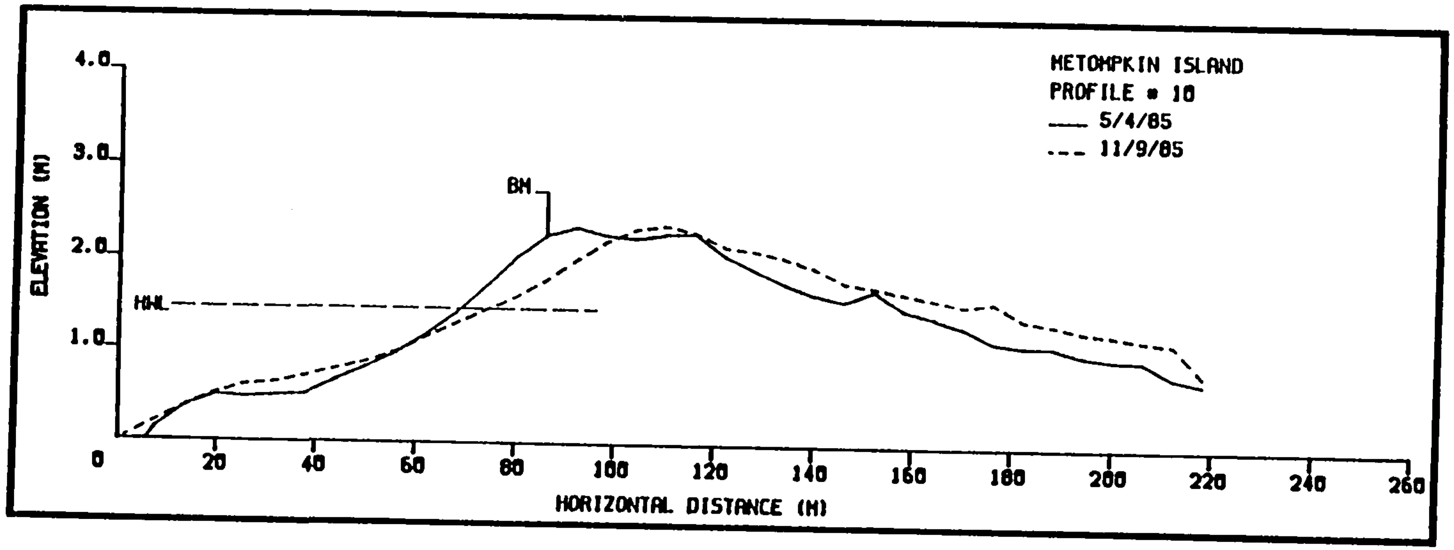

Figure 48. Post-hurricane adjustment in profile shape at transect 10 illustrating a 24-m landward translation of the island crest.

TABLE 10 - SOUTHERN METOMPKIN ISLAND PROFILE CHANGES - NOVEMBER 1985

May 1985 - November 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	-1.48	-5.45	-5.40	18.20	7.12	19.33	16.72	1.67
12	-7.67	-14.04	-8.33	11.11	16.20	-11.73	3.44	2.16
14	7.34	5.18	13.73	5.56	5.47	-0.22	12.90	10.65
16	-45.45	-24.32	-16.15	-2.00	-1.23	8.05	-47.45	-25.55
18	------	------	------	------	------	------	------	------
AVERAGE	-7.94	-7.92	-1.79	8.26	8.21	0.58	0.32	0.29

November 1983 - November 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
10	-14.12	-1.11	-14.97	17.58	8.23	16.59	3.46	7.12
12	-23.05	-30.26	-20.48	20.43	18.97	8.84	-2.62	-11.29
14	11.17	-1.91	7.05	8.46	8.82	-0.80	19.63	6.91
16[a]	-23.56	-19.65	-7.93	12.99	11.34	19.65	-10.57	-8.31
18[a]	------	------	------	------	------	------	------	------
AVERAGE	-10.24	-15.85	-8.29	14.73	12.52	8.72	4.49	-3.33

(a = cumulative from February 1984)

lower. Still, sand additions to the landward profile by washover exceeded losses on the seaward profile.

At profile 14, sand transport resulting from Hurricane Gloria was unique in that deposition occurred on both sides of the island profile. Furthermore, deposition along the seaward profile exceeded additions on the landward profile, producing a slight increase in island elevation. In response to net deposition on the foreshore, the high water shoreline prograded 13.73 m.

Just 800 m to the north, profile 16 experienced severe foreshore erosion and a net reduction in island profile elevation (Figure 49). Deposition along the landward profile was overshadowed by erosion, producing a total island volume change of -47.45 m^3/m (Table 10). The high water shoreline transgressed -16.15 m.

At profile 18, the maximum impact of Hurricane Gloria could be seen where storm waves removed the profile benchmark, reduced island elevation to approximately 1 m above MLW, and created an inlet breach. Although absolute volume change could not be recorded, approximate losses were evaluated using field measurements and observations. Volume changes on the seaward side of the island exceeded -60 m^3/m while landward adjustments were greater than -69 m^3/m. The entire volume of sand above the high water line was eliminated, creating a nearly submerged region at the time of high water. Although this portion of southern Metompkin Island changed significantly in response to Hurricane Gloria, average profile change characteristics suggested a dynamic balance between seaward profile erosion (-7.94 m^3/m) and landward profile deposition (8.26 m^3/m)(Table 10). Furthermore, landward profile data confirmed qualita-

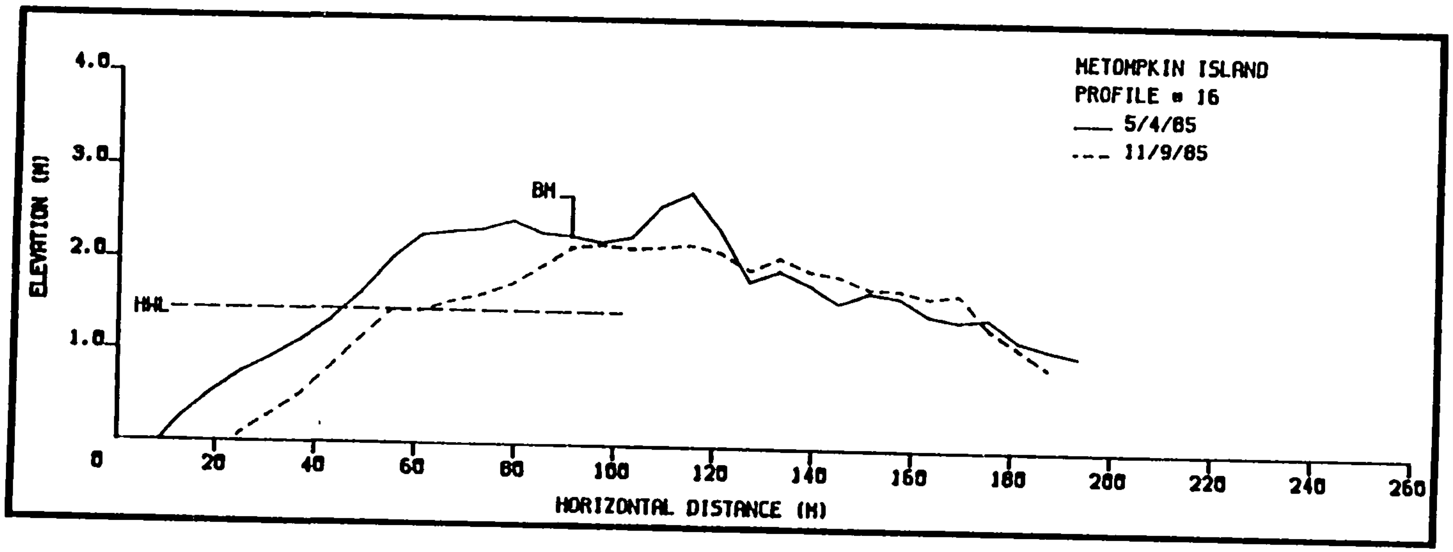

Figure 49. Plot showing extensive erosion along cross-island profile 16 as a result of inlet breaching at profile 18 due to surge from Hurricane Gloria.

tive shape consistency since the change in distance to the HWL was similar for both sides of the island.

Cumulative profile changes between November 1983 and November 1985 were similar to trends between May and November 1985. However, the magnitude of adjustments was greater. Since storm surge and eventual inlet breaching affected only a small portion of southern Metompkin Island, cumulative change to November 1985 associated with profiles 10-16 likely represented average conditions along the southern island shoreline. Average total volume change along seaward profiles was -10.24 m^3/m but significant additions of sand along landward profiles by washover (14.73 m^3/m) resulted in a net volume increase of 4.49 m^3/m of sand. Average change in distance to the HWL was -8.29 m, producing an average island retreat rate of 4.15 m/yr.

Northern Metompkin Island. Five cross-island profiles were surveyed at six time periods between November 1983 and November 1985 for a 3.2 km stretch of shoreline along northern Metompkin Island. Due to time constraints in November 1983, profile 24 was initially surveyed in February 1984. Spatial and temporal changes were evaluated in a manner similar to that for southern island transects.

February 1984. Sand volume adjustments along seaward profiles from November 1983 to February 1984 were concentrated mainly on the lower foreshore. Additions exceeded losses at all transects producing an average total volume change of 8.15 m^3/m (Table 11). However, the high water shoreline translated an average 3.36 m landward in response to erosion on the middle to upper foreshore.

TABLE 11 - NORTHERN METOMPKIN ISLAND PROFILE CHANGES - FEBRUARY 1984

November 1983 - February 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
24	------	------	------	------	------	------	------	------
26	12.37	-0.79	-3.57	-2.47	-3.28	-1.00	9.90	-4.07
28	12.83	-1.23	-4.08	12.32	9.91	7.83	25.20	8.68
30	3.08	-6.33	-5.47	21.11	19.27	15.30	24.19	12.94
32	4.63	-2.74	2.48	-5.71	-2.00	1.80	-1.08	-4.74
AVERAGE	8.15	-3.11	-3.36	9.78	8.85	7.84	17.93	5.74

Profiles 26 and 28 exhibited similar changes in seaward profile volume and position of the high water shoreline. Only a small portion of the middle to upper foreshore showed erosion while significant deposition occurred on the lower foreshore (Figure 50). A wedge of sand was deposited by washover at profile 28 whereas a small amount of erosion characterized the landward portion of profile 26. Consequently, net accretion at profile 28 was approximately 2.5 times greater than at profile 26.

The beach at profile 30 exhibited erosion on the upper foreshore and deposition on the lower foreshore, producing a net gain in sand volume of 3.08 m^3/m (Table 11). Sand additions on the landward side of the island produced a net gain of 24.19 m^3/m for the island profile. Island profile 32 illustrated a near balance between seaward profile additions and landward profile losses, resulting in a net total volume deficit of 1.08 m^3/m. In addition, the high water shoreline prograded 2.48 m in response to deposition on the foreshore.

June 1984. Total volume change on the seaward side of profile 24 illustrated erosion on the foreshore (-21.95 m^3/m) from February to June 1984. Significant washover deposition occurred on the landward profile (Figure 51). A net volume deficit of 4.48 m^3/m was recorded across the entire transect and the high water shoreline translated 6.98 m landward (Table 12). A similar pattern of profile development was measured at profile 26. However, washover deposition on the landward profile exceeded volume losses on the foreshore, producing a net volume change of 6.65 m^3/m along the island profile. Although a large amount of sand was eroded from the seaward profile, it occurred below the HWL. Therefore,

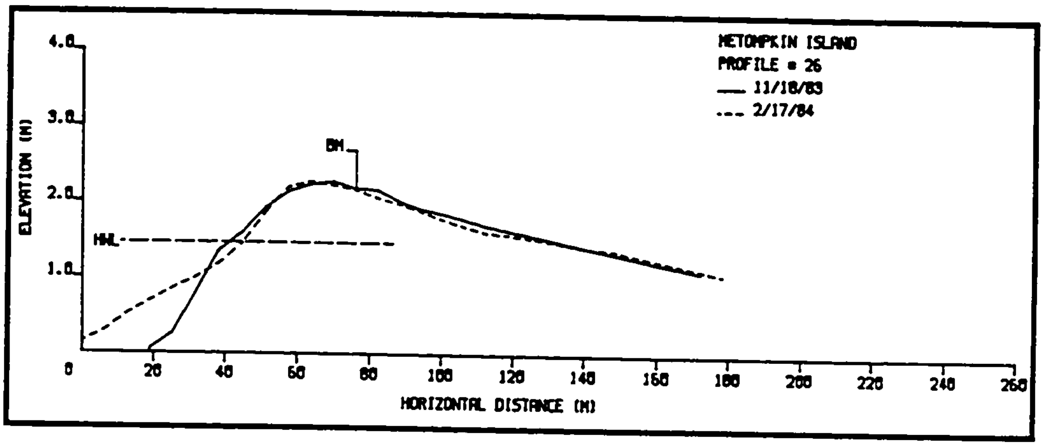

Figure 50. Plot of beach changes at profile 26 illustrating significant deposition on the lower foreshore and a net reduction in foreshore slope.

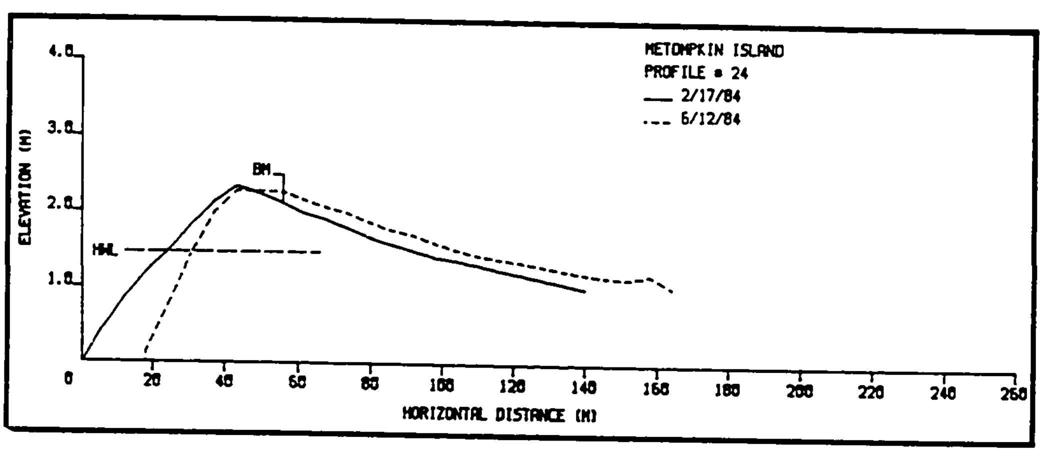

Figure 51. Adjustments in the beach profile at transect 24 showing a large loss of sand on the foreshore and a near-equal amount of washover deposition on the landward profile.

TABLE 12 - NORTHERN METOMPKIN ISLAND PROFILE CHANGES - JUNE 1984

February 1984 - June 1984

Profile #	Seaward Profile: Total Volume Change (m^3/m)	Seaward Profile: Volume Change Above HWL (m^3/m)	Seaward Profile: Change in Dist. to HWL (m)	Landward Profile: Total Volume Change (m^3/m)	Landward Profile: Volume Change Above HWL (m^3/m)	Landward Profile: Change in Dist. to HWL (m)	Island Profile: Total Volume Change (m^3/m)	Island Profile: Volume Change Above HWL (m^3/m)
24	-21.95	-2.98	-6.98	17.47	8.35	14.04	-4.48	5.37
26	-20.21	2.14	0.03	26.86	14.29	30.00	6.65	16.43
28	-11.31	6.24	-0.19	0.40	-0.68	-4.18	-10.91	5.56
30	-17.41	-5.63	-3.39	-16.59	-15.83	-4.50	-34.00	-21.46
32	2.53	3.83	2.13	1.66	4.37	18.05	4.19	8.20
AVERAGE	-14.66	-0.10	-1.49	5.06	1.04	9.34	-9.60	0.94

November 1983 - June 1984

Profile #	Seaward Profile: Total Volume Change (m^3/m)	Seaward Profile: Volume Change Above HWL (m^3/m)	Seaward Profile: Change in Dist. to HWL (m)	Landward Profile: Total Volume Change (m^3/m)	Landward Profile: Volume Change Above HWL (m^3/m)	Landward Profile: Change in Dist. to HWL (m)	Island Profile: Total Volume Change (m^3/m)	Island Profile: Volume Change Above HWL (m^3/m)
24[a]	-21.95	-2.98	-6.98	17.47	8.35	14.04	-4.48	5.37
26	-7.84	1.35	-3.54	24.39	11.01	29.00	16.55	12.36
28	1.57	5.01	-4.27	12.72	9.23	3.65	14.29	14.24
30	-14.33	-11.96	-8.86	4.52	3.44	10.80	-9.81	-8.52
32	7.16	1.09	4.61	-4.05	2.37	19.85	3.11	3.46
AVERAGE	-7.00	-1.64	-4.46	12.09	7.26	15.10	5.09	5.62

(a = cumulative from February 1984)

the high water shoreline was stable during this time period. Cumulative changes from November 1983 exhibited a net increase in sand volume along the island profile (16.55 m^3/m) while high water shoreline position translated 3.54 m landward (Table 12).

The beach at profile 28 exhibited an increase in foreshore slope due to erosion below the HWL and deposition on the upper foreshore. The position of the high water shoreline remained constant from February to June 1984. Net landward profile adjustments were insignificant but total volume change along the island profile showed a deficit of 10.91 m^3/m. Between November 1983 and June 1984, deposition of sand on seaward and landward profiles produced an island profile volume change of 14.29 m^3/m. In addition, a thin layer of sand was washed onto marsh deposits extending the landward profile. The position of the high water line moved 4.27 m landward.

Between February and June 1984, sand was eroded from the entire seaward side of profile 30. Net volume change was -17.41 m^3/m while the high water shoreline receded 3.39 m (Table 12). Sand volume adjustments from November 1983 to June 1984 showed a similar volume deficit on the seaward profile but considerably more sand was eroded from the middle to upper foreshore, producing a -8.86 m shift of the HWL (Figure 52). Relatively small cumulative changes in landward profile volume resulted in a net loss of 9.81 m^3/m along the island profile. At profile 32, accretion on the foreshore produced a net island profile volume change of 3.11 m^3/m from November 1983 to June 1984.

Average change in total volume between February and June 1984 exhibited significant erosion on the seaward profile. However, since net

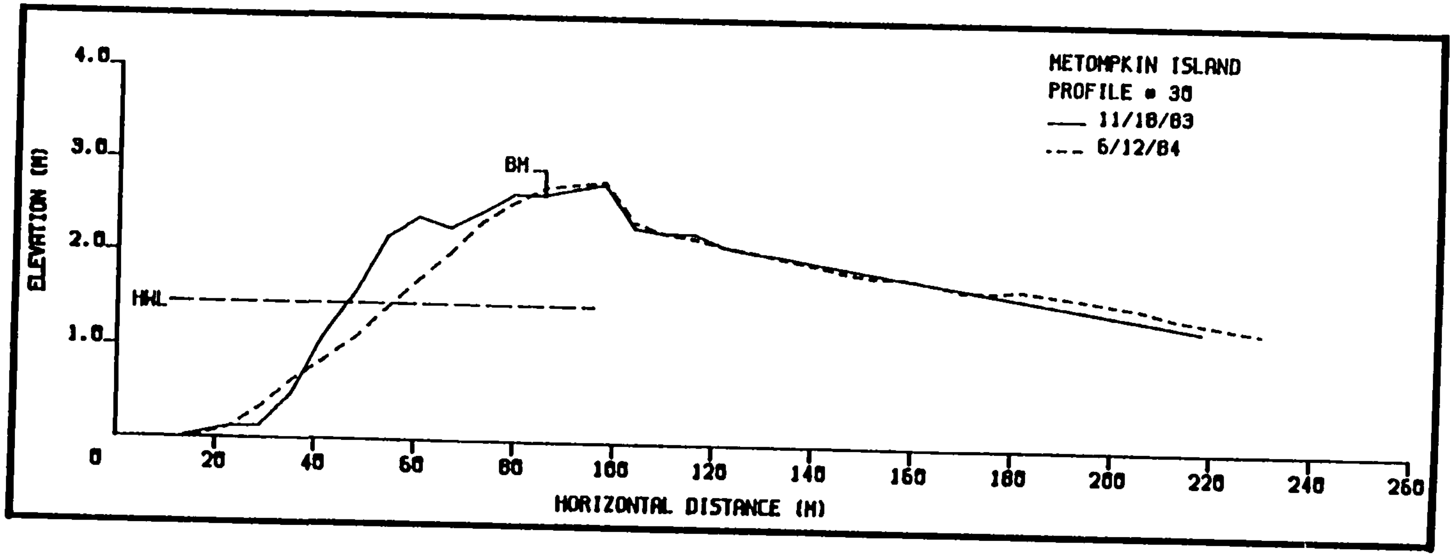

Figure 52. Plot showing changes in shape at profile 30 where a significant amount of sand was eroded from the middle and upper foreshore creating a net reduction in slope.

volume adjustments above the HWL were minimal, the associated change in distance to the high water shoreline was small (-1.49 m).

September 1984. Total volume change on the seaward side of southern Metompkin Island exhibited accretion at all profiles between June and September 1984, producing an average change of 9.51 m^3/m (Table 13). However, the magnitude of change varied. The beach at profile 24 showed small changes in volume and shoreline change. Just 800 m to the north, deposition on the foreshore at profile 26 increased net sand volume by 11.17 m^3/m. However, a thin veneer of sand was eroded from the landward profile in response to aeolian transport on the washover flats, resulting in a relatively small net increase in island profile volume. At profile 28, a relatively small amount of deposition on the seaward profile added to washover deposition on the landward profile, producing a surplus of 18.78 m^3/m of sand along the cross-island transect.

Profiles 30 and 32 exhibited deposition landward and seaward of the island crest from June to September 1984. A large wedge of sand was deposited on the upper foreshore at profile 30 while a thick layer of sand accumulated on the middle to lower foreshore at profile 32 in response to onshore bar migration (Figure 53). Deposition at profile 32 was most significant, producing a 9.67 m progradation of the high water shoreline. Changes in total volume along the two profiles reflected additions on both sides of the island axis, totaling 24.90 m^3/m for profile 30 and 29.21 m^3/m for profile 32.

Cumulative changes in seaward profile characteristics from November 1983 to September 1984 showed a deficit of 20.91 m^3/m at profile 24, a surplus of 24.62 m^3/m at profile 32, and less significant changes else-

TABLE 13 - NORTHERN METOMPKIN ISLAND PROFILE CHANGES - SEPTEMBER 1984

June 1984 - September 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
24	1.04	-0.28	-0.51	-1.63	0.26	0.96	-0.59	-0.02
26	11.17	2.36	3.69	-7.54	-3.88	-8.00	3.63	-1.52
28	4.00	2.51	2.07	14.78	6.38	6.85	18.78	8.89
30	13.63	10.10	3.95	11.27	9.90	18.00	24.90	20.00
32	17.46	5.36	9.67	11.75	7.88	8.79	29.21	13.24
AVERAGE	9.51	4.38	3.57	5.89	4.12	5.43	15.40	8.50

November 1983 - September 1984

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
24[a]	-20.91	-3.26	-7.49	15.84	8.61	15.00	-5.07	5.35
26	3.33	3.71	0.15	16.85	7.13	21.00	20.18	10.84
28	5.57	7.52	2.20	27.50	15.61	10.50	33.07	23.13
30	-0.70	-1.86	-4.91	15.79	13.34	28.80	15.09	11.48
32	24.62	6.45	14.28	7.70	10.25	28.64	32.32	16.70
AVERAGE	2.51	2.74	-0.89	17.98	11.38	20.53	20.49	14.12

(a = cumulative from February 1984)

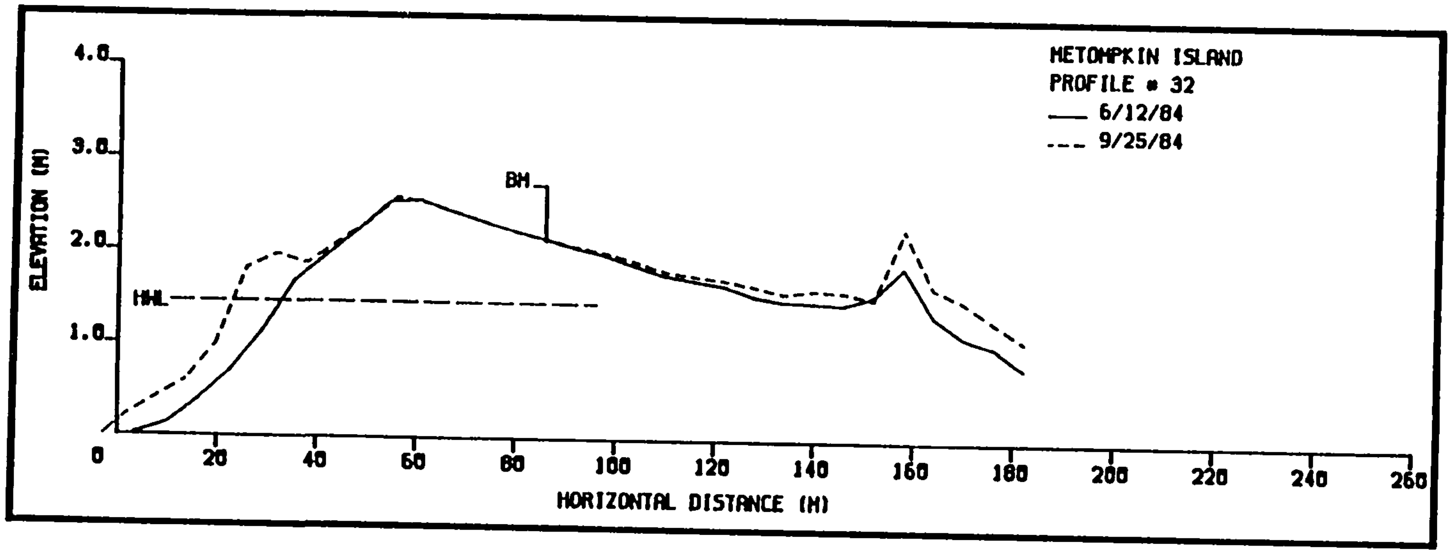

Figure 53. Profile change plot at transect 32 illustrating significant accretion on the middle and lower foreshore in response to onshore bar migration.

where. This produced an average change of 2.51 m^3/m (Table 13). Landward profile adjustments were all positive and averaged 17.98 m^3/m. Consequently, island profile volume change showed an average surplus of sand.

May 1985. Between September 1984 and May 1985, seaward profile adjustments in total volume were similar at profiles 24, 30, and 32. Large quantities of sand eroded from the entire seaward side of the island (Figure 54). Sand losses on the foreshore at profile 32 were approximately 2 times greater (-54.35 m^3/m) than those recorded at profiles 24 and 30. As a result, the high water shoreline moved -13.55 m at profile 24 and 30, and -31.88 m at profile 32. Although the position of the island crest remained unchanged at profile 30, approximately 20 m of landward displacement was illustrated at profiles 24 and 32. This magnitude of change governed adjustments in seaward profile response from November 1983 to May 1985.

The pattern of foreshore evolution was similar at profiles 26 and 28 from September 1984 to May 1985. Lower foreshore deposition and middle to upper foreshore erosion produced a reduction in beach slope and landward translation of the HWL (Figure 55). Although the direction of change was consistent with the other profiles, the magnitude of sand loss was much less. Cumulative trends from November 1983 showed a similar pattern of change.

Average response of the beach along the seaward side of northern Metompkin Island showed a 19.19 m^3/m loss of sand for the 3.2 km segment of shoreline between September 1984 and May 1985. Cumulative profile volume change from November 1983 reflected this change and averaged

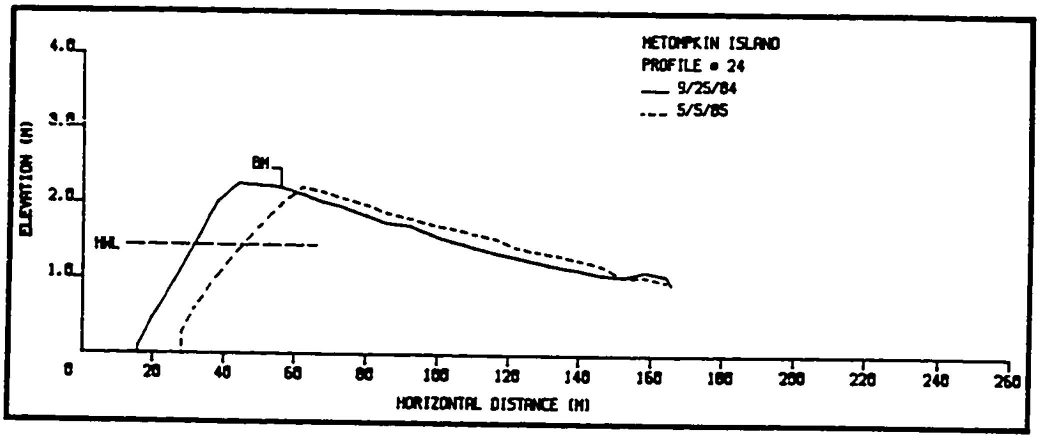

Figure 54. Plot showing large losses of sand on the seaward side of profile 24 and only small additions (washover) along the landward profile.

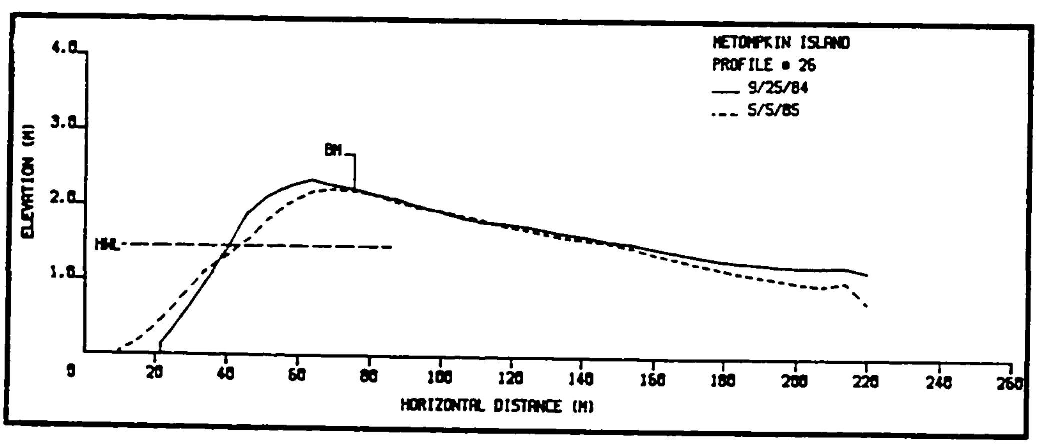

Figure 55. Plot of beach changes at profile 26 showing upper foreshore erosion and lower foreshore deposition, producing a net reduction in beach slope.

-16.68 m^3/m (Table 14). For both time periods, resultant change in distance to the HWL was approximately -13 m.

Sand losses along landward profiles from September 1984 to May 1985 were exhibited at all but profile 24, where washover nourished the beach on the back side of the island. Consequently, average change in total volume was -11.33 m^3/m (Table 14). Just the opposite trend characterized changes from November 1983 to May 1985. Only profiles 30 and 32 showed small net losses in sand volume; thus, average change in landward profile volume was 6.65 m^3/m of sand.

Resultant island profile volume changes from September 1984 to May 1985 exhibited large sand losses since both landward and seaward profiles exhibited net erosion. The beach along northern Metompkin Island had an average deficit of 30.52 m^3/m. Cumulative changes from November 1983 were not as dramatic due to net deposition on the landward profile. Therefore, total volume change averaged -10.03 m^3/m for 3.2 km of shoreline.

November 1985. The most dramatic change in profile shape developed between May and November 1985 in response to Hurricane Gloria. All seaward profiles, except 24, showed a loss of sand volume of at least 20 m^3/m. At profile 24, deposition on the lower foreshore balanced losses on the middle to upper foreshore, producing an insignificant change in volume (Figure 56). However, the HWL transgressed 37.69 m while the berm crest moved 44 m landward due to this one storm event. Average total volume change for all profiles on the seaward side of the island was -27.47 m^3/m (Table 15). As a result, the change in distance to the high water shoreline was -18.30 m. In all cases, the berm crest migrated farther landward than the HWL due to a net reduction in foreshore slope.

TABLE 14 - NORTHERN METOMPKIN ISLAND PROFILE CHANGES - MAY 1985

September 1984 - May 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
24	-28.84	-12.56	-13.55	10.88	7.05	12.25	-17.96	-5.51
26	-0.84	-6.60	-3.06	-7.00	-1.73	-5.00	-7.84	-8.33
28	-6.87	-16.60	-12.92	-21.84	-10.39	-11.40	-28.71	-26.99
30	-27.45	-22.32	-13.55	-17.04	-14.28	-32.80	-44.49	-36.60
32	-54.35	-26.63	-31.88	-9.72	-6.83	-31.64	-64.07	-33.46
AVERAGE	-19.19	-16.28	-13.06	-11.33	-6.57	-14.77	-30.52	-22.85

November 1983 - May 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
24[a]	-49.75	-15.82	-21.04	26.72	15.66	27.25	-23.03	-0.16
26	2.49	-2.89	-2.91	9.85	5.40	16.00	12.34	2.51
28	-1.30	-9.08	-15.12	5.66	5.22	-0.90	4.36	-3.86
30	-28.15	-24.18	-18.46	-1.25	-0.94	-4.20	-29.40	-25.12
32	-29.73	-20.18	-17.60	-2.02	3.42	-3.00	-31.75	-16.76
AVERAGE	-16.68	-13.54	-13.95	6.65	4.81	5.76	-10.03	-8.73

(a = cumulative from February 1984)

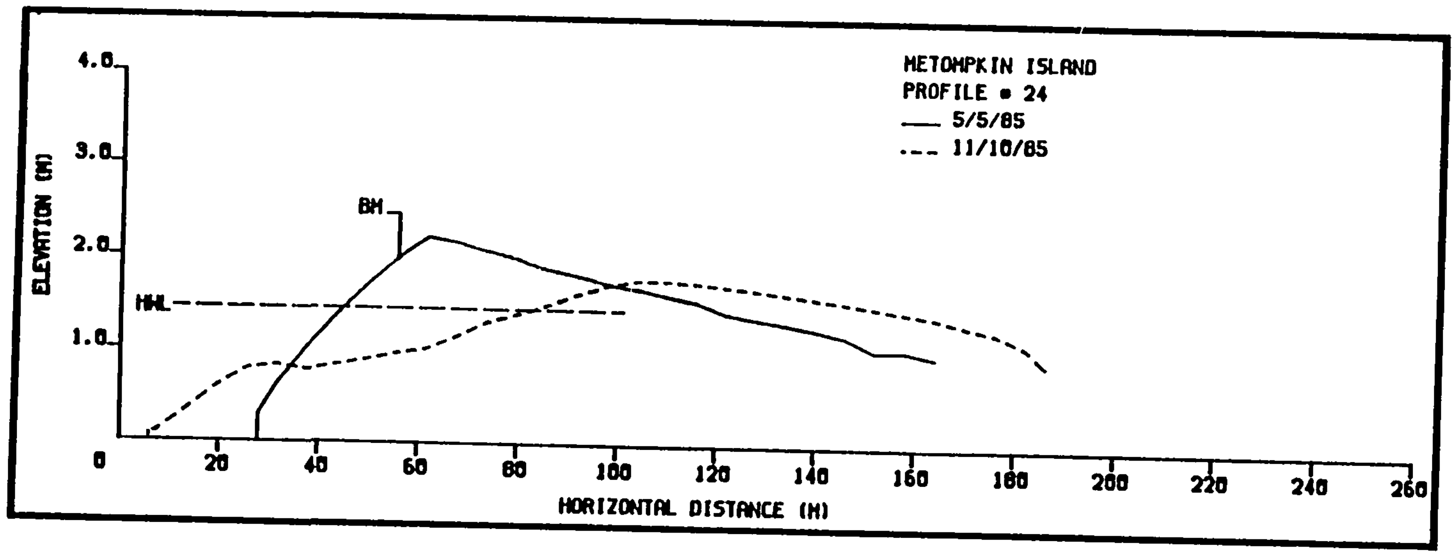

Figure 56. Post-hurricane adjustments in profile shape at transect 24 illustrating a 44-m landward displacement of the island crest, a reduction in island elevation, and significant sand additions to the landward profile by washover.

TABLE 15 - NORTHERN METOMPKIN ISLAND PROFILE CHANGES - NOVEMBER 1985

May 1985 - November 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
24	-0.37	-2.94	-37.69	-2.32	-13.78	38.90	-2.69	-16.72
26	-43.56	-16.63	-25.73	19.27	11.26	23.50	-24.29	-5.37
28	-32.33	-6.14	-16.00	12.64	8.36	13.50	-19.69	2.22
30	-20.93	-8.95	-20.85	31.66	27.24	47.40	10.73	18.29
32	-25.79	-9.72	-10.50	20.42	18.39	30.20	-5.37	8.67
AVERAGE	-27.47	-9.51	-18.30	18.16	12.29	29.73	-9.31	2.78

November 1983 - November 1985

	Seaward Profile			Landward Profile			Island Profile	
Profile #	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
24[a]	-50.12	-18.76	-58.73	24.40	1.88	66.15	-25.72	-16.88
26	-41.07	-19.52	-28.64	29.12	16.66	39.50	-11.95	-2.86
28	-33.63	-15.22	-31.12	18.30	13.58	12.60	-15.33	-1.64
30	-49.08	-33.13	-39.13	30.41	26.30	43.20	-18.67	-6.83
32	-55.52	-29.90	-28.10	18.40	21.81	27.20	-37.12	-8.09
AVERAGE	-44.15	-23.05	-32.25	24.81	17.10	35.49	-19.34	-5.95

(a = cumulative from February 1984)

Between November 1983 and November 1985, seaward profile response was dominated by changes resulting from Hurricane Gloria. Total volume change on the beach along seaward profiles averaged -44.15 m^3/m. Sixty-two percent of this change could be associated with Hurricane Gloria. The high water shoreline responded by moving an average 32.25 m landward. Thus, the average rate of island retreat during the two-year study was -16.13 m/yr.

Although massive erosion occurred at most seaward profiles due to Hurricane Gloria, not all of the sand was removed from the subaerial beach along northern Metompkin Island. Deposition along landward profiles by washover was an important sand transfer mechanism for maintaining continuity along the island profile. Contributions due to washover were significant at all cross-island profiles, especially at profile 30 where a sheet of sand 0.5 m thick blanketed the landward side of the island (Figure 57). However, all but one island profile registered greater erosion on the seaward side of the island. Therefore, only 66% of seaward losses could be accounted for by landward transfers of sand and an average total volume change of -9.31 m^3/m was recorded between May and November 1985 (Table 15). Cumulative changes from November 1983 exhibited a similar trend except washover could only account for 56% of erosion at seaward profile positions. Consequently, average island profile volume change was increased to -19.34 m^3/m.

<u>Temporal Summary of Island Dynamics</u>. Table 16 provides a summary of cumulative average profile changes during the two-year study. Trends in average island profile volume were fairly consistent between November 1983 and September 1984, where net accretion was common at most profiles

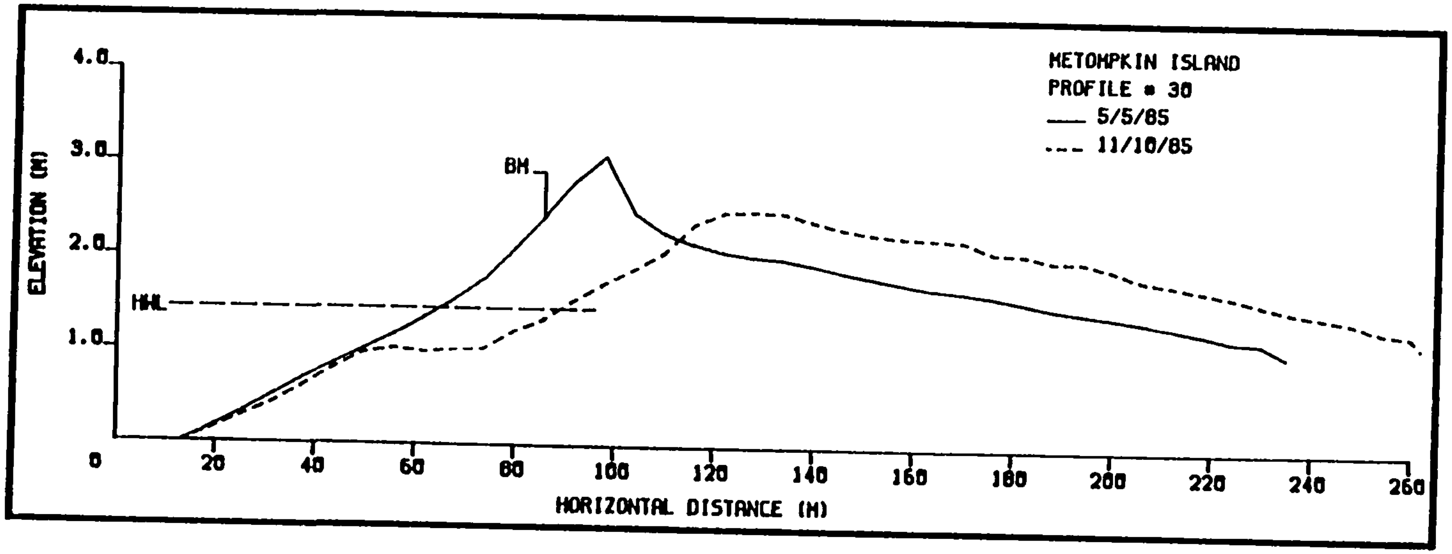

Figure 57. Plot of cross-island profile changes at transect 30 showing significant losses of sand on the middle and upper foreshore and equally significant deposition on the landward profile by washover.

TABLE 16 - SEDIMENT BUDGET AND SHORELINE DYNAMICS FOR SOUTH AND NORTH METOMPKIN ISLAND
NOVEMBER 1983 TO NOVEMBER 1985

Southern Metompkin Island

	Average Seaward Profile			Average Landward Profile			Average Island Profile	
Date	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
2/84[a]	7.62	2.33	1.95	14.57	10.90	12.83	22.19	13.23
6/84	8.29	1.00	3.86	0.61	1.62	-0.85	8.90	2.62
9/84	8.37	3.61	4.51	5.43	2.45	11.21	13.80	6.06
5/85	0.64	-6.09	-4.29	6.67	4.72	7.54	7.31	-1.37
11/85[b]	-10.24	-15.85	-8.29	14.73	12.52	8.72	4.49	-3.33

Northern Metompkin Island

	Average Seaward Profile			Average Landward Profile			Average Island Profile	
Date	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)	Change in Dist. to HWL (m)	Total Volume Change (m^3/m)	Volume Change Above HWL (m^3/m)
2/84[c]	8.15	-3.11	-3.36	9.78	8.85	7.84	17.93	5.74
6/84	-7.00	-1.64	-4.46	12.09	7.26	15.10	5.09	5.62
9/84	2.51	2.74	-0.89	17.98	11.38	20.53	20.49	14.12
5/85	-16.68	-13.54	-13.95	6.65	4.81	5.76	-10.03	-8.73
11/85	-44.15	-23.05	-32.25	24.81	17.10	35.49	-19.34	-5.95

(a = profiles 10-14 only; b = profiles 10-16 only; c = profiles 26-32 only) along north and south Metompkin Island. The high water shoreline along the southern island segment prograded 4.51 m in response to 8.37 m^3/m of foreshore accretion. Although average island profile volume change was greater along northern Metompkin Island, 88% of this sand volume was associated with deposition on the landward profile. Therefore, an insignificant amount of high water shoreline movement was illustrated.

Between September 1984 and May 1985, significant changes in sand volume and shoreline position occurred along the entire island. However, average volume change from November 1983 to May 1985 illustrated that erosion along north Metompkin Island was much more severe. Average seaward profile volume change was -16.68 m^3/m and the HWL had retreated 13.95 m. Although deposition occurred on the landward side of the island, total volume change averaged -10.03 m^3/m. Southern Metompkin Island showed insignificant net volume change on the seaward side of the island and net accretion along landward profiles, producing a surplus of sand for the entire island segment; however, the HWL moved 4.29 m landward.

Adjustments in average profile shape and volume were most severe between May and November 1985. Erosion on the seaward side of the island and deposition landward of the island crest was exhibited at all profile locations. However, the magnitude of change between November 1983 and November 1985 was greatest along north Metompkin Island where an average 44.15 m^3/m of sand was eroded from the seaward side of the island and 24.81 m^3/m was deposited landward of the island crest. The high water shoreline regressed an average of 16.13 m/yr during this time. Washover deposition of sand was significant but not enough to maintain continuity during landward retreat of the island. If this represents a perpetual loss of sand from the barrier island environment, the island segment may increase its rate of migration and slowly dissipate through time.

South Metompkin Island responded quite differently since average accretion on the landward side of the island exceeded net foreshore erosion. The average HWL shifted -4.15 m/yr during the two-year study and a surplus of sediment was recorded. However, extreme erosion along the northern portion of this shoreline segment produced an inlet breach at mid-Metompkin Island.

Results of this study show a very different trend in shoreline response as compared with recent historical records. Between 1957 and 1981, south Metompkin Island was migrating about 2.5 times the rate of north Metompkin Island. From November 1983 to November 1985, north Metompkin Island migrated at approximately 4 times the rate of the southern shoreline segment. However, the island was a continuous feature from Metompkin Inlet to Gargathy Inlet during this time. Furthermore, north Metompkin Island projected approximately 400 m seaward of the shoreline to the south and may have acted as a local shelter to storm waves from the northeast. Finally, if historical trends provide accurate indicators of shoreline change, recent inlet breaching along south Metompkin Island will mean an increase in the present rate of shoreline movement.

Stratigraphic Sequences

Sixteen cores along four transects were used to determine the three-dimensional character of coastal lithosomes associated with the Metompkin Island complex. The transect lines, from south to north, are: 1) Joynes Neck to south Metompkin Island; 2) Parker Neck to Metompkin Island; 3)

Whites Neck to Metompkin Island; and 4) southern Hog Neck to Gargathy Beach (Figure 8). Dip sections enable comparison of resultant sedimentation sequences in relation to the ongoing marine transgression. Facies comparisons between transects provide information about longshore variations in lithosome occurrence and geometry. The following discussion provides a description of lithofacies characteristic of the Metompkin barrier island system. Lithofacies refers to the sedimentary record of any depositional environment, including physical and organic characteristics that influence the appearance, composition, and texture of the deposit (Bates and Jackson, 1980). Shepard (1954) nomenclature was used for sand-silt-clay ratios. Core logs are presented in Appendix B and grain size statistics are given in Appendix C.

Determination of the Pre-Holocene Boundary

Many cores recovered from backbarrier locations penetrated both Holocene and older deposits. Recognition of the boundary between these units generally is accomplished using several well-defined characteristics. A sea level lowstand during the Wisconsinan glacial stage enabled fluvial processes and subaerial erosion to shape the land surface now found below more recent Holocene deposits. Consequently, coarse-grained fluvial sediment is chronostratigraphically distinct from overlying fine-grained Holocene backbarrier deposits. Subaerially weathered soil horizons often provide another distinct demarcation signifying the Holocene - pre-Holocene boundary. Although most contacts are manifested by these characteristics, transitions between two fine-grained facies may not be easily recognized. Therefore, a series of sedimentologic and paleontologic attributes were used for distinguishing

Holocene and pre-Holocene deposits.

Many stratigraphic studies in modern barrier island environments have described some of the basic distinctions encountered at this contact (Kraft et al., 1973; Halsey, 1978; Kraft and John, 1979; Moslow, 1980; Shideler et al., 1984; Finkelstein, 1986). Coarse, sandy sediment often marks the Holocene - pre-Holocene boundary but it is more than just the presence of sand that makes this contact distinct. Changes in compaction and color are often noted where previously subaerial pre-Holocene deposits are highly dewatered and exhibit purple, orange, and yellowish hues (Halsey, 1978; Ludwick and Oertel, 1982; Finkelstein, 1986). Sand deposits are often devoid of microfauna (Ludwick and Oertel, 1982; Otvos, 1982; Shideler et al., 1984). Where weathered soil horizons are found, highly dewatered sediment is again characteristic, often exhibiting reddish-brown hues and a lack of marine fauna. Both of these conditions were encountered in the Metompkin backbarrier region. In addition, mineralized organic deposits were recognized as high density contrasts on x-ray radiographs and were seen only in pre-Holocene sections (Figure 58).

Finally, many studies have used the presence of basal peat deposits to mark this contact, stating that it represents marsh growth associated with the first occurrence of sea water during the Flandrian transgression (Newman and Rusnak, 1965; Newman and Munsart, 1968; Morton and Donaldson, 1973; Kraft and Chrzastowski, 1985; Finkelstein, 1986). This provides the most distinctive physical marker and an associated date for marine inundation. Lack of this organic layer implies either rapid inundation or dominant erosional processes during sea level rise. Deposits below this horizon are also dewatered and often lack calcareous fossils.

Figure 58. Positive image of x-ray radiograph with small black spots outlining worm burrow indicating diagenetic changes in pre-Holocene deposits.

In summary, the basic characteristics used for distinguishing pre-Holocene from Holocene deposits include: 1) very clean, coarse, poorly sorted sand overlain by fine-grain backbarrier muds; 2) highly dewatered sediment at and below the contact; 3) the presence of an overlying basal peat; 4) changes in sediment color reflecting subaerial exposure; 5) a complete lack of fossil microfauna; and 6) high-density contrasts on x-ray radiographs from mineralized organic deposits.

Joynes Neck to South Metompkin Island

Modern deposition at this southernmost transect (Figure 59) was strongly influenced by hydrodynamics associated with Metompkin Inlet. Numerous inlet-related sand shoals, developed as a result of fluctuating tidal currents and sediment supply, controlled recent sedimentation patterns.

Core M1 was taken on the berm crest along southern Metompkin Island (+1.40 m MSL), about 2.3 km from the mainland shoreline. Five unique lithofacies characterized the sedimentary sequences that extended 5.90 m below MSL. The uppermost modern beach unit (0.7 m thick) was a tan to light brown, medium to fine, clean quartz sand. A 0.69 m unit of tan to dark grey, medium to fine sand with abundant heavy minerals (mostly garnet) and horizontal to sub-horizontal laminations was beneath the present day beach. Immediately below these deposits, a 0.5 m thick organic-rich (*Spartina alterniflora* roots and stems), brown to very dark grey, clayey silt facies was encountered. This appeared identical to modern marsh deposits. A 0.99 m section of grey to dark grey, fine to very fine, quartz sand characterized the following unit. Radiographic examination revealed a highly bioturbated, featureless deposit, similar

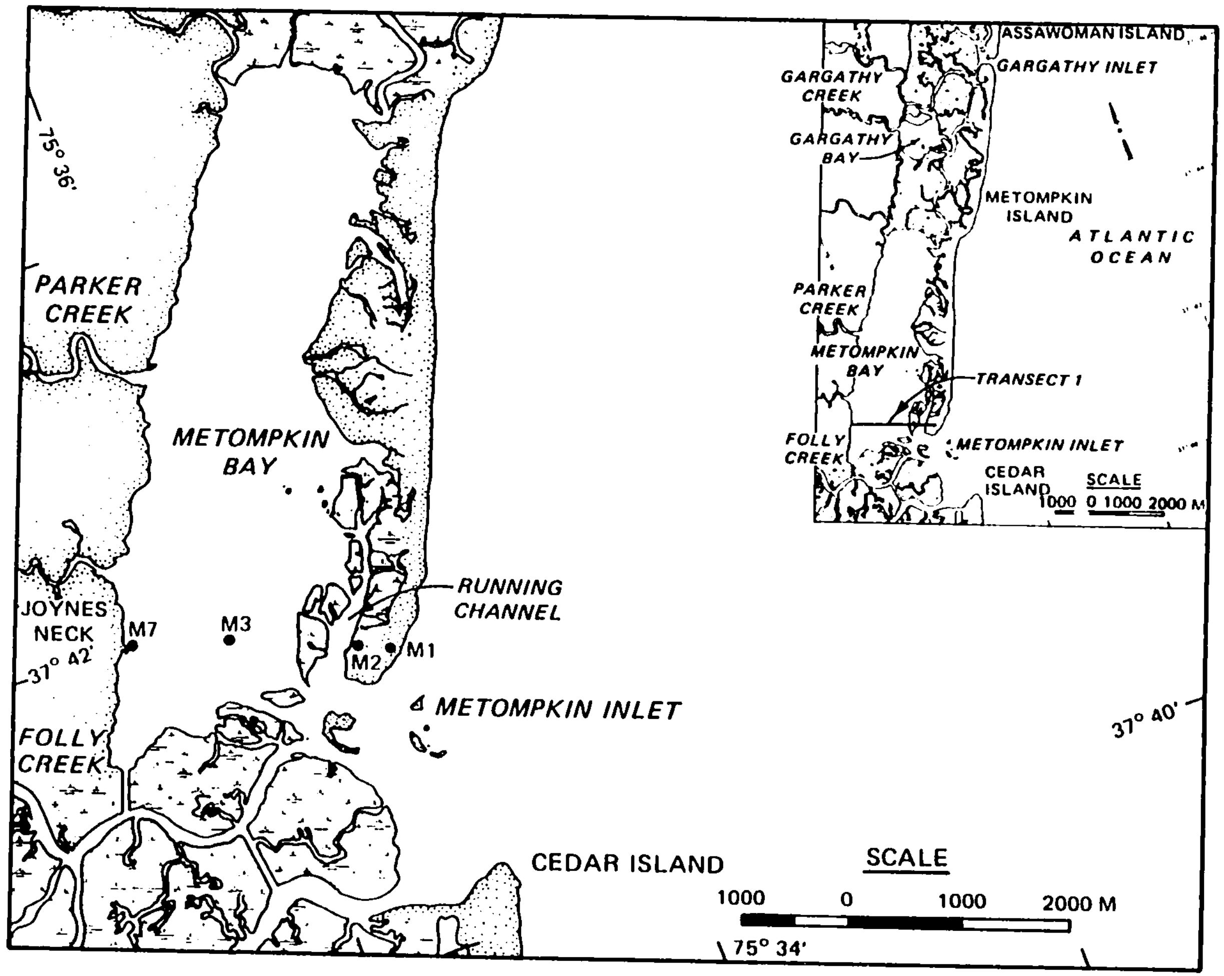

Figure 59. Map showing location of cores along transect 1.

to that described by Howard and Frey (1985) for amphipod locomotion bioturbation (Figure 60). This graded into a 4.43 m thick, grey to dark grey, sandy silt to clayey silt unit with some flaser and lenticular bedding. Polychaete burrows and macrolocomotion features thoroughly disturbed most physical structures, creating swirling textural contrasts. *Littorina irrorata* and *Crassostrea virginica* shells were present. The bottom 0.54 m of this unit appeared slightly more dewatered and exhibited a small increase in sand content, with considerably less biogenic reworking. Although there were some minor variations in sediment textural trends, the major units produced an overall coarsening upwards sequence. Kraft and Chrzastowski (1985) and Kraft and John (1979) classified this trend as a typical transgressive barrier sequence.

Core M2 was obtained from the back side of southern Metompkin Island on the seaward sandy margin of Running Channel (Figure 59). Penetration reached -4.09 m MSL. The top 0.54 m of section consisted of grey, medium to fine sand with heavy minerals. Horizontal to sub-horizontal laminae were recognized on radiographs, as well as thin current ripple laminae accented with heavy minerals. However, microlocomotion bioturbation was also present. This surface deposit characterized a typical sandy tidal flat, its source being littoral sediment transported through Metompkin Inlet during flooding tide. A 0.46 m, organic-rich, grey to dark grey, clayey silt to silty sand unit existed below the upper sand facies. It contained interbedded mud and sand with some lenticular and flaser bedding and minor locomotion bioturbation. Below this was a 3.38 m thick sand facies characterized by grey to light grey, fine to very fine, quartz sands. Faint current ripple laminations and planar cross-bedding

Figure 60. X-ray radiograph from core M1 showing massive-type appearance due to amphipod locomotion bioturbation.

accompanied horizontal to sub-horizontal laminae. Mud and organic flasers were evident while amphipod bioturbation and polychaete burrows were abundant on radiographs. Mean grain size increased slightly towards the bottom of this unit. One razor clam shell (*Ensis directus*), found towards the base of the sequence (-3.88 m MSL), provided tenuous environmental significance, since this species is ubiquitous to sandy bottoms of coastal waters. However, sedimentologic characteristics were very similar to those of the surface facies. On average, mean grain size decreased and samples became more poorly sorted up section.

Core M3 was taken on a sand flat in the middle of southernmost Metompkin Bay at low tide. Three facies dominated this overall coarsening upwards sequence. The top 1.40 m represented the modern sandy tidal flat environment. It was characterized by a light brownish grey, very fine to fine, quartz sand. Horizontal to sub-horizontal laminations were occasionally outlined by heavy minerals. Very thin current ripple laminae could be seen on radiographs in addition to stringers and pockets of organic material. Again, microlocomotion bioturbation was very apparent. The following unit was 3.15 m thick and exhibited a high mud content. Dark grey to very dark grey, silty sand to clayey silt characterized sediment texture while interbedded sand and mud disturbed by macrolocomotion was common. Numerous whole and fragmented periwinkle (*Littorina irrorata*) shells were encountered. This organism can be found in most backbarrier environments and was likely responsible for creating the swirling textural contrasts. The bottom unit was a 3.85 m thick, greyish-brown to grey, clayey silt facies exhibiting extensive bioturbation, thus creating a massive appearance. Four distinct oyster (*C.*

virginica) zones could be identified along with a few *L. irrorata* shells. This typical transgressive sequence illustrated a change in backbarrier energy characteristics from a quiet, protected, fine-grained environment at the base of the section to a more active, sand-dominated intertidal sand flat at the surface.

The landwardmost core (M7) along transect 1 was again taken on an exposed intertidal sand flat, just seaward of Joynes Neck, at low tide (Figure 59). The top 1.81 m of core contained a grey to very dark grey, fine to medium quartz sand facies. Bioturbation was present throughout, however, interbedded muds and sands with some flasers were recognized. Grain size was typically coarser than previously described sand flat environments, probably due to core position (103 m from mainland) and subsequent mixing with coarser subaerial and subaqueous pre-Holocene sediment. The basal unit of core M7 was a pre-Holocene sand facies. The upper 0.70 m represented the subaerially weathered horizon developed prior to encroachment of the sea. It was a structureless sand horizon with the presence of some thin, vertical worm burrows or rootlets. The bottom 1.93 m was represented by light grey to light brownish grey, fine to medium, quartz sand. Horizontal to sub-horizontal laminations with some planar cross-bedding were common. This was the only encounter with the pre-Holocene surface along transect 1.

Six distinct lithofacies characterized deposition along the southernmost transect in the Metompkin Island system. They are: 1) a seaward subaerial sand facies (A); 2) an organic-rich, clayey silt facies (B); 3) a laminated intertidal fine sand facies (C); 4) a silty sand to sandy silt facies (D); 5) a clayey silt facies (E); and 6) a pre-Holocene coarse to medium sand facies (H). Deposition associated with Metompkin Inlet strongly influenced sedimentation patterns. Sediment characteristic of pre-Holocene deposits was found only along the mainland fringe at core M7.

Parker Neck to Metompkin Island

Sedimentation patterns along transect 2 (Figure 61) recorded considerable influence from ephemeral inlet and washover activity. As shown by Harrison (1971), extensive surficial silty sand and sandy silt deposits extended well into Metompkin Bay as coalescing lobate surface features (Figure 62). Cores M13 and M14 were taken approximately 50 m apart on the backside of mid-southern Metompkin Island (1.9 km from the mainland shoreline). Historical maps and aerial photographs indicated ephemeral inlet-washover surge channels at these locations in the recent past (Rice et al., 1976). Both sequences illustrated inlet-fill characteristics for the uppermost unit. A tan to grey, coarse to fine, quartz sand facies, with numerous shell fragments, dominated the top 2.61 m of core M13. Very distinct horizontal to sub-horizontal laminae outlined with heavy minerals, coquina (*Donax variablis*), and small surf clam (*Mulinia lateralis*) shells were abundant. In addition, ripple and megaripple(?) foresets along with trough cross-bedding and numerous microripple laminations were common. Three distinct fining upward event beds, with basal shell lags, were recognized and showed little bioturbation. Below this sand sequence was a 0.5 m thick, extensively bioturbated, dark grey, silty sand facies, with *L. irrorata* shells. The bottom 0.59 m of core consisted of a dark grey, clayey silt facies. Micro-locomotion bioturbation, with some worm burrows and plant stem fragments,

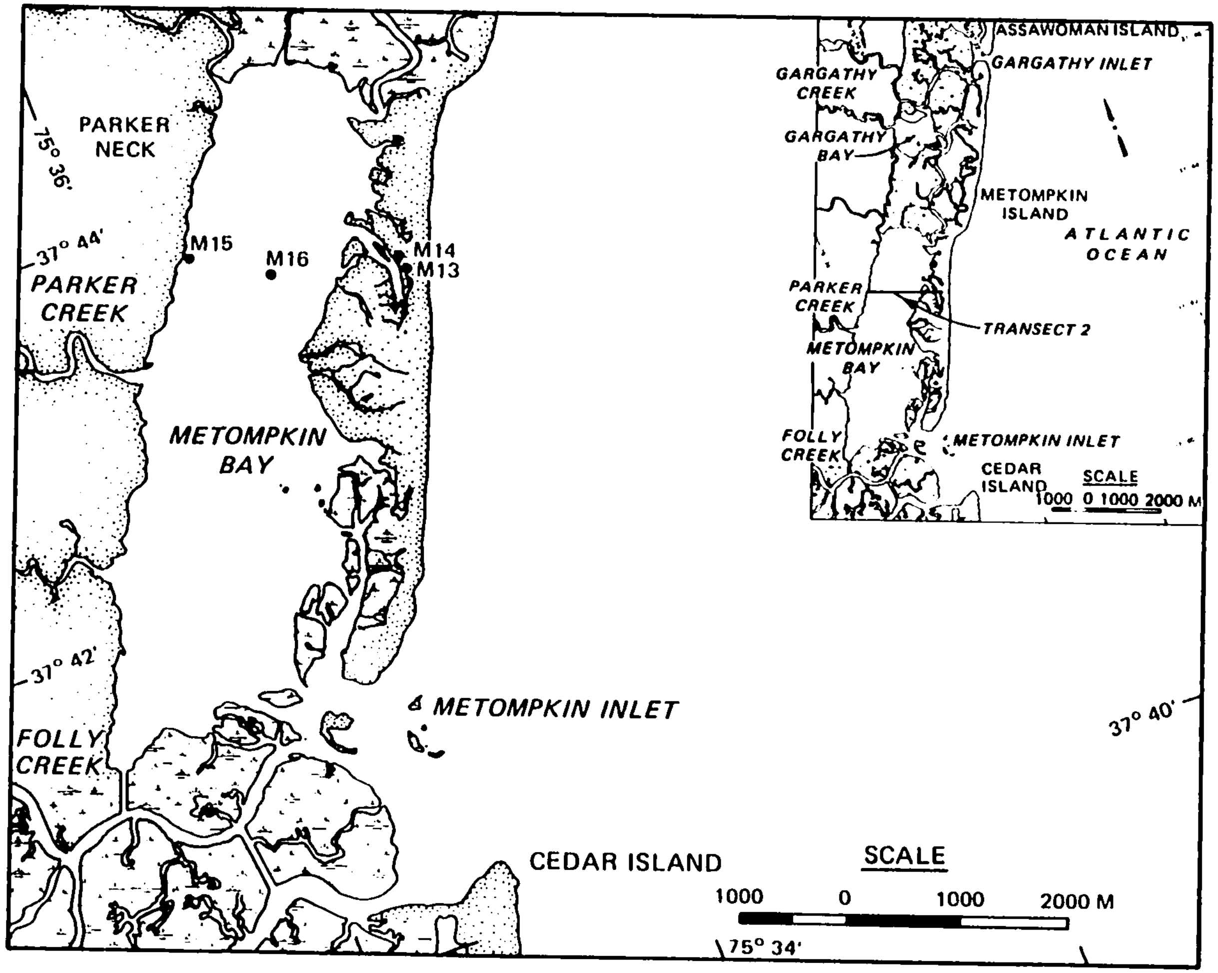

Figure 61. Map showing location of cores along transect 2.

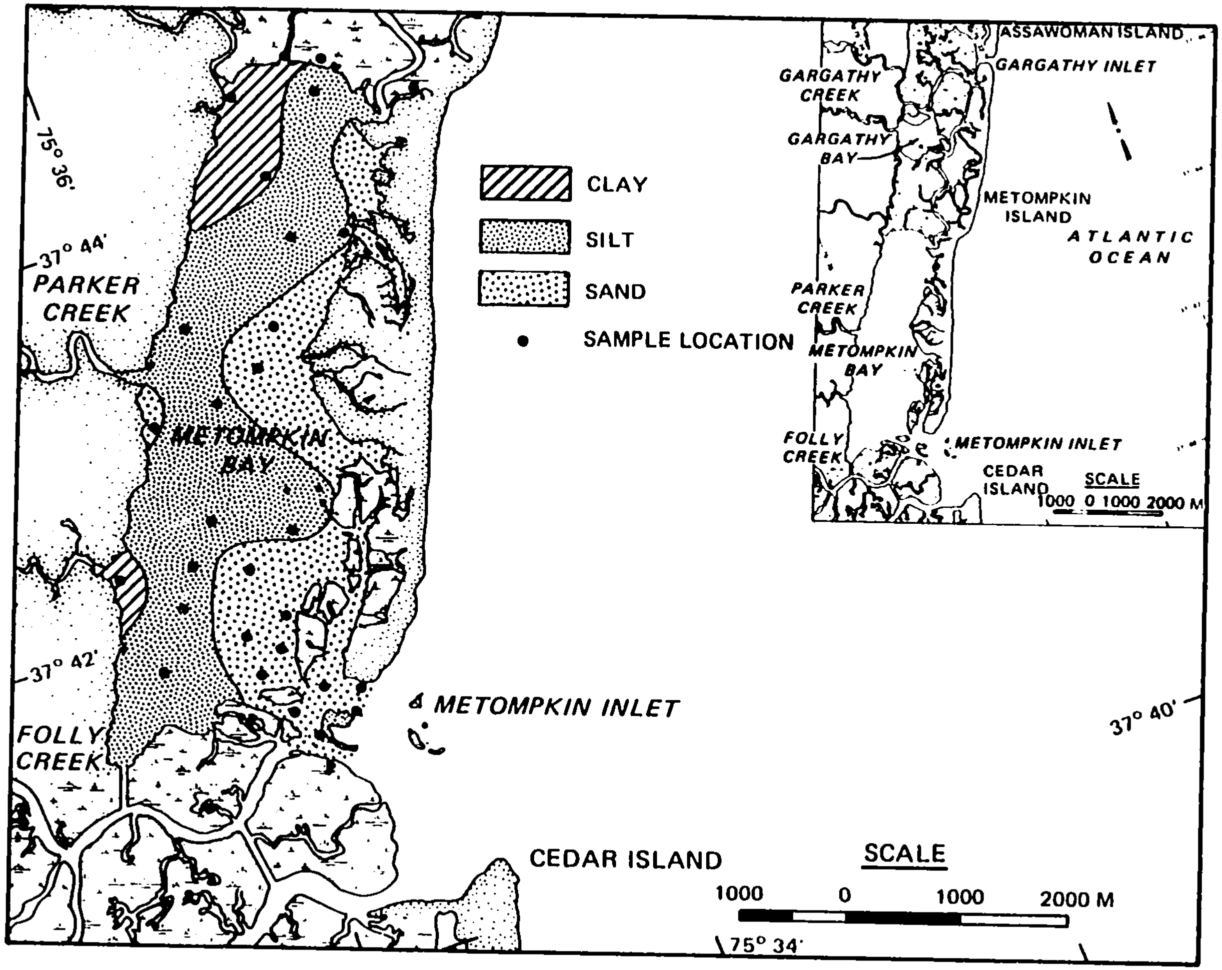

Figure 62. Map showing distribution of surface sediment in Metompkin Bay (from Harrison, 1971).

created a physically structureless unit.

The upper 1.58 m of core at M14 was a tan to pale brown, fine to medium, quartz sand facies with numerous *C. virginica*, *Mercenaria mercenaria* (quahog clam), and *Spissula solidissima* (surf clam) shell fragments. Very few horizontal to sub-horizontal laminations could be identified and bioturbation was not extensive. Unlike M13, the remainder of the sequence (1.44 m) was a dark grey, clayey silt facies with some organics towards the top of the unit. Very faint traces of near horizontal laminations were identified on radiographs in an otherwise completely bioturbated (amphipods) deposit. This core section was situated along the channel margin of the historic inlet feature.

Core M16 was obtained from mid-Metompkin Bay on a man-made oyster reef. This shell mound occupied the top 0.40 m of core. The following 2.10 m unit was characterized by alternating sand and mud lenses creating a grey to dark grey, silty sand to sandy silt facies. On average, pockets and lenses of very fine sand were encased in a typically mud matrix. Macrolocomotion bioturbation marks (swirling textural contrasts) were common in addition to numerous polychaete worm burrows. *C. virginica* and *L. irrorata* shell fragments were abundant. The basal Holocene unit (2.31 m thick) was a dark grey, completely bioturbated, clayey silt facies. Small shell and organic fragments were interspersed throughout this massive mud unit. A 0.15 m transitional muddy sand deposit was encountered at -4.66 m MSL. This may have represented an area of interfacial mixing at the pre-Holocene boundary in response to the Holocene marine transgression. Below this zone was a dark grey to white, coarse to very fine, pre-Holocene quartz sand facies. A relatively well-developed soil horizon could be recognized in the top 0.5 m of section. Mineralized polychaete burrows or rootlets(?) were present on radiographs along with very few physical structures. Very coarse, white, quartz sand and pebbles were found in the bottom 0.30 m of this unit.

Very little Holocene sediment was cored at M15, along the scarped mainland shoreline (Figure 61). The top 0.40 m was a dark grey, organic-rich, sand-silt-clay facies. *Spartina alterniflora* roots and stems dominated this completely bioturbated thin Holocene unit. Immediately beneath this zone was an area of intense physical reworking, representing the transition between Holocene and pre-Holocene deposits. The basal pre-Holocene section was characterized by a light grey to pale brown to yellow-brown, coarse to fine, quartz sand facies. Horizontal to sub-horizontal laminae, outlined by heavy minerals, were common at the base of the unit. No other sedimentary structures were visible.

Four distinct sedimentary facies were described for this mid-bay transect along Metompkin Island. They are: 1) a coarse to fine, quartz sand facies with abundant shell material (F); 2) a bioturbated silty sand to sandy silt facies (D); 3) a clayey silt facies (E); and 4) a pre-Holocene fine to coarse sand with gravel facies (H). In addition, a texturally well-mixed transition zone at the base of the Holocene sequence was encountered in half of the cores.

Whites Neck to Metompkin Island

Transect 3 crosses the southern half of the marsh-filled backbarrier region of northern Metompkin Island (Figure 63). This extensively vegetated area provided the longest core sequences in the entire study area. Although pre-Holocene deposits yielded a variety of facies

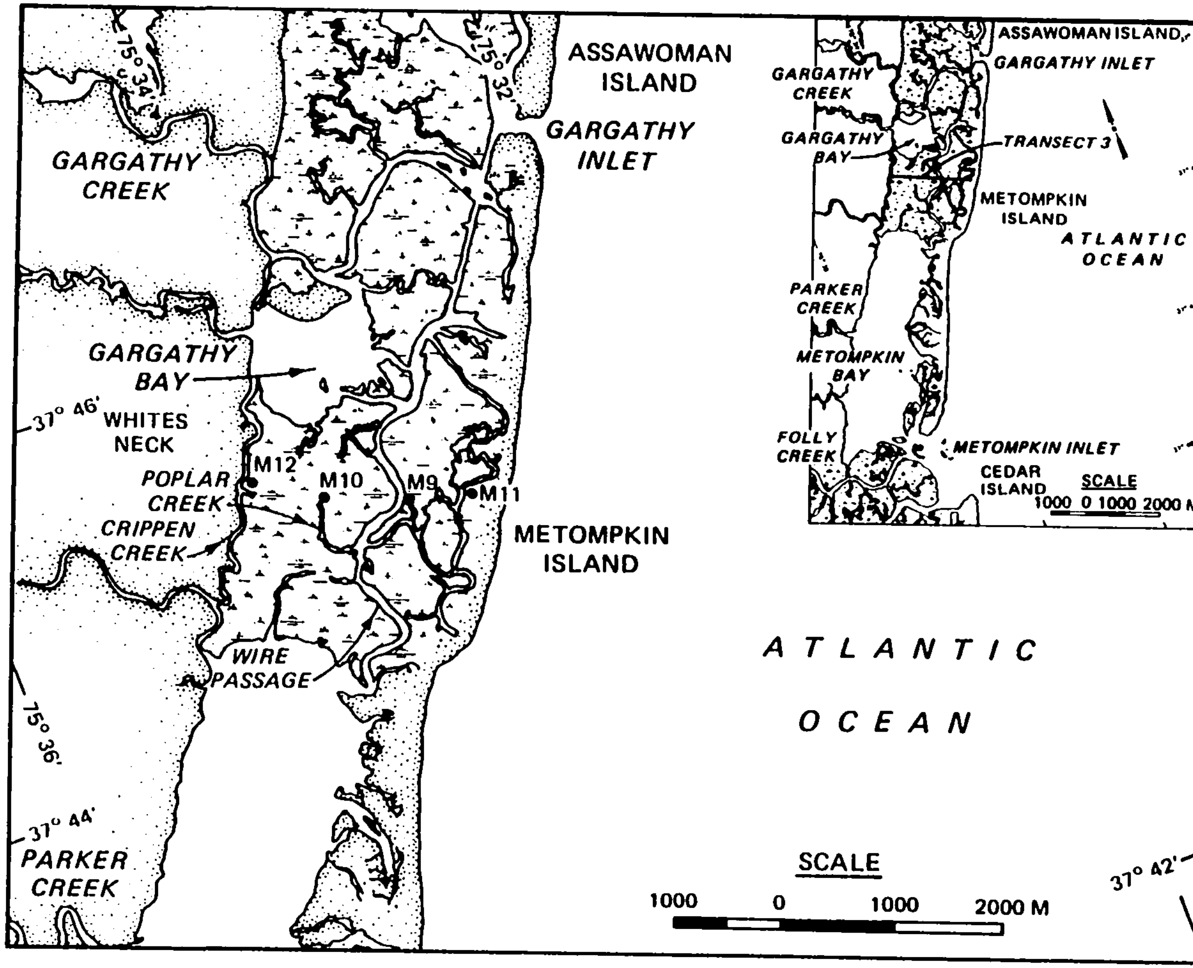

Figure 63. Map showing location of cores along transect 3.

characteristics, a clayey silt lithosome dominated most Holocene sequences to a maximum depth of -7.07 m MSL. This indicated a relatively well-protected, backbarrier region during island transgression.

Core M11 was collected from the backbarrier island-marsh fringe, approximately 2.1 km from the mainland shoreline. The top 0.61 m of core was dominated by an organic-rich (*Spartina patens* and *Spartina alterniflora* roots and stems), dark grey, clayey silt facies, completely bioturbated by marsh floral activity. Directly below was a 0.84 m, dark grey, clayey silt facies with a lower percentage of *Spartina* roots and some macro-locomotion bioturbation, created mainly by *L. irrorata*. Below the upper fine-grained deposits, at an abrupt change in lithology (-0.78 m MSL), was a predominantly fine sand to silty sand facies with sets of 0.02 to 0.04 m thick clayey silt and organic tabular beds throughout. This tan to grey unit had some ripple laminations and flaser bedding interspersed throughout a sequence dominated by horizontal to near-horizontal tabular beds. Towards the base of the unit was a 0.02 m pre-Holocene clay inclusion, indicating active reworking of existing clay deposits (Oomkens and Terwindt, 1960). Katuan and Ingram (1974) found similar deposits in cores collected from tidal channels in Pamlico Sound, NC. A *C. virginica* shell marked the bottom of this unit at -5.45 m MSL. The basal 1.62 m of sedimentary sequence was characterized by a grey to dark grey, clayey silt to silty clay facies. Radiographs illustrated horizontal micro-laminae disturbed by amphipod bioturbation.

Section M9 was taken on high marsh deposits just seaward of a large meander on Wire Passage (Figure 63). A 0.85 m thick, dark grey, organic rich clayey silt facies characterized the surficial unit. Extensive root bioturbation was apparent throughout this deposit. Between -0.13 m and -6.20 m, a grey to dark grey, clayey silt to silty clay Holocene sequence typified core lithology. Two zones of *Spartina* root and stem accumulations were present in this clayey silt facies. The presence of these Holocene organic layers is possibly the result of 1) fluctuations in local sedimentation patterns during backbarrier infilling, 2) short-term variations in the rate of relative sea-level rise, or 3) transport of eroded deposits from areas of active marsh growth. Organic decomposition in these zones increased with depth. The entire unit exhibited extensive microlocomotion bioturbation and few physical structures. A *C. virginica* shell marked the Holocene - pre-Holocene contact. A grey to light blue-grey and purple, highly dewatered, clayey silt facies identified this 0.80 m thick pre-Holocene deposit. The unit was completely bioturbated, creating a homogenous, massive appearance.

Core M10 was located on high marsh, approximately 20 m north of the end of Poplar Creek (Figure 63). The top 0.64 m of column contained a grey to dark grey, organic-rich, clayey silt facies. Extensive root bioturbation (*Spartina*) created a relatively homogenous unit. Directly underlying this zone was a 4.73 m thick, grey to dark grey, clayey silt facies. Physical sedimentary structures were detectable only on radiographs as faint horizontal to sub-horizontal laminations, disturbed by microlocomotion bioturbation. In addition, a few layers of decomposing *Spartina* stem and root fragments were found between -2.87 m and -3.17 m MSL. *L. irrorata* shells and *C. virginica* fragments were scattered throughout the unit. The basal contact of the Holocene section (-4.64 m MSL) was marked by a 0.19 m, grey to dark brown, organic-rich, muddy transition zone overlying a 0.59 m, dark brown to black peat layer. This marked the pre-Holocene subaerial surface encountered during Holocene sea level rise. Immediately beneath this was a black to blue-grey to yellowish-tan, medium sand to sandy silt (with pebbles) soil horizon (0.99 m) that contained plant rootlets. Below this was a 0.61 m thick, blue-grey to grey, silty clay facies with very finely laminated sand and mud, and some mineralized root traces or worm burrows(?). The basal portion of the pre-Holocene section (-7.04 to -7.48 m MSL) contained a grey to black, medium to coarse sand and silty sand facies. Organic layers were common and a second peat layer was encountered at the very bottom of the sequence.

Core M12 was collected on high marsh on the outside of a meander along Crippen Creek (Figure 63). The upper 0.62 m was a dark grey, organic-rich, clayey silt facies that was extensively bioturbated by *Spartina* roots. This graded into a homogeneous, grey to dark grey, clayey silt facies. Although polychaete burrows could be identified on radiographs, locomotion bioturbation structurally characterized the deposit. *Littorina* and *Crassostrea* shells and fragments, with some small sand pockets, were intermittent. A relatively thick basal peat (0.69 m), with some wood chips and sand layers (possibly transported), was overlain by a grey, poorly sorted, clayey sand transition zone (-3.18 to -3.77 m MSL) that contained *C. virginica* and *Ensis directus* (razor clam) shells. Below -4.46 m MSL was a 0.96 m thick, light grey to white, very coarse to fine, quartz sand facies. Alternating tabular layers of gravel and sand, with some horizontal laminae, were common. Finally, the pre-Holocene basal unit was characterized by a grey to dark grey, silty sand to clayey silt facies. Horizontal to sub-horizontal laminations, ripple foresets, and planar cross-bedding were present throughout the entire 0.43 m section.

Five lithofacies were recorded across the southern marsh-filled backbarrier region of northern Metompkin Island. They are: 1) an organic-rich clayey silt facies (B); 2) an interbedded clayey silt and fine sand facies (G); 3) a clayey silt to silty clay facies (E); 4) a highly dewatered, pre-Holocene clayey silt facies (I); and 5) a coarse to fine sand facies with gravels (H). In addition, peat layers were encountered in the two most landward cores. A thoroughly mixed transition zone was also found overlying the peats and a well-developed soil horizon at M10 indicated post-depositional weathering. The consistent trend in grain size throughout most of the section (mostly clayey silt) suggested a stable, quiescent system in this region.

<u>Southern Hog Neck to Gargathy Beach</u>

The northernmost transect traverses an extensively developed marsh complex between the drowned Gargathy Creek estuary and Metompkin Island (Figure 64). Like transect 3, the dominant lithosome was a clayey silt deposit that extended to depths greater than -8.44 m MSL. Local variations in sediment type, associated with modern channel features, were recorded. In addition, the pre-Holocene surface was encountered at the landwardmost two cores. Stratigraphic homogeniety provided evidence supporting a protected, low-energy backbarrier region for fine-grained sediment accumulation during the late-Holocene transgression. Being an area of historic inlet breaching, marsh deposits were not being exhumed on the upper shoreface. However, lagoonal muds were being actively modi-

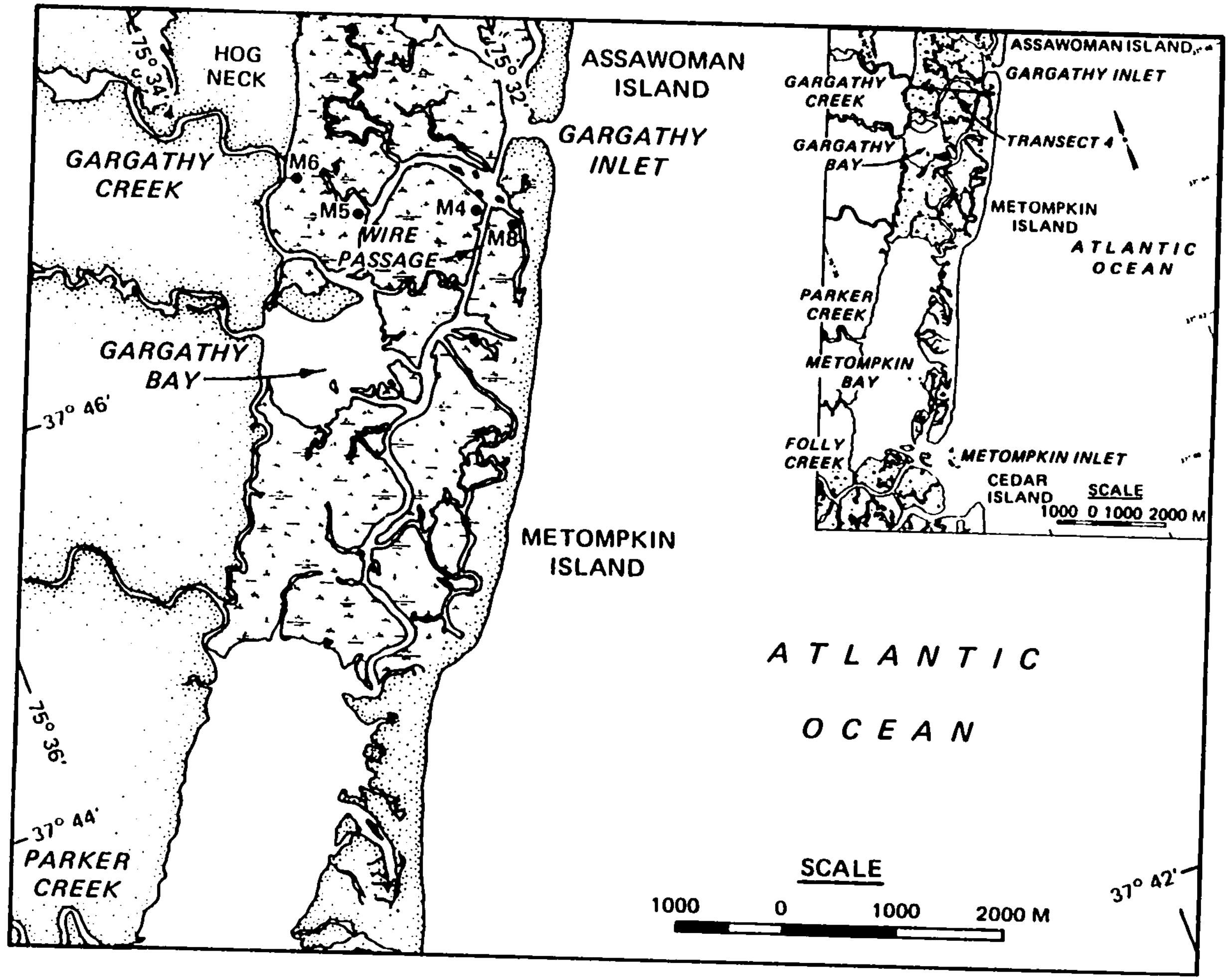

Figure 64. Map showing location of cores along transect 4.

fied by coastal processes just offshore (approximately 1.5 m below MLW).

The seawardmost core (M8) was located approximately 2.25 km from the mainland shoreline on low marsh at the beach-marsh fringe along the backside of northern Metompkin Island. The upper 0.88 m of core was an organic-rich, grey to dark grey, silty sand facies with a dense mat of roots (0.25 m thick) above interbedded mud and sand. Below this unit was a 7.85 m thick, dark grey, very poorly sorted, silty clay to clayey silt facies. Three prominent *C. virginica* shell layers were located between -1.0 and -2.0 m MSL while *L. irrorata* shells and oyster shell fragments were interspersed throughout the deposit. Physical structures were absent due to amphipod bioturbation and polychaete burrowing but some organic layers were noted. A zone of *Spartina* stems and roots was present at -2.41 to -3.46 m MSL and a few thin lenticular beds were noted on radiographs. Microlocomotion bioturbation structures were dominant throughout the unit. Overall, this massive sequence represented the thickest deposit of lagoonal mud throughout the entire system. Periwinkle shells were present and a few lenticular beds could be seen on radiographs.

Core M4 was taken on the marsh surface approximately 10 m landward of Wire Passage (Figure 64). The top 0.19 m was a dark grey, clayey silt facies dominated by *S. patens* and *S. alterniflora*. This organic-rich lithosome was underlain by a 7.12 m unit of grey to dark grey, silty sand to sandy silt. Horizontal to sub-horizontal laminae were present but for the most part, this deposit was characterized by extensive microlocomotion (amphipod) bioturbation with occasional larger swirling macrolocomotion features. A few oyster shells and *Spartina* stems were found around

-2.50 m MSL. Horizontal to sub-horizontal interbedded muds and sands were found at deeper positions in the sedimentary sequence where minor locomotion bioturbation and polychaete burrow structures were less prominent. In addition, organic-rich flaser and lenticular beds with occasional faint ripple foresets were noted below -2.55 m MSL. Overall, the sequence was quite variable and sedimentation was associated with channel infilling at Wire Passage.

Lithologic characteristics associated with M5 illustrated a typical, fine-grained transgressive Holocene sequence. Located 10 m landward of Gargathy Creek and north of Gargathy Bay, this modern sedimentary sequence was capped by a 2.0 m thick, organic-rich, grey to dark grey, sandy silt to silty clay facies. *Spartina patens* vegetation was predominant in the upper 0.54 m of section whereas structures created by *Spartina alterniflora* roots and stems were recognized on radiographs (Howard and Frey, 1985) for the bottom 1.46 m. Sediment mixing by floral growth processes produced a totally bioturbated unit. Below this was a grey to dark grey, clayey silt to silty clay facies. A few faint sub-horizontal laminae were obscured by amphipod and polychaete biogenic structures. A 0.18 m basal peat marked the bottom of the Holocene sequence (-2.80 to -2.98 m MSL). Immediately below this was a 0.58 m thick, black to grey, silty sand to clayey sand, subaerially weathered soil horizon. Radiographic examination of this zone illustrated mineralization associated with ancient polychaete burrows or plant rootlets. High density particles were also observed on radiographs in the bottom pre-Holocene unit; a 0.89 m thick, yellowish-brown, coarse to fine, quartz sand facies with no apparent physical sedimentary structures.

Core M6 was located on the seaward side of an ancient spit extending south along Hog Neck (Figure 64). A very thin Holocene section was deposited over an extremely variable pre-Holocene section. The top 0.22 m was a dark grey, silty clay facies with abundant *Spartina* roots and stems. This graded into a 0.99 m thick, dark grey, clayey silt facies. Microlocomotion bioturbation typified structure with a few small polychaete burrows. A *C. virginica* shell was encountered at the base of the unit followed by a 0.31 m, dark grey, clayey sand transition zone. A well-developed soil horizon was encountered at -0.96 m MSL and was characterized by brown to dark brown, very coarse to fine, quartz sand. Organic layers were present throughout this highly dewatered horizon and very faint horizontal to sub-horizontal laminations were evident on radiographs. A very coarse sand and pebble zone (-1.69 and -2.07 m MSL) rested on a 1.08 m thick, tan to pale brown, medium to fine, clean quartz sand facies. This lower unit contained horizontal to sub-horizontal laminae and small ripple foresets.

Four sedimentary facies were recognized across this northernmost transect. They are: 1) an organic-rich (*S. patens* and *S. alterniflora*), clayey silt facies (B); 2) clayey silt to silty clay facies (E); 3) a silty sand to sandy silt facies (D); and 4) a coarse to fine, clean quartz sand facies with gravels (H). One basal peat was identified and a pre-Holocene weathered soil horizon was encountered at the two landward core positions.

Table 17 provides a summary of sedimentary facies recognized throughout the Metompkin barrier island system. Basic sedimentologic characteristics are tabulated for each facies. In addition, core locations are identified where facies were encountered.

TABLE 17

Metompkin Island Sedimentary Facies

Name	Characteristics	Cores
A	subaerial medium to fine quartz sand	M1
B	organic-rich, clayey silt	M1, M2, M4, M5, M6, M8, M9, M10, M11, M12, M15
C	laminated fine to very fine sand	M1, M2, M3, M4, M7
D	sandy silt to silty sand	M1, M3, M13, M14, M16
E	clayey silt to silty clay	M3, M5, M6, M8, M9, M10, M11, M12, M13, M14
F	coarse to fine sand with abundant shell material	M13, M14
G	interbedded clayey silt and fine sand	M4, M11
H	fine to coarse sand with gravel (pre-Holocene)	M4, M5, M6, M7, M10, M12, M15, M16
I	highly dewatered clayey silt (pre-Holocene)	M5, M9, M10, M12

Pre-Holocene Surface Characteristics

Pre-Holocene topography has an important influence on the migration, development, and formation of modern barrier island deposits. Slope of the transgressed surface likely affects the rate of island retreat in response to coastal submergence. In addition, shore-normal ancestral valleys may become the positions of present-day inlet systems, thus defining the island's initial longshore extent. Island configuration may be continually modified during transgression as a function of wave and current dynamics and sediment supply but the geologic characteristics of submerging mainland shores may determine the response of the entire system.

The submerged mainland surface beneath the Metompkin barrier island complex varies considerably. It was cored eight times, at least once along each transect. The deepest it was encountered was -6.8 m MSL, 1.25 km from the mainland coast (M9). However, core M3 penetrated Holocene sediment to -8.25 m MSL at 1.24 km from the mainland shore with-out encountering pre-Holocene deposits, and core M8 exhibited Holocene mud deposits for the entire sequence to -8.44 m MSL at 2.25 km from the mainland. These variations suggested the presence of alongshore undulating topography. A three-dimensional plot of pre-Holocene surface shape along all four transects supports this observation (Figure 65).

Along transect 1, the pre-Holocene surface was found at just one location (M7). This made profile characteristics difficult to define, but M3 indicated that it had to be at least 8.25 m below MSL. Consequently, a steep, concave surface was envisioned. This type of overall configuration was assumed in light of evidence supporting the view that the mainland shoreline behind Metompkin Island represents an ancient

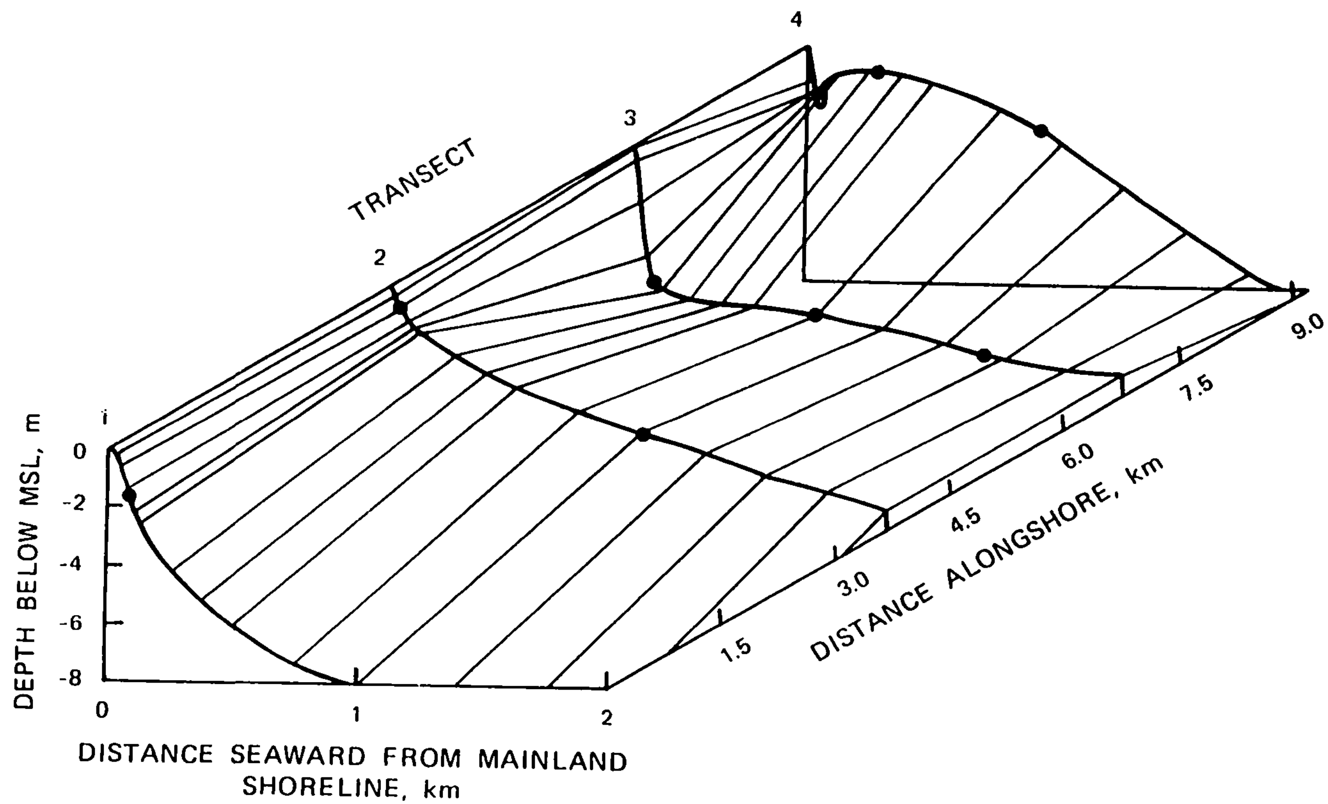

Figure 65. Three-dimensional plot of pre-Holocene surface behind Metompkin Island.

wave- and current-formed coastline (Halsey, 1978; Mixon, 1985; Demarest and Leatherman, 1985), similar in shape to recent shoreface profiles. Two cores along transect 2 penetrated pre-Holocene sediment. General curve shape was consistent with that assumed for the southern profile, however, concavity was much less pronounced and surface elevation was approximately 4 m higher 1 km from the mainland coast. The three landwardmost cores along transect 3 recovered pre-Holocene sediment, again suggesting a concave surface with a slope between M12 and M9 of 0.12°. This was not quite as steep and less elevated than along transect 2 but both were quite similar in configuration to the modern shoreface surface. On the other hand, transect 4 exhibited significantly shallower pre-Holocene deposits, possibly related to deposition associated with the ancient Hog Neck shoreline. This elevation anomaly is just the opposite of what was encountered at the southernmost transect, where the ancestral valley of Folly Creek(?) has provided for thick Holocene backbarrier sequences.

A plot of depth to the pre-Holocene surface versus distance seaward from the mainland shoreline illustrates this trend (Figure 66). The two line segments were determined using linear regression. Samples near the scarped, subaerial and subaqueous mainland coastal segment had an average slope of 2.50°, a typical foreshore beach slope. A gently seaward-dipping horizon, situated beneath the modern barrier complex and approximately 200 m down-dip of the mainland coast, showed a two order of magnitude decrease in average slope to 0.08°. Excessively irregular topography was not found along transects 1-3, providing a potentially smooth surface for uninterrupted island recession. However, pre-Holocene

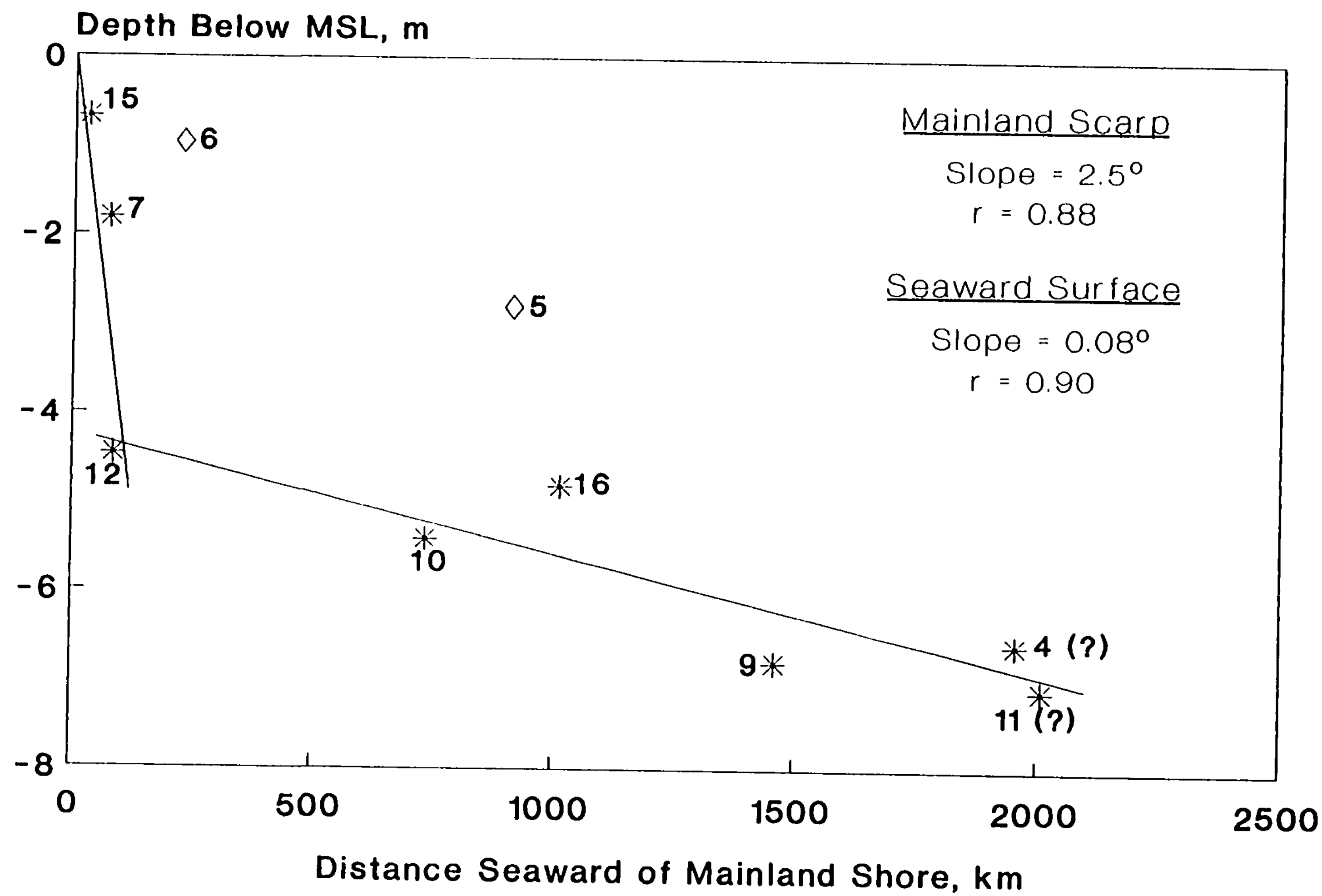

Figure 66. Plot of depth to pre-Holocene surface versus distance seaward from mainland shoreline. Cores 5 and 6 penetrated the elevated pre-Holocene surface a transect 4 and were not used in regression analysis.

deposits occur at relatively shallow depths along transect 4 (cores 5 and 6) and provided an elevated surface for fine-grained deposition and subsequent marsh growth. Furthermore, a general increase in depth to the pre-Holocene surface in a southward direction may in part be responsible for the presence of a well-developed backbarrier marsh complex to the north versus an open-water bay behind southern Metompkin Island.

Analysis of Sediment

Most analyses of grain size data have utilized elementary statistical measures in summarizing basic characteristics of the sample distribution. In an effort to describe similarities among groups of samples, bivariate plots of selected statistical parameters have been used (Friedman, 1967). However, these summary statistics have provided limited success in associating specific samples with known sedimentary environments. Straight line log-normal subpopulations on a probability cumulative frequency curve have also been utilized and associated with specific sediment transport mechanisms (Visher, 1969). Consequently, samples with similar graphical trends could be related with specific sedimentary environments. However, LeRoy (1981) demonstrated that these line segments could be understood as purely mathematical artifacts.

Many researchers have become dissatisfied with the subjectivity of traditional methods and have sought new techniques of sample classification which incorporate the massive data handling capabilities of computers. In the present study, 149 sediment samples were used to initially classify sedimentary deposits in the Metompkin barrier island system. Hierarchical cluster analysis was employed to group samples based on similarities among 30 individual weight classes used to describe the distribution. A basic review of cluster analysis techniques and practical applications is given in Romesburg (1984). Specific geological examples utilizing hierarchical cluster analysis include Bonham-Carter (1965), Park (1974), Ali et al. (1976), Khaiwka et al. (1981), and Doyle and Feldhausen (1981). Results of this procedure are usually graphically displayed by means of a dendogram.

The purpose of classification is to describe the structure and relationships of the constituent objects to each other and to similar objects, and to simplify these relationships in such a way that general statements can be made about classes of objects (Sokal, 1974). Data comparisons, calculated as distance similarity coefficients, were clustered by the unweighted pair-group method using a computer program developed by Bonham-Carter (1967). Variable normalization procedures were not utilized due to object homogeneity (all percent values). However, R-mode cluster analysis was used to eliminate redundancy among variables (Park, 1974). Redundancy is a problem with grain size data and generally undesirable because it represents a selective weighting for a particular variable in proportion to the number of variables involved. Principal components analysis has been suggested to remove redundancy (Parks, 1969; McCammon, 1975), but strong redundancies usually result from duplication of a particular environmental response and can be removed easily by combining or deleting variables (Ali et al., 1976; Doyle and Feldhausen, 1981).

After testing the original 149 by 30 data matrix, three sets of sample variables were found to be correlated at 88% or greater similarity coefficients (Figure 67). Park (1974) and Ali et al. (1976) have utilized the same general boundary criterion for eliminating highly redundant data. Consequently, three variables (size classes) were removed from the entire data set producing a 149 by 27 matrix. Although redundancies at lower levels of correlation cannot be resolved as easily, it is also difficult to interpret the meaning of individual principal components. Not only did this procedure reduce biases due to high correlation among variables, it also eliminated any problems that may have occurred due to the effects of closure (constant sum problem with percentage formation) (Butler, 1979).

Percentage values for the 1.50 and 1.75 ϕ size classes were correlated at an 88.24% level of association while 5.5 and 6.0 ϕ classes were correlated at 88.40%. Size classes 9.0 and 10.0 ϕ exhibited the highest level of correlation at 91.40%. This analysis provides an indication of the effectiveness of variable selection, illustrating only limited redundancy at high levels of correlation between a large number of specific variables (sieve intervals). Therefore, the scheme adopted for characterizing sediment samples appeared effective for delineating sample attributes.

Sample Classification

Q-mode cluster analysis was used to partition samples into environmentally significant classes. As a first step procedure, cluster analysis was used to organize data into groups with similar attributes. In many cases, clusters may be clearly represented at rather high levels of association while others are rather equivocal. Consequently, as more qualitative sample attributes are considered, cluster boundaries may be subject to redefinition during the interpretive phase of analysis.

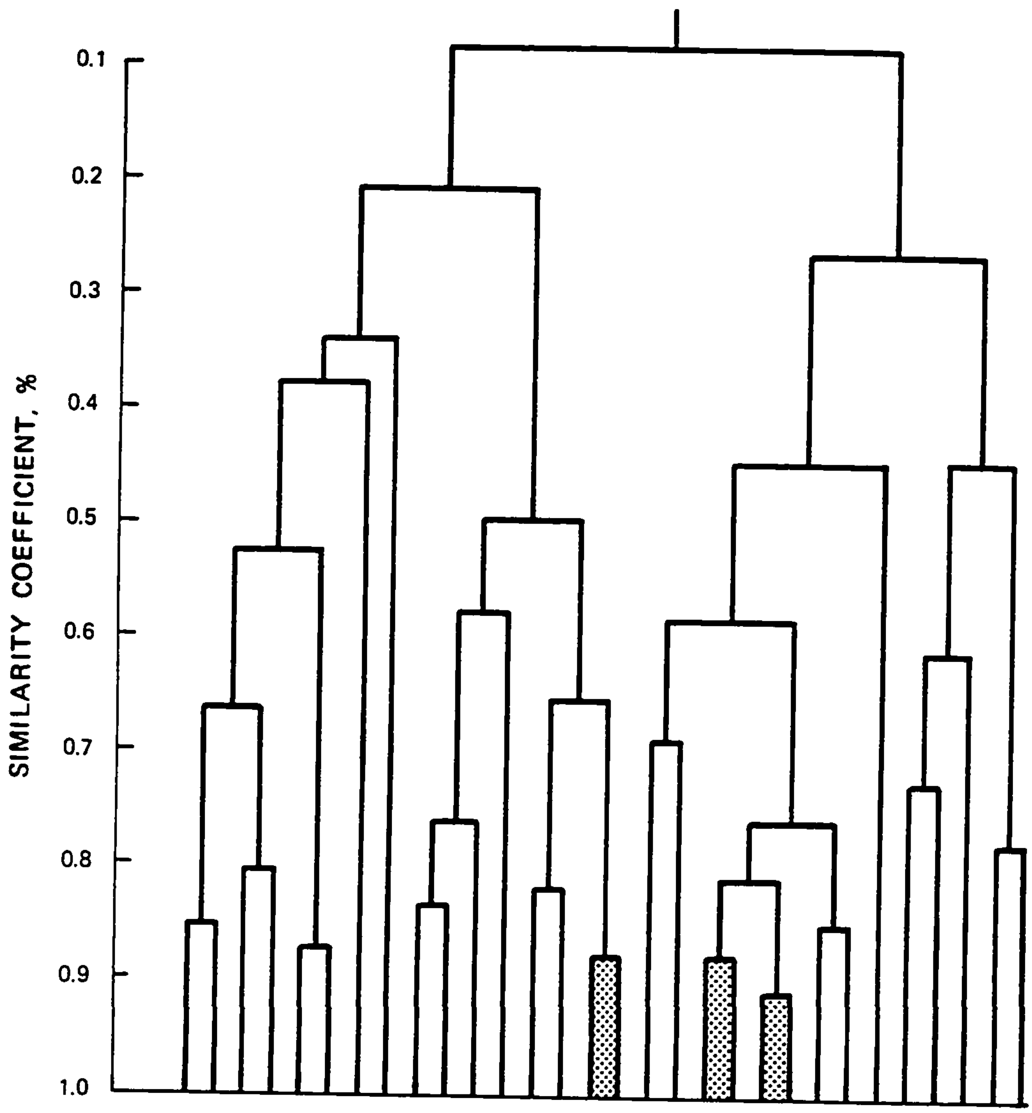

Figure 67. R-mode cluster dendogram of grain size data.

The Bray-Curtis similarity coefficient (equivalent to Sorensen's coefficient), given by

$$C_{jk} = \frac{2\left[\sum_{i=1}^{n} \text{Min}\,(X_{ij}, X_{ik})\right]}{\sum_{i=1}^{n} X_{ij} + \sum_{i=1}^{n} X_{ik}} \qquad (4)$$

was used to analyze the 149 by 27 grain size data matrix. In equation 4, X is evaluated for the i^{th} variable in the j^{th} and k^{th} samples, respectively.

<u>Cluster Facies Characteristics</u>. Seven clusters were identified for the entire data set. Two large cluster groups were recognized at a 12.36% level of association. Figure 68 represents a muddy sand to sandy mud group. Three distinct clusters are present at similarities ranging from 48.18 to 76.90%. Highest values of similarity coincide with smallest mean grain size. Figure 69 contains four distinct clusters for muddy sand to gravelly sand material. Levels of association range from 57.84 to 70.72%. Although groupings at higher and lower associations were possible, it was felt that the present range of intercluster similarities represented the best partitioning of the entire data set. Table 18 provides a summary of average grain size characteristics for the seven cluster sedimentary facies. The following discussion addresses the specific characteristics of each cluster facies. Cluster data summary statistics are provided in Appendix D.

Cluster Facies 1. This silty sand facies contained 19 samples associated at a 48.18% similarity level. Mean grain size ranged from 3.09 to 5.67 ϕ, producing a coarse silt arithmetic mean of 4.21 ± 0.87 ϕ (Table 18). This poorly sorted, strongly fine-skewed cluster facies

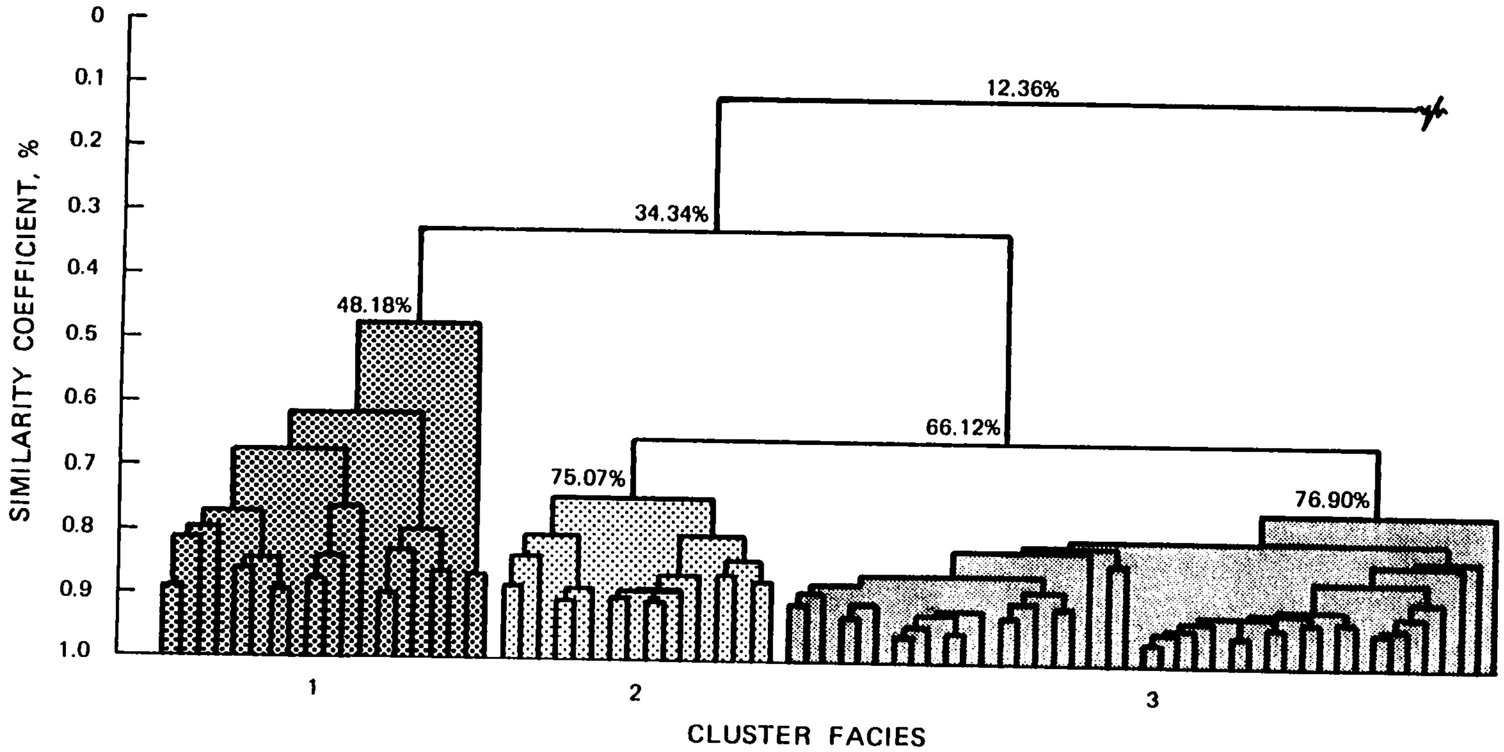

Figure 68. Q-mode cluster dendogram of three cluster facies in the muddy sand to sandy mud group.

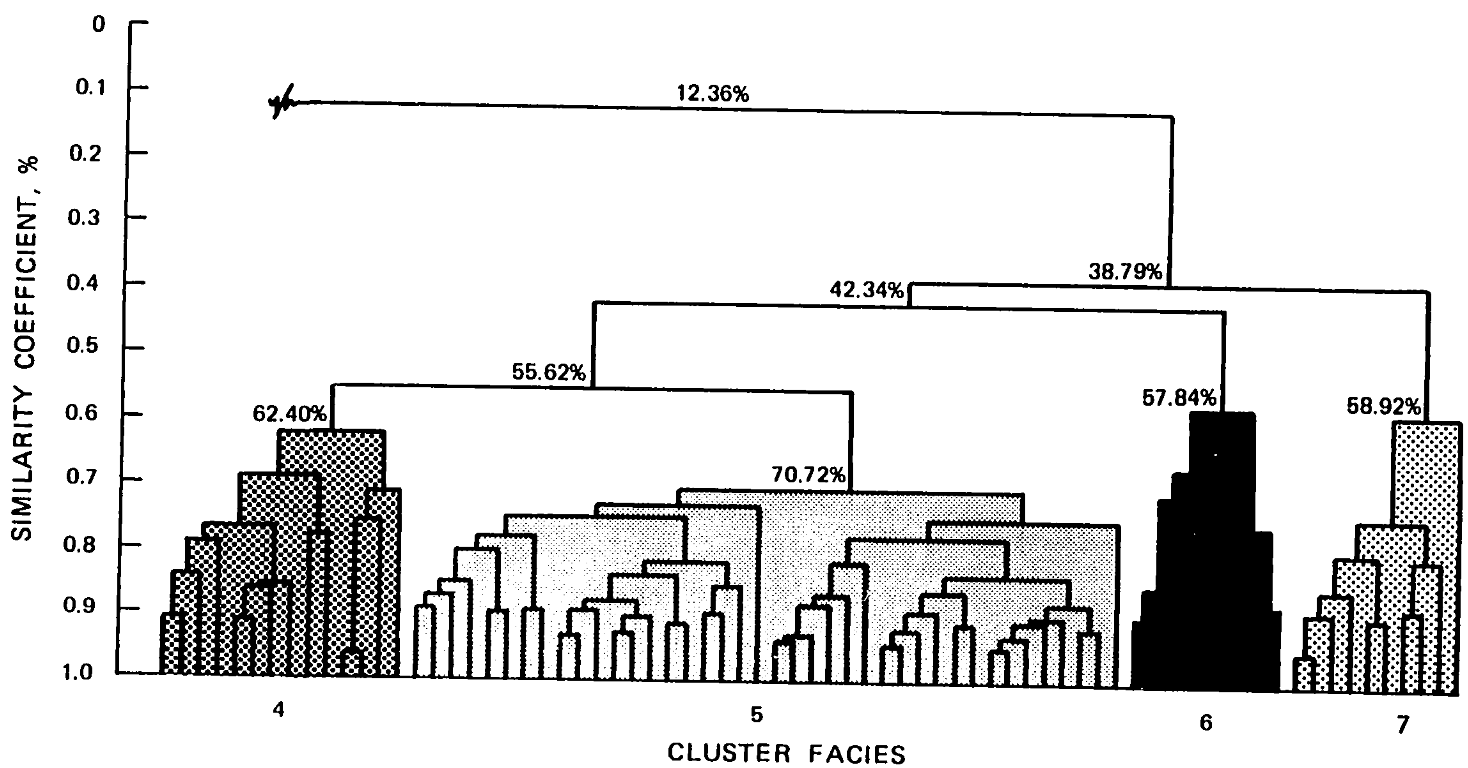

Figure 69. Q-mode cluster dendogram of four cluster facies in the muddy sand to gravelly sand group.

TABLE 18

CLUSTER SEDIMENTARY FACIES CHARACTERISTICS

Cluster	1	2	3	4	5	6	7
Facies Name	Silty Sand	Clayey Silt	Clayey Silt	Fine Muddy Sand	Medium to Fine Sand	Gravelly Coarse Sand	Fine Sand
Number of Samples	19	16	41	14	40	9	10
Mean Grain Size (phi)							
Arithmetic Mean	4.21	6.61	7.90	2.98	1.98	0.57	2.61
Standard Error	0.87	0.31	0.45	1.36	0.40	0.46	0.18
Sorting (phi)							
Arithmetic Mean	1.71	2.92	2.54	2.57	0.85	1.25	0.57
Standard Error	0.77	0.17	0.26	1.01	0.60	0.47	0.30
Skewness							
Arithmetic Mean	0.59	0.42	0.15	0.46	0.04	-0.02	0.16
Standard Error	0.15	0.20	0.15	0.26	0.27	0.19	0.23
% Gravel							
Arithmetic Mean	0.01	----	0.03	0.84	0.71	14.07	0.00
Standard Error	0.04	----	0.12	1.27	2.10	13.55	0.00
% Sand							
Arithmetic Mean	64.60	19.08	3.17	74.76	95.37	83.67	96.04
Standard Error	20.08	7.18	3.97	15.25	5.71	14.11	3.22
% Silt							
Arithmetic Mean	25.25	50.65	51.27	12.97	1.64	0.47	1.39
Standard Error	15.69	7.79	6.12	9.02	3.02	0.30	1.95
% Clay							
Arithmetic Mean	10.14	30.27	45.63	11.43	2.28	1.79	2.57
Standard Error	5.90	5.05	6.29	7.15	2.71	0.98	1.50

included a mixture of transitional samples between mud and sand facies. The average primary mode for the 19 object cluster was between 3.25 and 3.50 ϕ (Figure 70) while the median was 3.51 ϕ. A little more than one quarter (26.64%) of the average sample distribution was finer than 4 ϕ and 10.14% represented clay-sized particles.

Thirteen of the nineteen (68%) cluster samples were from five different cores taken along the southern half of the Metompkin barrier system. This was expected since textural mixing has a much greater chance of occurring in this shallow water, bay-backed portion of the island. Numerous storm-related, ephemeral inlet breaches have provided large quantities of sand to Metompkin Bay (Figure 71). Frequent overwash events supplemented these additions. Furthermore, 69% of these samples could be directly linked to depositional processes associated with Metompkin Inlet. Samples collected from three cores along northern Metompkin Island were also related to channel deposition. Consequently, this cluster appears to encompass textural mixing characteristics associated with tidal channel and inlet hydraulics.

Cluster Facies 2. This sixteen object, clayey silt facies (near sand-silt-clay) was highly associated at 75.07% (Figure 68). Sediment was generally very poorly sorted and strongly fine-skewed with an arithmetic mean of 6.61 ± 0.31 ϕ (Table 18). Mean grain size ranged from 5.98 to 7.08 ϕ but the average primary mode was well defined between 4.0 and 4.50 ϕ (Figure 72). The average median was 5.59 ϕ and 30.27% of all particles were clay-sized.

Representative samples were fairly evenly distributed over the entire study area at depths ranging from 0.50 to -6.13 m MSL. Fifty

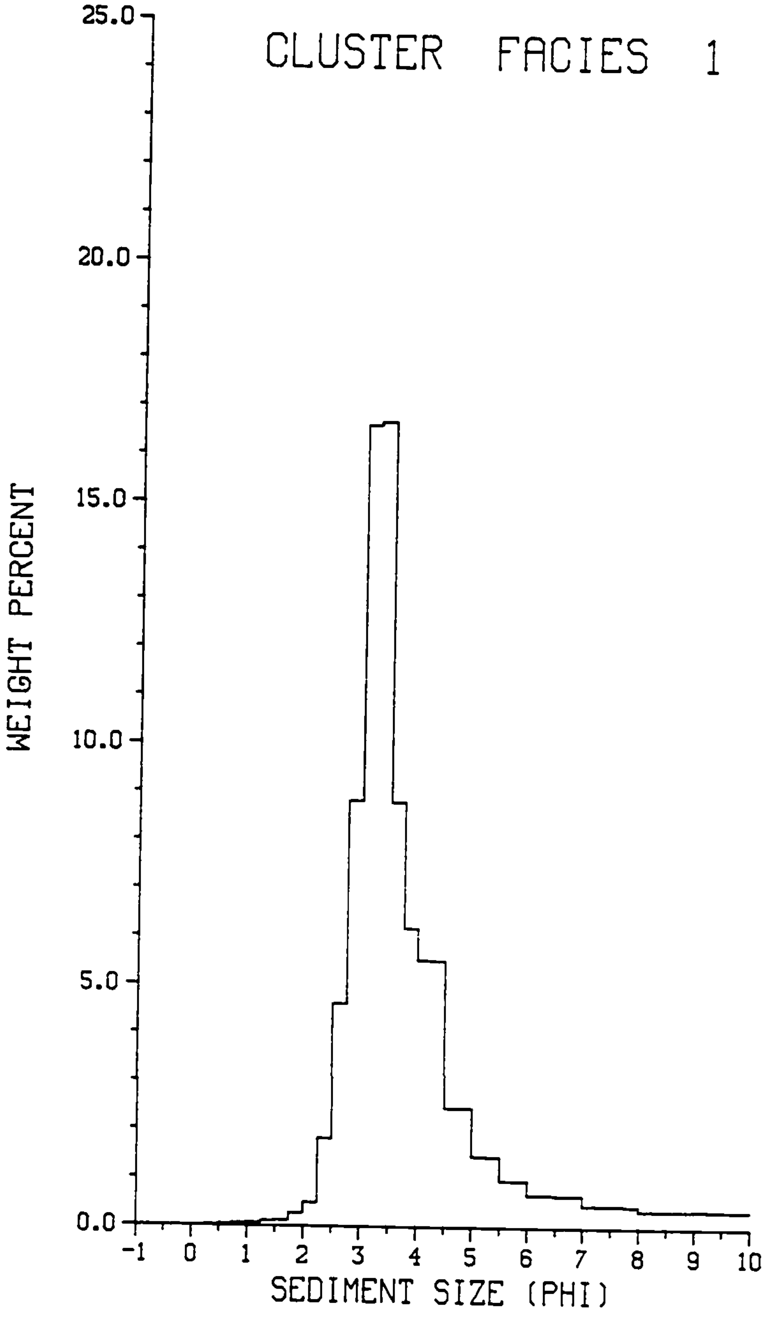

Figure 70. Histogram of average grain size distribution for cluster facies 1.

Figure 71. Aerial photograph of storm-related, ephemeral inlet breaches along southern Metompkin Island after Hurricane Gloria.

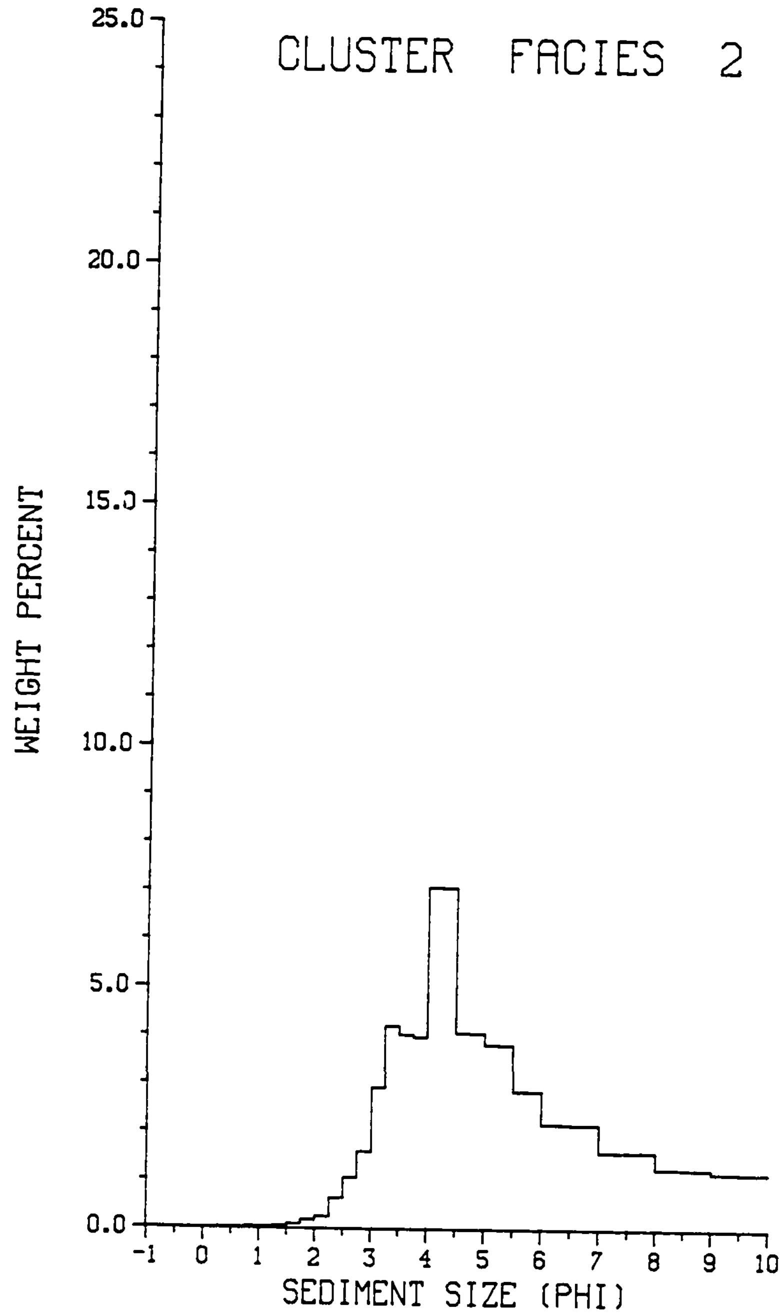

Figure 72. Histogram of average grain size distribution for cluster facies 2.

percent of all samples were collected from five different core locations along northern Metompkin Island, whereas four cores from the southern region contained the remaining samples. This cluster facies represented a transitional group between silty sands (Cluster 1) and clayey silts (Cluster 3). However, the statistical distinction was not recognized when physically logging the cores. Therefore, this method potentially provides a means of fine-tuning significant changes in sedimentologic characteristics, reflecting variations in hydrodynamic conditions.

Cluster Facies 3. A clayey silt cluster facies was the most clearly defined group of objects, with a 76.90% level of association. Although most samples were again very poorly sorted, mean grain size was slightly finer than that for facies 2, producing an arithmetic mean of 7.90 ± 0.43 ϕ (very fine silt). Samples were generally fine-skewed to near-symmetrical, producing an average fine-skewed cluster facies for the 41 object group (Table 18). The average primary mode was between 5.5 and 6.0 ϕ although a broader peak between 5.0 and 7.0 ϕ existed (Figure 73). The average median grain size was 7.59 ϕ and 45.63% of particles were clay-sized.

The geographic distribution of samples within this cluster is highly weighted towards the northern half of the system. All eight core locations along northern Metompkin Island were represented by at least one sediment sample. In fact, 75.7% of all samples were obtained from varying vertical positions at these eight locations. Sixty two percent of all Holocene samples collected from this area were grouped in cluster facies 3. This fine-grained population typified the dominant sediment texture pattern in the northern, marsh-filled, backbarrier region. The

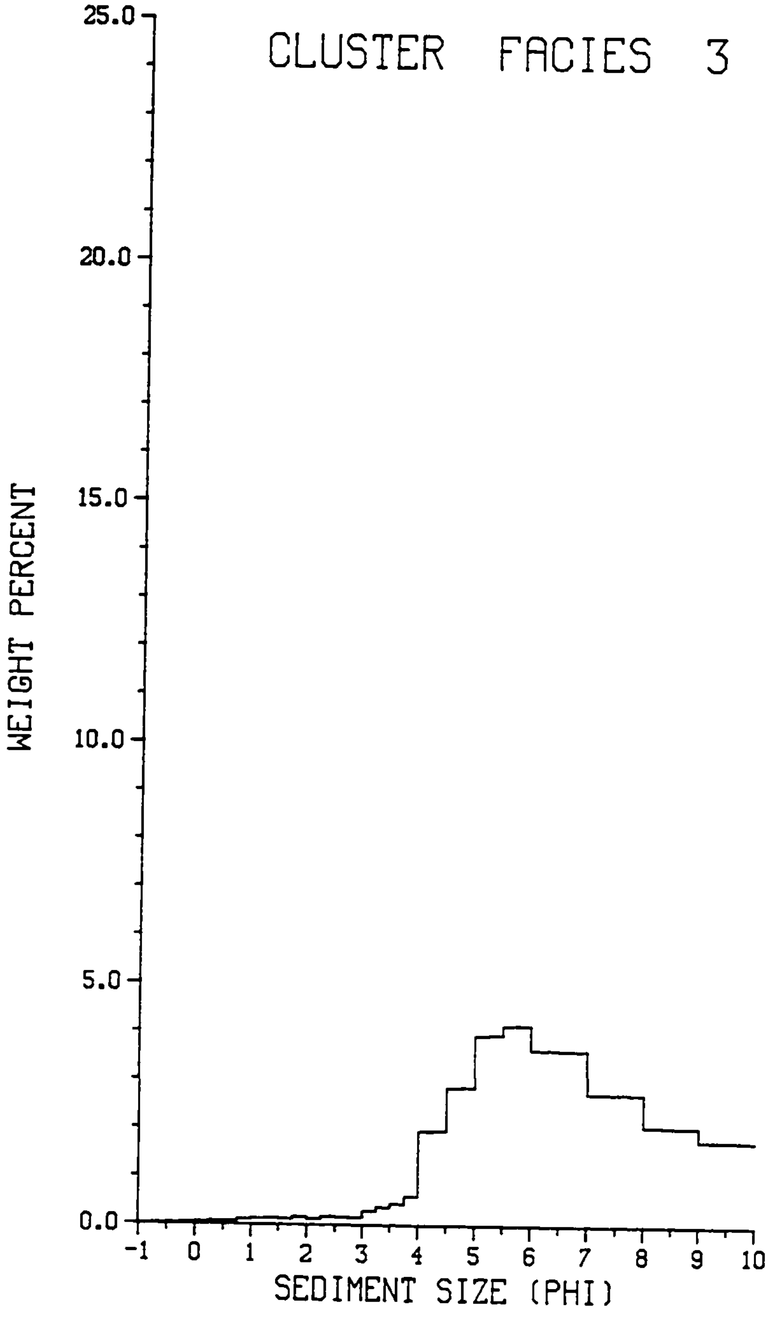

Figure 73. Histogram of average grain size distribution for cluster facies 3.

magnitude of fine-grain deposition suggested that hydrodynamic conditions consistent with backbarrier infilling were prevalent during the Holocene transgression.

Cluster Facies 4. Thirteen pre-Holocene samples and one Holocene sample characterized this fine to very fine muddy sand cluster facies. Objects were associated at a 62.4% level (Figure 69). Sediment was very poorly sorted and strongly fine-skewed as evidenced by the composite cluster histogram (Figure 74). Mean grain size varied considerably from 1.42 to 5.20 ϕ, producing an arithmetic group mean of 2.98 ± 1.36 ϕ. A fairly well-defined average primary mode existed between 1.0 and 2.0 ϕ with a dominant peak at 1.25 to 1.50 ϕ. In addition, a poorly defined secondary peak was evident between 5.5 and 7.0 ϕ. This was the only evidence of bimodality among any of the cluster facies. The average cluster median was 1.83 ϕ and 24.4% of all particles were silt and clay (Table 18).

Since most cores that penetrated the pre-Holocene surface were located behind northern Metompkin Island, it was not surprising to find that all but two samples in the group were from this area. The one Holocene sample (M15-1) was located on the mainland fringe along transect 2 and may actually be more sedimentologically representative of the sandy, pre-Holocene mainland deposit due to sediment mixing at the boundary. It was labelled Holocene because it was associated with an active marsh deposit, although considerable influence from mainland sand sources was apparent; more than half of the sample (56.95%) was sand. This was the only marsh sample that classified with the sand groupings. It appeared as though there was some pre- and/or post-depositional

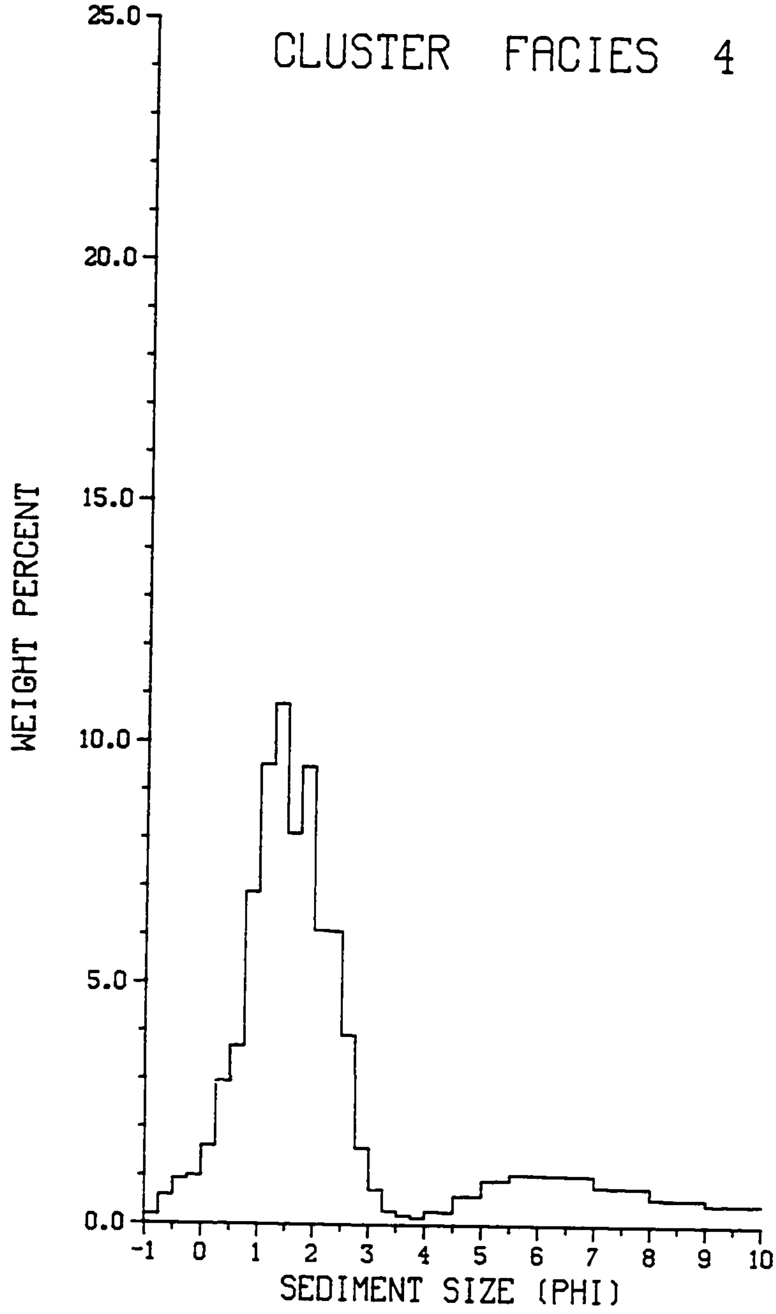

Figure 74. Histogram of average grain size distribution for cluster facies 4.

environmental control that segregated this group of pre-Holocene samples, thus providing a potential mechanism for identifying the time-stratigraphic signature of unknown samples of similar texture.

Cluster Facies 5. This 40 object cluster facies represented a combination of pre-Holocene and Holocene medium to fine sand samples grouped at a 70.72% level of association (Figure 69). Samples ranged from well-sorted to very poorly sorted, creating a moderately sorted group average. Mean grain size was 1.98 ± 0.40 ϕ and samples ranged from strongly fine-skewed to strongly coarse-skewed, producing a near-symmetrical average classification (Table 18). A well-defined primary mode existed between 1.75 and 2.0 ϕ (Figure 75). The average median was 1.95 ϕ and only 3.92% of all particles were finer than sand.

Greater than 80% of the composite cluster distribution was influenced by samples from transects along southern Metompkin Island. Six of the eight southern core locations were represented. At core M7, all eight sediment samples characterizing the stratigraphic section were included in this cluster facies. Forty five percent of all samples were from pre-Holocene sand deposits while 25% were surficial beach samples. Unlike cluster facies 4, time-stratigraphic sedimentologic distinctions could not be identified, suggesting similar environments of deposition.

Cluster Facies 6. This nine object, gravelly coarse sand cluster facies contained pre-Holocene samples associated at 57.84% (Figure 69). Mean grain size ranged from coarse to very coarse sand, producing an arithmetic group mean of 0.57 ± 0.46 ϕ. Samples were moderately to poorly sorted and strongly fine- to coarse-skewed. The average primary mode was broadly defined at 0.25 to 1.5 ϕ, peaking at 9.13% between 0.75

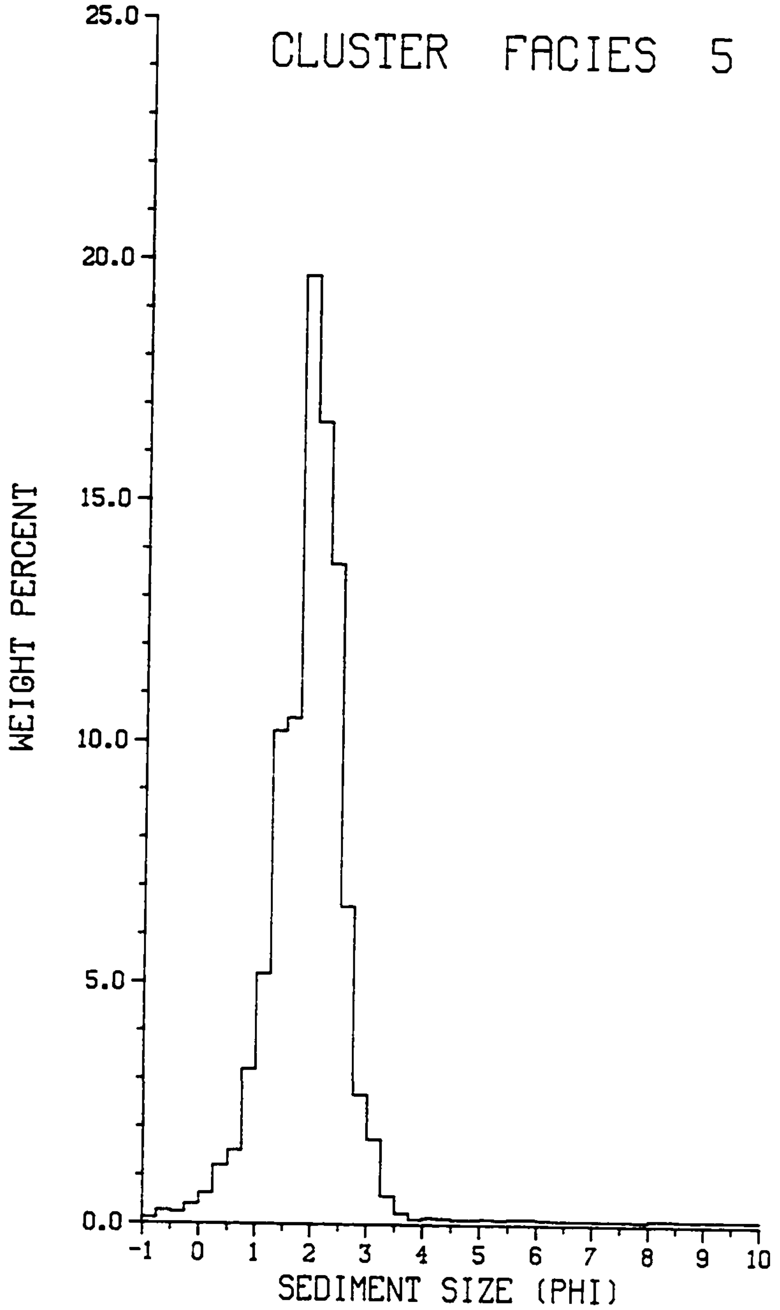

Figure 75. Histogram of average grain size distribution for cluster facies 5.

and 1.0 ϕ (Figure 76). The average median was 0.75 ϕ and 14.07% of all particles were coarser than sand. The greatest percentage of sediment coarser than sand was found in sample M6-9 (38.11%) where pebbles greater than 0.01 m in diameter were common.

Similar to cluster facies 4, all but two samples were from cores behind northern Metompkin Island. In addition, all samples were associated with pre-Holocene marine or fluvial(?) deposits as described during core logging. Very clean, light tan to white, orthoquartzitic, coarse sand deposits characterized this very distinct cluster facies. Although cluster analysis was probably not required in assembling this set of samples, it was necessary in delineating cluster facies 4. Consequently, the cluster analysis utility was useful in segregating these unique sets of samples from the remaining sand group.

Cluster Facies 7. Samples from this 10 object, fine sand cluster were grouped at a 58.92% level of similarity (Figure 69). Sediment was moderately well sorted and fine-skewed with an arithmetic group mean of 2.61 ± 0.18 ϕ (Table 18). The average primary mode was well-defined between 2.25 and 2.75 ϕ (Figure 77) while the average cluster median was 2.57 ϕ. Less than four percent of all particles were finer than sand and gravel was not present.

Sixty percent of the samples were located at four different geographic positions along southern Metompkin Island. All samples were extracted from Holocene deposits. In all cores, these clean, fine-grained sands could be related to historical or modern inlet or tidal channel deposition. Deposition associated with tidal flows spreading across backbarrier flats and into adjacent channels was thought to be the

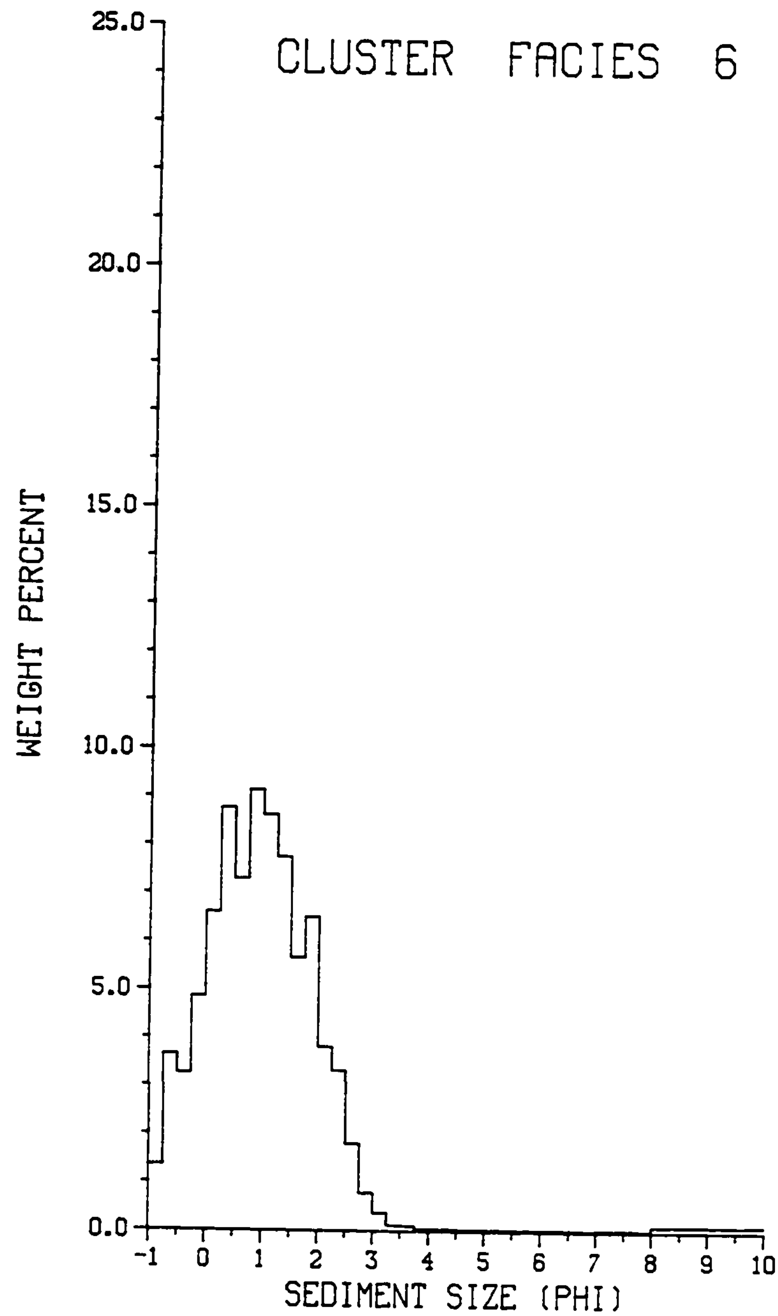

Figure 76. Histogram of average grain size distribution for cluster facies 6.

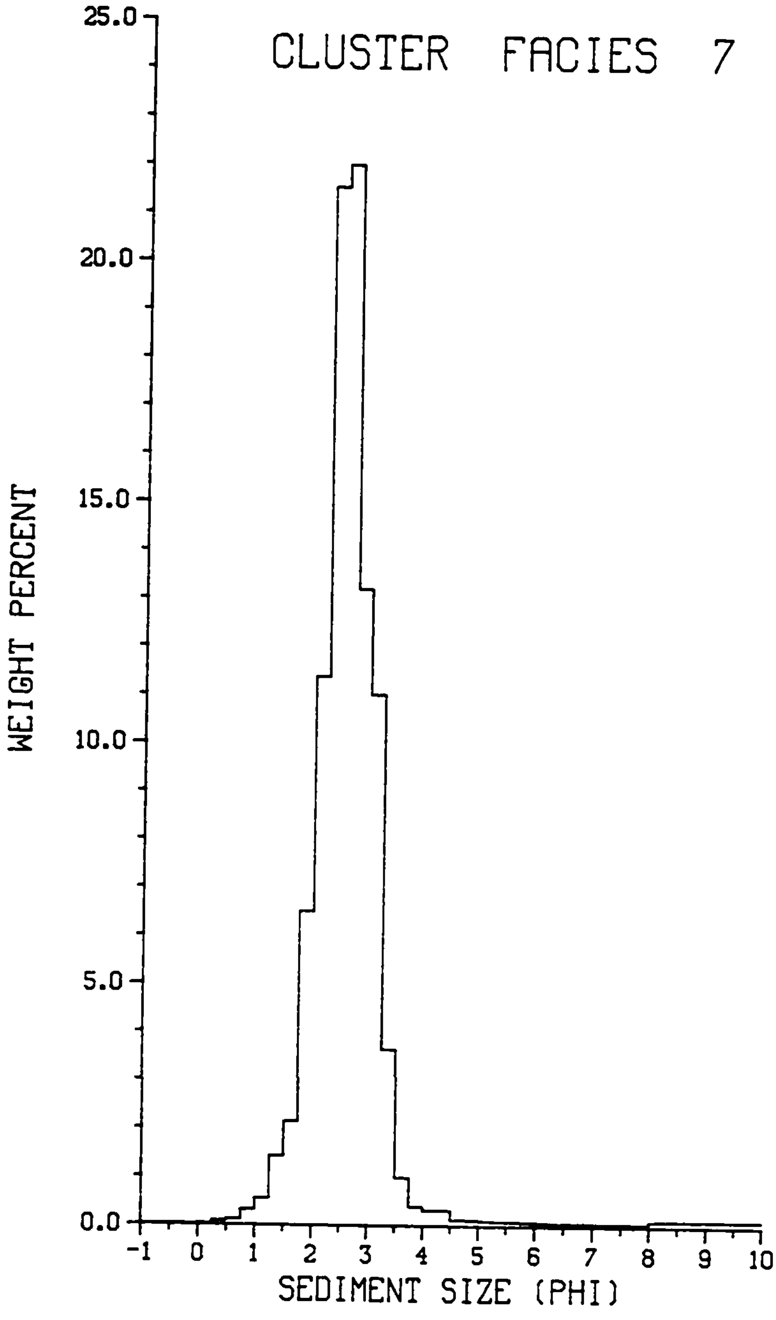

Figure 77. Histogram of average grain size distribution for cluster facies 7.

most likely source of sediment. Although a few samples from cluster 1 were initially regarded as being similar to those in cluster 7, it is apparent that many sedimentologic differences exist, suggesting potentially different hydrodynamic interpretations for the two clusters.

Foraminiferal Distribution and Abundance

Benthic foraminifera are useful indicators of modern coastal sedimentary environments and their fossils offer a potential means for interpreting ancient depositional environments. The surface distribution of living foraminifera in recent sedimentary deposits is a function of varying ecologic factors such as temperature, salinity, and substrate type (Phleger, 1954; Murray, 1973). In addition, preservation of death assemblages from marginal marine environments is controlled by post-depositional energy fluctuations and biogeochemical factors (Murray, 1973; Culver and Banner, 1978). Therefore, the occurrence and abundance of foraminiferal species in the Metompkin Island area were used to characterize sedimentary facies and resultant depositional environments of the barrier island system.

Numerous studies have catalogued the surface distribution of foraminifera in modern coastal and nearshore deposits along the Atlantic coast (Culver and Buzas, 1980). Since the purpose of this study was to characterize foraminiferal distributions in subsurface deposits, results from a number of these studies were used for associating the presence of specific foraminifera with known depositional environments (see Chapter 2, page 93). Appendix E lists the foraminiferida found in sediment associated with the Metompkin barrier island system including synonymy, geographic distribution, and environmental classification.

To aid in the classification of depositional environment, 29 sediment samples (at least two from each sedimentary facies) were extracted from 14 different cores for microfaunal analysis. A total of 4606 individuals were identified representing 24 genera and 42 species. All three Holocene suborders, Miliolina, Rotaliina, and Textulariina, were represented. The most common species was *Elphidium excavatum* (62.6%) followed by *Haynesina germanica* (9.6%), *Trochammina inflata* (5.8%), and *Ammonia parkinsoniana* forma *typica* (4.9%). The remaining 17.1% of individuals were represented by a wide variety of coastal and nearshore forms of which one, *Fischerina rhodiensis*, has not been previously recorded in the western North Atlantic (Culver and Buzas, 1980). Frequency and occurrence of foraminiferida in the samples studied are presented in Table 19. Sediment samples used for foraminiferal analysis contained approximately 35 cm^3 of material per sample.

Distribution by Sedimentary Facies

Sedimentary Facies A. MF-1, MF-2, and M1-1 were used to represent the medium to fine, quartz sand facies. Samples MF-1 and MF-2 were collected 0.10 m below the surface on a small washover fan on the backside of the island (approximately 1 m above MLW) and on the upper foreshore (approximately 2.8 m above MLW) midway along southern Metompkin Island (Figure 8). Forty specimens were identified for MF-1, 32 of which were *E. excavatum*, whereas only eight forams were found in MF-2 (Table 20). M1-1 (sediment samples were numbered sequentially down section) was taken 0.35 m below the surface (+1.05 m MSL) along the southern end of

TABLE 19

FORAMINIFERIDA SPECIES LIST

SAMPLE NUMBER	MF-1	MF-2	M1-1	M1-9	M2-4	M2-7	M3-2	M3-5	M3-7	M4-3
NUMBER OF SPECIES	3	3	7	12	13	10	14	16	8	10
NUMBER OF INDIVIDUALS PER 100g DRY WEIGHT OF SEDIMENT	200	120	1230	9640	22060	8510	3780	15400	170	830
Ammobaculites dilitatus									7	
Ammonia parkinsoniana forma tepida	1	3		19	43	7	5	2		2
A. parkinsoniana forma typica			1	16	34	14	2	11		1
Ammotium salsum								1		
Asterigerina carinata							1			
Brizalina lowmani								2		
Buccella frigida			4	15	13	16	11	16		1
Buccella sp.			1							
Buliminella elegantissima								4		
Cribrostomoides crassimargo										
Cribrostomoides sp.										
Eggerella advena							2			2
Elphidium articulatum										
E. excavatum	32	4	257	467	454	444	359	279	1	56
E. galvestonense			4		5	3	3			
E. galvestonense forma mexicanum										
E. gunteri				1		1				
E. incertum			3	2	1	2				
E. margaritaceum							1			
E. poeyanum				36	11	2	5	23		
E. tumidum						1				
Elphidium sp.					1					
Eoeponidella pulchella								1		
Fischerina rhodiensis				4						
Fissurina laevigata								2		
Fursenkoina fusiformis								1		
Glabratella wrightii				1	1			1		
Guttulina lactea				1						
Haynesina germanica	7		5	16	47	30	22	26	4	7
Helenina anderseni					1					
Miliammina fusca									1	
Quinqueloculina seminula				9						
Reophax nana										
Reophax sp.										
Rosalina floridana				1				1		
Textularia candeiana							1			
T. earlandi										
Trochammina inflata					5	2	8	9	9	26
T. macrescens							1			1
T. ochracea							4	9	5	3
T. squamata		1			2		5	1		13
Trochammina sp.										1
Indeterminate sp.					1				2	

TABLE 19 (cont.)

SAMPLE NUMBER	M5-2	M5-3	M5-9	M6-13	M8-5	M9-1	M9-8	M10-1	M10-2	M10-7
NUMBER OF SPECIES	1	9	0	0	3	12	0	3	16	1
NUMBER OF INDIVIDUALS PER 100g DRY WEIGHT OF SEDIMENT	30	750	0	0	240	490	0	50	6780	4
Ammobaculites dilitatus		3				19		3		
Ammonia parkinsoniana forma tepida									56	
A. parkinsoniana forma typica						3			116	
Ammotium salsum						6			1	
Asterigerina carinata										
Brizalina lowmani										
Buccella frigida									8	
Buccella sp.										
Buliminella elegantissima										
Cribrostomoides crassimargo										
Cribrostomoides sp.										
Eggerella advena						8				
Elphidium articulatum									1	
E. excavatum					3	4			92	1
E. galvestonense									2	
E. galvestonense forma mexicanum										
E. gunteri										
E. incertum										
E. margaritaceum										
E. poeyanum									4	
E. tumidum									20	
Elphidium sp.										
Eoeponidella pulchella										
Fischerina rhodiensis										
Fissurina laevigata										
Fursenkoina fusiformis										
Glabratella wrightii										
Guttulina lactea										
Haynesina germanica						1			242	
Helenina anderseni										
Miliammina fusca		3				9		3	2	
Quinqueloculina seminula										
Reophax nana									1	
Reophax sp.		2				2			2	
Rosalina floridana										
Textularia candeiana										
T. earlandi		2								
Trochammina inflata	5	78			46	13		5	19	
T. macrescens		2			1					
T. ochracea		6				5				
T. squamata		3				22			1	
Trochammina sp.										
Indeterminate sp.		1				1			2	

TABLE 19 (cont.)

SAMPLE NUMBER	M11-3	M11-4	M11-7	M12-7	M13-2	M13-4	M14-2	M16-3	M16-5
NUMBER OF SPECIES	7	8	3	0	2	1	2	14	6
NUMBER OF INDIVIDUALS PER 100g DRY WEIGHT OF SEDIMENT	320	8900	90	0	30	20	60	3530	90
Ammobaculites dilitatus								10	9
Ammonia parkinsoniana forma tepida		1						15	
A. parkinsoniana forma typica		5					2	22	
Ammotium salsum	1								
Asterigerina carinata		2							
Brizalina lowmani									
Buccella frigida			1					74	
Buccella sp.									
Buliminella elegantissima									
Cribrostomoides crassimargo								7	1
Cribrostomoides sp.									1
Eggerella advena	2							7	
Elphidium articulatum									
E. excavatum		282	13		7	1	6	120	3
E. galvestonense		2						1	
E. galvestonense forma mexicanum		8							
E. gunteri		2							
E. incertum									
E. margaritaceum									
E. poeyanum		3						3	
E. tumidum									
Elphidium sp.		1							
Eoeponidella pulchella									
Fischerina rhodiensis									
Fissurina laevigata									
Fursenkoina fusiformis									
Glabratella wrightii									
Guttulina lactea									
Haynesina germanica		9			1			23	
Helenina anderseni									
Miliammina fusca	1								
Quinqueloculina seminula									
Reophax nana									
Reophax sp.								4	1
Rosalina floridana									
Textularia candeiana									
T. earlandi								10	
Trochammina inflata	14		2					24	1
T. macrescens	3								
T. ochracea	1							10	
T. squamata	7							40	
Trochammina sp.									
Indeterminate sp.									

TABLE 20

FORAMINIFERIDA SAMPLES AND ASSOCIATED SEDIMENTARY FACIES

Sample	Sample Depth (MSL)	Individual* Counts	Sedimentary Facies
MF-1	------	40	A
MF-2	------	8	A
M1-1	+1.05m	275	A
M5-2	-0.39m	5	B
M9-1	+0.40m	93	B
M10-1	+0.11m	11	B
M2-4	-0.81m	619	C
M2-7	-2.49m	522	C
M3-2	-0.99m	430	C
M1-9	-5.87m	588	D
M3-5	-4.27m	390	D
M16-3	-1.60m	370	D
M3-7	-6.11m	29	E
M5-3	-1.59m	100	E
M8-5	-3.32m	50	E
M10-2	-1.58m	569	E
M11-7	-5.74m	16	E
M16-5	-4.17m	16	E
M13-2	+0.31m	8	F
M14-2	+0.12m	8	F
M13-4	-0.93m	1	F
M4-3	-0.57m	113	G
M11-3	-1.63m	29	G
M11-4	-2.33m	315	G
*********************** PRE-HOLOCENE SAMPLES ***********************			
M5-9	-3.63m	0	H
M6-13	-2.92m	0	H
M12-7	-5.07m	0	H
M9-8	-7.07m	0	I
M10-7	-6.77m	1	I

* - sediment samples were extracted from cores in 3-cm wide semi-circular layers, producing approximately 35 cm^3 of material.

Metompkin Island. *Elphidium excavatum*, a ubiquitous foram in coastal and nearshore waters, was dominant in the sample (257 out of 275 individuals). This dramatic contrast in abundance may be related to inlet sedimentation patterns associated with Metompkin Inlet. Net longshore transport is to the south and large ebb-tidal delta shoals were observed welding to the shoreline in the vicinity of core M1 between May and June 1984, thereby increasing the potential number of foraminifera found in beach sediment. This is consistent with findings of Grossman and Benson (1967) for ebb delta shoals of Ocracoke Inlet, North Carolina.

All specimens from this group of samples exhibited a consistent size range (0.2-0.5 mm). Mean grain size was 0.2 mm (fine sand). Test abrasion was evident and small specimens were absent. Consequently, post-depositional transport likely controlled the distribution of specimens in this facies. Eight modern beach samples (MB-10, MB-13, MB-16, MB-20, MB-24, MB-27, MB-30, MB-33; Figure 8) were also collected and qualitatively examined for microorganisms. These samples were not included in Table 20 since only a qualitative assessment was needed. A total of only one foraminifer was identified from all eight samples, indicating a rather barren high energy sand facies. These findings are similar to related studies on beach environments (Todd and Low, 1961; Phleger, 1954).

Sedimentary Facies B. Organic-rich, clayey silt samples consistently had fewer forams than other facies, 97% of which were agglutinated. Most specimens in this group of samples (M5-2, M9-1, M10-1) were of the genus *Trochammina*. Occurrence and abundance data were consistent with those reported in the literature for marsh environments (Phleger, 1954;

Ellison and Nichols, 1970; Murray, 1971; Scott and Medioli, 1980). Samples M5-2 and M10-1 contained small numbers of specimens. *T. inflata* was the only species in M5-2 whereas *A. dilitatus* and *M. fusca* were present in M10-1. Conversely, a variety of calcareous and agglutinated species were associated with M9-1, including *Trochammina squamata*, *Ammobaculites dilitatus*, *A. parkinsoniana*, and *Eggerella advena*. Since this sample was located on a meander bend of Wire Passage, a major tidal channel behind northern Metompkin Island, substantial influence from Wire Passage tidal flows may have influenced abundance and diversity.

M9-1 contained 143 specimens that have been identified as thecamoebians. Parker (1952b) and Phleger (1954) incorrectly recorded similar individuals in Long Island Sound and on Gulf coast marshes as a foraminifera (*Leptodermella variablis*). Bolli and Saunders (1954) claimed that this species was synonymous with *Centropyxis sp.*, a freshwater thecamoebian. Medioli and Scott (1983) classified this form as *Centropyxis aculeata*. They stated that this species was reported from brackish water of the Baltic Sea. In addition, *C. aculeata* was the only thecamoebian consistently found fossilized in cores at the transition between marine and non-marine deposits (Medioli and Scott, 1983). This was the only occurrence of this species in the study area. Its presence may be related to localized ponding of rainwater on elevated marsh surfaces, such as that found at core M9.

Most foraminifera species were less than 0.15 mm in size, representing a population of relatively small specimens. This may be due to undesirable environmental conditions (Murray, 1973) or size sorting at the time of deposition or may represent a predominantly juvenile population. All species present in this group have been identified with varying test size in other samples. Therefore, it is unlikely that specimens are from characteristically small species.

Sedimentary Facies C. Samples M2-4, M2-7, and M3-2 were chosen for examination of microfossils in the laminated fine to very fine sand facies located near Metompkin Inlet. M2-4 was on a sand flat on the seaward edge of Running Channel, an active flood and ebb distributary for Metompkin Inlet, and produced the highest counts (22,060 forams/100 g dry weight of sediment (dws); 13 species). Although an order of magnitude lower, abundance at M2-7 was relatively high (8510 forams/100 g dws; 10 species) while diversity was similar at M3-2 (3780 forams/100 g dws; 13 species). Individuals of all growth stages were common to all three samples and test size ranged from 0.09-0.4 mm. In addition, test abrasion was not prevalent. Although some species were possibly transported to this deposit, species illustrating a wide range in test size probably developed *in situ*.

E. excavatum was the dominant species in all samples. However, common estuarine calcareous species represented all but 1% of the remaining individuals in M2-4 and M2-7, whereas 5% (21) of foraminifera in M3-2 are from the genera *Ammobaculites*, *Ammotium*, *Eggerella*, *Textularia*, and *Trochammina*. As indicated in Appendix E, specimens of these genera were typically associated with intertidal mud and sand flats. In addition, centric diatoms and a few ostracods were found at this location only. *Haynesina germanica*, *Ammonia parkinsoniana*, and *Buccella frigida* were the next most common species in all cases although percent occurrence varied. These species are indigenous to intertidal lagoon and estuarine environments along the Atlantic and Gulf coasts.

Sedimentary Facies D. An important stratigraphic component behind the southern half of Metompkin Island was a sandy silt to silty sand facies with abundant fine shell fragments. Samples from facies D typically produced the most diverse foraminiferal populations. Murray (1968) also found that foram populations from silty sands rich in shelly material were abundant in Buzzards Bay, Massachusetts.

Three samples, including two from transect 1 (M1-9, M3-5) and one from transect 2 (M16-3), ranged in abundance from 3530 forams/100 g dws to 15,400 forams/100 g dws. The magnitude of abundance decreased with distance away from the influence of Metompkin Inlet. This inlet has been a permanent feature in historical records. Sample M16-3 was related more to ephemeral inlet breaching since 1957 and had the lowest total population. Sample M3-5 was positioned northeast of Metompkin Inlet on the flood-tidal delta at -4.27 m MSL. Abundance was high (15,400 forams/100 g dws) and diversity was (16 species), suggesting considerable water-sediment exchange from the inlet (Grossman and Benson, 1967; Kraft and Margules, 1971). M1-9 was obtained from a depth of -5.87 m MSL in the now transgressed Round Rock Channel (Figure 78). All three major Holocene suborders were represented in this sample, producing relatively high abundance (9640 forams/100 g dws) and diversity (12 species). This sample had the highest number of miliolids in addition to containing a wide array of other microorganisms including ostracods, diatoms, and bryozoans. Parker (1952a), Grossman and Benson (1967), and Schnitker (1971) have reported increases in the abundance of miliolids with greater

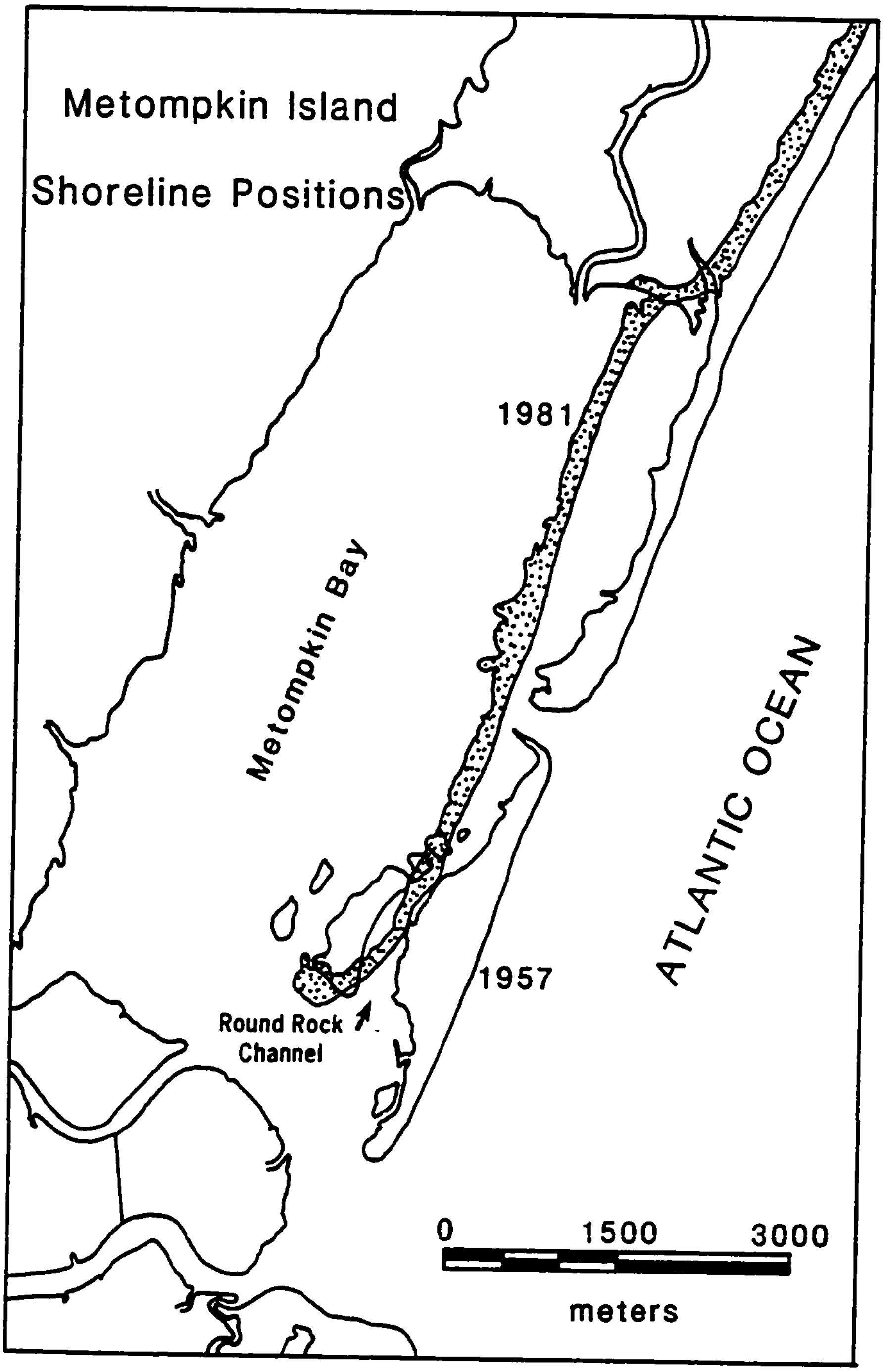

Figure 78. Map showing position of recent Metompkin shoreline relative to position of Round Rock Channel (from Galvin, 1982).

marine influence. In addition, species diversity increases with greater marine influence. Consequently, it is inferred that deposition associated with samples in this group is related to sediment exchange between upper shoreface and backbarrier areas at Metompkin Inlet.

A wide range of sizes was observed for foraminifera species in sedimentary facies D. In addition, very clean, unabraded tests were abundant. Only a few of the largest specimens (*E. excavatum*) indicated post-depositional transport (abrasion). The most common species in all four samples was *E. excavatum*, although *A. parkinsoniana*, *B. frigida*, *H. germanica*, and *Elphidium poeyanum* all contributed significantly. M1-9 contained no textularids while M16-3 had 30% agglutinated species, illustrating a shift in biofacies within similar textural units. Patterns of flow dispersal associated with water and sediment exchange between backbarrier and nearshore shelf regions may have influenced species abundance and diversity in these texturally mixed Holocene deposits.

Sedimentary Facies E. The most extensive facies throughout the backbarrier complex was a clayey silt to silty clay deposit. Consequently, the largest number of samples (6; all transects were represented) was used to describe the micropaleontologic attributes of this facies. Abundance values were low except at M10-2 where a wide variety of calcareous and agglutinated foraminifera, as well as ostracods, characterized the sample (6780 forams/100 g dws; 16 species). At this site, *H. germanica* and *A. parkinsoniana* were dominant, followed by *E. excavatum*.

According to Poag (1978), *A. parkinsoniana* can occur as two distinct ecophenotypes (variations in test morphology due to changing ecologic conditions); forma *typica* and *tepida*. Forma *typica* possesses a prominent umbilical plug, more thickly calcified sutures, more numerous chambers, and often a larger test. Forma *tepida* has a heavily indented umbilical region and was found to be concentrated in areas of maximum salinity and temperature in San Antonio Bay (Poag, 1978). On the other hand, forma *typica* was most abundant in regions of minimum salinity and temperature. Therefore, an abundance of *A. parkinsoniana* forma *typica* at M10-2 suggested a lower salinity, brackish environment (Poag, 1981; Mechler and Grady, 1984). The dominance of *H. germanica*, a species common to intertidal mud and sand flat environments, supports this interpretation (Banner and Culver, 1978; Culver and Banner, 1978). However, the presence of other littoral calcareous specimens, including *E. galvestonense, E. poeyanum, and E. tumidum*, and the absence of similar species in the other five samples suggests that ocean and bay tidal mixing processes associated with Poplar Creek (Figure 63) may have contributed to greater sample diversity.

Agglutinated foraminifera, particularly *Trochammina*, were the dominant forms in samples M3-7, M5-3, and M8-5. Several species of this genus are typical of shallow, brackish-water environments. Scott and Medioli (1980) reported *T. inflata* as being abundant in the lower part of coastal marshes and upper estuarine areas in Nova Scotia. Todd and Low (1961) found greatest abundances of this species where open waters of Nantucket Sound wash over submerged bog deposits. Other species of *Trochammina* have been associated with brackish water areas along the east and Gulf coast of the United States (see Appendix E). Sample M16-5 contained a smaller number of specimens and *A. dilitatus* was dominant.

Although muddy samples have been shown to support large numbers of living foraminiferida, postmortem changes in population structure may be drastically altered under reducing conditions in response to organic decay (Phleger, 1954; Murray, 1973). Dissolution of calcium carbonate tests, due to increased acidity, may selectively remove individuals from the population, effectively biasing the importance of unaffected species (textularids). It is believed that this process played an important role at M3-7, M5-3, M8-5, and M16-5 where significantly reduced numbers of calcareous species were evident. However, sample M11-7 (16 specimens found) contained only two agglutinated tests and numerous centric diatoms, thus presenting a peculiar anomaly. Some variety in size distribution was present but very small specimens (0.09-0.18 mm) were abundant for all six samples. This was consistent for calcareous and agglutinated species.

Sedimentary Facies F. An ephemeral inlet feature was cored along transect 2 and examined for microfauna. This coarse to fine sand facies, with numerous shell fragments, exhibited low foraminiferal abundance and diversity. M13-2 (30 forams/100 g dws), M13-4 (20 forams/100 g dws), and M14-2 (60 forams/100 g dws) were all collected between +0.30 and -0.94 m MSL. *E. excavatum* was the most abundant specimen in this group. A recent surge channel deposit (MF-1), located 300 m south of this area, was also sampled for comparison with historical deposits. Although abundance was slightly higher (200 forams/100 g dws), the types of species identified were similar to those associated with sedimentary facies F. Relatively few specimens were found, thereby defining this sand facies as near-barren. In addition, the specimens identified were always abraded and had a similar size range (0.3-0.5 mm). This finding was not surprising since wave energy associated with storm breaching can be quite intense and the most likely source of post-storm infilling sand would be the barren beach deposits seaward of and adjacent to the surge channel.

Sedimentary Facies G. The final Holocene unit, an interbedded clayey silt to fine sand facies, was characterized by three samples collected from two cores, both in close proximity to active or historically active channels. M11-3 was in a sand-silt-clay unit within an interbedded sand and mud sequence. The genus *Trochammina* dominated the fine-grained sample where relatively low abundance (320 forams/100 g dws) was exhibited. The sand counterpart (M11-4) provided completely different foraminiferal characteristics where abundance was much higher (8900 forams/100 g dws) and *E. excavatum* was dominant. A wide range of sizes was found for all species in sample M11-3 (0.09-0.36 mm) whereas most specimens in M11-4 were in one size range (0.36-0.45 mm) and often showed abrasion.

Sample M4-3 was extracted from a relatively thick, less well-defined, alternating sand and mud facies. Sedimentologically it was similar to M11-3 but micropaleontologically it was quite different. Eleven different species were present while abundance was fairly low (830 forams/100 g dws). Well preserved specimens characterized the sample and various sizes were represented. *E. excavatum* and the genus *Trochammina* accounted for 88% of all specimens in the sample. Periodic historical inlet migration at Gargathy Inlet possibly resulted in more direct contact with nearshore sediment at core M4. This may account for the increase in diversity as compared with samples M11-3 and M11-4.

Pre-Holocene Samples. Five pre-Holocene samples, representing all grain size variations, were examined for microfossil content. Only one individual, *E. excavatum*, was found. This specimen was collected from sample M10-7 in a clayey silt facies (sedimentary facies I). Although foraminifera have been found in pre-Holocene coastal environments (Finkelstein, 1986), the present findings were not completely unexpected since similar trends were noted along the Gulf coast (Otvos, 1982) and southern Delmarva Peninsula (Ludwick and Oertel, 1982; Shideler et al., 1984). Syn- or post-depositional leaching may provide a plausible explanation for the near entire absence of calcareous tests. However, agglutinated forms, unaffected by leaching, were also absent, possibly due to physical destruction or decay of organic material needed to maintain test structure. Regardless, this dramatic contrast in foraminiferal abundance between Holocene and pre-Holocene deposits potentially provides a means for locating the Holocene-pre-Holocene contact where lithology is otherwise similar.

Assemblage Structure

Numerous techniques have been implemented in an attempt to provide comparable indices for qualitative examination of microfauna (Murray, 1973). In the present study, absolute abundance (# of foraminiferida present per 100 grams dry weight of sediment), Fisher's α index, the Shannon-Weiner information function (H(s)), species equitability (E'), and a triangle plot of suborders were used for comparison. Absolute abundance was the simplest to calculate and provided the most basic means of comparison (Table 20). Low values were generally associated with increased wave energy along open coasts and sheltered, fine-grained backbarrier regions, while magnitude increased proportionately with marine influence (Todd and Low, 1961; Grossman and Benson, 1967; Kraft and Margules, 1971).

The Fisher α index (Fisher et al., 1943) is a diversity measure that uses both number of individuals and number of species. However, it assumes the distribution of species abundances to be approximated by a simple log series. Several authors have shown this assumption to be limited (see Buzas, 1972), advocating instead the use of information theory and related measures which assume no distribution to measure species diversity. The most commonly used form of the Shannon-Weiner information function is given by the equation

$$H(s) = -\sum P_i \ln P_i \qquad (2)$$

where P_i is the proportion of the i^{th} species. One drawback is that all species do not contribute equally to the value of H(s). Very abundant and very rare species contribute less than moderately abundant ones (Gibson and Buzas, 1973). As the value of H(s) increases to a maximum (H(s) = lnS; where S = # of species), the uncertainty associated with choosing an individual of a particular species at random from the population is at a maximum. Species equitability (E′) is a measure of the evenness of species abundance within a distribution. Gibson and Buzas (1973) defined this parameter as

$$E' = \frac{e^{(H(s))}}{S} \qquad (3)$$

where $E' = 1$ when all species are equally distributed. The most attractive attribute of utilizing the information function is that it minimizes problems of comparing diversity with varied sample size.

Finally, since all modern foraminifera with hard tests fall into three suborders, it was convenient to use a plot in comparing the ratio of relative abundance. Murray (1973) provided a summary triangle plot, showing the boundaries for many coastal environments, which was used for sample comparison and environmental analysis. In addition, a summary of the range of diversity for the same environments was provided for the α index diagram.

Tables 21 and 22 summarize all remaining sample data associated with foraminiferal analysis. Figure 79 illustrates the relative position of samples in relation to the α index while Figure 80 shows sample position on a suborder ternary diagram. Since the range of ecological factors affecting species diversity and abundance is relatively consistent in coastal environments, most information related to environmental association was fairly limited. Samples were placed in the correct general location (ie. backbarrier complex) but provided limited detail on sub-environment relationships. Furthermore, species diversity (H(s)) provided no consistent trend within quite a small range. Samples illustrating large absolute abundance values generally showed low species diversity because most specimens were associated with one or two dominant species. This supported the notion of relatively low diversity in marginal marine environments.

Cluster Assemblages. Q-mode hierarchical cluster analysis (unweighted pair-group method) was utilized to objectively evaluate simul-

TABLE 21

SPECIES ABUNDANCE AND DIVERSITY STATISTICS FOR METOMPKIN ISLAND SYSTEM

Sample #	Absolute Abundance	Information Function H(s)	Information Function E'	Fisher Index Value	Fisher Index Environment*
MF-1	200	0.58	0.59	0.6	HRM
MF-2	120	0.97	0.88	0.7	HRM
M1-1	1230	0.35	0.20	1.0	HOL
M1-9	9640	0.87	0.20	1.3	HONS
M2-4	22060	0.98	0.21	1.5	HONS
M2-7	8510	0.66	0.19	1.1	HONS
M3-2	3780	0.80	0.16	1.9	HONS
M3-5	15400	1.20	0.21	1.9	HONS
M3-7	170	1.75	0.72	1.9	HRM
M4-3	830	1.50	0.45	1.7	HOL/NMM
M5-2	30	----	----	only one species	
M5-3	750	0.96	0.29	1.5	NMM
M8-5	240	0.32	0.46	0.6	HRM
M9-1	490	2.13	0.70	2.3	HRL
M10-1	50	1.07	0.97	0.7	HRM
M10-2	6780	1.47	0.27	2.0	HONS
M11-3	320	1.46	0.62	1.3	HRL/M
M11-4	8900	0.51	0.21	0.9	HONS
M11-7	90	0.60	0.60	0.7	HRM
M13-2	30	0.38	0.73	0.5	HRM
M13-4	20	----	----	only one species	
M14-2	60	0.56	0.88	0.5	HRM
M16-3	3530	2.06	0.56	1.9	HONS
M16-5	90	1.33	0.63	1.5	HRM
************************ PRE-HOLOCENE SAMPLES ************************					
M5-9	0	----	----	---------------	
M6-13	0	----	----	---------------	
M9-8	0	----	----	---------------	
M10-7	4	----	----	only one species	
M12-7	0	----	----	---------------	

HRM - hypersaline marsh
HOL - hyposaline lagoon
HOL/NMM - hyposaline lagoon/normal marine marsh
NMM - normal marine marsh
HRL - hypersaline lagoon
HONS - hyposaline and nearshore shelf seas
HRL/M - hypersaline lagoon/marsh

* - after Murray (1973)

TABLE 22

PERCENT OCCURRENCE OF FORAMINIFERIDA BY SUBORDER

Sample #	% Rotaliina	% Textulariina	% Miliolina	Environment*
MF-1	100.0	0.0	0.0	HOM/HRL
MF-2	87.5	12.5	0.0	HOM/HRL
M1-1	100.0	0.0	0.0	HOM/HRL
M1-9	97.8	0.0	2.2	HOM/HRL
M2-4	98.8	1.1	0.0	HOM/HRL
M2-7	99.6	0.4	0.0	HOM/HRL
M3-2	95.1	4.9	0.0	HOM/HRL
M3-5	94.9	5.1	0.0	HOM/HRL
M3-7	17.3	79.3	3.4	HOL/MS
M4-3	59.3	40.7	0.0	HOM/L
M5-2	100.0	0.0	0.0	HOM/HRL
M5-3	0.0	97.0	3.0	HOM/L
M8-5	6.0	94.0	0.0	HOM/L
M9-1	8.6	81.7	9.7	NMM
M10-1	0.0	72.7	27.3	NMM
M10-2	95.0	4.6	0.4	HOM/HRL
M11-3	0.0	96.6	3.4	HOM/LS
M11-4	100.0	0.0	0.0	HOM/HRL
M11-7	87.5	12.5	0.0	HOM/HRL
M13-2	100.0	0.0	0.0	HOM/HRL
M13-4	100.0	0.0	0.0	HOM/HRL
M14-2	100.0	0.0	0.0	HOM/HRL
M16-3	69.7	30.3	0.0	HOM/L
M16-5	18.8	81.2	0.0	HOM/L

HOM/LS - hyposaline marsh/lagoon to shelf
HOM/L - hyposaline marsh/lagoon
HR/HOL - hypersaline/hyposaline lagoon
HOL/MS - hyposaline lagoon/most shelf areas
HOM/HRL - hyposaline marsh/hypersaline lagoon
NMM - normal marine marsh

* - after Murray (1973)

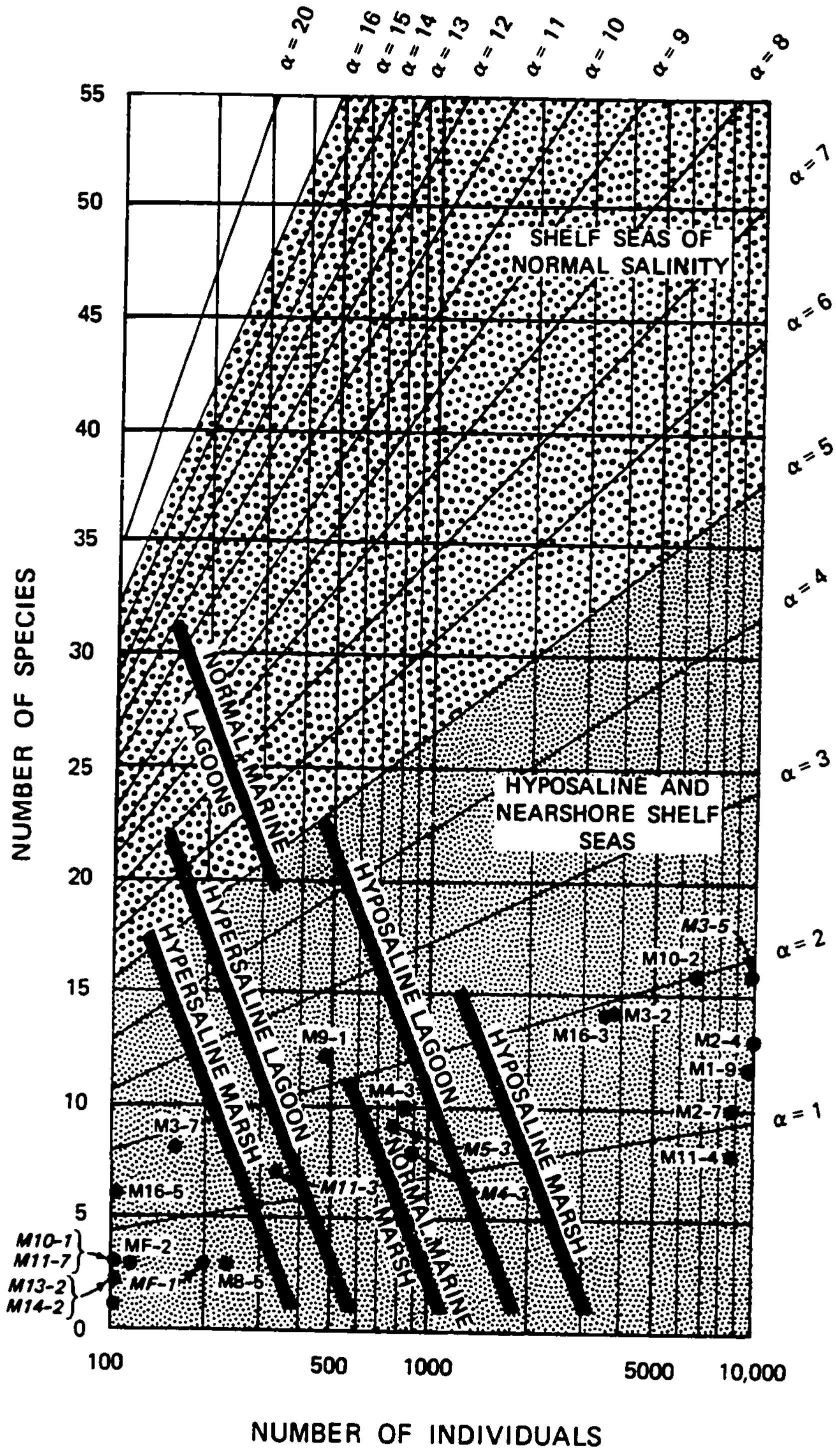

Figure 79. Summary of the range and diversity of Metompkin Island samples (from Murray, 1973).

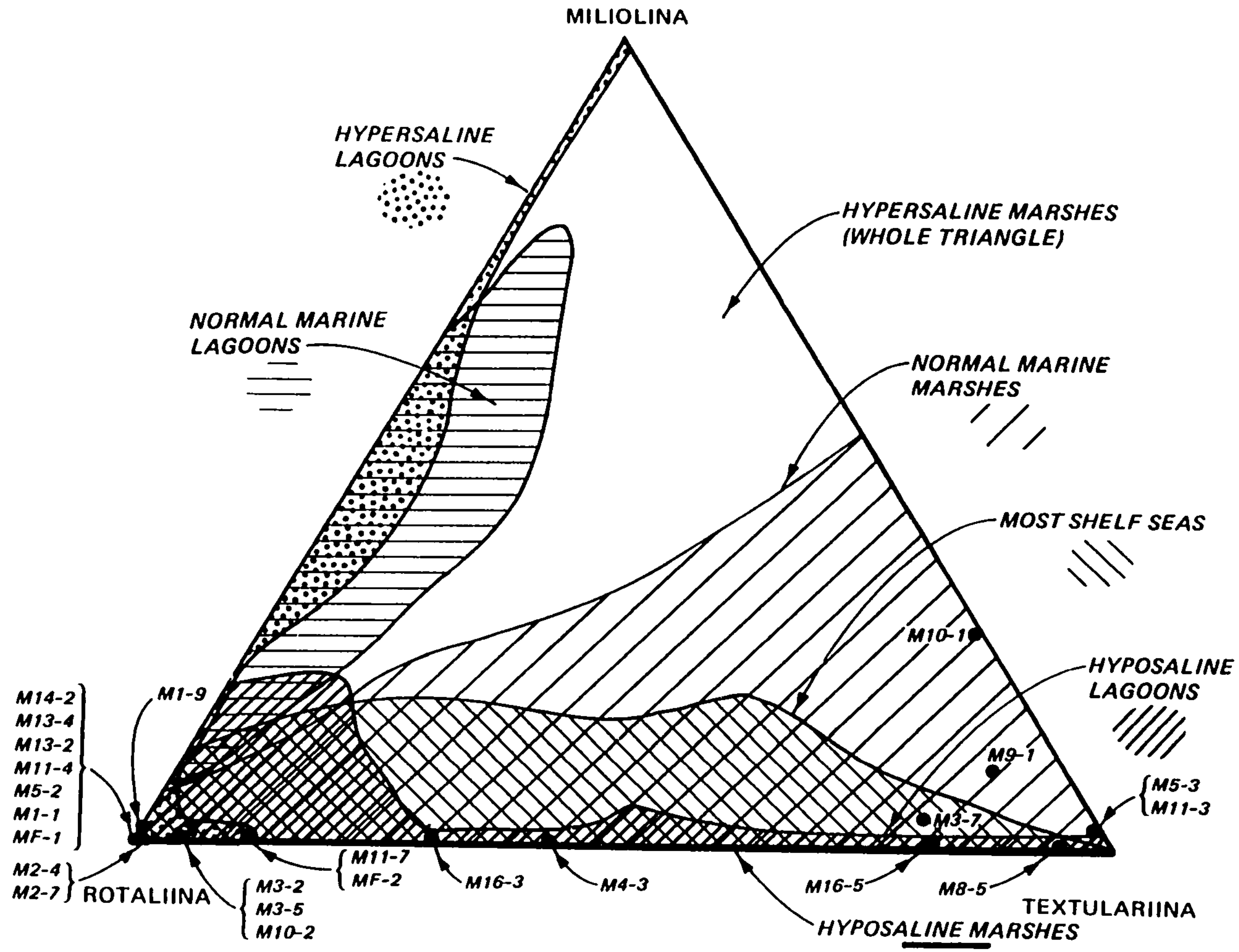

Figure 80. Triangle diagram showing a comparison of foraminiferida samples for the Metompkin Island System (from Murray, 1973).

taneous variations in population structure. Using the Bray-Curtis resemblance coefficient (Bray and Curtis, 1957; Romesburg, 1984), five naturally occurring clusters were identified on the basis of absolute abundance data (Figure 81). Only Holocene samples were clustered. Two major groups first delineated near-barren and abundant samples; three clusters were identified within the near-barren group and two within the abundant group. Foraminiferal assemblages were distinguished from each other by proportionate composition of the species occurring in each cluster.

Cluster Assemblage 1. This group was comprised mainly of the genus *Trochammina*, in particular *T. inflata* and *T. squamata*. Average abundance associated with the group was relatively high (526 forams/100 g dws) for the near-barren group of clusters. *T. inflata*, a dominant constituent of coastal marshes and brackish-water lagoons, was the only species common to all five samples. Approximately 15% of all specimens were calcareous, mostly *E. excavatum*.

Cluster Assemblage 2. Samples in this group contained two dominant species, *T. inflata* and *Ammobaculites dilitatus*. However, average abundance was very low (85 forams/100 g dws), making assemblage classification rather tenuous. Approximately 86% of all specimens were agglutinated. Both dominant species are typical of brackish-water bays and marshes. *T. inflata* was the only common species among all four samples.

Cluster Assemblage 3. Average abundance was again very low (87 forams/100 g dws) for this six-sample cluster group. However, *E. excavatum* was the most prominent (78% of all specimens) constituent in all samples. In addition, all but three individuals (6%) were cal-

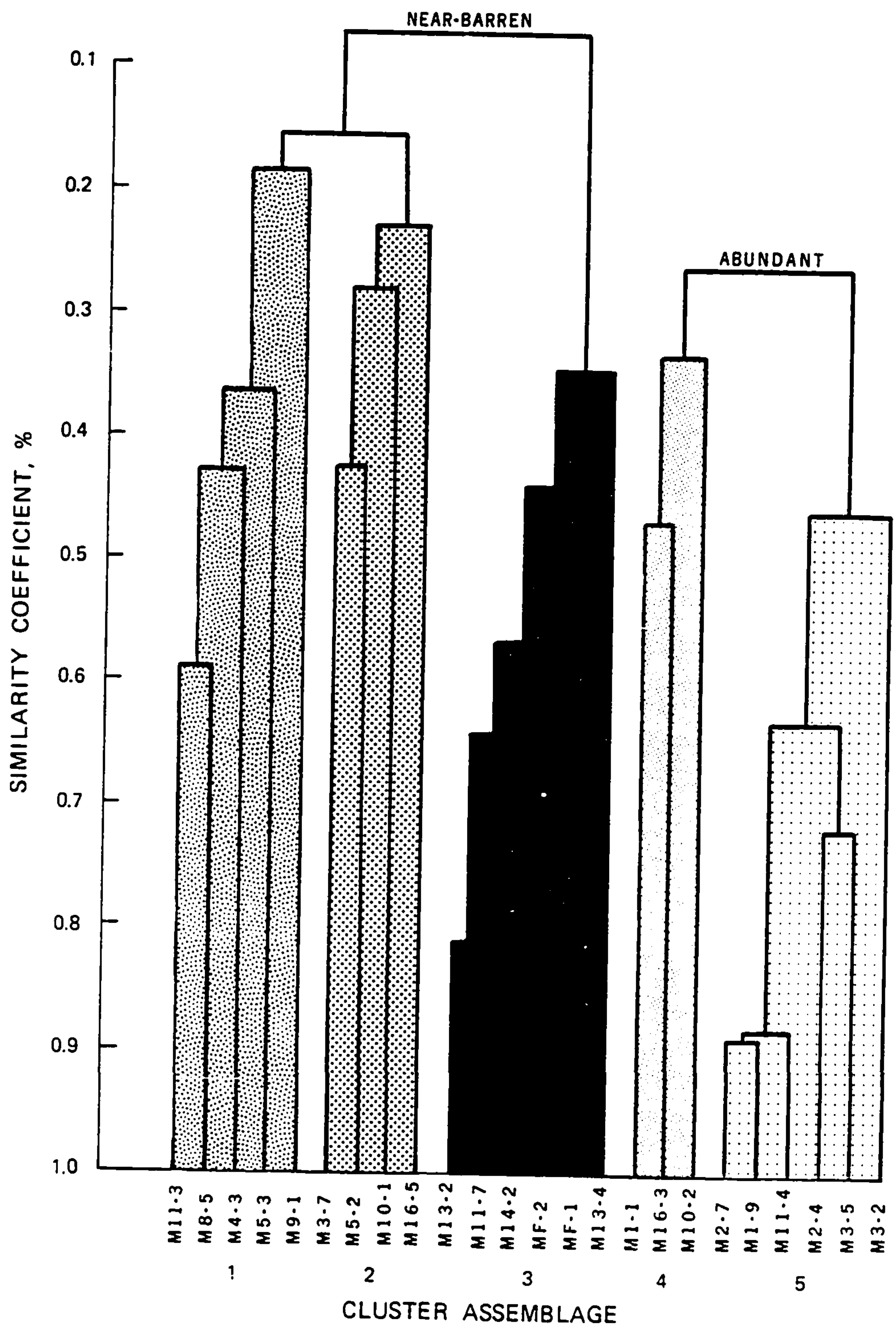

Figure 81. Q-mode cluster dendogram of foraminiferida samples showing five cluster assemblages.

careous. This suggests more frequent contact with normal marine environments such as the littoral zone of open coasts and nearshore shelf regions. Low average abundance values associated with sand deposits suggest regions of high wave energy such as beaches on open coasts (Todd and Low, 1961).

Cluster Assemblage 4. *E. excavatum, H. germanica, A. parkinsoniana* forma *typica*, and *B. frigida* were the main constituents in this three sample group. Together they represented 79% of all individuals. Average abundance was relatively high (3847 forams/100 g dws) as was species diversity (22 different species representing all three suborders). *E. excavatum* was the only abundant species (greater than 25% of the total assemblage population) but the other three main constituents plus *E. galvestonense* were also common to all three samples. This group contained species characteristic of intertidal mud and sand flats (*A. parkinsoniana, H. germanica*), shallow, nearshore waters and brackish bays (*E. excavatum, E. galvestonense*), normal marine inner shelf areas (*B. frigida*), and marsh and estuarine backbarrier environments (*T. inflata, T. squamata*) (Murray, 1973; see Appendix E). The wide variety of shallow water species possibly indicates regions of intense tidal mixing.

Cluster Assemblage 5. This group of six samples contained the most diverse set of samples. Although *E. excavatum* represented 80% of the total population, 32 different species were identified. Other important constituents included *H. germanica, A. parkinsoniana* forma *typica* and *tepida, Elphidium poeyanum*, and *B. frigida*. Species occurrence and abundance indicated more normal marine conditions than those reflected by assemblage 4. Inner continental shelf and inlet associated species such as *Quinqueloculina seminula, Fissurina laevigata, Eoeponidella pulchella, Buliminella elegantissima, Brizalina lowmani*, and *Fischerina rhodiensis* were associated with this assemblage only (Appendix E; Figure 78). In addition, average absolute abundance (11,382 forams/100 g dws) and simple diversity considerations (total # of species) supported the interpretation of increased marine influence.

<u>Summary</u>

A comparison of assemblage structure and sedimentary facies showed that assemblage 3 characterized near-barren subaerial beach and ephemeral inlet-fill sand. Near-barren clayey silts, some with organics, were classified in assemblage 2 while assemblage 1 contained samples with a greater absolute abundance and clayey silt to silty clay substrate. Three completely different sedimentologic samples formed assemblage 4. Since all three samples are associated with deposition near ephemeral and active tidal channels, it is possible that tidal mixing and island dynamics may provide important controls on the distribution of this biofacies. Assemblage 5 illustrated the influence of more normal marine conditions. All but sample M11-4 can be associated with sand to sandy silt deposits resulting from shoaling at Metompkin Inlet. Abundance and simple diversity are high and typical nearshore open marine specimens consistently occurred in this group of samples only.

SYNTHESIS

The examination of spatial and temporal variations in the geologic, historic, and recent development of the Metompkin barrier island system has provided a comprehensive understanding of the driving mechanisms responsible for depositional trends. A link between coastal processes and environmental response can be recognized by examining lateral changes in vertical facies successions and the history of shoreline change. From this, the occurrence of Holocene sedimentary deposits throughout the barrier complex may be associated with known depositional events. The following discussion synthesizes data collected by this time-integrated approach and a model for system evolution is proposed.

Barrier Island Migration

One of the main objectives of this study was to examine the response of the barrier island depositional environment to varying stratigraphic characteristics of backbarrier environments and to the frequency and magnitude of storm activity. Temporal and spatial changes in island morphology also affect interactions among barrier island system elements and nearshore processes. Consequently, analysis of historical shoreline position data was performed to assess trends in island response during recession and a short-term island profiling study was initiated to provide quantitative estimates of sand volume changes. Most investigations have not been able to quantitatively evaluate barrier rollover as a driving mechanism during landward retreat but Metompkin Island provided an ideal study area for addressing this fundamental process and assessing the importance of normally dominant geologic-type processes on a short time scale. It was possible to relate spatial change in shoreline sedimentation patterns to the magnitude of high-energy events and varying backbarrier depositional environments.

Washover Sedimentation and Island Maintenance

Well-developed barrier island sub-environments, including primary and secondary dune systems, often provide protection to backbarrier regions against storm wave conditions. Although significant sand losses have occurred along many barrier shorelines as shown in historical records, barrier islands are not being completely destroyed in response to slowly rising sea level or rapidly fluctuating water levels related to storm events. Consequently, a time-independent landward sediment transfer process must account for island maintenance during recession.

Many studies have used aerial photography to document the importance of washover (eg. Hosier and Cleary, 1977; Nummedal et al., 1980) while others have quantitatively examined sand volume additions landward of the island crest at longshore positions associated with overwash (eg. Leatherman, 1976; Fisher and Stauble, 1977; Kochel and Dolan, 1986). The present data set produced one of the few large-scale quantitative verifications of the rollover hypothesis for an entire island system (others include Armon and McCann, 1979).

An analysis of historic changes in island position revealed that Metompkin Island has rolled landward of its original boundaries at least once in the past 25 years (see Figure 41). Data from a 2-year island profiling study were used to identify and quantify the mechanics of island recession. Segments of bay and ocean shoreline for north and south Metompkin Island were analyzed separately based on trends in historical retreat rates. Data indicated that losses of sand volume along seaward profiles often were associated with deposition along the landward extension of transects. In a number of cases, landward additions through washover exceeded losses along seaward profiles or were accompanied by gains on the seaward side of the island (eg. Tables 6, 10, and 13). Associated changes in island shape reflected these additions as evidenced by thin horizontal deposits of sand across landward profile segments (see Appendix A). Although these trends were present during average conditions, extreme storm events accentuated the washover process.

Kochel and Dolan (1986) presented similar results for southern Assateague Island, VA, indicating that both large and small magnitude storms resulted in permanent contributions to the island sediment budget, with a greater percentage of total accretion attributed to less frequent, large scale storm events. In contrast, investigations of the contribution of washover at discrete positions along northern Assateague Island documented significant sediment transfers associated with small and large scale storms, however, subsequent aeolian activity resulted in partial or complete deflation of the overwashed material (Fisher et al., 1974; Leatherman, 1976; Fisher and Stauble, 1977; Leatherman et al., 1977). Consequently, it was suggested that overwash does not provide a significant source of sand to the interior portions of the island.

Significant losses of sand volume were indicated along Metompkin Island between November 1983 and November 1985, mainly related to Hurricane Gloria. However, changes in distance to the high water shoreline were associated with near equal displacements of the shoreline on the landward side of the island (see Table 16). Therefore, even though sand volume was not conserved, washover provided the impetus for maintenance of island form during landward retreat (Figure 57; Appendix A).

The magnitude of profile adjustment was quite different for north and south Metompkin Island. This was related to changes in barrier width and height along the island. Washover was dominant during all time periods along the northern island segment where maximum elevation averaged 2.50 m. Large changes in sand volume and shoreline displacement were common. On the other hand, the southern island segment was slightly more elevated (2.67 m) and wider (147 m versus 129 m). As a result, shoreline and volume adjustments were less dramatic between November 1983 and November 1985, although washover deposition still characterized most post-storm profiles where sand was transported over the island crest and into Metompkin Bay.

Significance of Different Backbarrier Morphology

Initial observations of longshore variation in island trend focused attention on abrupt changes in backbarrier morphologic features. Examination of differences in lagoonal stratigraphy throughout the system generally indicated thicker Holocene backbarrier sequences towards the east and south over a gently undulating but increasingly deeper pre-Holocene surface. As a result, northern Metompkin Island is backed by extensive marsh deposits while the southern half of the island is migrating into Metompkin Bay.

The prominent island offset at a position midway along Metompkin Island is directly associated with the abrupt change in lagoonal characteristics. Marsh deposits in the north have provided an elevated and relatively stable platform for barrier island sand deposition during recession. In addition, marsh deposits outcropping in the surf zone potentially provide a buffer to destructive wave energy while longshore continuity limits inlet breaching to areas where tidal channels are transgressed. Consequently, the likelihood of inlet breaching along the northern segment has been limited.

Bay-backed island deposits to the south exhibited dramatically different sedimentation trends. Washover sediment is transported into Metompkin Bay, becoming temporarily lost as a source to the barrier island environment. However, as the island migrates landward, these sand deposits become sources of sediment for maintaining island continuity. Absence of a subaerial barrier platform may have produced greater instability, causing the rate of island change to be higher. In addition, the potential for inlet breaching is increased since subaerial structural support is absent along the bay-backed shoreline; hydrodynamic processes in Metompkin Bay are in direct contact with the landward island shoreline. Although these factors tend to enhance island dynamics, sand-sized sediment deposited in the lagoon potentially provides a fairly stable platform for island migration.

Historical records showed uninterrupted parallel retreat as long as an island width of approximately 200 m was maintained (Figure 82). Although island width continued to decrease after initial inlet breaching in 1957, adjustments between 1980 and 1985 illustrated insignificant

Barrier Island Width Versus Time

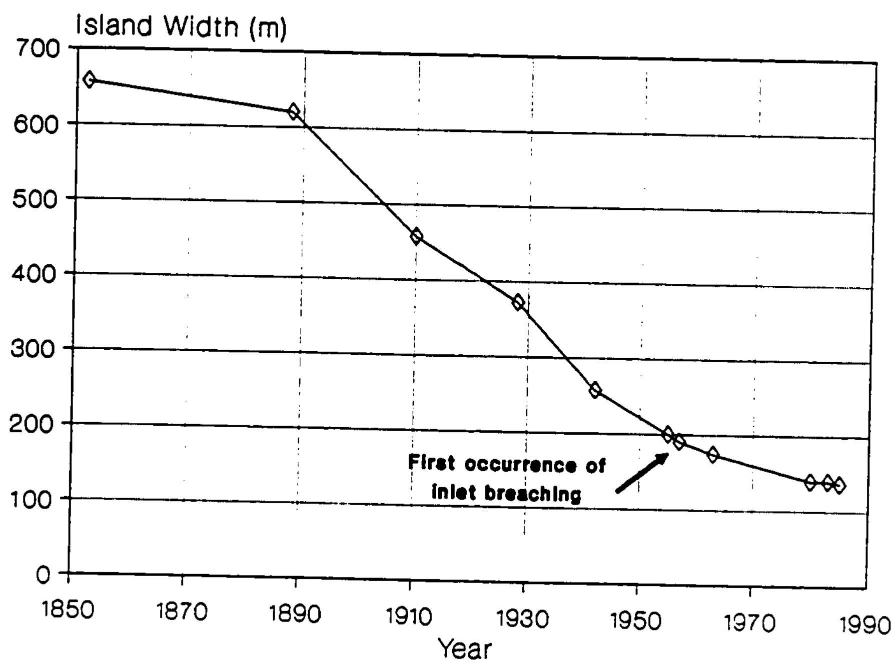

Figure 82. Plot showing changes in barrier island width versus time for the Metompkin barrier island system (data from 1852 to 1981 from Rice et. al., 1976; Galvin, 1982; NOS-CERC, 1984).

variations. Between 1983 and 1985, island width averaged 140 m prior to and 136 m after Hurricane Gloria, suggesting that washover deposition was maintaining island width during transgression. This is consistent with data for northern Assateague Island where Leatherman (1979 b, c) found that overwash became an effective transport mechanism for island migration when barrier island width was between 122 and 213 m.

Significance of Storm Events and Inlet Breaching

Until 1955, historical records indicated that Metompkin Island was one continuous unit exhibiting seaward erosion without migration. Extensive dune systems may have provided protection against storm conditions but as island width decreased, elevation likely decreased and the occurrence of extensive storm washover deposits and ephemeral inlet breaches increased. Barrier island migration via rollover probably became a dominant process affecting island evolution.

Once breaching occurred, longshore variations in the rate of island recession responded to dynamic conditions at inlet entrances and varying backbarrier characteristics. Longshore transport along the southern island segment was interrupted by cross-shore flows at inlet breaches. This potentially decreased the amount of sand being transported to downdrift beaches, thereby increasing the rate of shoreline retreat. By 1980, inlet breaching had temporarily ceased and a 400 m island offset was established midway along the island (Figure 41). The differential influence of inlet breaching on island mobility was very apparent.

Post-storm island changes associated with the passage of Hurricane Gloria (September 27, 1985) were monitored for 10 locations along the island. Significant changes in shoreline position were associated with washover and inlet breaching. For the first time since 1980, continuity in longshore sediment transport was disrupted by an inlet along the northern portion of south Metompkin Island. This region was particularly vulnerable to inlet breaching due to low island elevation (2.24 m) and narrow island width (131 m). The large opening likely developed at the time of peak storm surge. Severe losses of sand volume at this location could be directly related to inlet formation. Since storm surge and associated wave processes removed the benchmark at profile 18, absolute volume change could not be calculated. However, approximate losses were evaluated for an average island elevation of approximately 1 m above MLW (estimated from field measurements). Volume change on the seaward side of the island exceeded -63 m^3/m while landward adjustments were greater than -69 m^3/m. All sand above the HWL was removed from the profile. Conversely, sand losses along northern Metompkin Island were associated with offshore and longshore sediment transport processes.

Table 16 provides details on average changes in shoreline position and sand volume for northern and southern island segments, allowing a comparison of storm-related adjustments. Since large-scale geomorphic backbarrier characteristics were unchanged between November 1983 and November 1985, the relative importance of inlet activity versus back-barrier geology could be examined. During the 2-year period, the average high water shoreline translated landward 32.25 m and 19.34 m^3/m of sand were eroded from the marsh-backed segment of Metompkin Island . Along the bay-backed portion of Metompkin Island, excluding the area of inlet breaching, average changes were -8.29 m and 4.49 m^3/m, respectively. This is the opposite of historical trends (1955-1980) where the southern island segment had been migrating approximately 2.5 times the rate of the northern island segment (Table 5). These data suggest that the rate of migration along southern Metompkin Island is directly related to the presence or absence of ephemeral inlets.

An important result of storm activity was the abundance of washover deposits along the length of the island. Except in the area of inlet breaching, mass transfer of material during landward retreat enabled the volume of sand stored in the island environment to remain conserved for southern Metompkin Island. However, a sand volume deficit was recorded along northern Metompkin Island even though washover supplied large quantities of sand to the landward profile. Since island width remained relatively constant, volume losses were associated with a change in average island elevation (-0.40 m). Figure 83 provides an example of profile translation resulting from Hurricane Gloria, illustrating the importance of washover in maintaining island form during landward retreat.

Although the island profiling study covered only 2 years of record, it provided a means of evaluating the significance of the presence of inlets versus differing backbarrier characteristics in controlling the rate of island change. From this study and the analysis of historical records, it was shown that dynamic processes associated with inlet activity more significantly affected island sedimentation patterns than varying backbarrier morphology. However, if a marsh-filled lagoon had been present throughout the study area, inlet breaching probably would have occurred less frequently. This interactive mechanism makes it difficult to isolate dominant factors but inlet processes appear to more directly influence shoreline behavior.

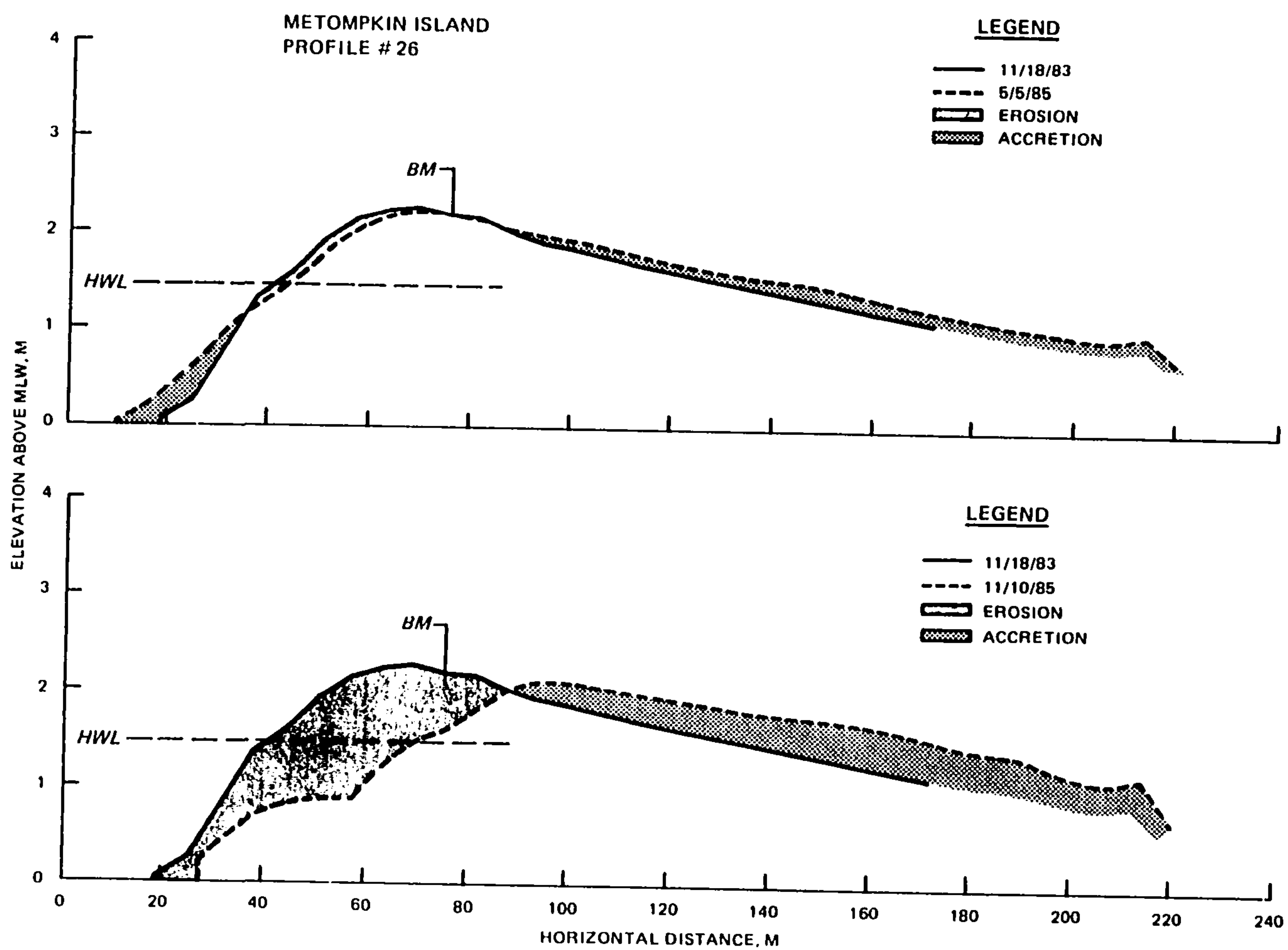

Figure 83. Diagram illustrating landward transfer of sand associated with Hurricane Gloria at profile 26 (from Byrnes and Gingerich, 1987).

Environmental Interpretation of Sedimentary Facies

Seven Holocene and two pre-Holocene sedimentary facies were identified along four transects in the Metompkin barrier island system. Cross-shore and longshore variations in sedimentary deposits resulted from changes in island morphology and inlet dynamics. The following section describes the environmental interpretation of sedimentary deposits and their spatial distribution.

Barrier Island-Beach

A medium to fine sand facies (A) characterized the seawardmost subaerial portion of the barrier island system. This geomorphic feature consists of sand deposits resulting from wind and wave action and provides protection to backbarrier environments against high-energy coastal hydrodynamics. Although only one core penetrated this environment, numerous surface samples from foreshore and backshore locations were analyzed. In addition, frequent marsh exposures at the base of the lower foreshore provided detailed information on stratigraphic positioning of this deposit.

Cluster analysis of grain size data showed that all samples from this environment grouped together in cluster facies 5. Average grain size was 1.98ϕ with greater than 95% sand. In addition, very low numbers of foraminifera were found in all samples. Cluster assemblage 3 included all samples where *E. excavatum*, a ubiquitous species in nearshore environments, was most common. These findings are consistent with those of Phleger (1954) and Todd and Low (1961) for high-energy littoral deposits on open coasts.

Marsh

The marsh environment was recognized only as a surface deposit in the Holocene record. Consequently, its sedimentary characteristics may vary in response to position within the backbarrier region relative to barrier island and tidal channel deposits. An organic-rich, clayey silt to silty clay facies (B) described most marsh deposits. Grain size increased for samples obtained from cores along the mainland fringe (muddy sand; M15-1) and the landward side of Metompkin Island (silty sand; M8-1). However, the most important distinguishing factor for this environment was the preponderance of *Spartina* vegetation. Root bioturbation was extensive, creating a thoroughly mixed surface layer. Backbarrier regions along northern Metompkin Island contained extensive marsh deposits while fringing marsh was more common along the southern half of the island system.

Since grain size varied slightly, sediment samples grouped in cluster facies 2 and 3. Both were fine-grained facies, averaging 6.61ϕ and 7.90ϕ, respectively, but cluster facies 2 had a higher percentage of sand (Table 18). Foraminiferal abundance was low but the species identified were indicative of marsh and lagoon environments (Phleger, 1954; Murray, 1973). Two agglutinated foraminifera, *T. inflata* and *A. dilitatus*, were dominant in samples representing this environment (cluster assemblage 2). Very few calcareous tests were found.

Sandy Tidal Flat

A laminated, fine to very fine sand facies (C) characterized the sandy tidal flat environment. Deposits were encountered along transect 1 only, where the influence of sedimentation at Metompkin Inlet could be directly associated. Horizontal to sub-horizontal laminae and current ripple structures were common at all positions in this laterally extensive deposit across southern Metompkin Bay. Sediment samples mainly grouped in cluster 1, with a group mean of 4.21ϕ. However, a few samples grouped in cluster facies 7 where mean grain size was coarser at 2.61ϕ. Sand content was always greater than 80% for samples taken from this environment.

Three sediment samples were selected for identification of microfauna; all were consistent and clustered in assemblage 5. Although *E. excavatum* represented 80% of the entire population, abundance and diversity were relatively high. Nearshore marine and lagoonal specimens were present in all samples, indicating the significance of water and sediment exchange at Metompkin Inlet. Both foraminiferal composition and sediment size data were typical of inlet-related sand deposits (Grossman and Benson, 1967; Moslow and Tye, 1985).

Mixed Tidal Flat

The mixed tidal flat environment contained a combination of sedimentary characteristics unique to deposits affected by fluctuations in fluid power. Spatial and temporal changes in energy input and sediment source created this texturally mixed sedimentary facies. A silty sand to sandy silt facies (D) was present throughout the entire backbarrier portion of southern Metompkin Island and could be associated with permanent and ephemeral inlet activity. Similar deposits were found along northern Metompkin Island where historic changes in the position of Gargathy Inlet may have played an important role in sedimentation dynamics.

Equal numbers of grain size samples from these deposits grouped in cluster facies 1 and 2. Differences in barrier island morphology, frequency of storm activity, and deposition near channel entrances influenced the presence and extent of this environment. Average mean grain size ranged from 4.21 to 6.61ϕ. Macrolocomotion bioturbation disturbed most evidence of physical structures and produced very distinct textural contrasts on x-ray radiographs.

Foraminiferal content exhibited high levels of diversity. Although calcareous and agglutinated species were present, calcareous forms were dominant. Samples were associated with cluster assemblages 4 and 5 where *E. excavatum* was the main constituent. A mixture of species common to intertidal mud and sand flats in backbarrier regions (*A. parkinsoniana, H. germanica, T. inflata*) and nearshore shelf and inlet environments (*B. frigida, B. elegantissima, Q. seminula*) were identified (Table 19). This variety of genera emphasized the importance of mixing processes associated with inlet activity.

Muddy Tidal Flat-Lagoon

Sedimentary deposits associated with the lagoon-muddy tidal flat environment provided the foundation for all other Holocene deposits. A clayey silt to silt clay facies (E) was contiguous throughout the study area and showed very little variability in textural composition. Most samples grouped in cluster facies 3, where average mean grain size was 7.90ϕ and 97% of the distribution was finer than sand. Microlocomotion bioturbation effectively eliminated any physical structures, producing a homogenous mud sequence. Foraminiferal content was generally low and calcareous forms were scarce. Agglutinated tests represented greater than 90% of all species found; *Trochammina* was the dominant genus. These findings were consistent with characteristics of well-protected back-barrier lagoon environments (Phleger, 1954; Kraft and Margules, 1968; Murray, 1973; Scott and Medioli, 1980). Sedimentation associated with this deposit probably occurred as the result of fine-grained settling of particles introduced to backbarrier regions through reworking of coastal sediment during transgression. The near absence of sand throughout the entire deposit supports the presence of a natural littoral barrier some distance seaward of the modern backbarrier region.

Inlet-Washover

Numerous, well-documented inlet breaches have occurred along southern Metompkin Island in response to intense storm activity (Figure 40). Deposits located in the vicinity of a breach resulting from the Ash Wednesday northeaster (1962) were cored in two locations on the landward side of the island along transect 2 to document the nature and significance of this feature. A coarse to fine sand facies (F) with abundant shell material characterized this depositional environment. In addition, horizontal to sub-horizontal laminae, trough cross-bedding, and micro-ripple laminations were common.

Sediment samples grouped with cluster facies 5, a medium to fine sand group with an average mean grain size of 1.98ϕ and greater than 95% sand. Most samples in the cluster were obtained from barrier island deposits, the source material for inlet fill and washover deposits. Foraminiferal abundance was very low; all samples clustered in assemblage 3 (along with barrier beach samples) where *E. excavatum* was most prominent.

Tidal Channel

Although similar sequences were identified in other locations, only core M11 exhibited well-defined channel-fill deposits. The sequence was characterized as an interbedded clayey silt and fine sand facies (G). Alternating tabular beds (≈0.02-0.04 m thick) marked the position and relative frequency of storm events from 0.78 m to 5.45 m MSL. Storm-tide inlet breaching and washover were historically associated with a small channel located about 5 m west of the core position. Discrete samples were obtained relative to natural layering to avoid mixing of depositional zones.

Five samples were extracted from this depositional sequence. Fine-grained samples grouped in cluster facies 2 (mean = 6.61ϕ) while coarser samples were in cluster facies 7 (mean = 2.61ϕ). Microfauna associated with fine-grained samples contained marsh and upper estuarine species such as *T. inflata* while sand samples had very low abundance (mainly *E. excavatum*) and were associated with more active environments such as the littoral zone.

Pre-Holocene Marine(?)-Fluvial(?)

Eight cores penetrated pre-Holocene deposits at varying depths throughout the barrier island system. Every transect contained at least one representative. Two distinctly different sedimentary facies were identified; a fine to coarse sand with gravel facies (H), and a clayey silt to silty clay facies (I). Sand deposits were initially encountered in all but two cases. Horizontal to sub-horizontal laminations, planar cross-bedding, and small ripple laminae were common. Fine-grained deposits often were completely bioturbated although some well-preserved physical structures were present.

Coarse-grained samples grouped with three different cluster facies (4, 5, and 6). Cluster facies 4 contained only pre-Holocene samples and was characterized as a muddy fine sand. Group mean grain size was 2.98ϕ and on average, greater than 20% mud was present. All samples were obtained from cores at least one-half mile from the mainland on a very gently seaward sloping surface (Figures 65 and 66). Sedimentologic characteristics were consistent with those associated with modern shoreface and sandy tidal flat environments. Consequently, a marine environmental interpretation is suggested.

Cluster facies 6 contained only pre-Holocene gravelly coarse sand samples with an average mean grain size of 0.57ϕ and an average of 14% gravel. All samples were taken from cores located in the vicinity of fluvial paleochannels (Gargathy Creek, Parker Creek). Halsey (1978) identified similar deposits along a cross-section just south of the study area and related these deposits to late Wisconsinan(?) regressive spit deposits. The configuration of Hog Neck at transect 4 (see Figure 64) and the predominance of samples from core M6 in this cluster facies possibly suggests a similar interpretation.

The remaining pre-Holocene sand samples were associated with medium to fine beach sands (cluster facies 5) of the modern barrier island system. Samples were taken from cores located near the scarped mainland shoreline. Average mean grain size for this group was 1.98ϕ and sand content was greater than 95%. Horizontal to sub-horizontal laminations and planar cross-bedding were common. Finkelstein (1986) described similar samples in pre-Holocene deposits along the southern Delmarva Peninsula and classified them as Pleistocene beach-shoreface units.

Microfaunal examination showed nearly devoid sand deposits; consistent with high-energy beach environments but uncommon for shoreface deposits (Todd and Low, 1961). It is possible that post-depositional leaching of these once subaerial deposits may have affected abundance.

Sediment collected from fine-grained pre-Holocene deposits grouped with Holocene lagoon-muddy tidal flat samples in cluster facies 3. Clayey silt to silty clay deposits were highly compacted, contained minor amounts of organic material, and exhibited faint microlaminations disturbed by microlocomotion bioturbation. These characteristics were consistent with those found in Holocene lagoonal deposits. However, fine-grained deposition in fluvial environments can produce similar sedimentary facies (Reineck and Singh, 1980).

Spatial Distribution of Primary Depositional Environments

Six primary depositional environments recorded the spatial significance of barrier island system elements during the Holocene transgression at four shore-perpendicular transects. Longshore variations in the distribution of specific lithosomes has had a important impact on barrier island evolution. Although little large-scale morphologic variability in backbarrier environments has occurred historically, island configuration has changed significantly. This section presents the spatial distribution of depositional environments in the Metompkin barrier island system.

Transect 1. Backbarrier deposition associated with transect 1 was affected by sedimentation processes at Metompkin Inlet. A sandy tidal flat environment characterized surface and near-surface deposits (approximately 1.5 m thick) in southern Metompkin Bay (Figure 84). This represents the modern flood-tidal shoal system associated with Metompkin

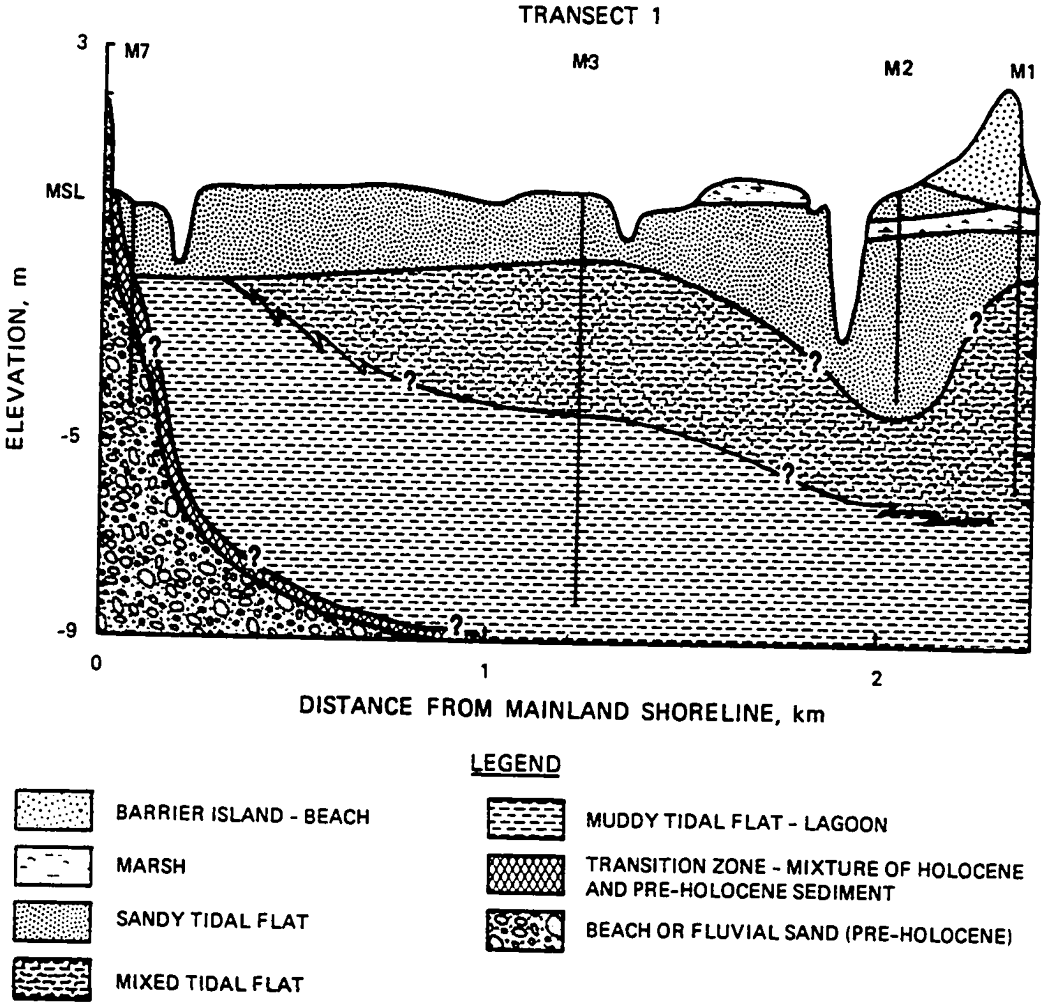

Figure 84. Cross-section illustrating primary depositional environments along transect 1.

Inlet. Below the sandy tidal flats was a mixed tidal flat environment, possibly resulting from less frequent contact with inlet processes when the island was seaward of its present position. Greater exposure to fine-grained deposition in backbarrier environments produced a silty sand mixture. The deepest Holocene unit represented a muddy tidal flat-lagoon environment. The deposit appeared to be the most prominent unit along transect 1. Barrier island sand deposits were perched upon a thin layer of marsh as well as sandy tidal flat sediment.

A transition zone between Holocene and pre-Holocene sediment was encountered in the landwardmost core only, even though core M3 reached a depth of -8.25 m MSL. This suggests the presence of an antecedent valley, possibly associated with the old Folly Creek drainage basin. Halsey (1978) has shown that the paleochannel of Folly Creek was filled with at least 15 m of Holocene lagoonal clayey silt, emphasizing the importance of this system as a sink for fine-grained material.

Transect 2. Patterns of deposition along transect 2 were influenced by ephemeral inlet activity and washover. Consequently, deposition of sand in Metompkin Bay was intermittent and produced a mixed sand and mud tidal flat. Since inlet breaching was fairly regular between 1957 and 1980, silty sand deposits extended to depths exceeding 2 m below MSL. However, sediment associated with a muddy tidal flat-lagoon environment was the dominant Holocene unit (Figure 85). Cores M13 and M14 penetrated barrier island-beach and inlet fill-washover deposits on the landward side of Metompkin Island. The two sections were approximately 50 m apart and depositional sequences were very similar. Thus M13 stratigraphically represents both cores on the cross-section.

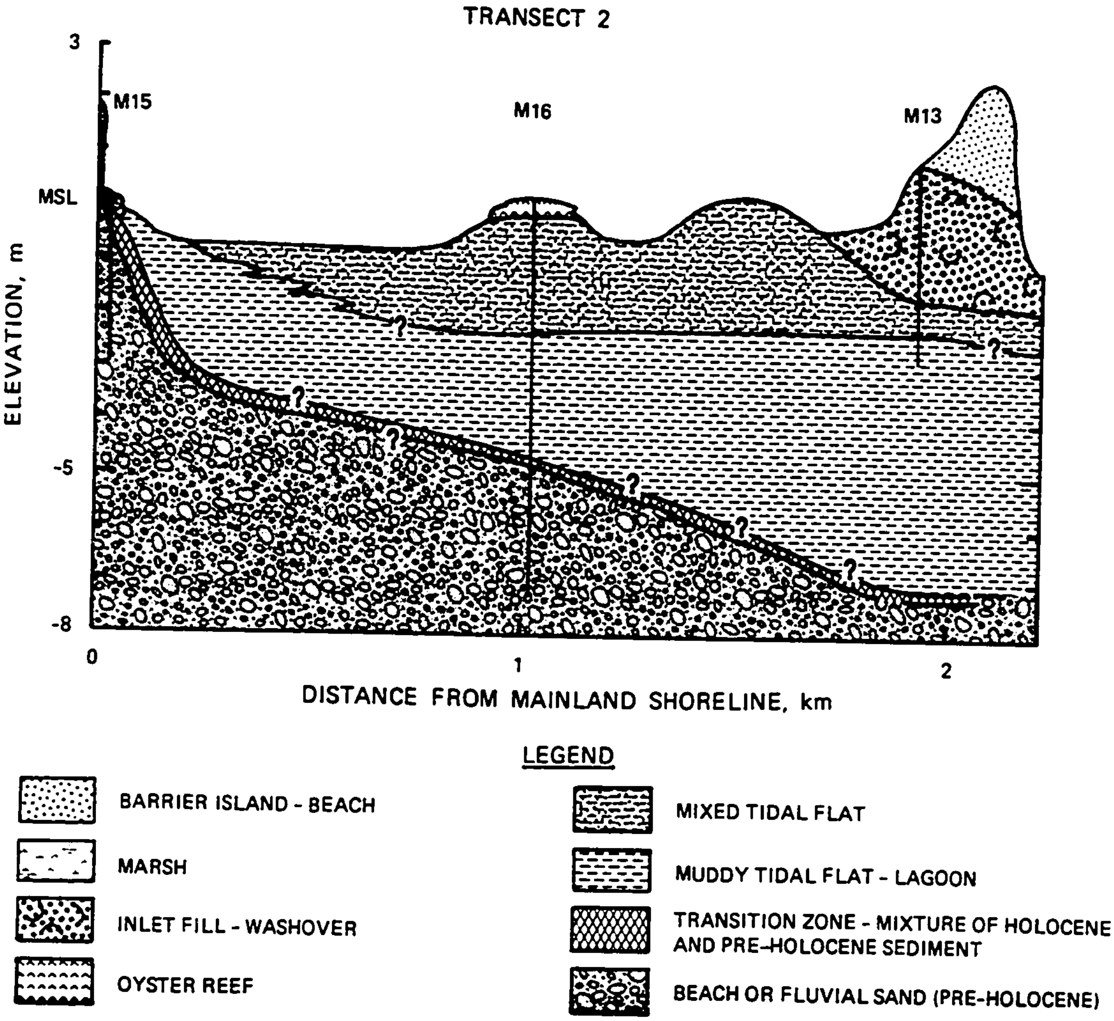

Figure 85. Cross-section illustrating primary depositional environments along transect 2.

The transition zone just above the pre-Holocene surface was encountered at -4.66 m MSL, 1 km seaward of the mainland shoreline at core M16, and at M15 where a thin layer of fringing marsh topped the pre-Holocene sequence. Beach or fluvial sand deposits were found at both positions. More importantly, the pre-Holocene surface was penetrated at a much more shallow position than that associated with transect 1. Therefore, less material may have been necessary for lagoonal infilling during the Holocene.

Transect 3. Deposition along transect 3 was associated with a muddy tidal flat-lagoon environment (Figure 86). Thick sequences of clayey silt and silty clay filled the backbarrier environment along northern Metompkin Island from the pre-Holocene surface. A layer of marsh caps this deposit and barrier island-beach sand (via washover) becomes perched on marsh as the island migrates landward. Thick deposits of marsh and lagoonal sediment outcrop on the seaward side of the island at MLW.

An extensive tidal channel fill sequence was found at M11 as alternating layers of lagoonal mud and littoral sand. Field observations suggest that deposition at this site possibly was associated with breaching at a nearby tidal channel where the island has since migrated over the nearby channel, leaving it exposed to littoral processes. This unit provided the only deviation from fine-grained lagoonal infilling at transect 3.

Pre-Holocene deposits were quite variable for this cross-section. A transition zone and basal peat layer capped pre-Holocene sand deposits at the two landwardmost cores while an erosional contact between Holocene and pre-Holocene lagoonal mud marked the boundary at M9. A highly

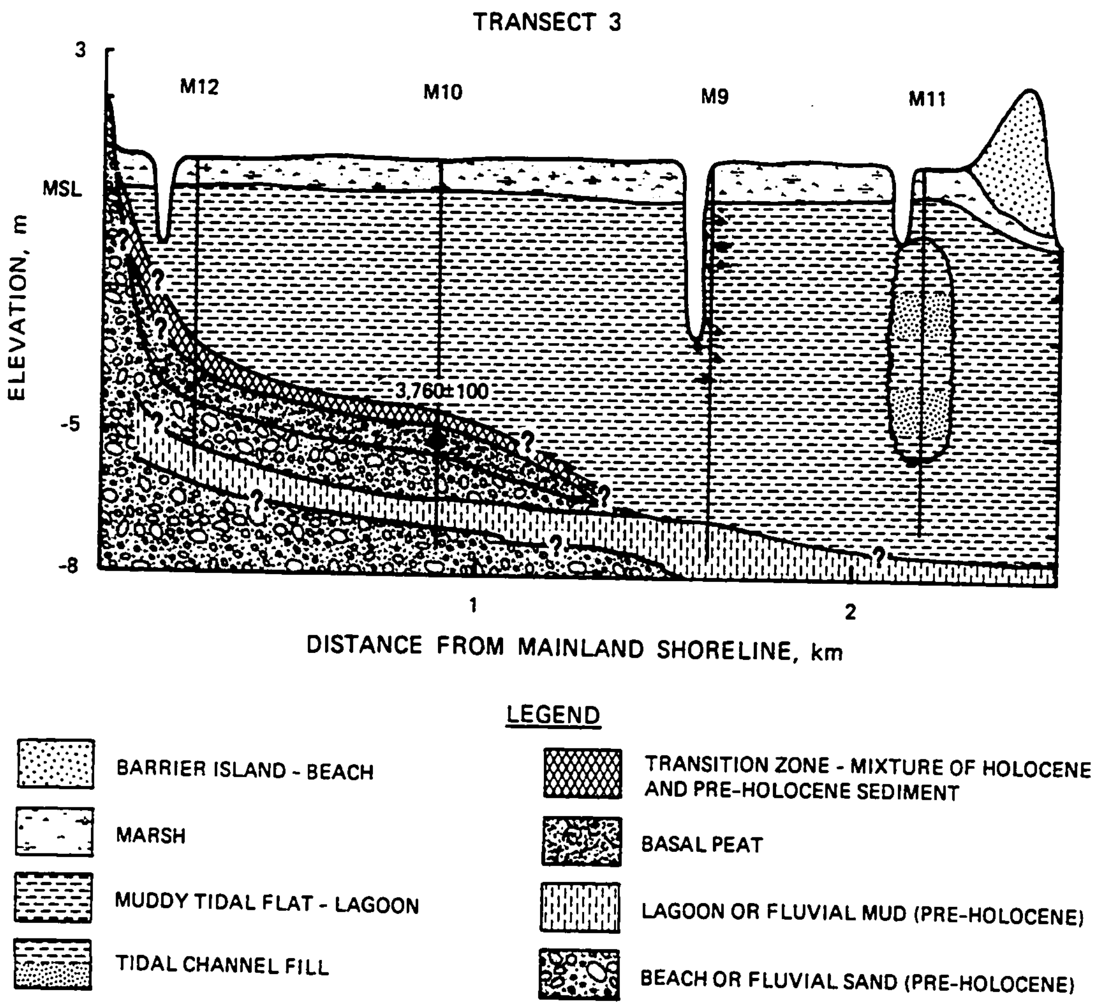

Figure 86. Cross-section illustrating primary depositional environments along transect 3.

dewatered, blue-grey, pre-Holocene clayey silt layer extended landward between two pre-Holocene sand and gravel layers. Several characteristics were used to distinguish pre-Holocene and Holocene clayey silt deposits including a dramatic change in sediment water content and color, the presence or absence of foraminiferida, and stratigraphic position relative to adjacent sequences. Although a date could not be associated with this boundary at M9 due to the absence of basal peat, Finkelstein and Ferland (1987) took a core 700 m due north of this position and dated a basal peat from approximately -6.3 m MSL at 4,620 ± 80 years BP.

Transect 4. The northernmost transect again illustrated an extensive muddy tidal flat-lagoon sequence (Figure 87). Barrier island-beach deposits rested on lagoonal sediment that could be traced to a position just seaward of the surf zone. Marsh deposits were well developed and up to 2 m thick. A tidal channel fill deposit was dominant at core M4 and could be associated with sedimentation at Wire Passage.

The landwardmost two cores had relatively thin Holocene sequences because the pre-Holocene was very shallow at these positions. As sea level rose over a relatively gently sloping surface during transgression, less fine-grained material was needed to fill the backbarrier lagoon, and fringing marsh deposits could develop a more extensive unit. Sand and gravel characterized most pre-Holocene samples at this transect.

Longshore Distribution. Table 23 summarizes the dominant sedimentary characteristics of each primary depositional environment and Figure 88 provides a general stratigraphic sequence for the Metompkin barrier island system. The muddy tidal flat-lagoon environment was dominant at all transects. Although deposits in this environment were laterally

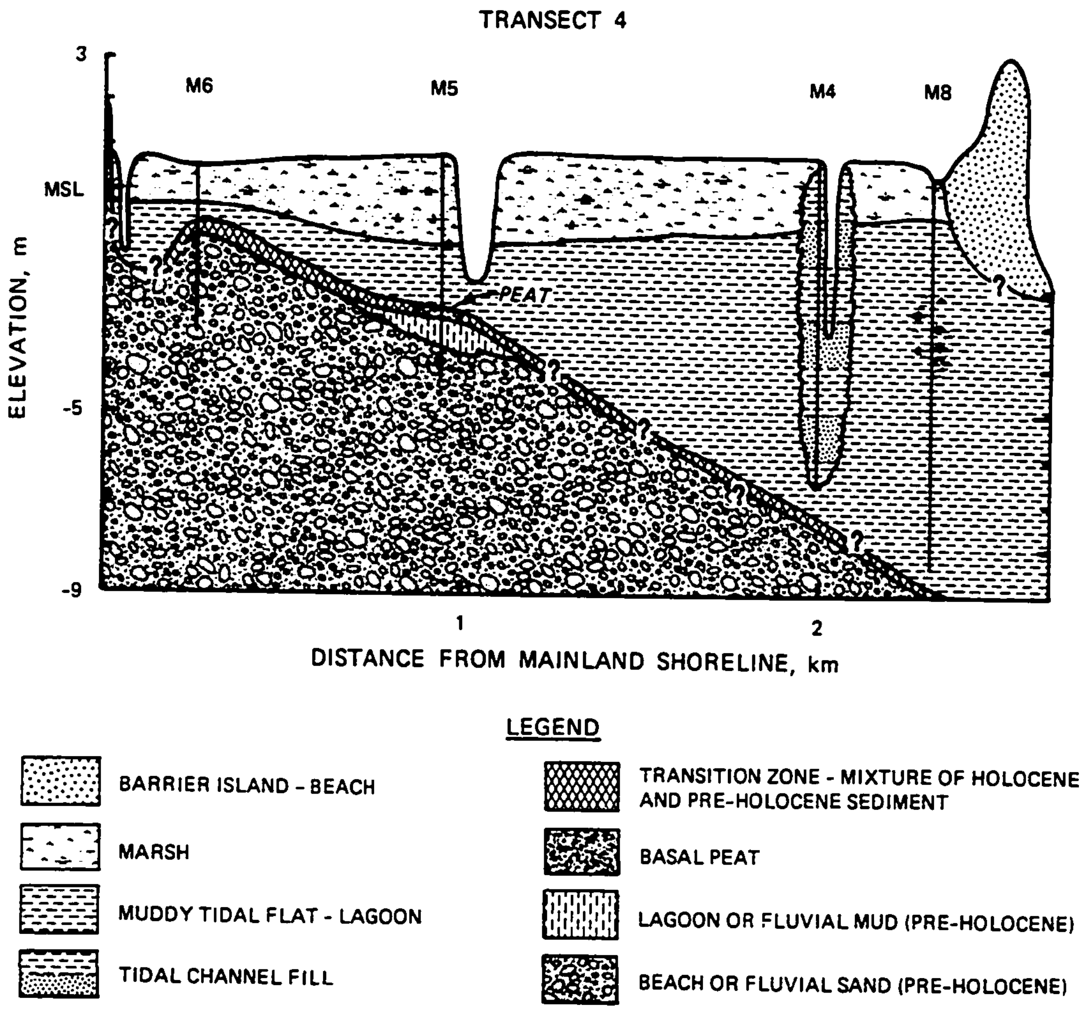

Figure 87. Cross-section illustrating primary depositional environments along transect 4.

TABLE 23

Characteristics of Primary Depositional Environments

Depositional Environment	Sedimentary Facies	Primary Sedimentary Structures	Thickness (m)	Biota
Barrier Island-Beach	tan to grey, M-F sand; well sorted	low-angle and horizontal planar laminae	2.5-3.0	numerous C. virginica and M. mercenaria shells and shell frags.; few calcareous forams
Marsh	grey to dark grey, organic rich, clayey silt to silty clay; very poorly sorted	extensive root bioturbation	0.5-2.0	S. alterniflora, S. patens C. virginica; very few agglutinated forams
Sandy Tidal Flat	light brownish-grey, F-VF sand; moderately well to poorly sorted	horizontal to sub-horizontal laminae; ripple laminations; planar cross-bedding; some microlocomotion bioturbation	0.5-3.0	few shell frags.; calcareous and agglutinated forams common - E. excavatum, A. parkinsoniana, H. germanica, B. frigida, genus Trochammina
Mixed Tidal Flat	grey to dark grey, silty sand to clayey silt; moderately to poorly sorted	flaser and lenticular bedding; interbedded mud and sand; macrolocomotion bioturbation common; polychaete burrows	2.0-4.0	L. irrorata, C. virginica; abundant forams; calcareous and agglutinated-E. excavatum, B. frigida, A. parkinsoniana, H. germanica, T. inflata, A. dilitatus
Muddy Tidal Flat-Lagoon	grey to dark grey, clayey silt to silty sand; very poorly sorted	bioturbation common; polychaete burrows; microlocomotion structures; some faint horizontal to sub-horizontal laminae	2.0-8.0	some marsh root fragments; L. irrorata, C. virginica; few forams, mostly agglutin.; T. inflata, T. squamata, M. fusca, H. germanica
Inlet-Washover	tan to grey, C-F sand with shells and shell fragments; very poorly sorted	very distinct horizontal to sub-horizontal laminae; ripple foresets and trough cross-bedding	1.0-2.5	Donax sp., Mulinia sp., C. virginica, M. mercenaria, S. solidissma; very few forams

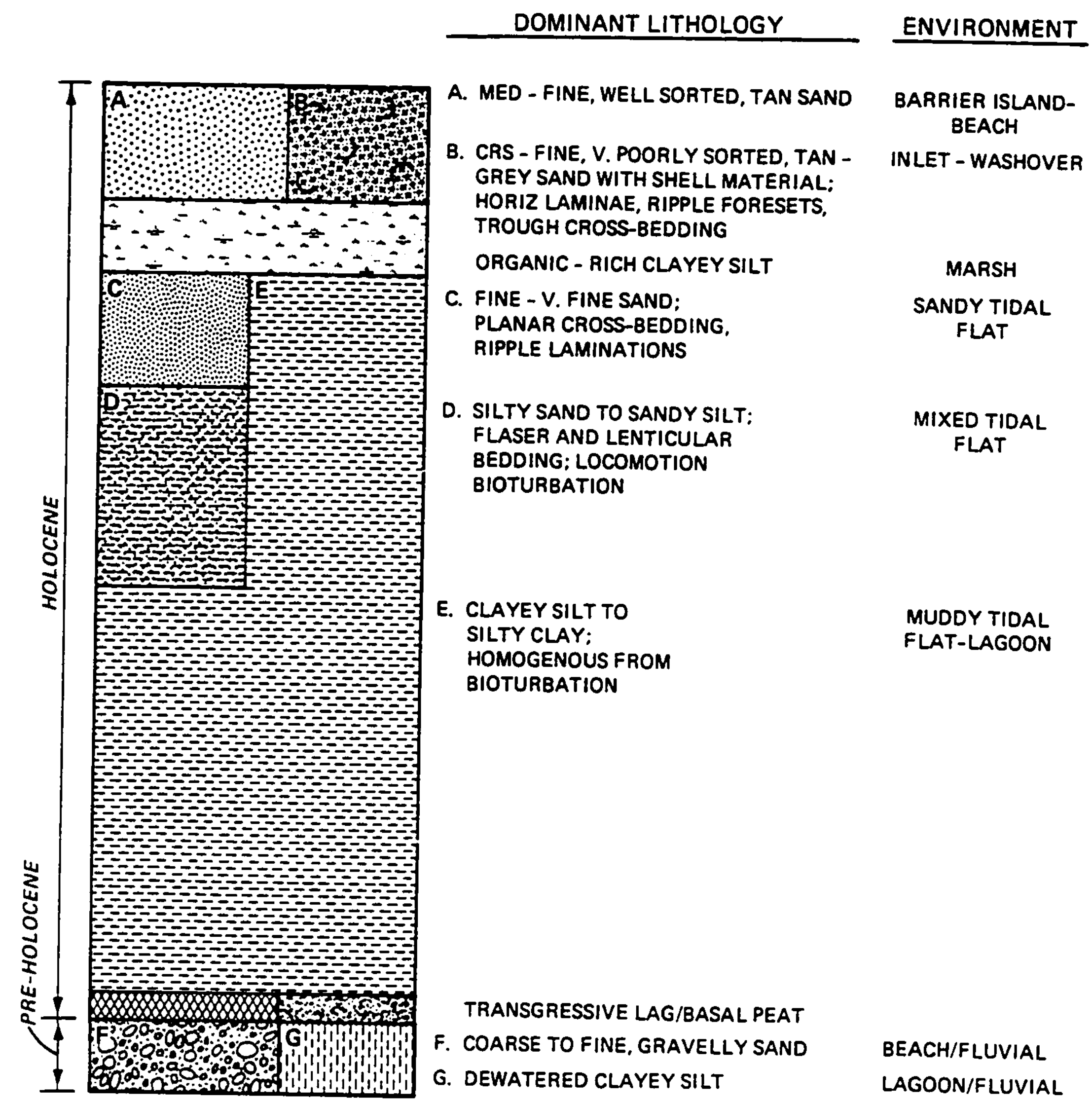

Figure 88. General stratigraphic sequence for the Metompkin barrier island system.

continuous, the vertical extent along transects varied systematically. The northern two transects were composed of this fine-grained facies from the pre-Holocene surface to the modern marsh surface. A carbon^{14}-dated basal peat in core M10 (-5.25 m MSL) supported the presence of an offshore barrier island for at least the past 3760 ± 100 years. In addition, historical lateral adjustments in the position of Gargathy Inlet appeared to have had little influence on lagoonal infilling as recorded by the spatial consistency of grain size. Sedimentation during geologic time also suggests a stable, protected backbarrier region, shielded from littoral processes by a seaward barrier.

At transect 4, sediment deposition in the marsh environment produced fine-grained units averaging 1.2 m thick, suggesting that backbarrier infilling was keeping pace with sea level rise. Finkelstein and Ferland (1987) obtained carbon^{14} dates of Holocene marsh deposits along a transect 700 m north of transect 3. Dates of 1,180 and 1,660 years BP were recorded at approximately 0.8 and 1.1 m below the marsh surface. Assuming marsh deposits represent growth with rising sea level, this suggests that fine-grained deposition without excessive marsh growth along transect 4 ceased approximately 2,000 years ago. Marsh deposits capping lagoonal sediment along transect 3 were on average 0.6 m thick, suggesting a longer period of time for lagoonal infilling. Again, earlier Holocene barrier island deposits may have provided a continuous natural barrier to coastal wave and current processes, enabling such a thick unit of fine-grained lagoonal sediment to be deposited.

Although sediment characteristics associated with mixed tidal flat deposits were similar at transects throughout the Metompkin barrier island system, position within the sequence and the occurrence of specific microfauna were different. Along transect 1, a silty sand and sandy silt facies was below an extensive modern sandy tidal flat environment and may be related to sedimentation processes at Metompkin Inlet during barrier island recession. Foraminifera populations were most diverse in samples associated with this historically stable inlet. At transect 2, this facies represented a surface deposit and could be related to storm washover and ephemeral inlet breaching. Since inlet closure has historically followed storm breaching, the influence from tidal exchange of water and sediment would be significantly reduced as compared to deposits resulting from continual exchange at stable openings. Consequently, a decrease in the absolute number and diversity of foraminiferida should be apparent since both increase with more marine influence (Murray, 1973). Although the occurrence of individuals did decrease, the number of species remained nearly constant (Table 19; M16-3 versus M3-5). However, the abundance of lagoonal species increased, possibly suggesting a decrease in the magnitude and duration of water exchange between the shoreface and lagoon at ephemeral inlets.

A pervasive morphologic characteristic common to southern Metompkin Island was the open-water backbarrier region. Only fringing marsh deposits were common, in contrast to northern Metompkin, where backbarrier regions were at least 90% marsh-filled. Inlet breaching has provided significant amounts of nearshore sand to backbarrier regions that subsequently provided a platform for island deposits during recession. Although relict inlet shoals are subaqueous and provide less subaerial support than the elevated marsh surface to the north, they become a source of beach sand during transgression.

Although the occurrence of lagoonal deposits becomes less significant along southern Metompkin Island, they still represented a major Holocene deposit, emphasizing the existence of a protective barrier seaward of the study area during geologic time. More recent deposition has been controlled by storm-generated inlet breaches but earlier historic records indicated a continuous island approximately 2 km seaward of the 1980 island shoreline (Figure 36).

Metompkin Island System Evolution

Geomorphic models have been used frequently to depict evolutionary trends in the development of a barrier island. Observations were generally based on comparative aerial reconnaissance surveys (McGowen and Scott, 1975; Hosier and Cleary, 1977) and field investigations of geological and ecological data (Godfrey and Godfrey, 1974). To date, a model of barrier island system development incorporating geomorphic and geologic characteristics, historical shoreline change data, and closely spaced cross-island surveys has yet to be developed for non-subsiding barrier coastlines. Boyd and Penland (1981) proposed a three-stage model depicting the evolution of barrier shorelines along abandoned Mississippi River deltas but regional subsidence trends provided a unique situation for development and subsequent response of these features. The model being proposed in this study specifically addresses rapidly migrating, low-profile barrier island systems along tectonically stable coastlines. However, high-profile barriers could be included in this scheme since the rate of coastal response is basically a function of island morphology and the intensity of coastal processes. In other words, low-profile island environments respond much more rapidly to specific storm events whereas islands of greater vertical and horizontal extent require longer or larger events to exhibit a similar response (Hayes, 1967).

The following discussion introduces a 5-stage evolution model for the Metompkin barrier island system:

Stage 1 - A radiocarbon date of 3,760 ± 100 years BP was obtained from a basal peat at -5.25 m MSL in core M10. Assuming this deposit represents fringing marsh formed when sea level began to inundate this region, its presence indicates that Metompkin Island existed as a coastal sand deposit at least 0.9 km seaward of its present position, at the -5.25 m depth contour, assuming no net offshore sedimentation during transgression. This distance represents a minimum since the island may have been further seaward and backed by a lagoon environment similar to that found in the modern barrier island system. Finkelstein and Ferland (1987) recorded a Holocene radiocarbon date of 4620 ± 80 years BP at -6.60 m from a core taken behind northern Metompkin Island. At this depth contour, the island would have been at least 1.1 km seaward of the modern shoreline. The island likely was extensive and stable since lagoonal mud was consistently the basal Holocene unit in cores recovered from the present backbarrier system.

As sea level rose, the lagoon began to slowly expand due to a relatively steeply-dipping, scarped mainland surface (Figure 66). However, the rate of coastal inundation was not uniform due to topographic variations on the pre-Holocene surface. Northern Metompkin was more elevated than other portions of the system and the rate of backbarrier infilling in the southern region around Metompkin Inlet probably was influenced by the antecedent valley of Folly Creek.

Stage 2 - Historical data indicate that the 1852 shoreline was 0.8 km seaward of its present position, suggesting that the island was relatively stable up to this time. Even if the island existed 1 km seaward of the minimum shoreline position established by carbon^{14} dating, long-term island retreat rates were insignificant compared to historical island adjustments. Therefore, continued rise in sea level produced a greater cross-sectional area in the lagoonal environment that continued to fill with fine-grained material. However, the rate of infilling could not keep pace with rising water level during early stages of backbarrier development. Clayey silt continued to deposit throughout ancient Metompkin Bay. Since there was no stratigraphic evidence of large-scale, pre-historic inlet breaching, as evidenced by relatively thick and contiguous Holocene fine-grained lagoonal deposits, it can be assumed that the barrier island may have been experiencing a period of relative stability. Furthermore, sea level was rising (Finkelstein and Ferland, 1987) and island morphologic change may have included upward growth and possibly seaward progradation. The source of beach sand was probably headland shorelines along the northern Delmarva Peninsula and southerly longshore transport nourished the beach along Metompkin Island (Corps of Engineers, 1973; Rice et al., 1976; Halsey, 1978; Kraft et al., 1979; Goettle, 1981). Consequently, fine-grained backbarrier deposition could continue uninterrupted.

Along northern Metompkin Island, the rate of lagoonal infilling likely varied relative to that in Metompkin Bay. Longshore variations in shape of the pre-Holocene surface exist beneath the modern backbarrier environment (Figure 65). The pre-Holocene surface is present at depths greater than -8 m MSL behind southern Metompkin Island where fine-grained sediment was filling the antecedent valley of Folly Creek during this time. Conversely, pre-Holocene deposits along northern Metompkin Island are present at depths as shallow as -1 m MSL. Therefore, as sea level rose, fine-grained sedimentation patterns throughout the evolving backbarrier environment probably were influenced by variations in pre-Holocene topography.

A potential source of fine-grained material to backbarrier environments was reworked coastal deposits exposed to nearshore processes during transgression. Fine-grained sediment from the ocean may be transported through inlets and into the lagoon where it accumulates at depths unaffected by wave resuspension. Newman and Munsart (1968) suggested this mechanism of infilling for lagoonal environments behind Parramore Island, Virginia. Harrison (1971) stated that large clasts of marsh peat found on Metompkin Island after storms, and mud found in bottom and near-bottom suspended sediment samples near Metompkin Inlet indicated that a majority of fine-grained sediment originated from exposures of marsh and tidal flat sediment seaward of the barrier island.

Based on carbon^{14} dates of Holocene marsh deposits (Finkelstein and Ferland, 1987), northern Metompkin backbarrier regions were filling with mud at a rate consistent with rising sea level approximately 1600 years ago. Continuous marsh deposits were between 0.6 to 2 m thick along transects 3 and 4. In addition, thicknesses decreased to the south, exhibiting the potential influence of varying topographic relief on the pre-Holocene surface. Metompkin Bay was still relatively deep (1 to 4 m) and remained active as a sink for fine-grained sediment.

Stage 3 - During historic times, shoreline recession was evident. Early rates along Metompkin Island were quite low (2 m/yr between 1852 and 1888) but a major regional change in shoreline trend in the mid to late 1800's dramatically affected island response. The formation of an extensive complex spit environment at the south end of Assateague Island (see Figure 1) effectively isolated island environments to the south from a needed source of beach sediment (Halsey, 1978; Goettle, 1981). As a result, the ocean beach at Metompkin Island became more susceptible to erosion. Continued downdrift extension of this feature since 1887 has created a 6 km offset, making it increasingly more difficult to transfer sand to downdrift beaches.

An increase in the extent of fine sand flood-tidal delta deposits in the open-water lagoon of Metompkin Bay is believed to be a response to an increase in island recession. Island width continued to decrease at a rate of approximately 7 m/yr until critical island dimensions were encountered and inlet processes controlled the rate of shoreline change (Figure 82).

Stage 4 - By 1955, the high water shoreline had moved about 500 m landward of its 1852 position and more importantly, island width narrowed to as little as 250 m. As a result, significant changes in backbarrier deposits could be associated with extremely dynamic island adjustments that occurred over the following 25 years. The process of storm washover and inlet breaching along southern Metompkin Island controlled the distribution of sand in northern Metompkin Bay while Metompkin Inlet supplied sand to southern bay regions (Figure 62).

Continual inlet breaching between 1955 and 1980 produced a highly mobile southern island segment, exhibiting a retreat rate up to 6 times greater than that recorded for the previous 100 years. Northern Metompkin also migrated during this time but the rate was significantly lower due to the absence of inlet breaching and the presence of a relatively stable marsh platform to migrate onto during recession.

Between 1980 and 1985, Metompkin Island responded to coastal processes as one continuous unit (no inlet breaches). From 1983 to 1985, cross-island profile measurements illustrated low rates of island retreat along southern Metompkin and rates similar to historical trends along the northern island segment. Uninterrupted longshore transport and the absence of inlets resulted in a reversal in short-term shoreline response. It appeared that coastal wave and current processes were attempting to redistribute sediment to produce a straightened coastline.

Stage 5 - Future island adjustments will continue to be controlled by variations in island morphology, particularly the presence or absence of inlets. If current recession trends continue, Metompkin Island will merge with the scarped mainland shoreline by 2150. Although the southern island segment is typically more dynamic, nearshore sand transported into Metompkin Bay as washover or flood-tidal deltas provides a recyclable source of sediment during island recession. Since northern Metompkin Island migrates onto an elevated marsh surface and marsh outcropping in the surf zone provides a barrier to onshore transport, longshore and offshore losses of sand during major storm events become essentially non-renewable. Therefore, northern Metompkin Island is much more likely to slowly dissipate during landward migration.

CONCLUSIONS

A time-integrated approach was adopted to examine the depositional patterns associated with barrier island evolution. Three data sets were utilized: 1) historical shoreline position data from 1852 to 1981; 2) two years of cross-island profile change data at 10 locations along 6.2 km of shoreline; and 3) stratigraphic, sedimentologic, and foraminiferal data from 16 vibracores along four coast-perpendicular transects. The main purpose of this study was to examine the extent to which lateral facies changes in the backbarrier region affect the migration and evolution of low-profile barrier island systems. Using Metompkin Island as an example, four major objectives were proposed: 1) to determine the importance of inlet and overwash processes on island evolution; 2) to quantify sediment mobility along two sections of barrier shoreline; 3) to determine lateral and vertical facies relationships of backbarrier lithosomes; and 4) to derive an evolutionary model for the development of the Metompkin barrier island system.

The following is a summary of major findings related to the evolution of Metompkin Island.

1) Analysis of historical shoreline position data indicate rapid island recession between 1955 and 1980. Differential rates of retreat were identified and associated with an abrupt break in backbarrier morphology at mid-Metompkin Island. The southern island segment migrated

about 3 times the rate of the northern barrier shoreline. However, intense inlet breaching also occurred during this time period along southern Metompkin Island and was considered to be the dominant influence on island evolution.

Subaerial shoreline position data from a two-year (1983-1985) island profiling study indicated a greatly reduced rate of shoreline recession along southern Metompkin Island. The barrier responded to varying coastal processes as one continuous unit until Hurricane Gloria created a breach along the southern bay-backed island segment in September 1985. Prior to Gloria, the rate of retreat along southern Metompkin was 2.9 m/yr compared to 9.3 m/yr for the northern island segment. Associated sand volume changes were 7.31 m^3/m and -10.03 m^3/m, producing a net total island deficit of 1.64 m^3/m. Although the island shoreline experienced landward migration, sand volume was nearly conserved. Net island adjustments determined from post-Gloria island measurements illustrated a surplus of sand along southern Metompkin where shoreline recession averaged 4.15 m/yr. However, the northern island segment exhibited a deficit of 19.34 m^3/m and a retreat rate of 16.13 m/yr. Although erosion was dominant, significant quantities of washover nourished the landward side of the island as it receded.

A comparison of short-term and historic shoreline recession trends suggested that inlet activity had significantly altered natural migration patterns and was the cause of the 400 m offset at a position midway along the island. Although morphologic changes in the backbarrier environment were considered secondary factors in controlling migration patterns, inlet breaching may not have occurred if Metompkin Bay had been filled with marsh. Consequently, storm processes and inlet breaching are believed to be the driving mechanisms for rapid change, however, the occurrence of inlets is influenced by geologic characteristics.

2) Holocene vertical sequence data support the generalized models of coastal evolution during transgression (Kraft et al., 1973; Kraft et al., 1979). Longshore variations in lithosome geometry and occurrence were related to sediment source and the presence or absence of inlets. Six major depositional environments characterized the system. They included: A) barrier island-beach (including dune and backshore sub-environments); B) inlet-washover; C) marsh; D) sandy tidal flat; E) mixed tidal flat; and F) muddy tidal flat-lagoon.

Along northern Metompkin Island, backbarrier infilling with fine-grained material from offshore created thick sequences of lagoonal silt and clay capped by extensive marsh deposits. Exhumed marsh and lagoon deposits on the seaward side of Metompkin Island provide a significant local source of mud. Conversely, thick, coarser-grained deposits associated with southern Metompkin backbarrier regions are related to the positions of permanent and ephemeral inlets and washover. Extensive sand and silty sand tidal flats were more pronounced towards the southern end of the island where Metompkin Inlet governed sedimentation patterns.

3) Pre-Holocene topographic changes partially controlled Holocene depositional patterns during lagoonal infilling. Holocene lagoonal sediment generally thickens from west to east and from north to south. The northern marsh-filled backbarrier region exhibited an elevated pre-Holocene surface relative to the antecedent valley of Folly Creek at southernmost Metompkin Island. The amount of material needed for

lagoonal infilling was significantly lower to the north where marsh growth is extensive whereas Metompkin Bay has very little marsh growth associated with backbarrier deposition. Metompkin Inlet likely occupied the position of this antecedent valley and an open-water lagoon still exists behind southern Metompkin Island.

4) A model of evolution for the Metompkin barrier island system utilized geologic and historic data in providing a description of the stages of development. A relatively stable, barrier island was situated at least 1 km seaward of its present position approximately 3500 to 4000 years ago. The presence of thick, contiguous, clayey silt deposits provided evidence for the existence of a well-protected backbarrier region during Holocene development. A relatively shallow pre-Holocene surface influenced backbarrier infilling behind northern Metompkin Island. Since *Spartina sp.* are associated with periods of subaerial and marine subaqueous exposure, thick marsh sequences (0.6-2 m) indicated that fine-grained deposition was keeping pace with sea level for approximately the past 1600 years. Fine-grained deposition in the antecedent Foliy Creek channel behind southern Metompkin Island could not keep pace with rising water level, thereby producing a thick sequence of lagoonal mud (Halsey, 1978). Variations in pre-Holocene topography likely influenced sedimentation dynamics and an open-water bay formed along the southern half of the system. Only fringing marsh deposits were observed in this area.

A period of relative shoreline stability existed until the supply of beach sediment was significantly reduced by the formation of Fishing Point at southern Assateague Island between 1859 and 1887 (Goettle, 1981). Concurrent with this event, the Metompkin Island shoreline began to recede at an average rate of 7 m/yr. Island width and possibly height decreased significantly, and by 1957, inlet breaching and overwash became primary driving mechanisms for subsequent island changes. Inlet processes controlled the rate of shoreline change along southern Metompkin Island and washover was significant along the entire island.

Subaerial sediment budget data from cross-island profiles illustrated partial sand volume loss associated with barrier rollover; more importantly, it showed that when inlets were present, the rate of shoreline retreat increased by a factor of eight. Inlet-related shoals were recognized in Metompkin Bay as sand deposits overlying lagoonal muds. An increase in the percentage of sand was directly related to inlet proximity and size. Coarsest backbarrier Holocene sand deposits were associated with Metompkin Inlet.

Supply of beach sediment to island environments is limited by longshore and onshore transport. Assuming that present trends in shoreline recession continue, predicted future adjustments place Metompkin Island at the mainland shoreline around the year 2150. However, sand volume losses associated with island transgression may eventually deplete the quantity of subaerial beach sediment, resulting in more rapid recession.

5) Finally, the proposed evolution model for Metompkin Island may have limited application to other low-profile barrier systems. Local variables such as sediment source and backbarrier characteristics make it difficult for universal application. However, the cycle of movement related to storm overwash and inlet breaching is predictable and may be applied to specific backbarrier conditions associated with any transgressive system.

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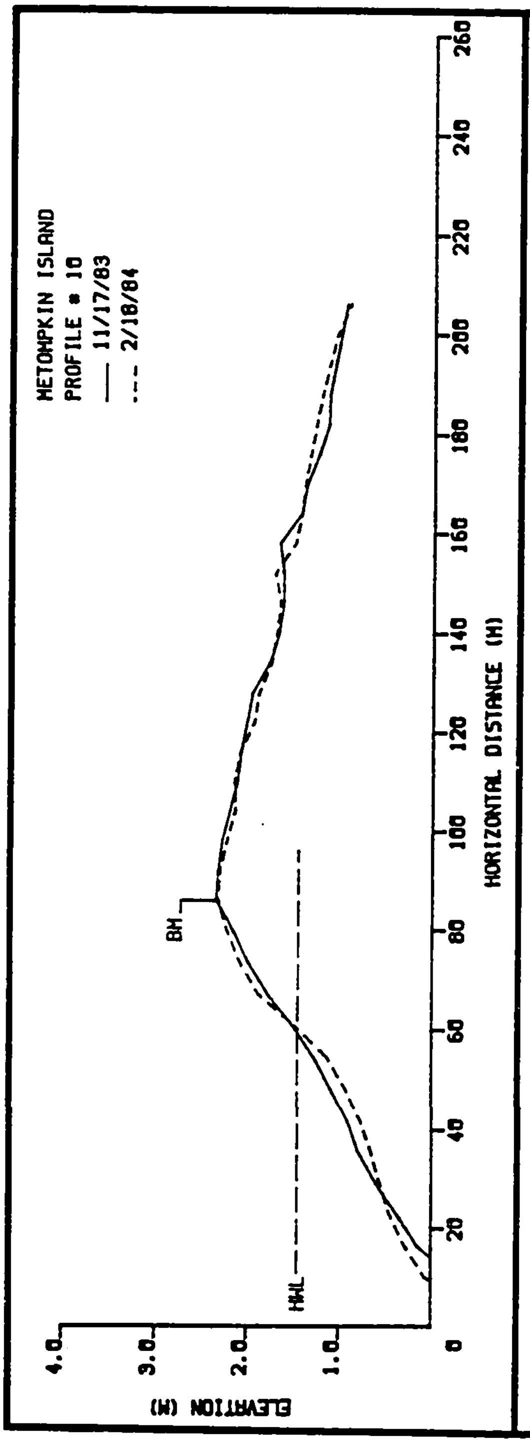
APPENDIX A

CROSS-ISLAND PROFILES

Southern Metompkin Island

Profiles 10-18

Incremental Change	Cumulative Change



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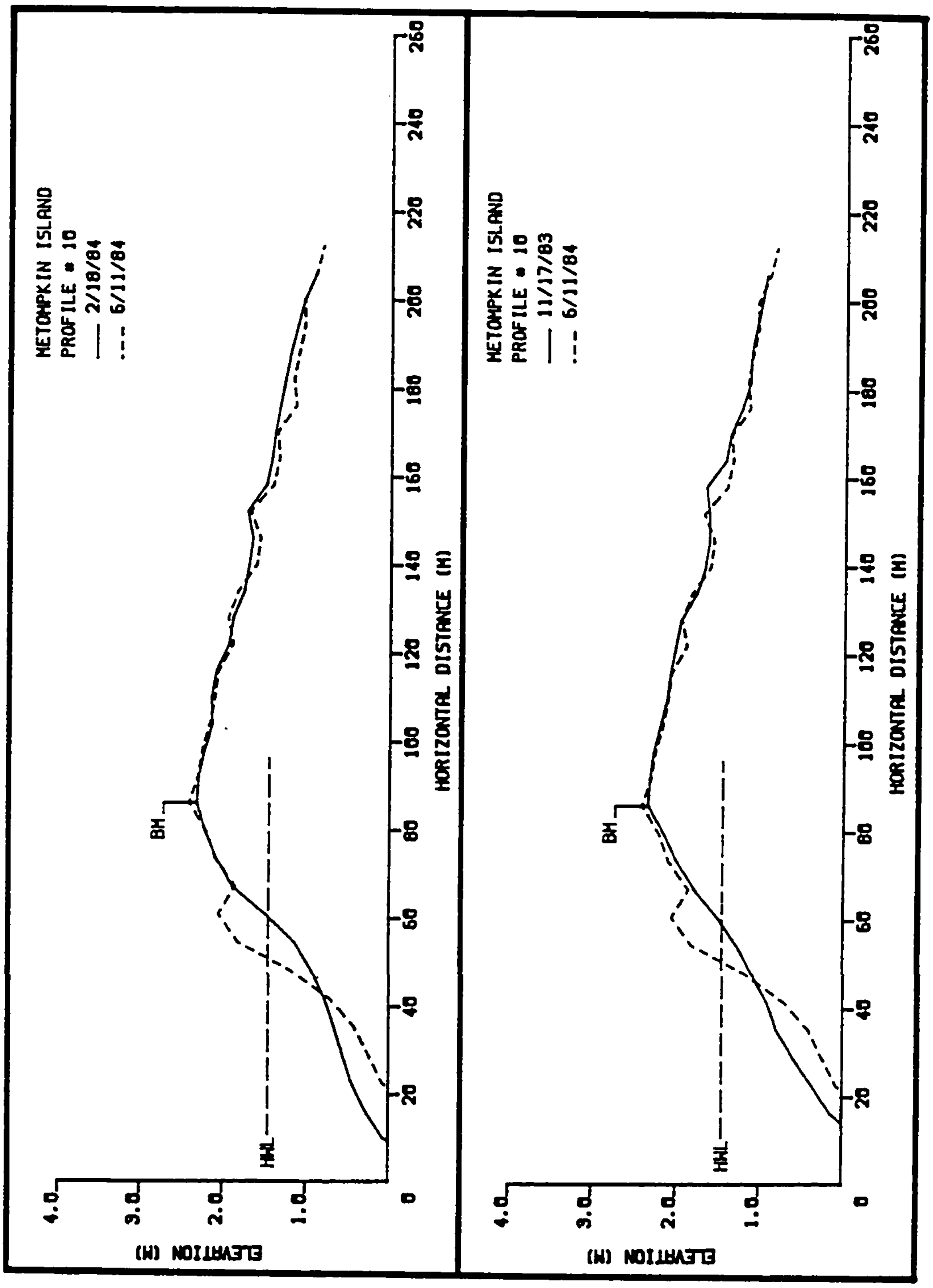
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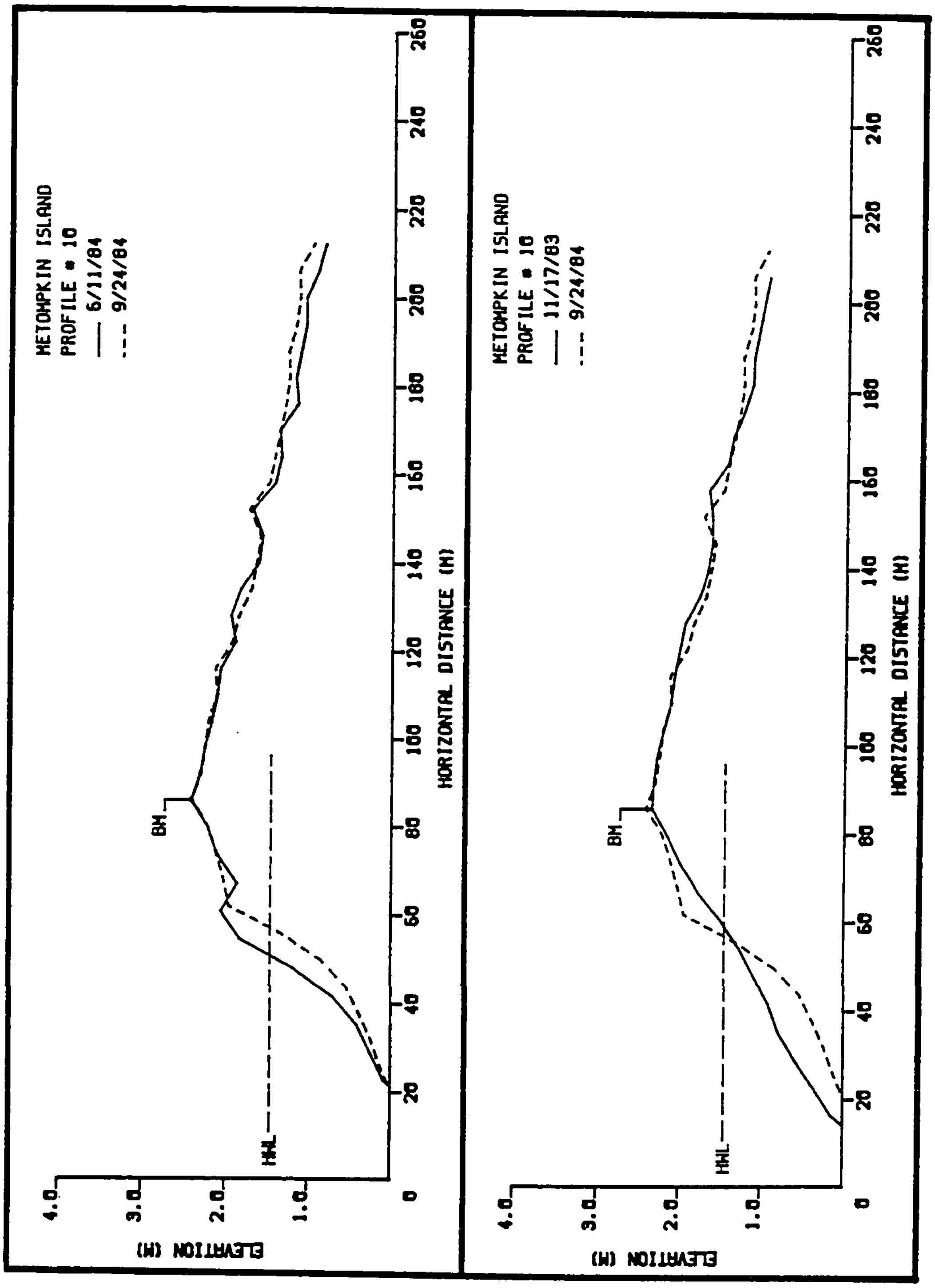
PROFILE = 10
—— 2/10/84
-·-- 6/11/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE = 10
—— 11/17/83
-·-- 6/11/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)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PROFILE # 10
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9/24/84
BM
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ELEVATION (M)
HORIZONTAL DISTANCE (M)
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ELEVATION (M)
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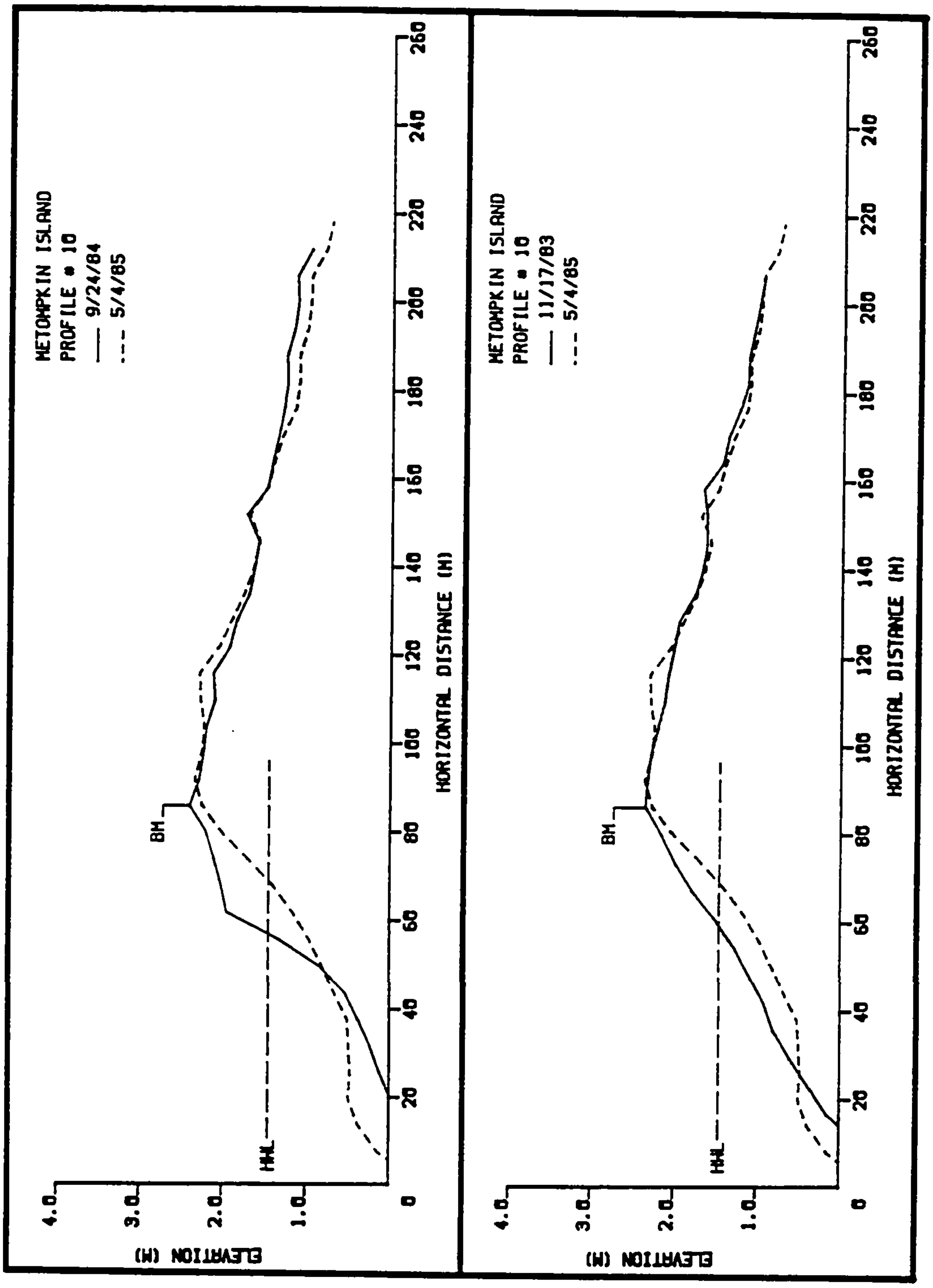
METOMPKIN ISLAND
PROFILE # 10
9/24/84
5/4/85
BM
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ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 10
11/17/83
5/4/85
BM
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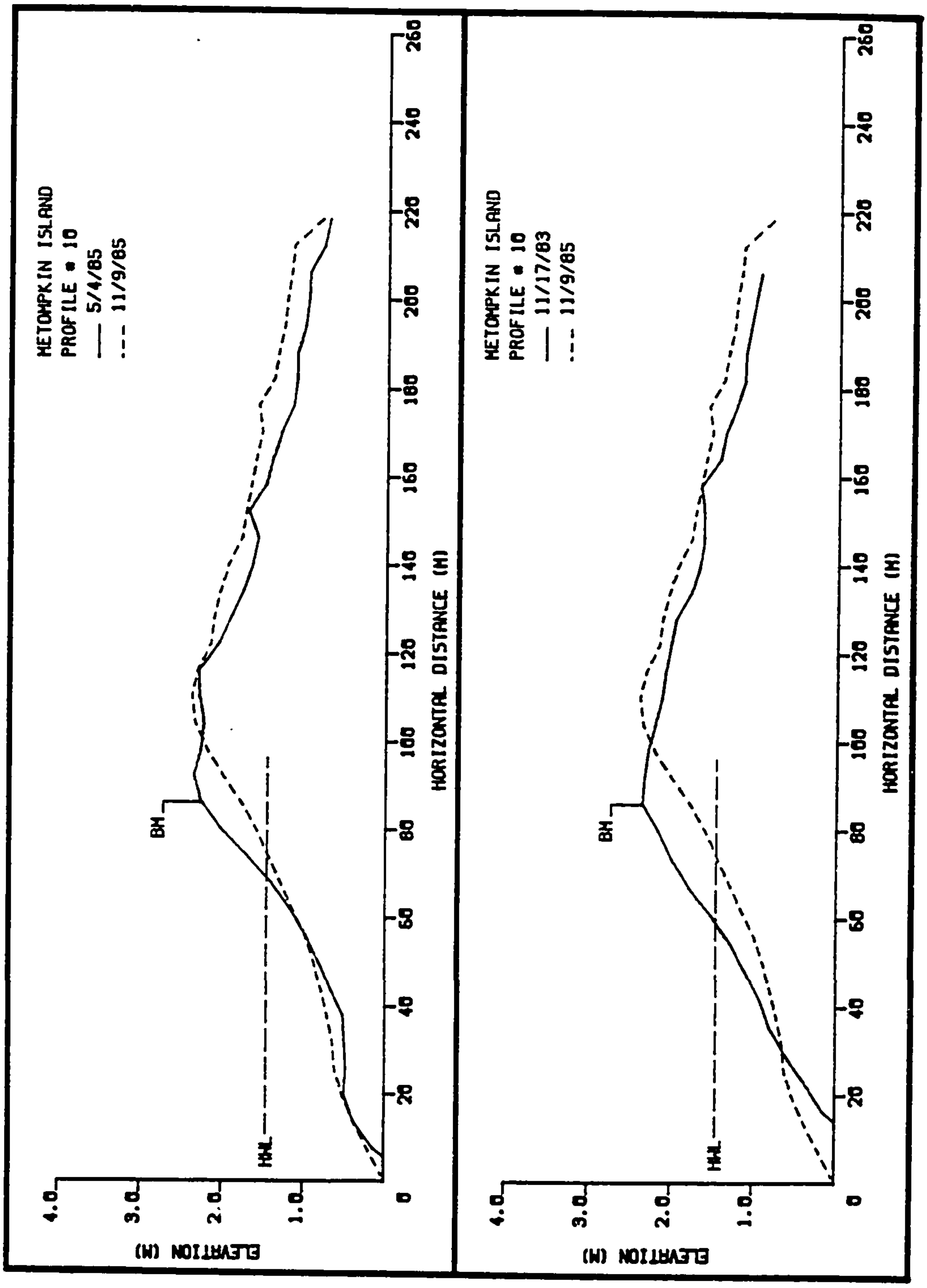
ELEVATION (M)
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 10
5/4/85
11/9/85
BM
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ELEVATION (M)
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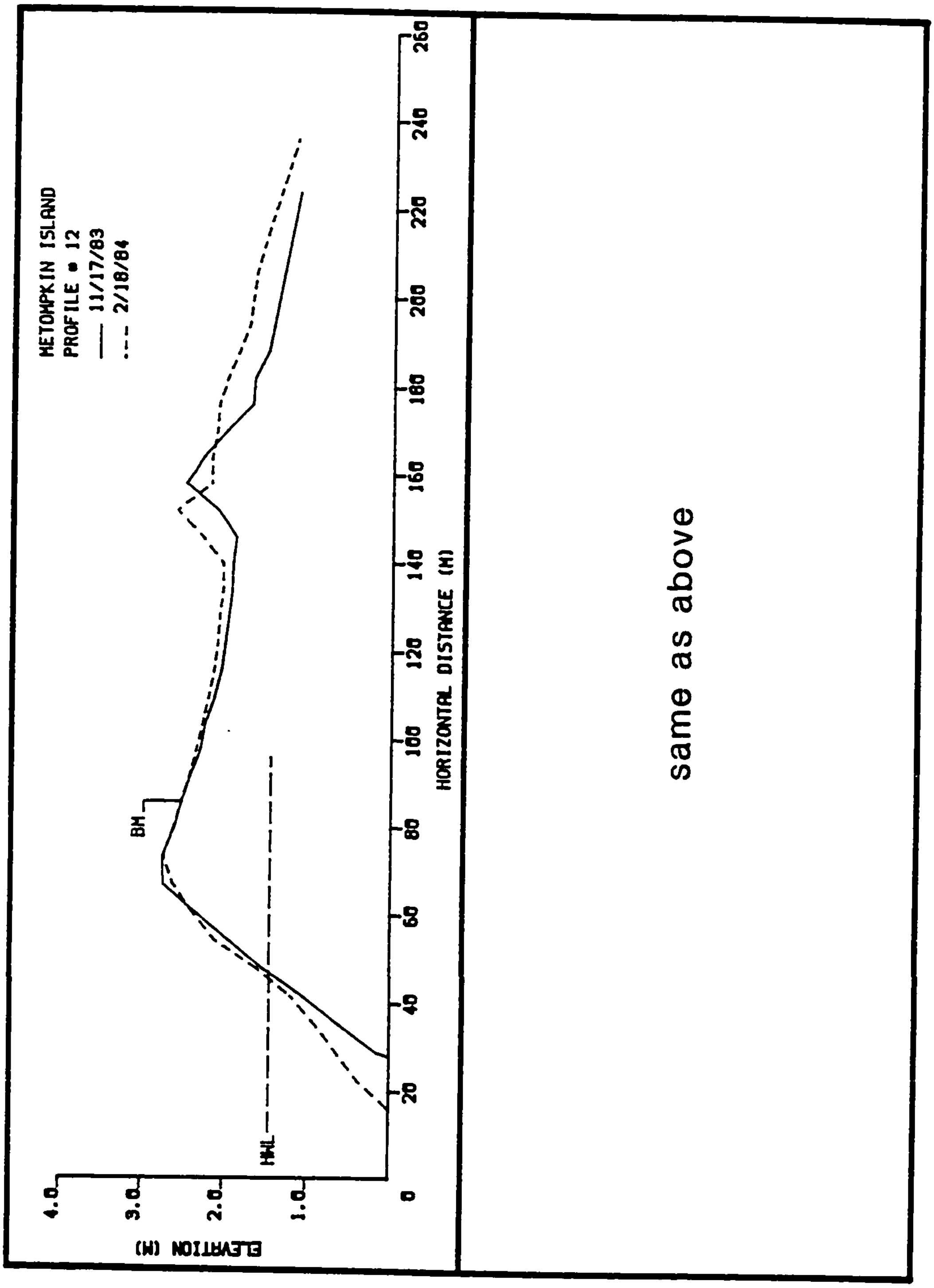
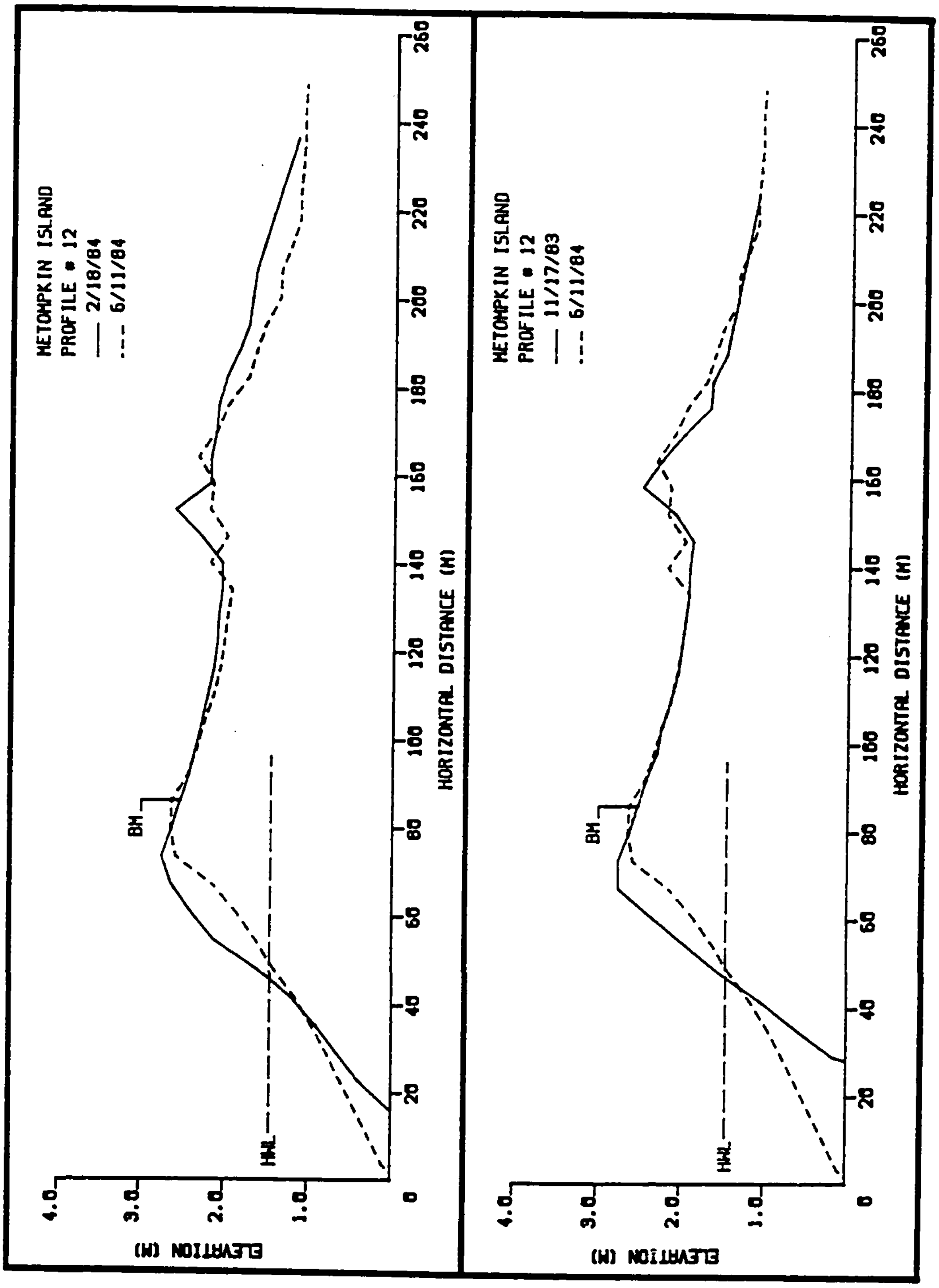
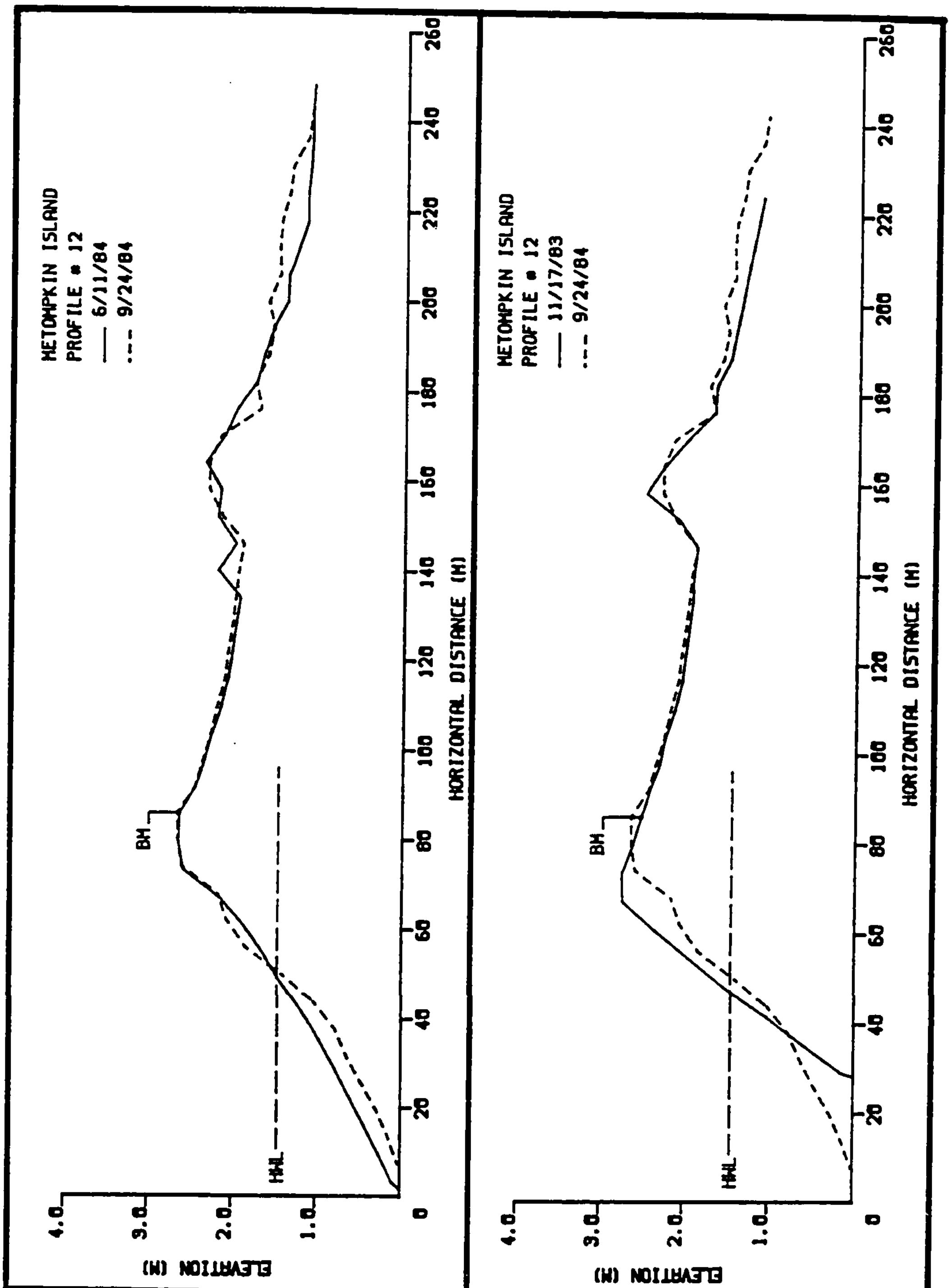
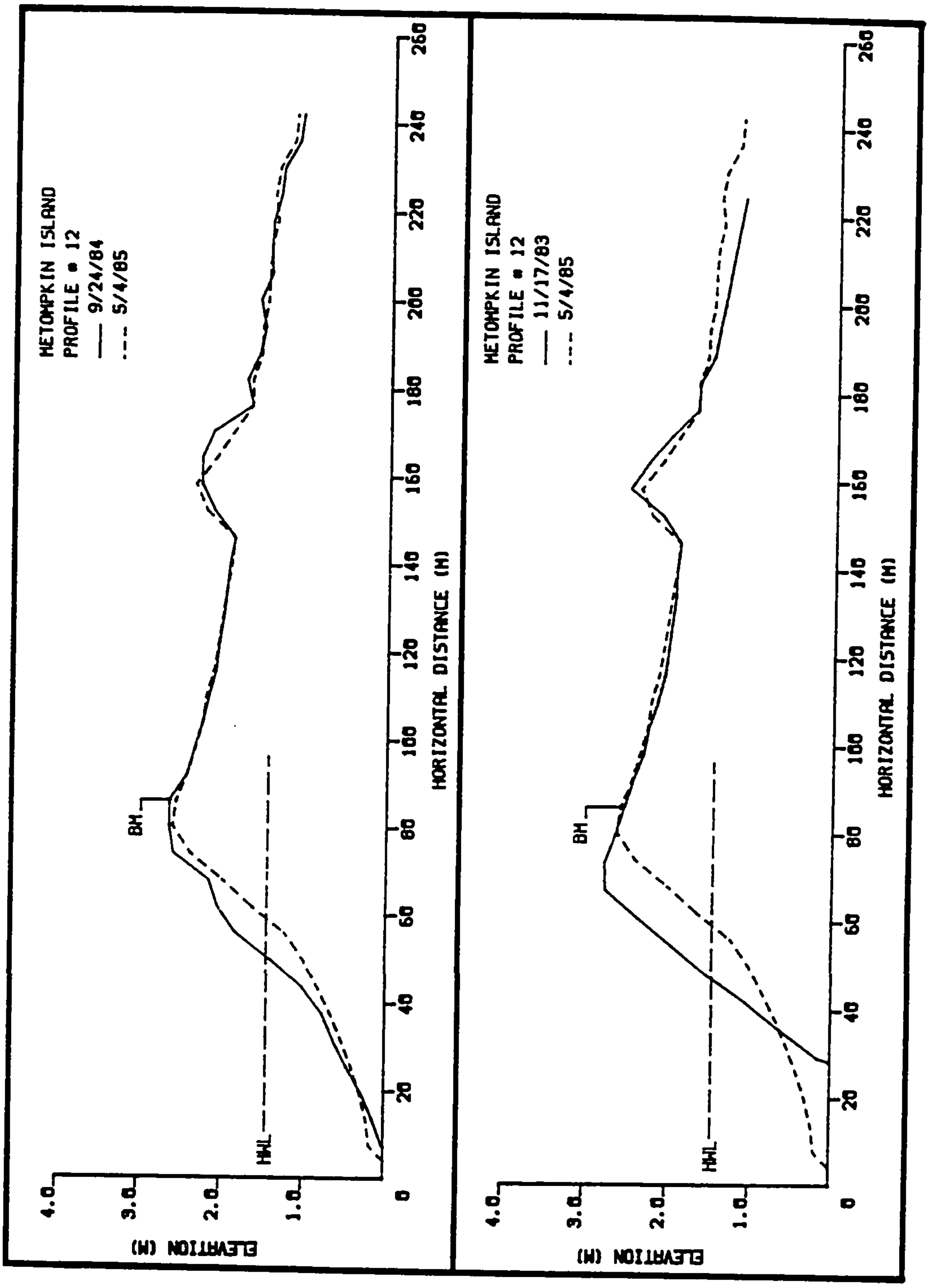
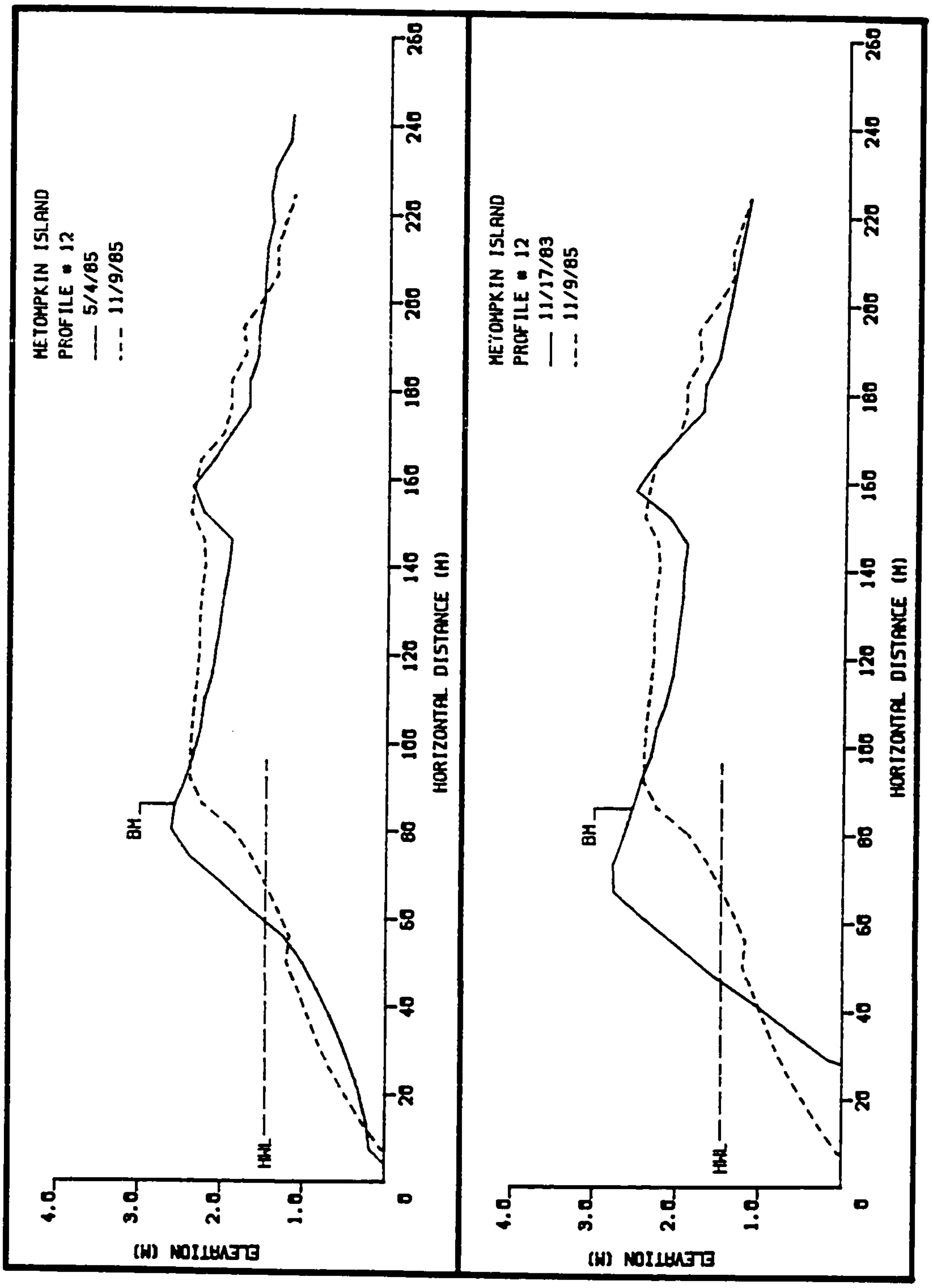
METOMPKIN ISLAND
PROFILE # 10
11/17/83
11/9/85
BM
MHW
ELEVATION (M)
HORIZONTAL DISTANCE (M)

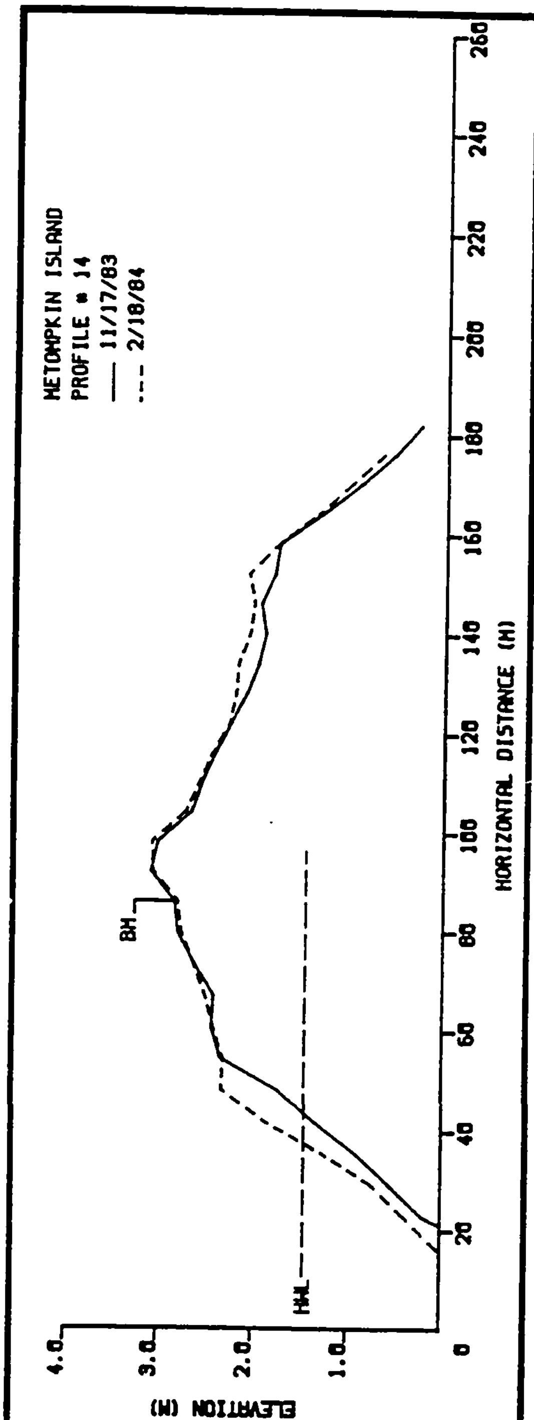

METOMPKIN ISLAND
PROFILE # 12
11/17/83
2/18/84
BM
ELEVATION (M)
HORIZONTAL DISTANCE (M)
same as above


METOMPKIN ISLAND
PROFILE # 12
—— 2/18/84
- - - 6/11/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 12
—— 11/17/83
- - - 6/11/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

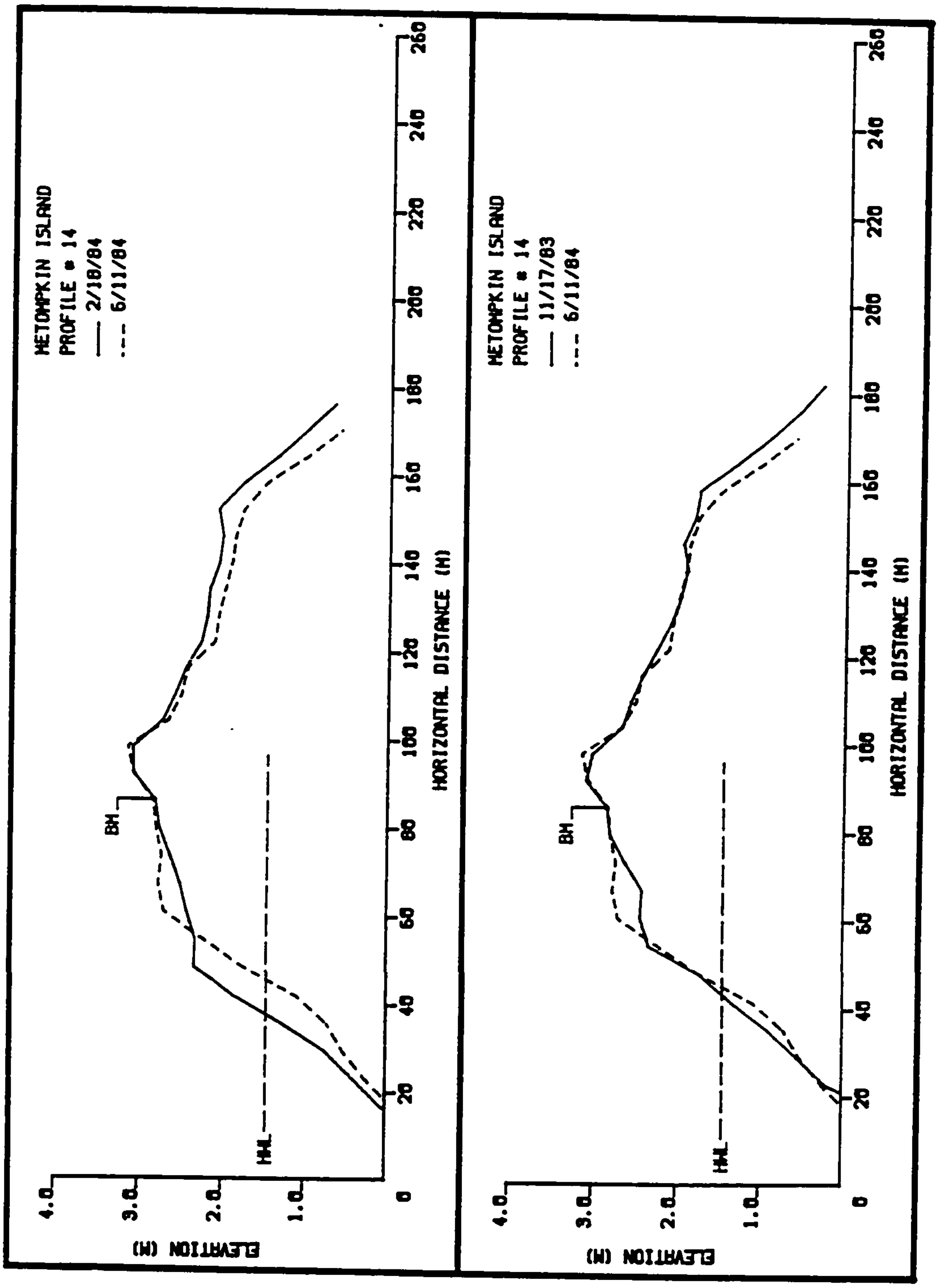

METOMPKIN ISLAND
PROFILE # 12
6/11/84
9/24/84
BM
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)
METOMPKIN ISLAND
PROFILE # 12
11/17/83
9/24/84
BM
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)

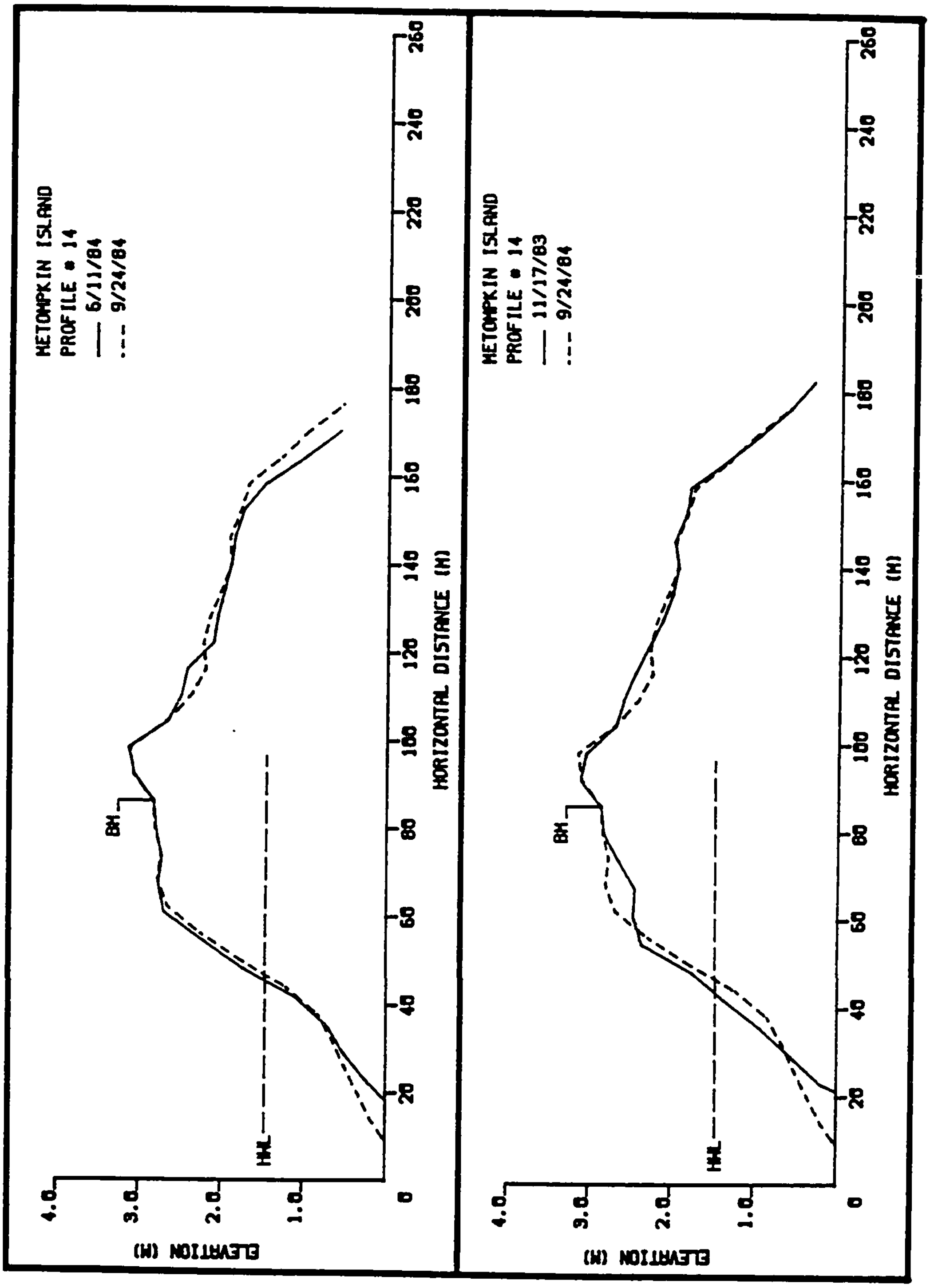

METOMPKIN ISLAND
PROFILE # 12
9/24/84
5/4/85
BM
HORIZONTAL DISTANCE (M)
ELEVATION (M)
METOMPKIN ISLAND
PROFILE # 12
11/17/83
5/4/85
BM
HORIZONTAL DISTANCE (M)
ELEVATION (M)

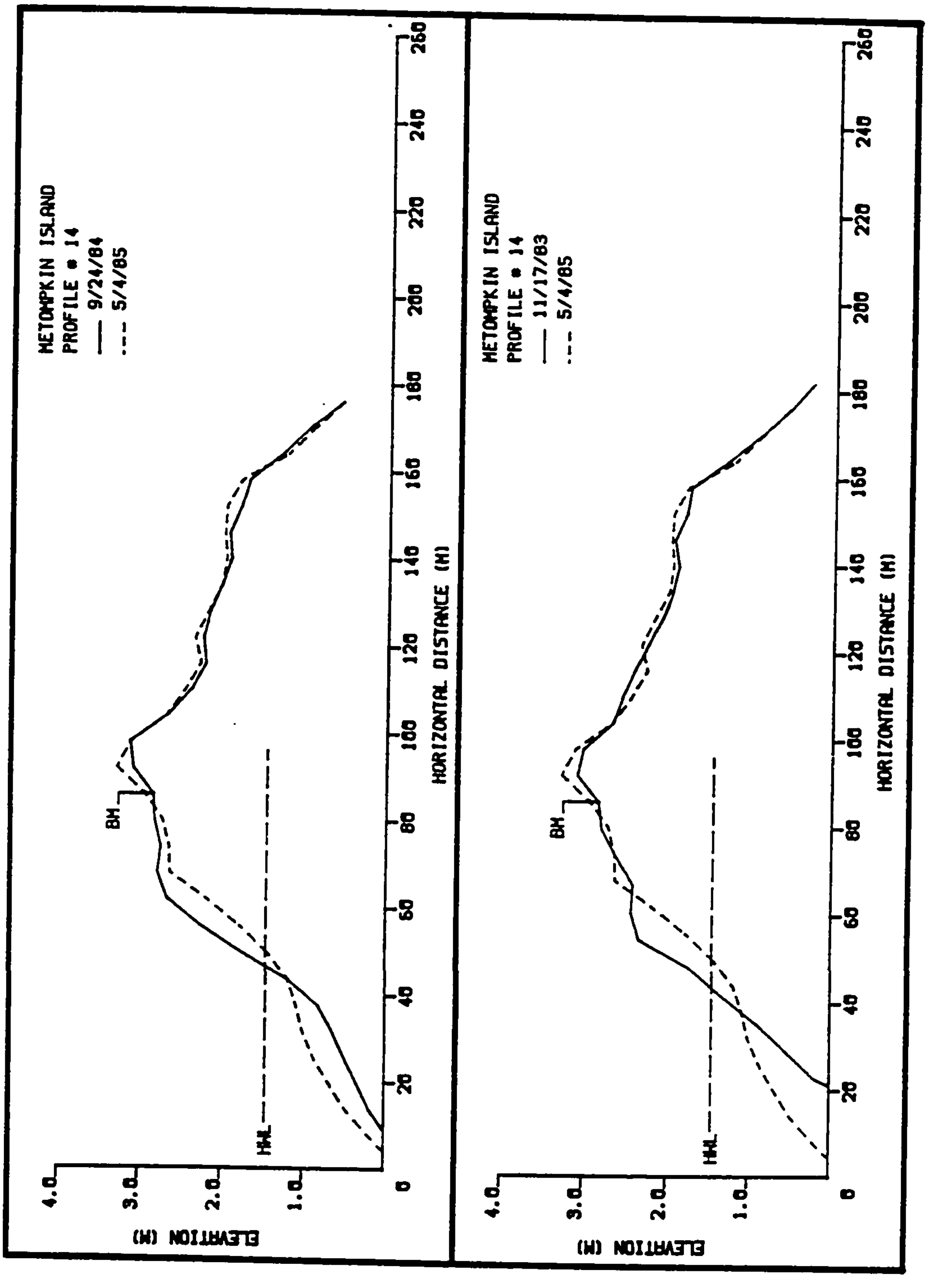

METOMPKIN ISLAND
PROFILE # 12
5/4/85
11/9/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 12
11/17/83
11/9/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

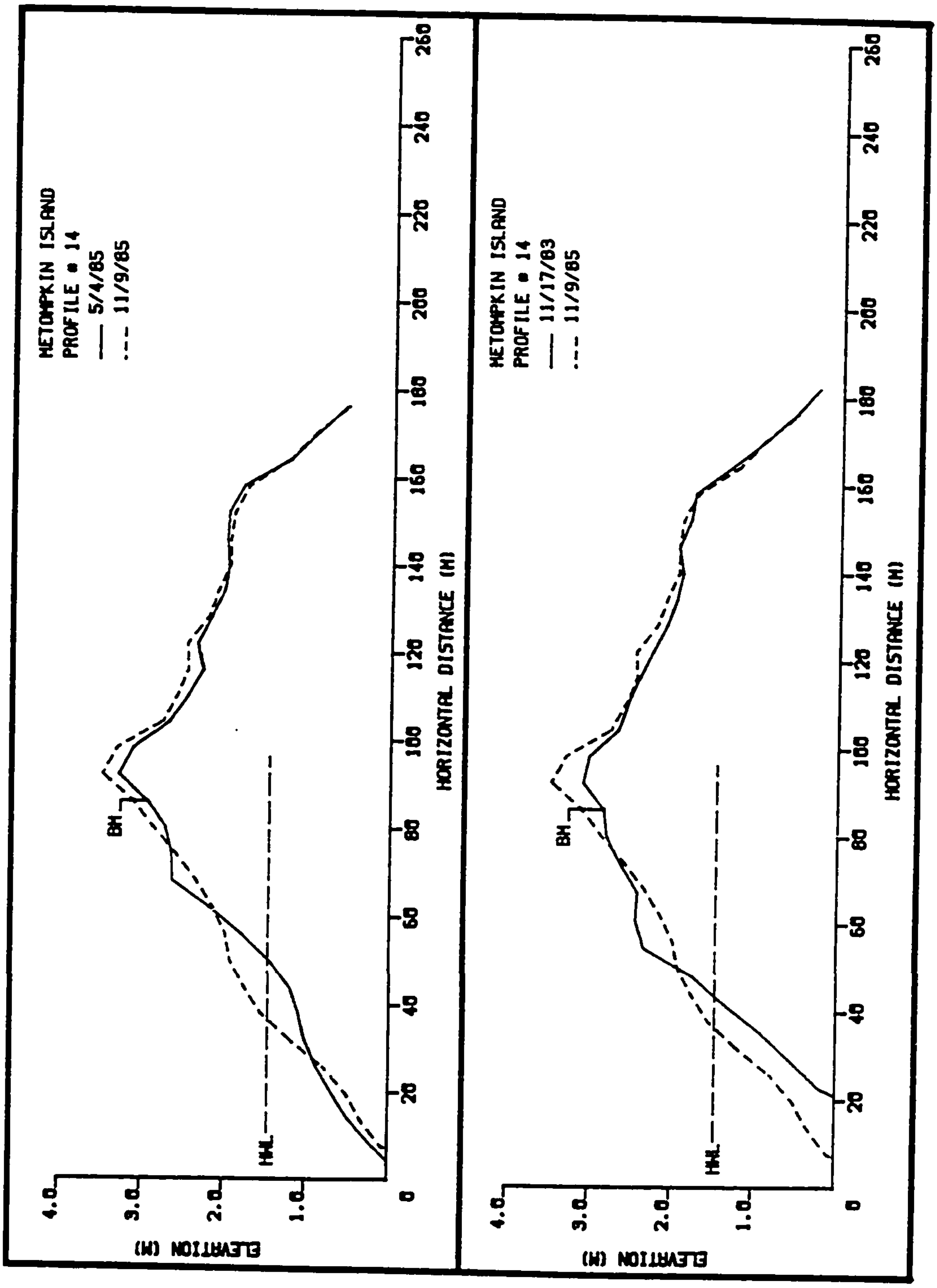


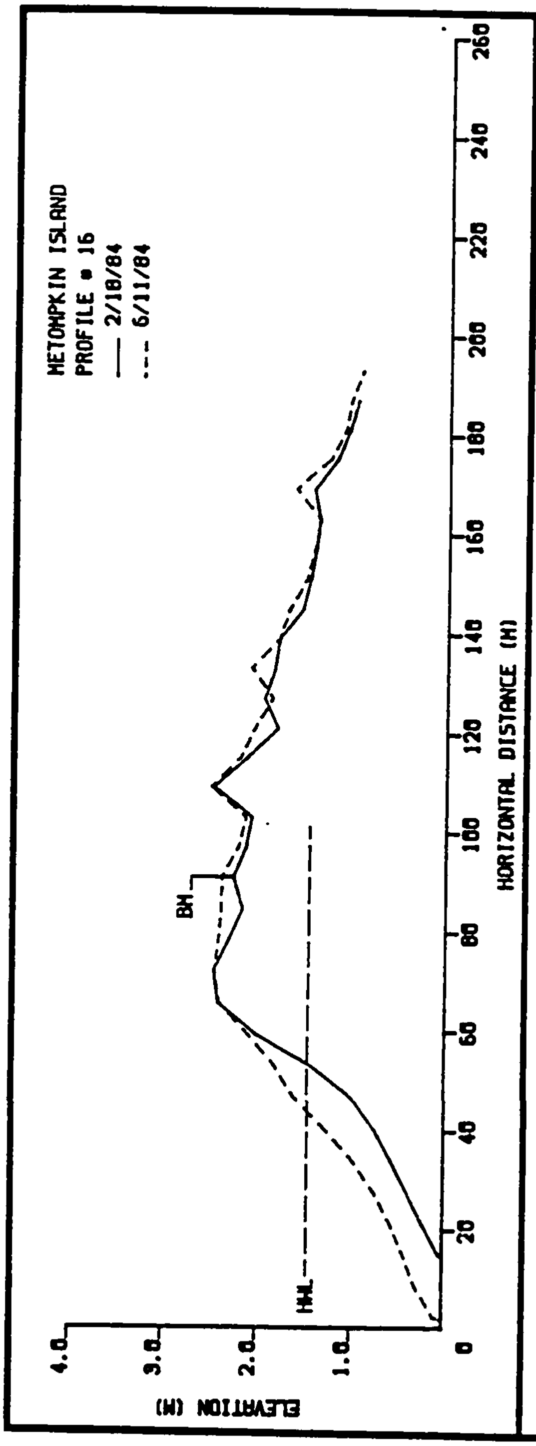
same as above


METOMPKIN ISLAND
PROFILE # 14
2/18/84
6/11/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 14
11/17/83
6/11/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

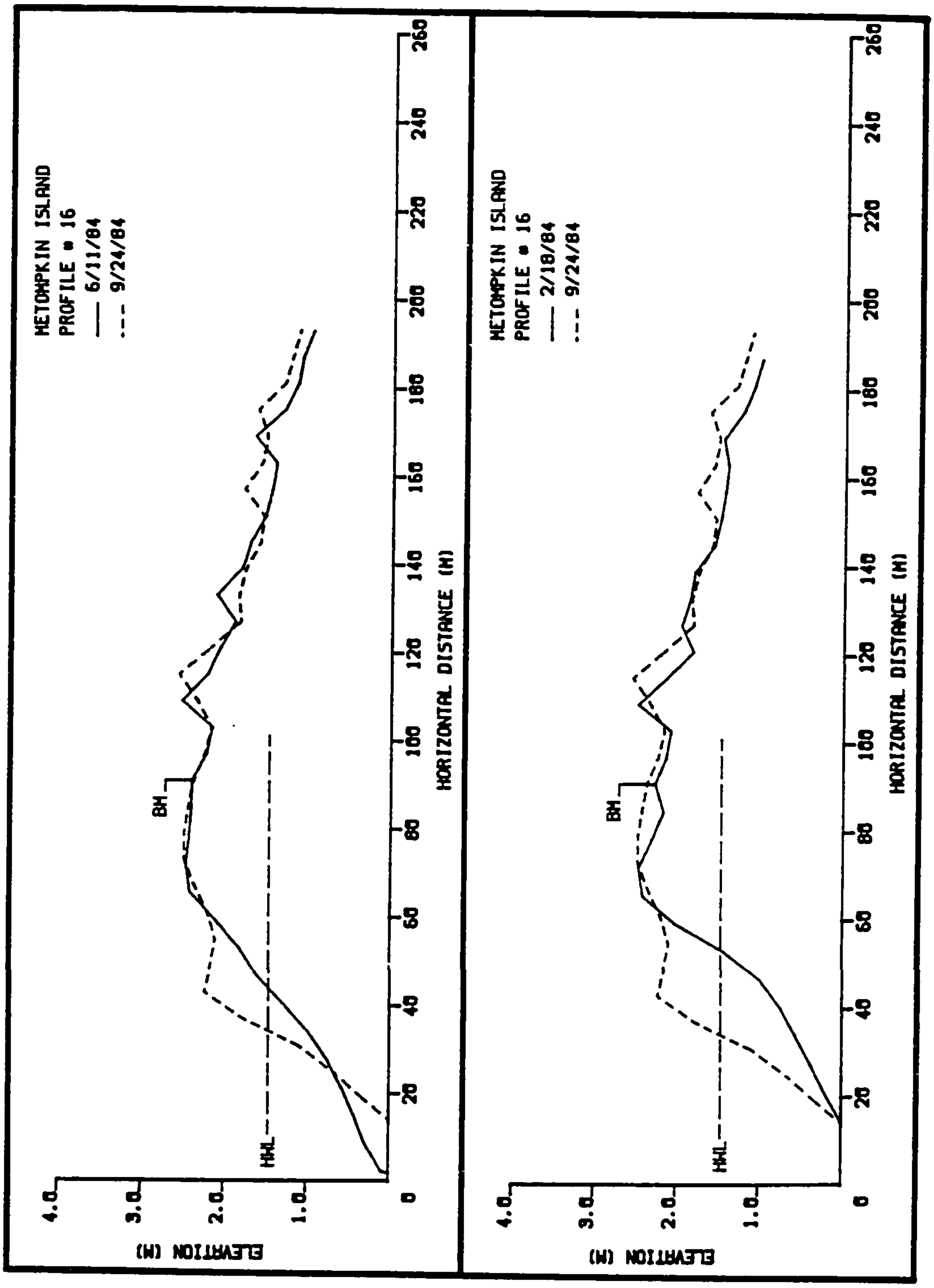

METOMPKIN ISLAND
PROFILE # 14
6/11/84
9/24/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 14
11/17/83
9/24/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

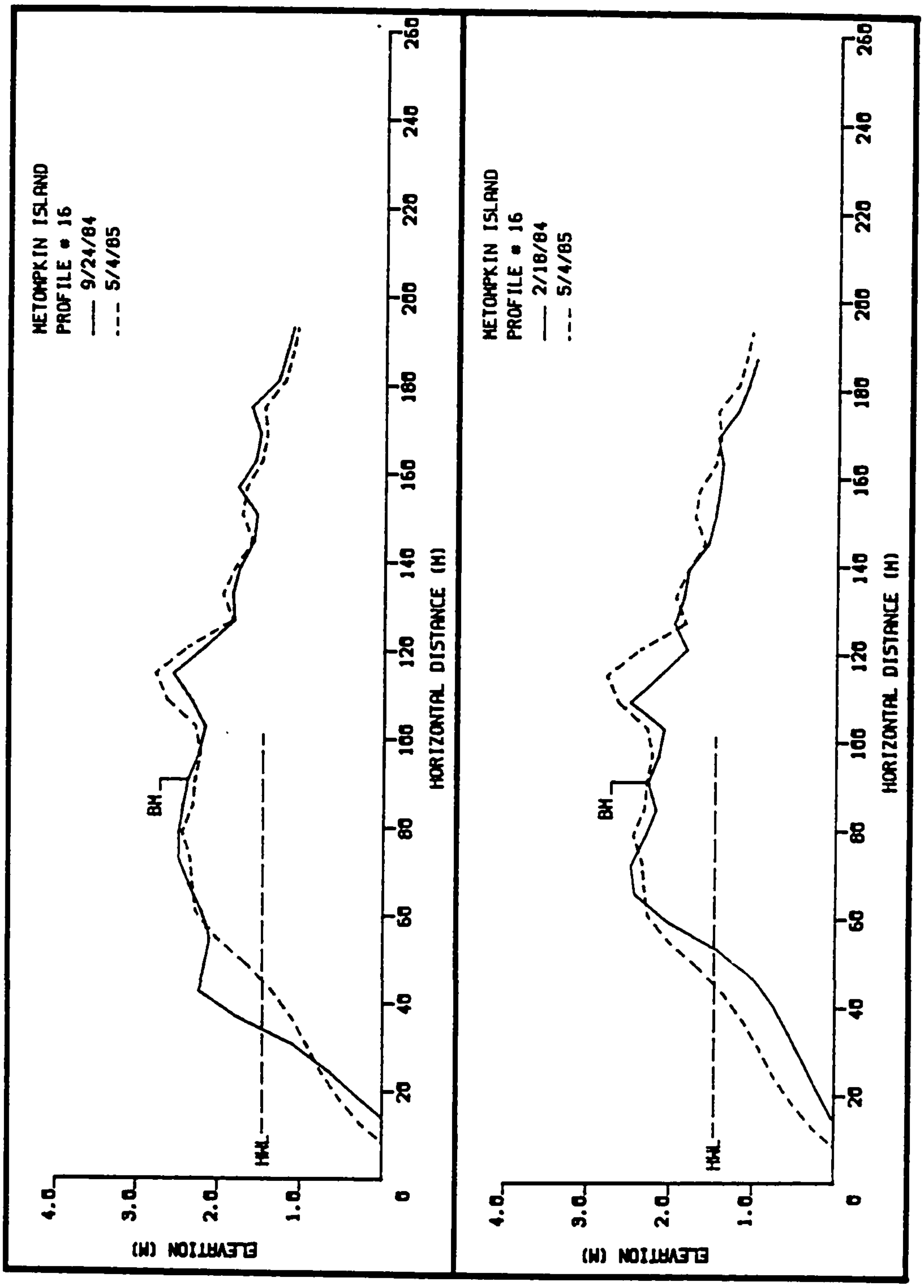

METOMPKIN ISLAND
PROFILE # 14
9/24/84
5/4/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 14
11/17/83
5/4/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 14
5/4/85
11/9/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 14
11/17/83
11/9/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

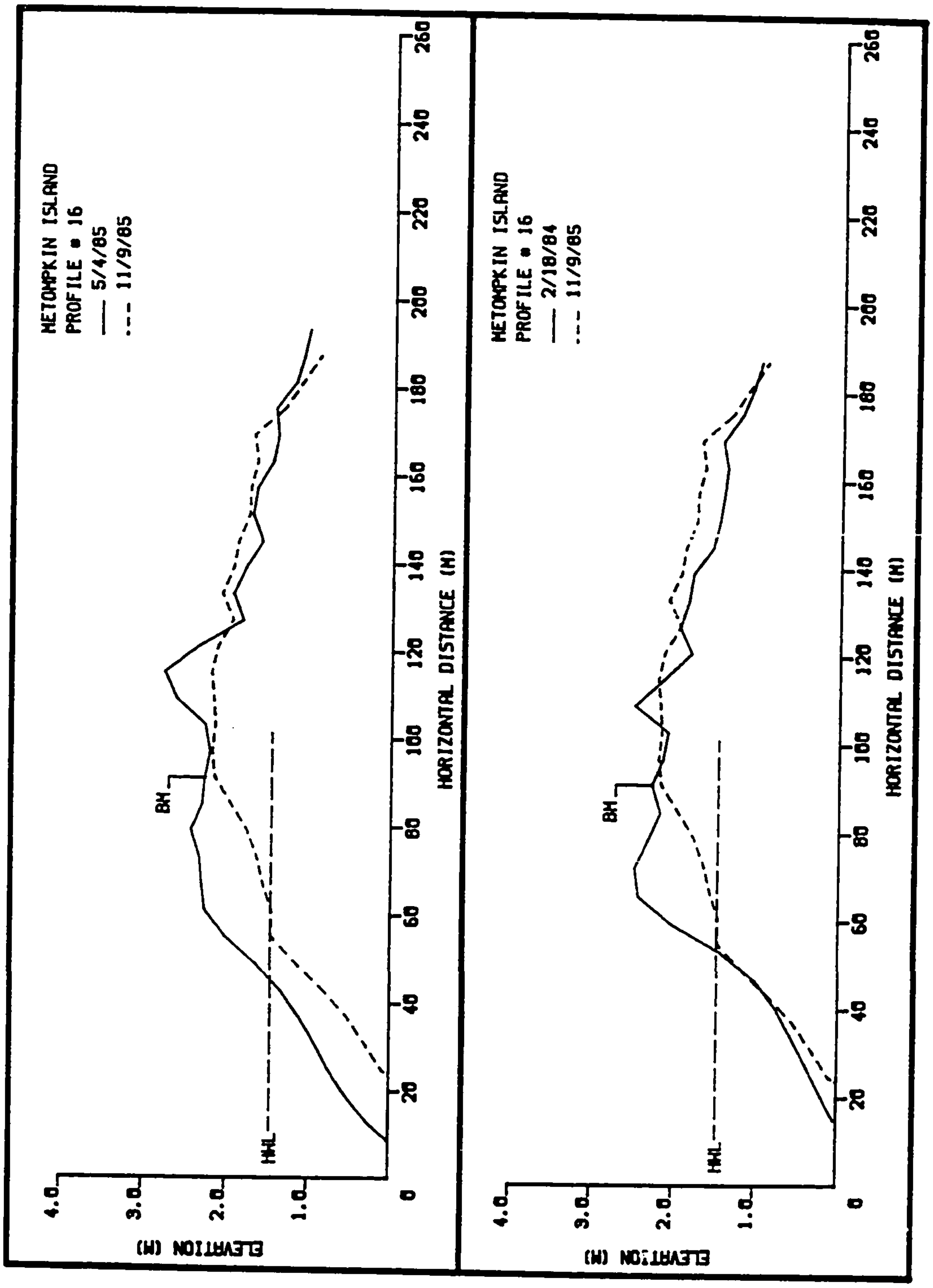


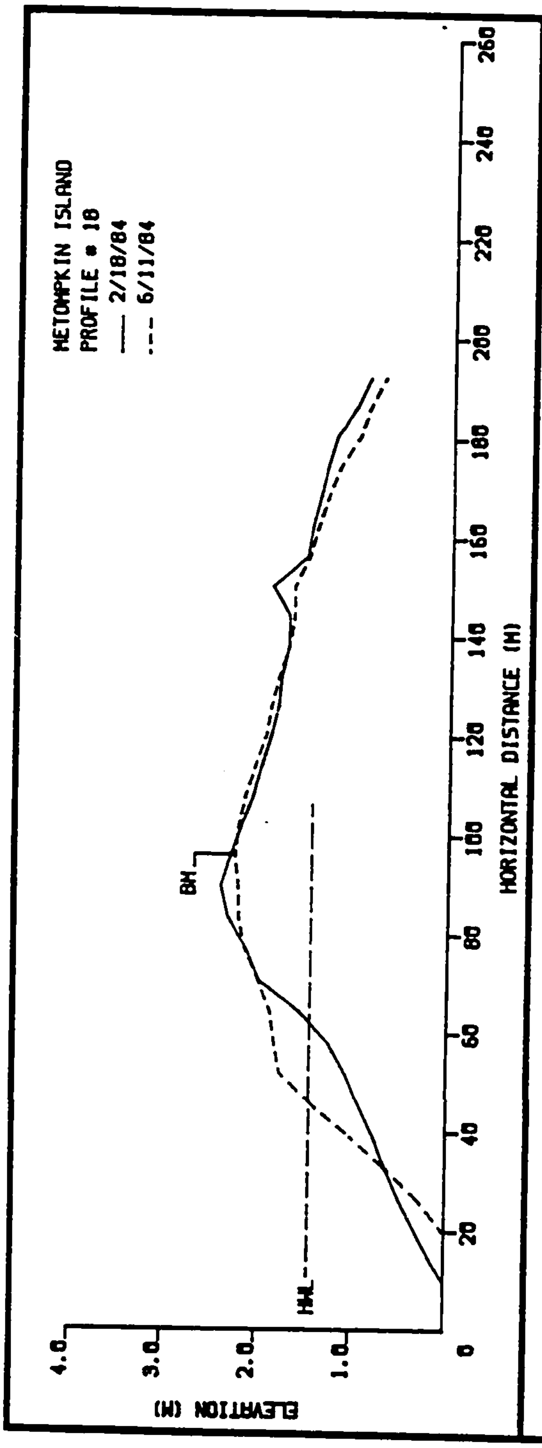
same as above


METOMPKIN ISLAND
PROFILE # 16
6/11/84
9/24/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 16
2/18/84
9/24/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

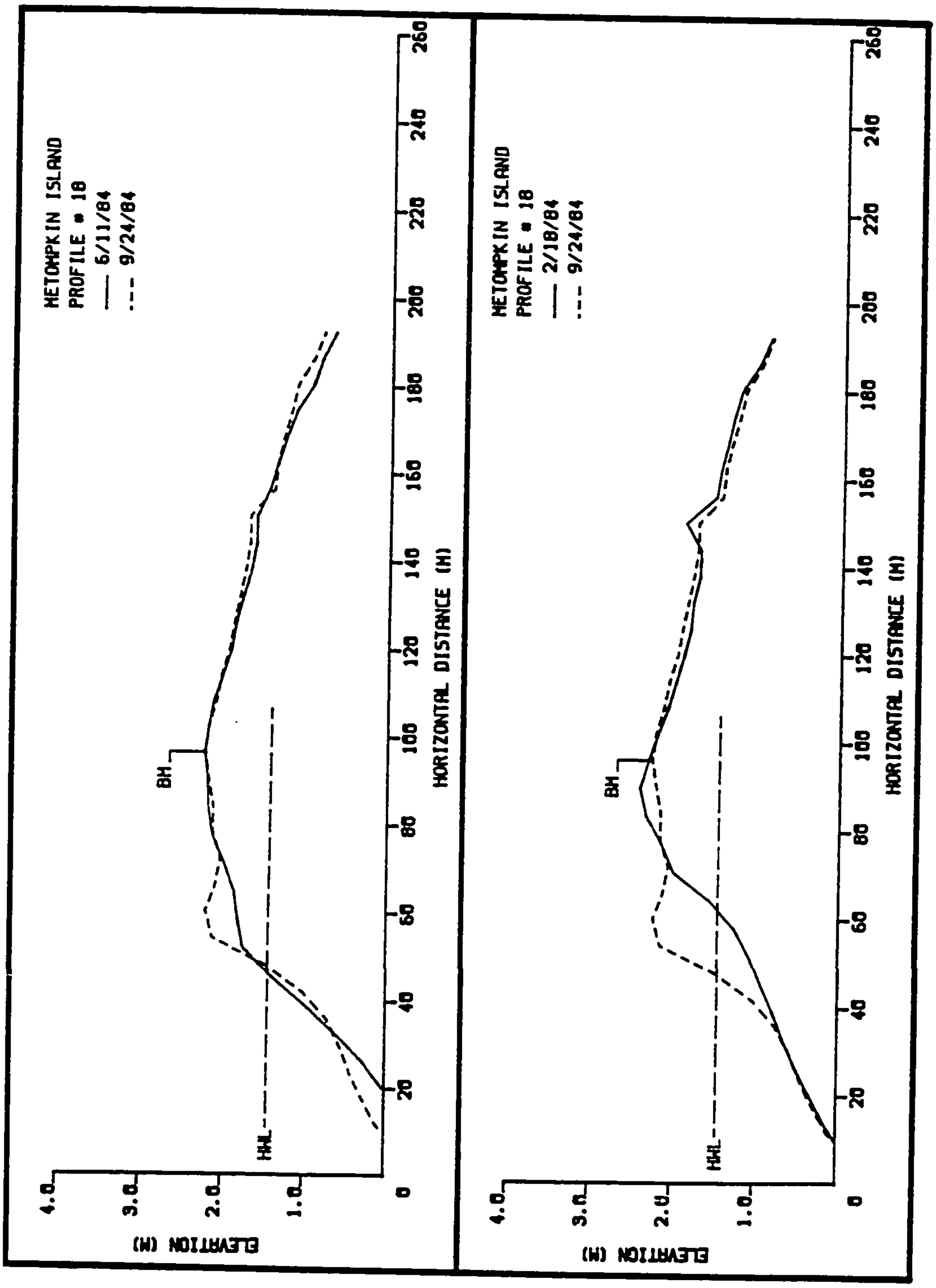


METOMPKIN ISLAND
PROFILE # 16
—— 9/24/84
- - - 5/4/85
METOMPKIN ISLAND
PROFILE # 16
—— 2/18/84
- - - 5/4/85
ELEVATION (M)
HORIZONTAL DISTANCE (M)
HWL
BM
0
1.0
2.0
3.0
4.0
20
40
60
80
100
120
140
160
180
200
220
240
260

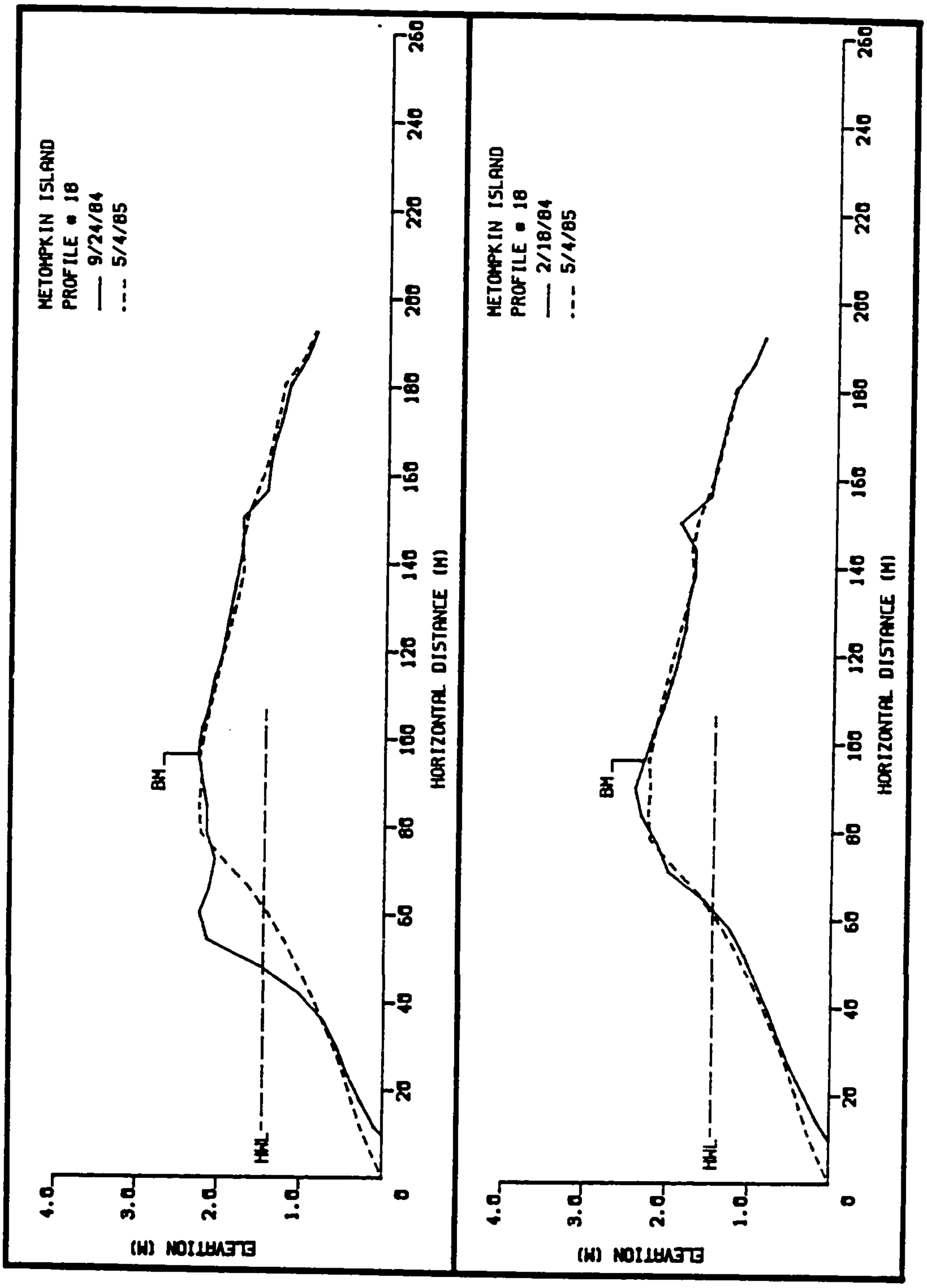

METOMPKIN ISLAND
PROFILE # 16
5/4/85
11/9/85
BH
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)
METOMPKIN ISLAND
PROFILE # 16
2/18/84
11/9/85
BH
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)



same as above



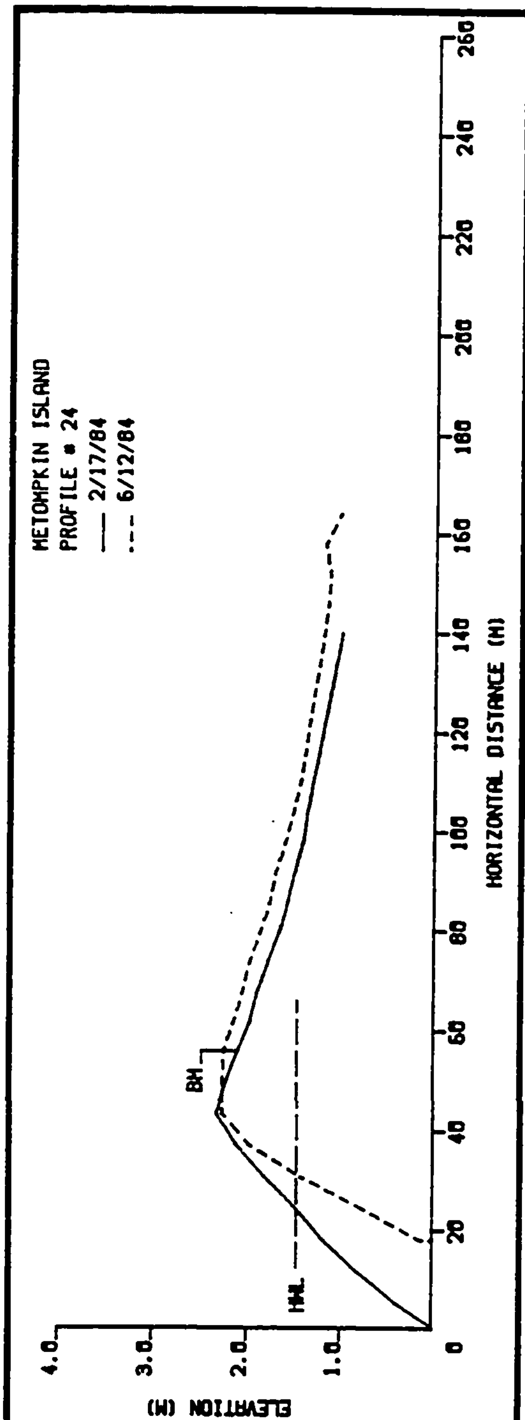
METOMPKIN ISLAND
PROFILE # 18
— 6/11/84
- - - 9/24/84
BH
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 18
— 2/18/84
- - - 9/24/84
BH
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 18
— 9/24/84
--- 5/4/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 18
— 2/18/84
--- 5/4/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

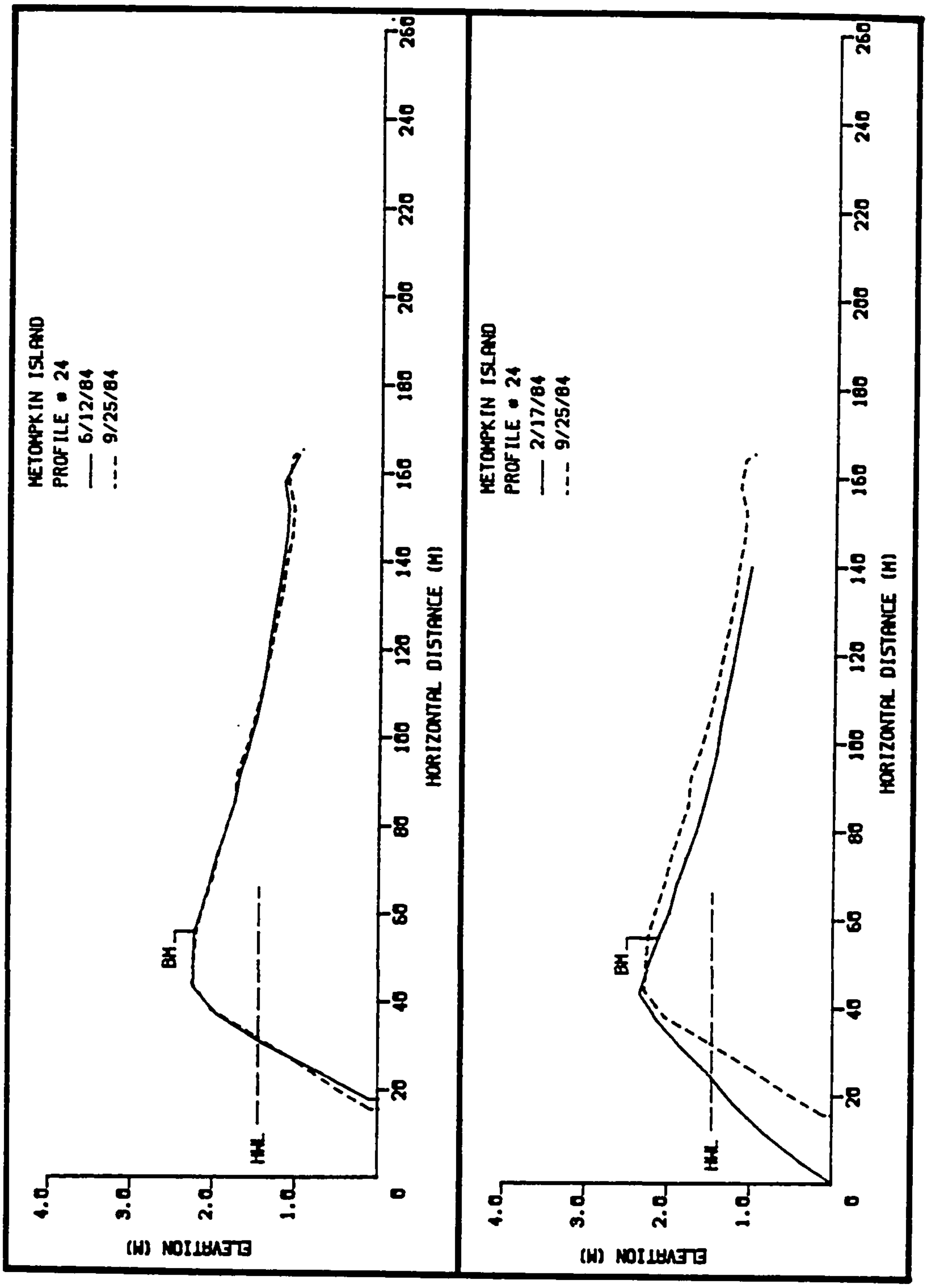
Northern Metompkin Island

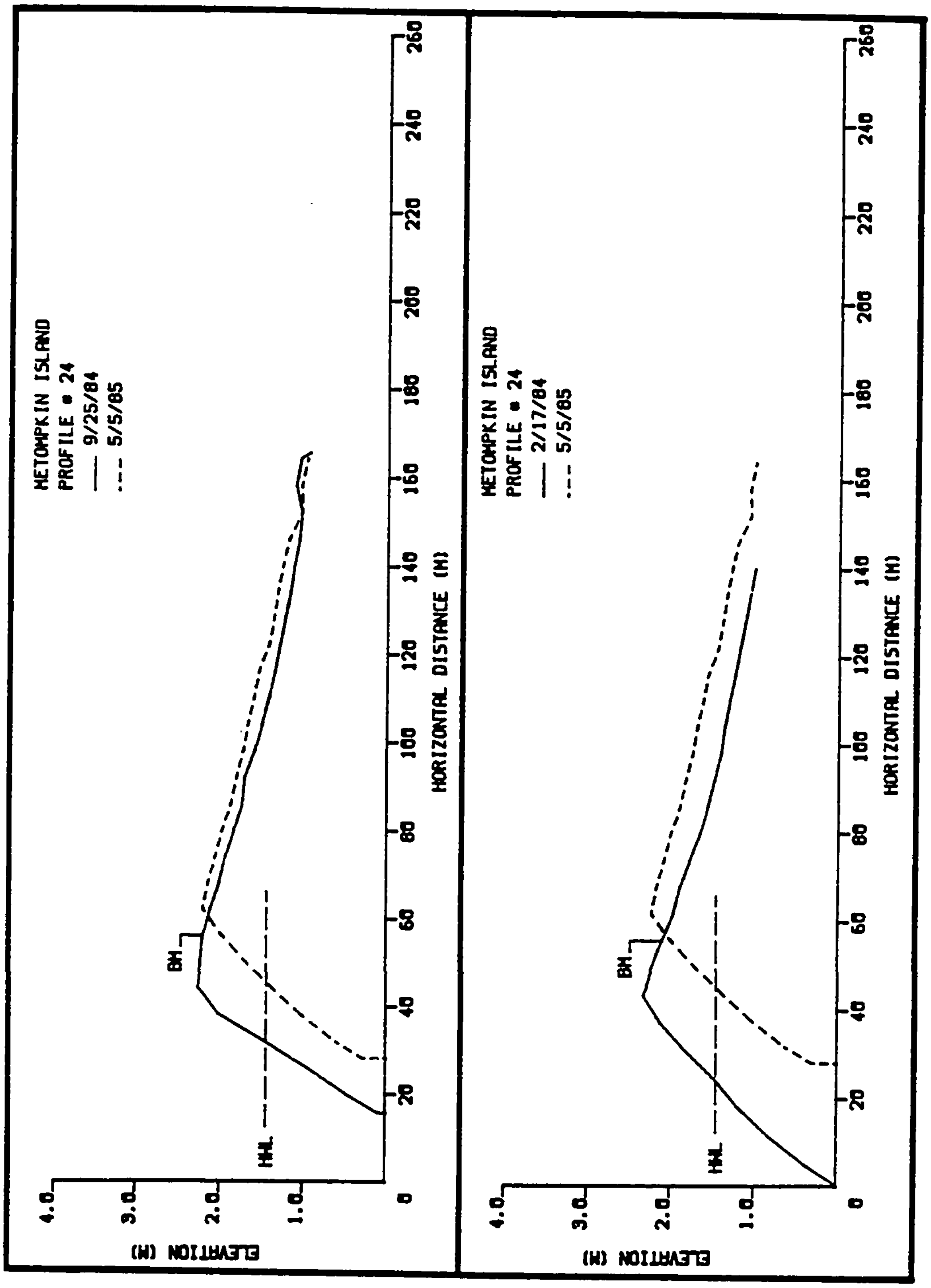
Profiles 24-32

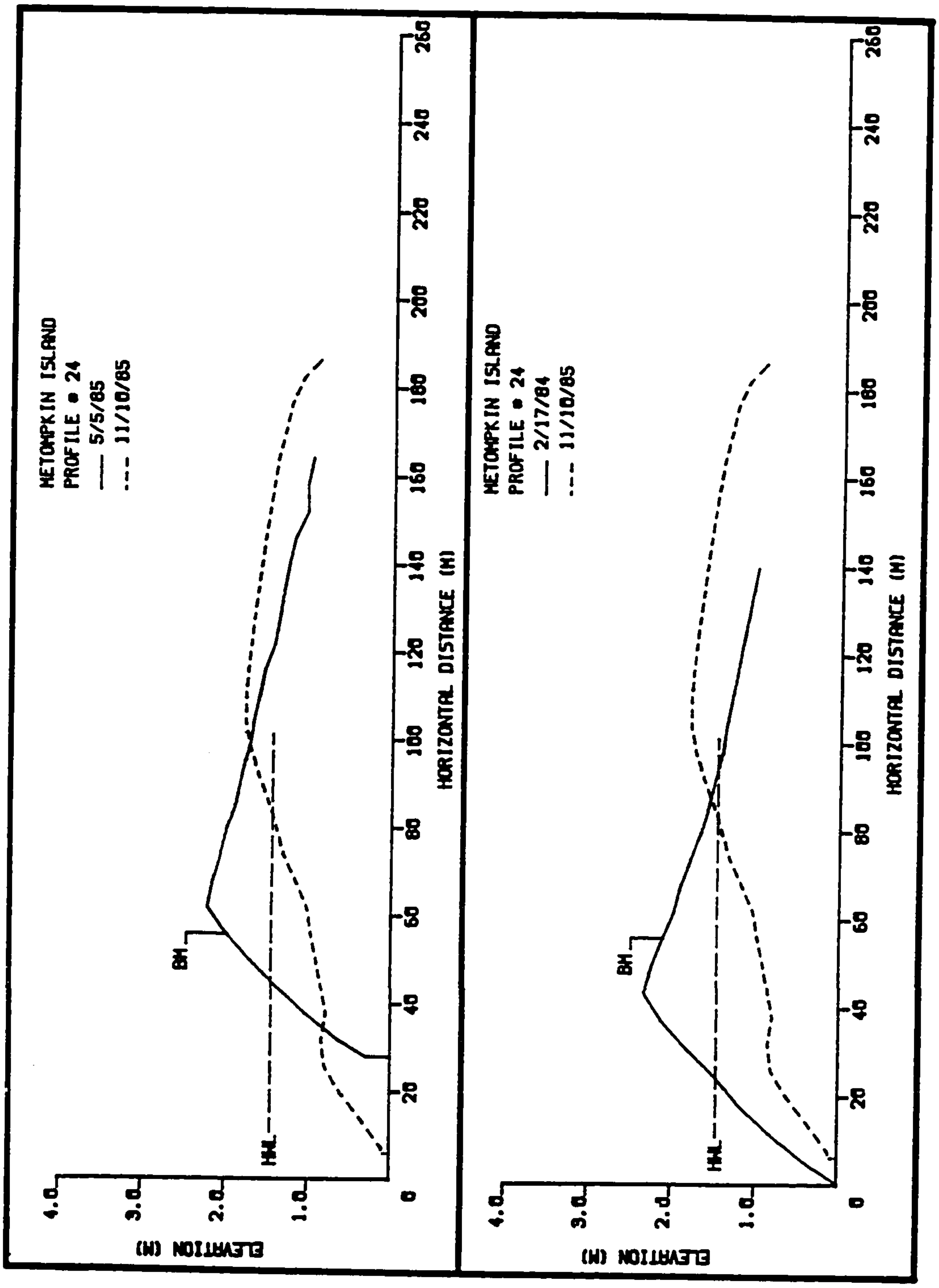
Incremental Change	Cumulative Change

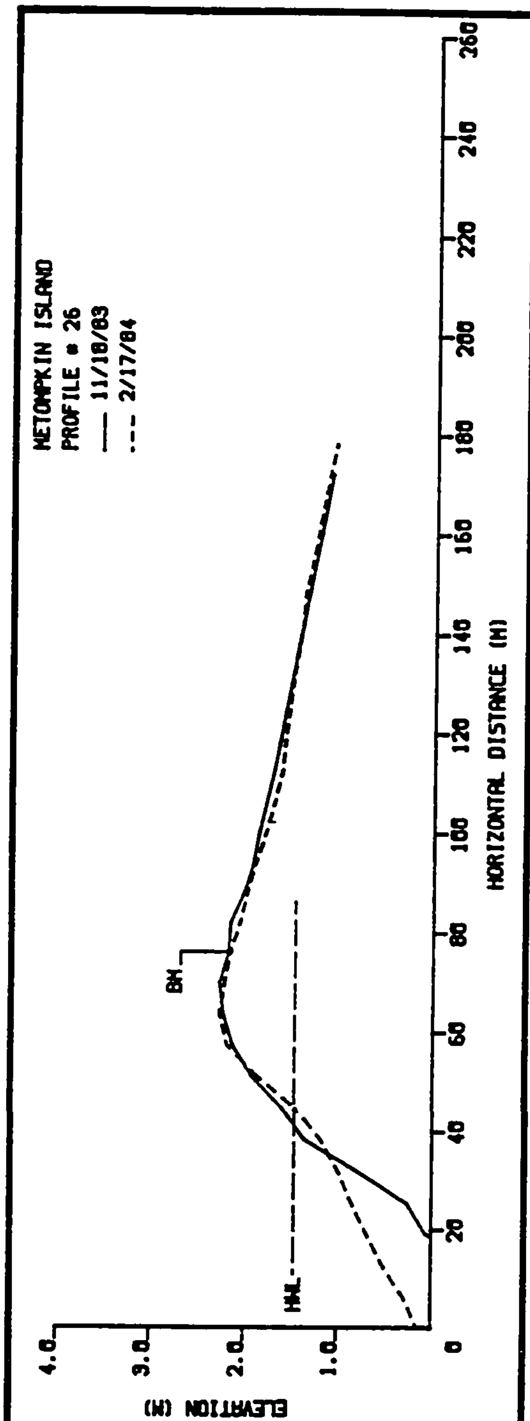


same as above

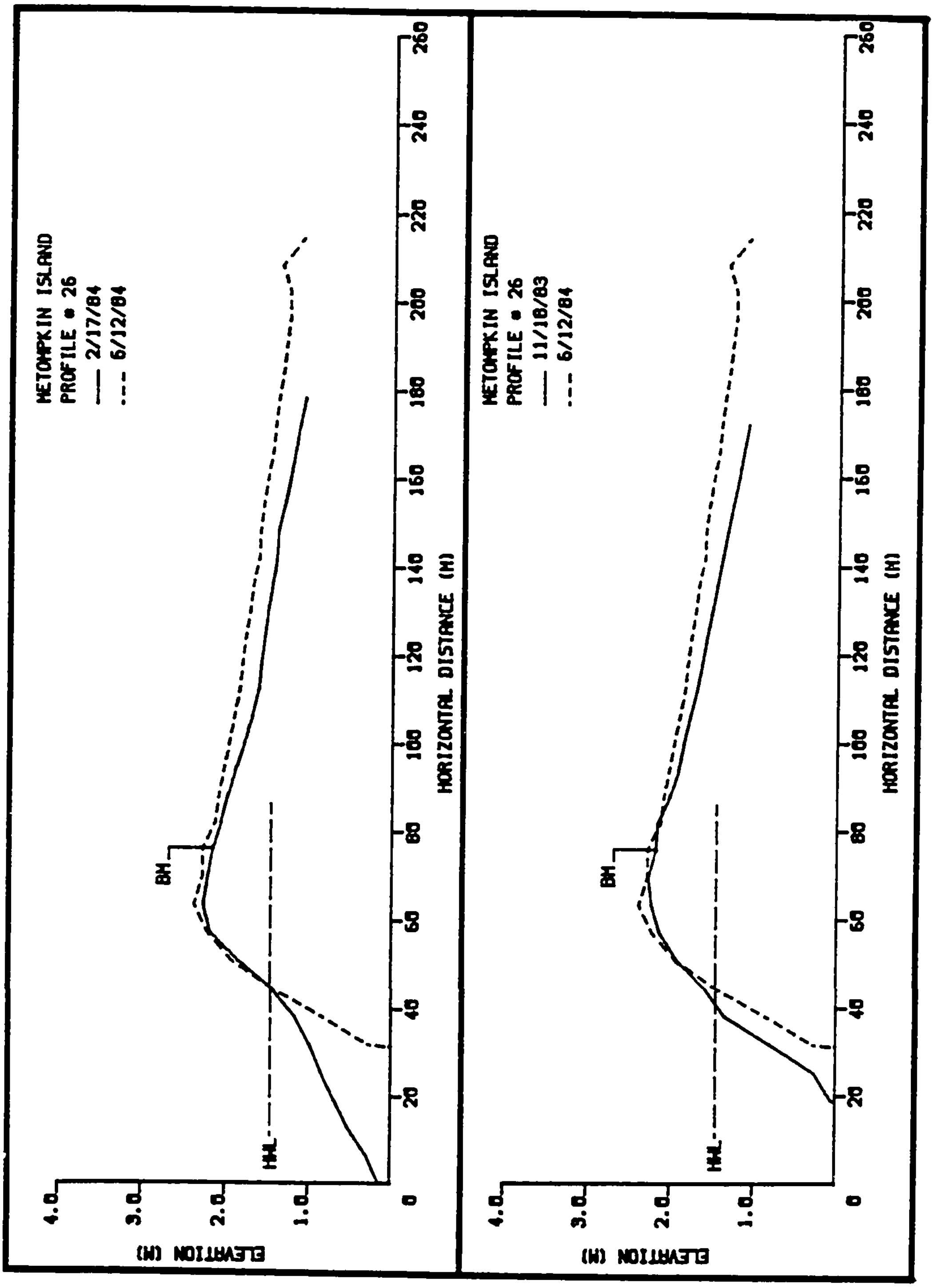

METOMPKIN ISLAND
PROFILE # 24
6/12/84
9/25/84
METOMPKIN ISLAND
PROFILE # 24
2/17/84
9/25/84
HORIZONTAL DISTANCE (M)
ELEVATION (M)
BM
HWL

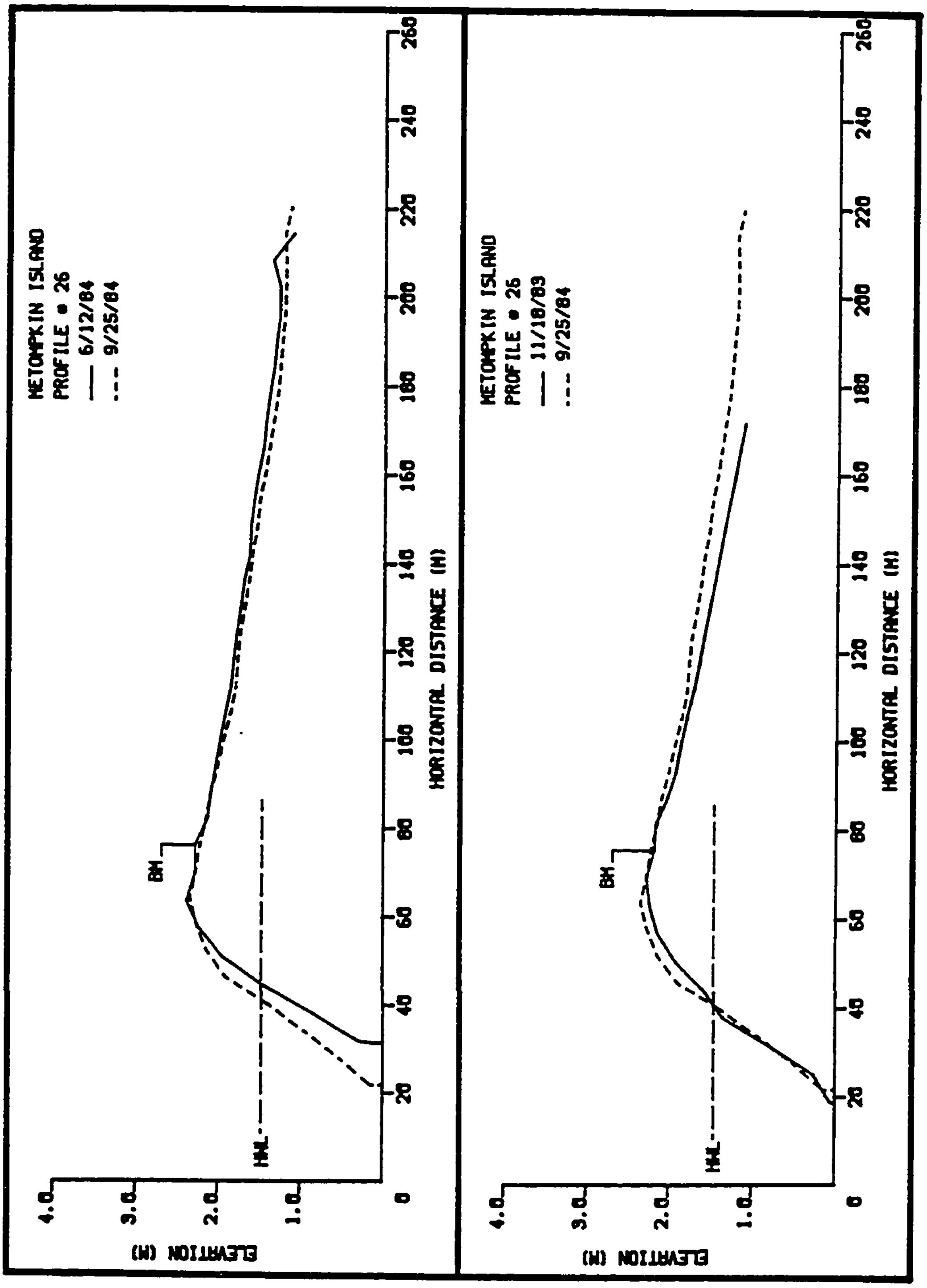

METOMPKIN ISLAND
PROFILE # 24
9/25/84
5/5/85
ELEVATION (M)
HORIZONTAL DISTANCE (M)
BM
HWL
METOMPKIN ISLAND
PROFILE # 24
2/17/84
5/5/85
ELEVATION (M)
HORIZONTAL DISTANCE (M)
BM
HWL

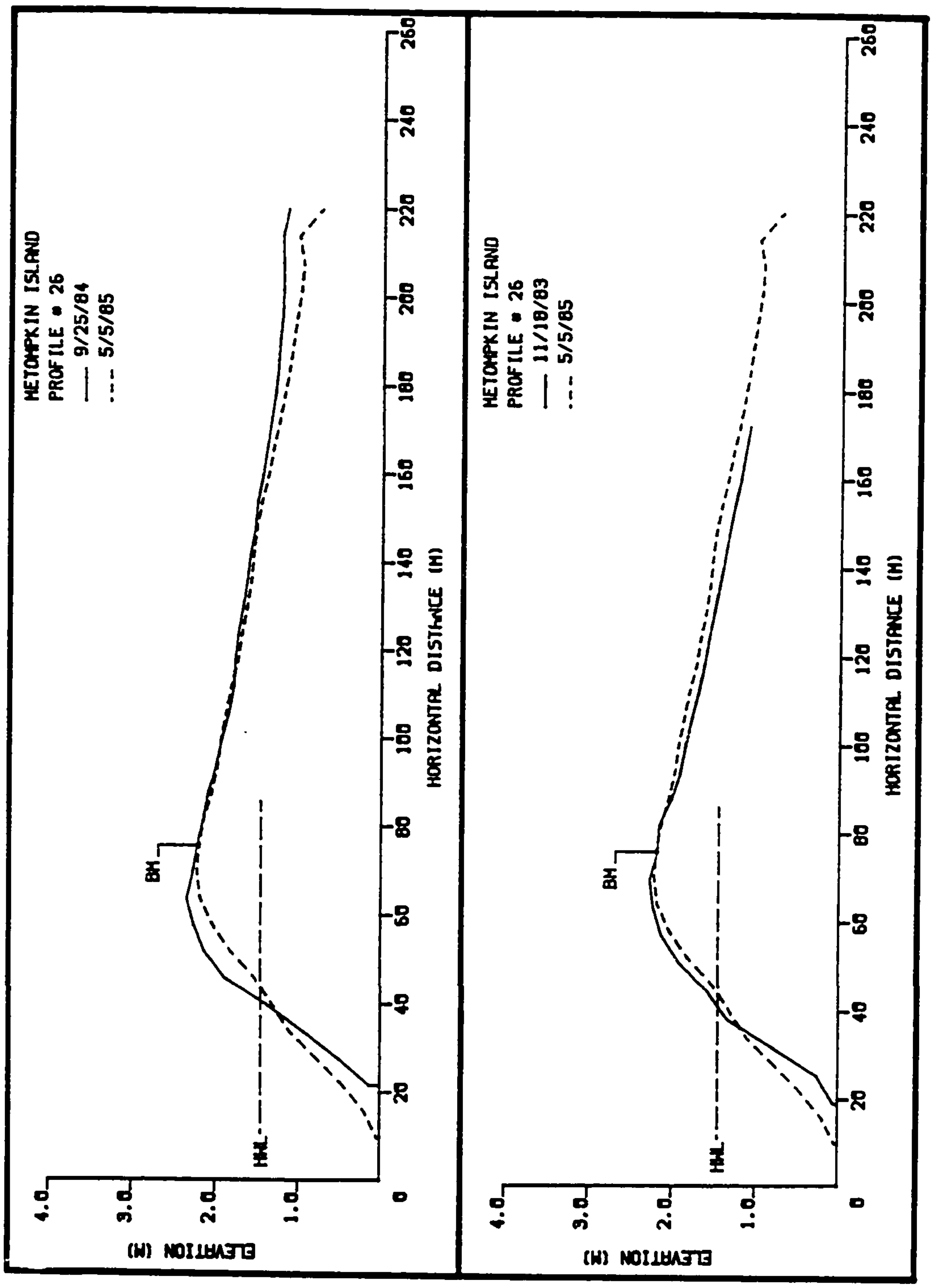

METOMPKIN ISLAND
PROFILE # 24
5/5/85
11/10/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 24
2/17/84
11/10/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

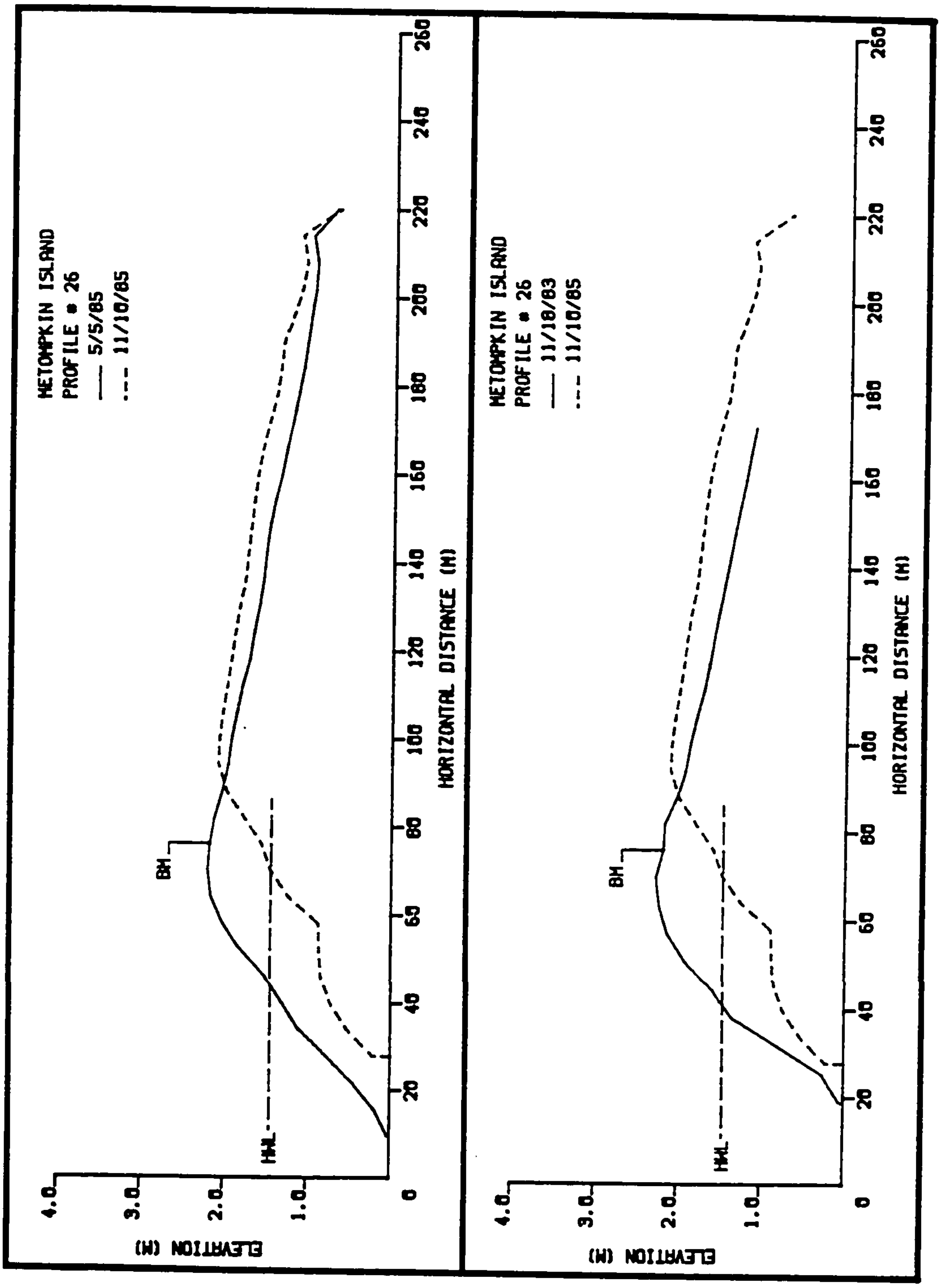


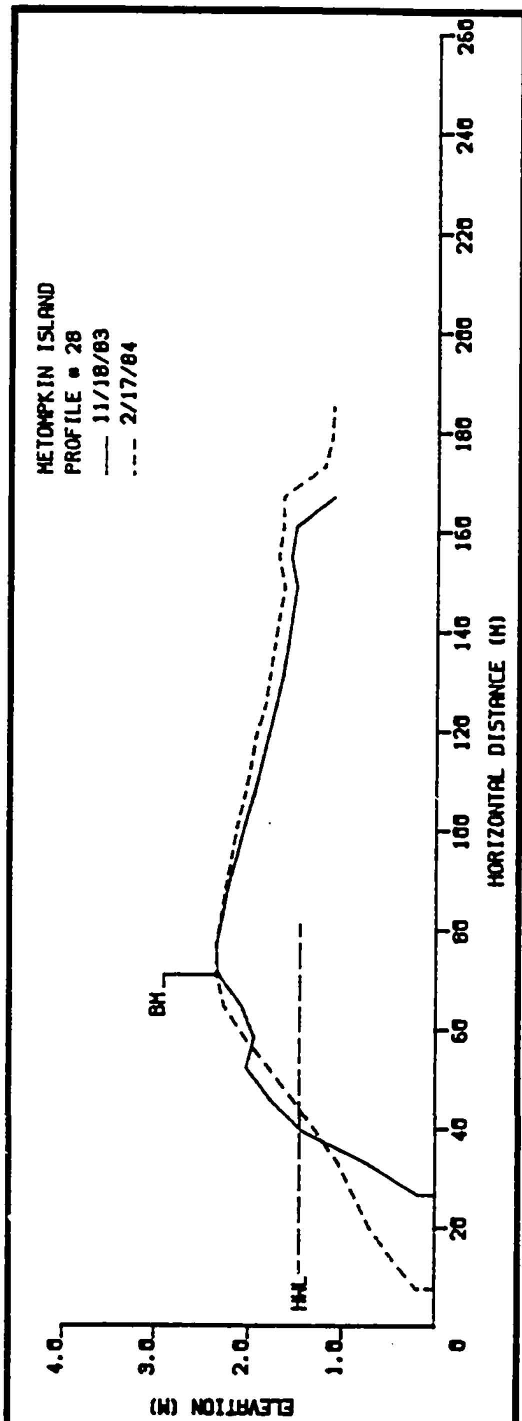
same as above


METOMPKIN ISLAND
PROFILE # 26
2/17/84
6/12/84
BM
MHW
HORIZONTAL DISTANCE (M)
ELEVATION (M)
METOMPKIN ISLAND
PROFILE # 26
11/18/83
6/12/84
BM
MHW
HORIZONTAL DISTANCE (M)
ELEVATION (M)

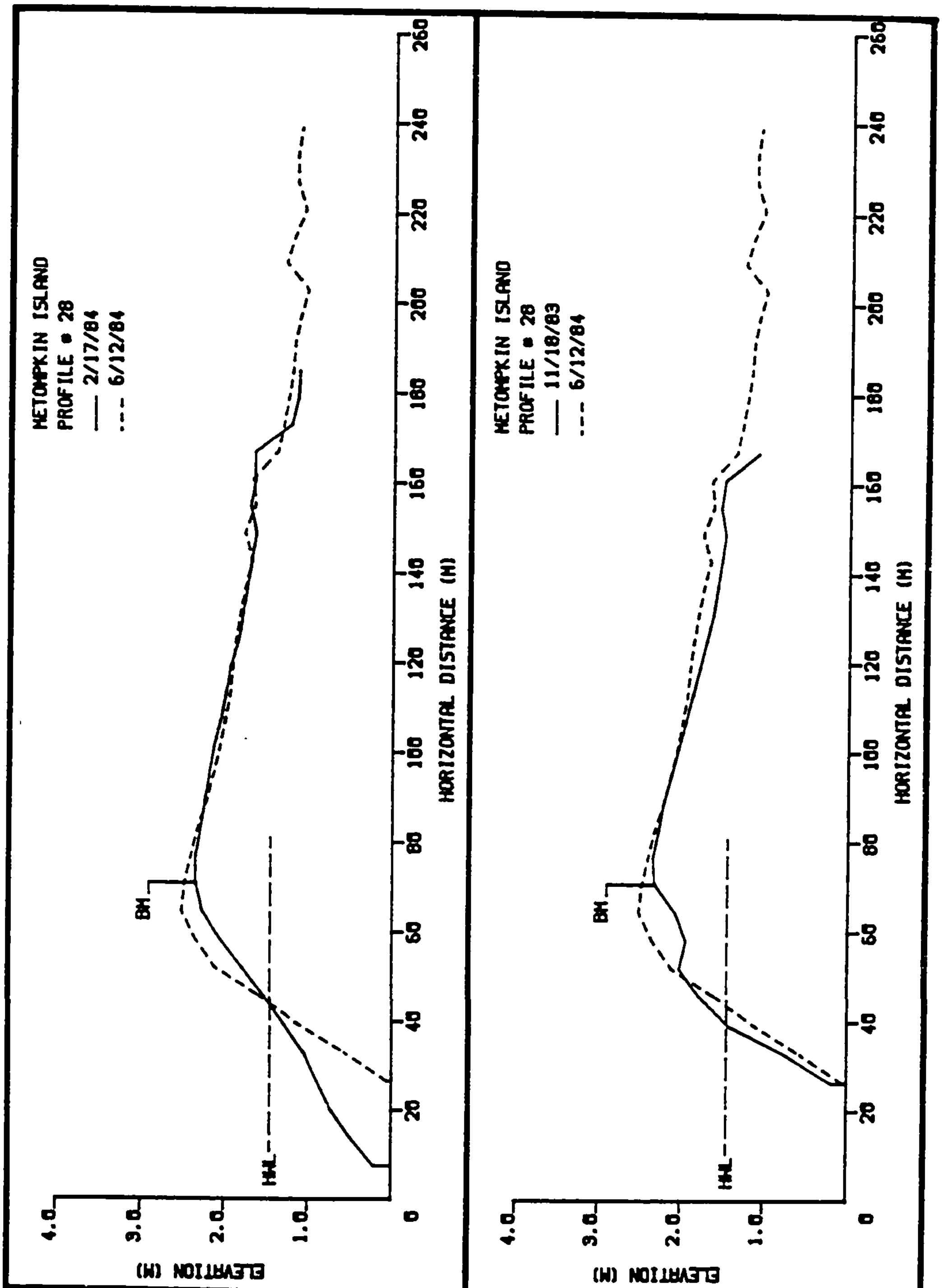

METOMPKIN ISLAND
PROFILE # 26
6/12/84
9/25/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 26
11/18/83
9/25/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

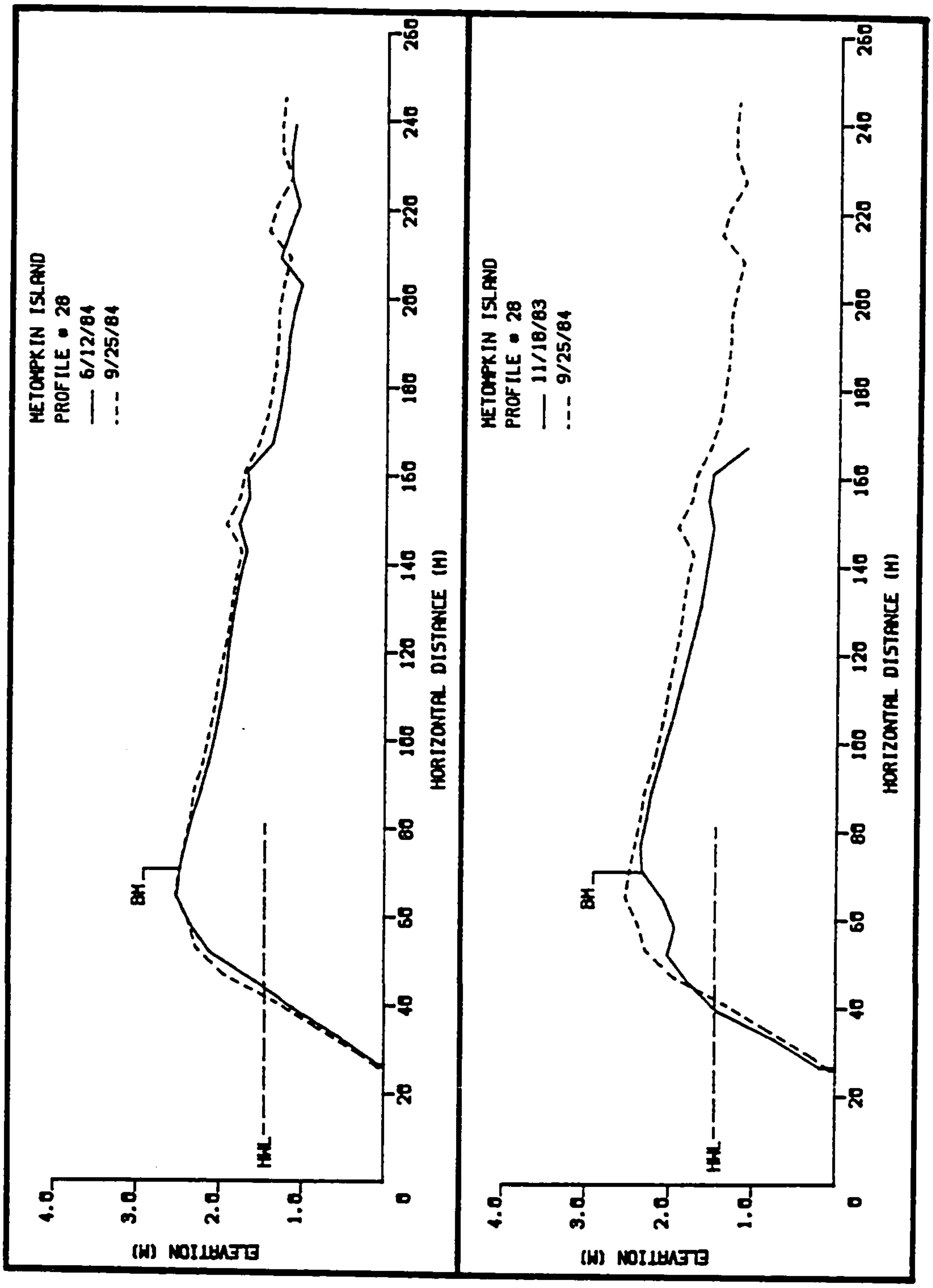

METOMPKIN ISLAND
PROFILE # 26
9/25/84
5/5/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 26
11/18/83
5/5/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

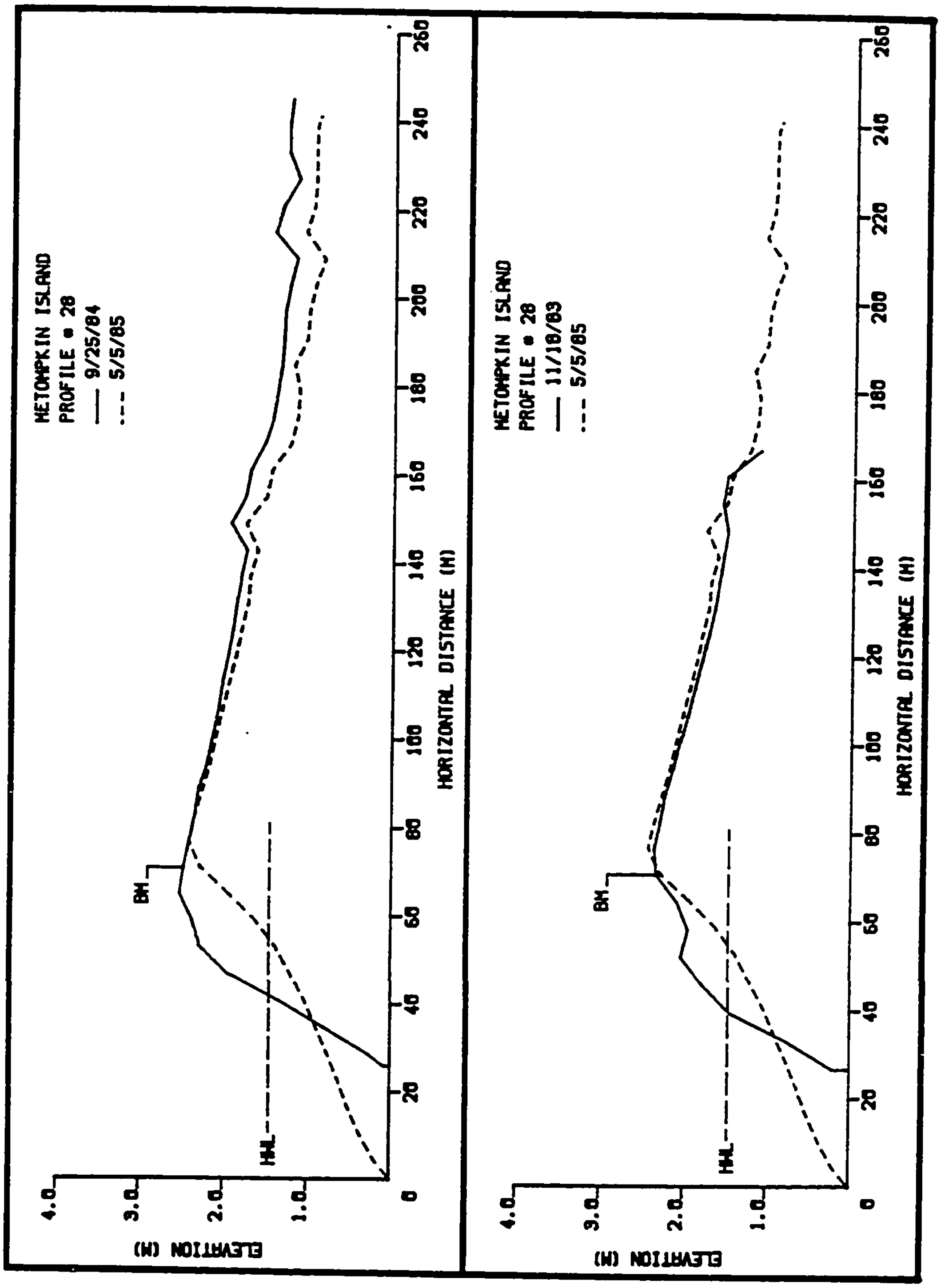

METOMPKIN ISLAND
PROFILE # 26
5/5/85
11/10/85
BM
MHL
ELEVATION (M)
4.0
3.0
2.0
1.0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 26
11/18/83
11/10/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

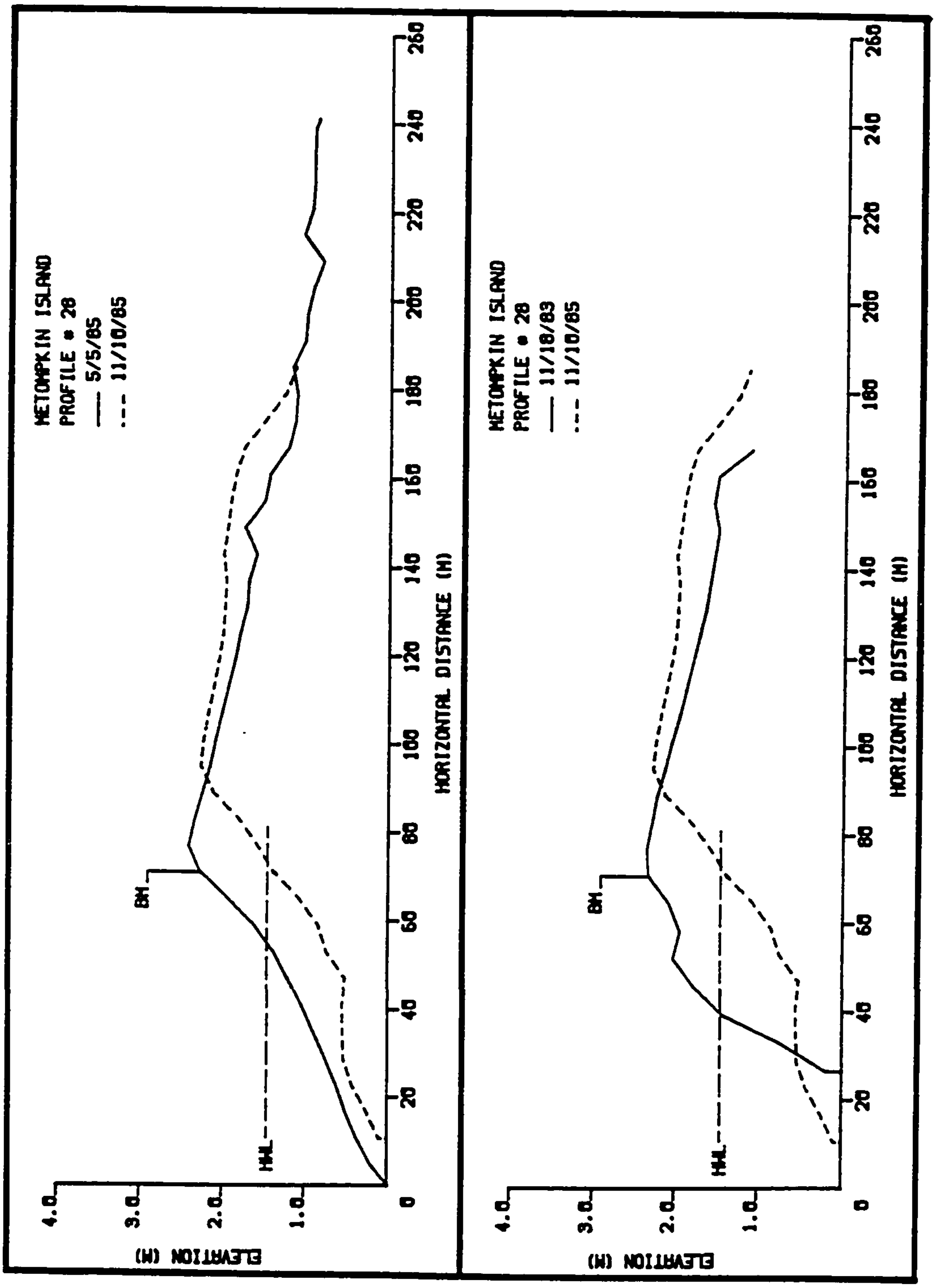


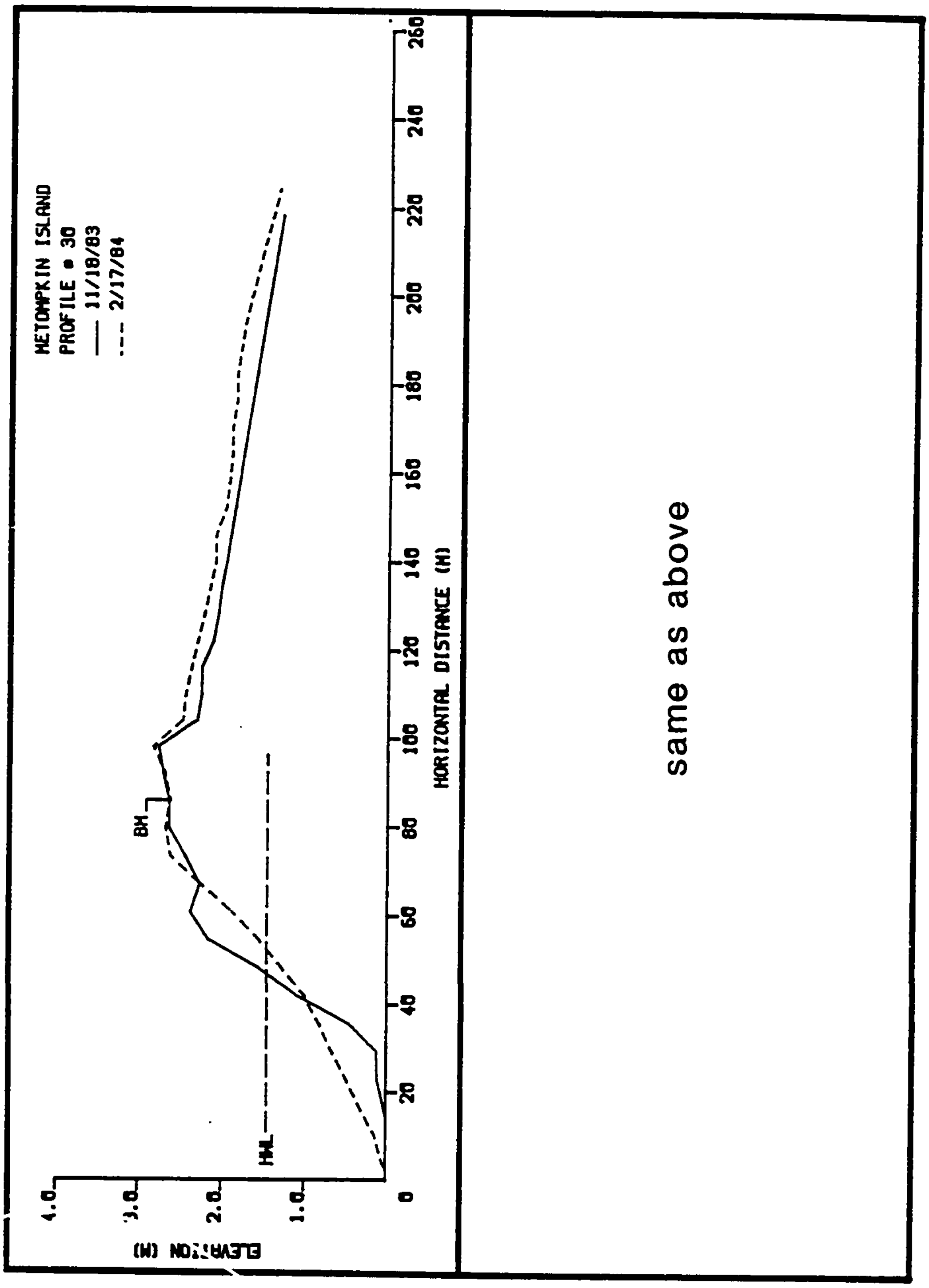
same as above

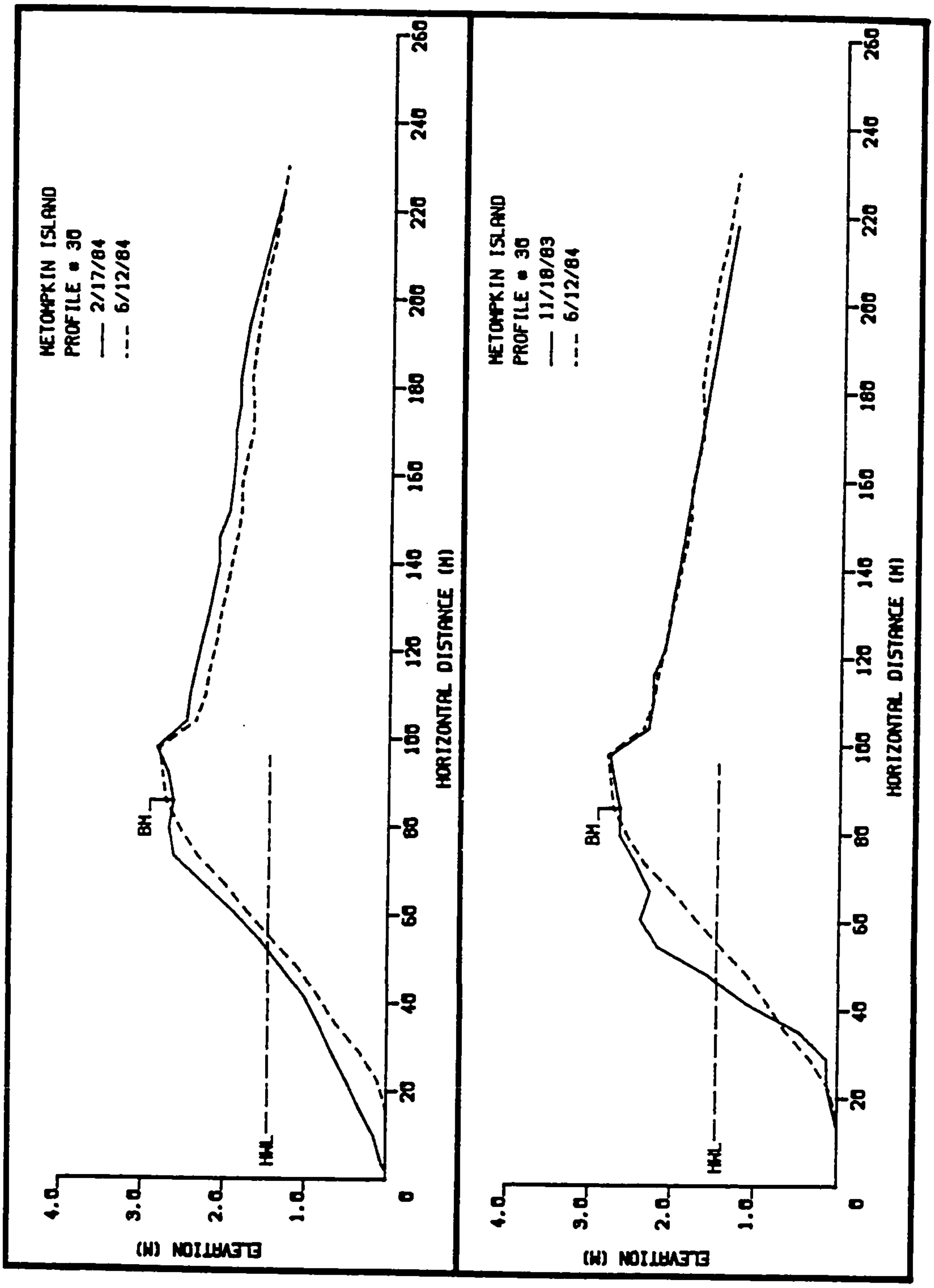

METOMPKIN ISLAND
PROFILE # 28
2/17/84
6/12/84
METOMPKIN ISLAND
PROFILE # 28
11/18/83
6/12/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 28
6/12/84
9/25/84
HORIZONTAL DISTANCE (M)
ELEVATION (M)
BM
METOMPKIN ISLAND
PROFILE # 28
9/25/84
HORIZONTAL DISTANCE (M)
ELEVATION (M)
BM

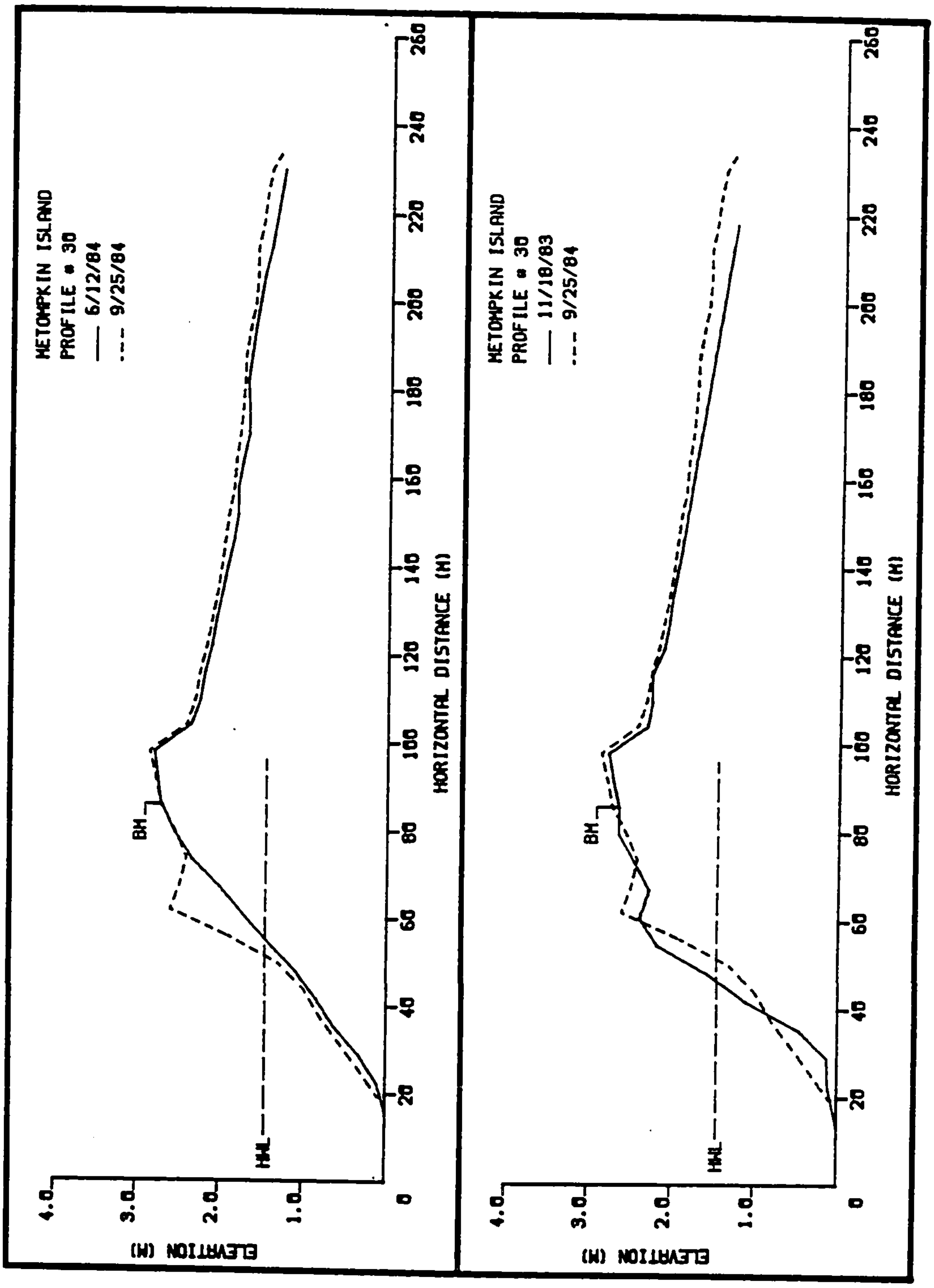

METOMPKIN ISLAND
PROFILE # 28
9/25/84
5/5/85
BM
MHL
ELEVATION (M)
0
1.0
2.0
3.0
4.0
HORIZONTAL DISTANCE (M)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
METOMPKIN ISLAND
PROFILE # 28
11/18/83
5/5/85
BM
MHL
ELEVATION (M)
0
1.0
2.0
3.0
4.0
HORIZONTAL DISTANCE (M)
0
20
40
60
80
100
120
140
160
180
200
220
240
260

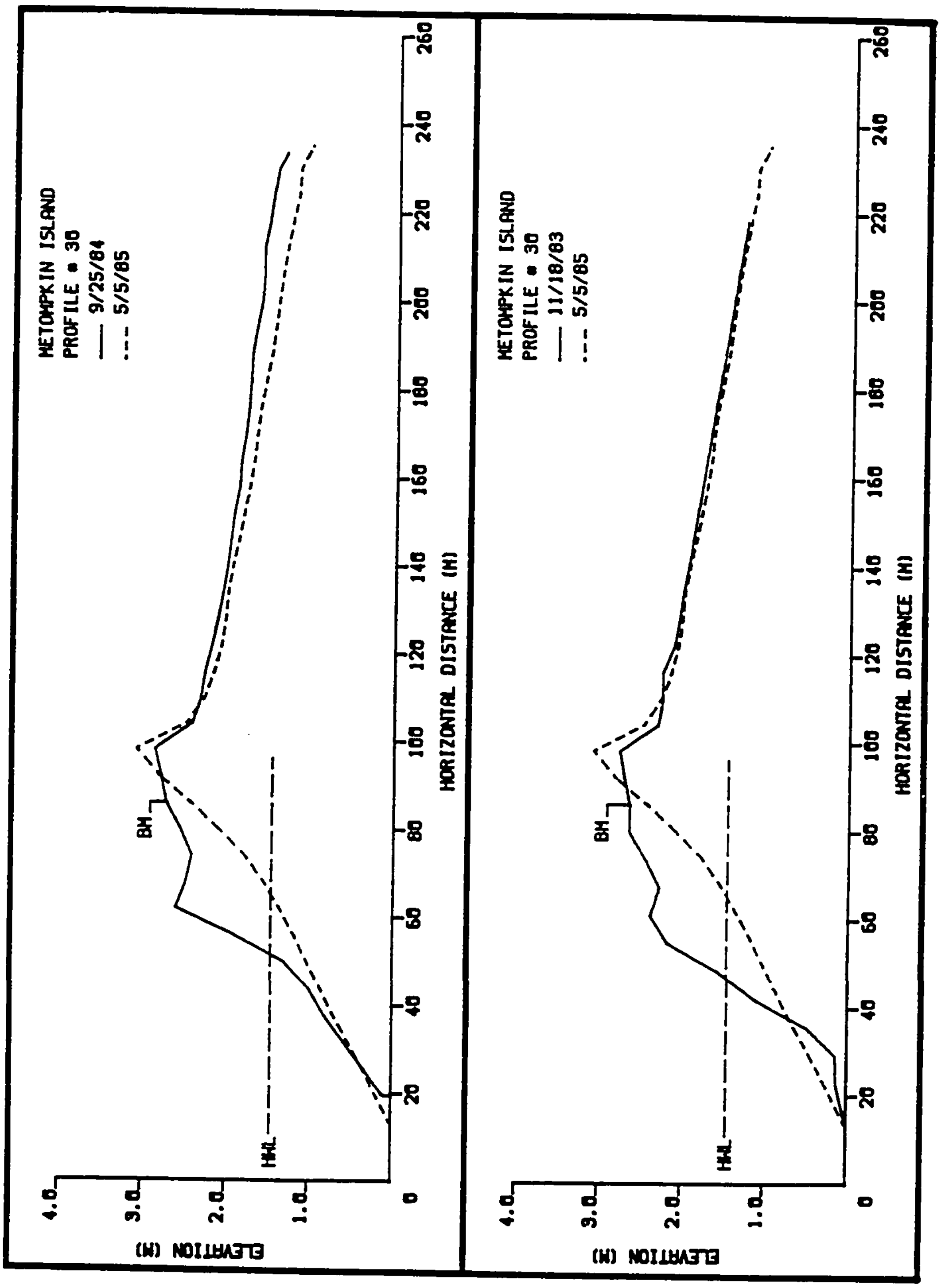

METOMPKIN ISLAND
PROFILE # 28
5/5/85
11/10/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 28
11/18/83
11/10/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

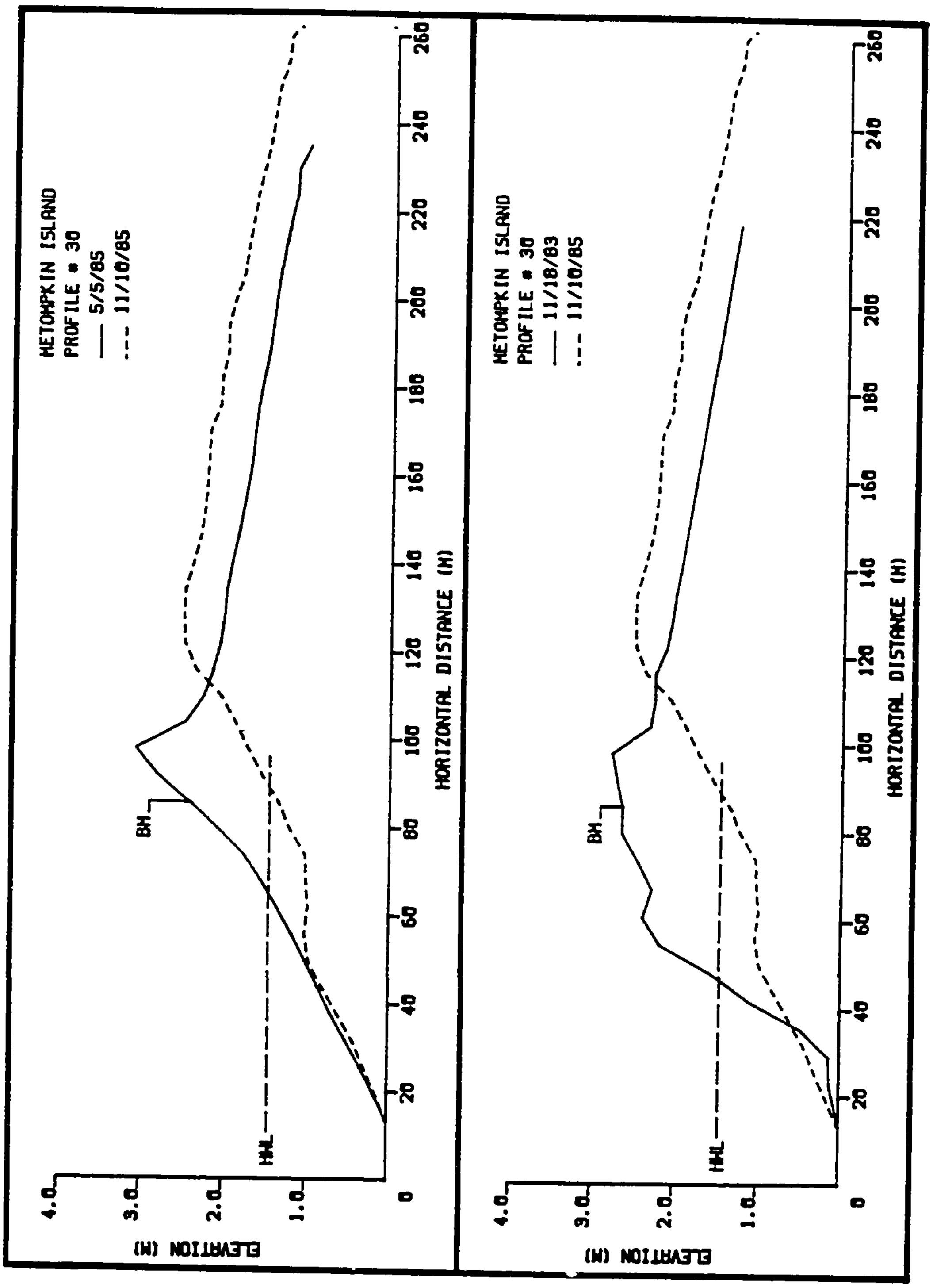

METOMPKIN ISLAND
PROFILE # 30
11/18/83
2/17/84
BM
HORIZONTAL DISTANCE (M)
same as above

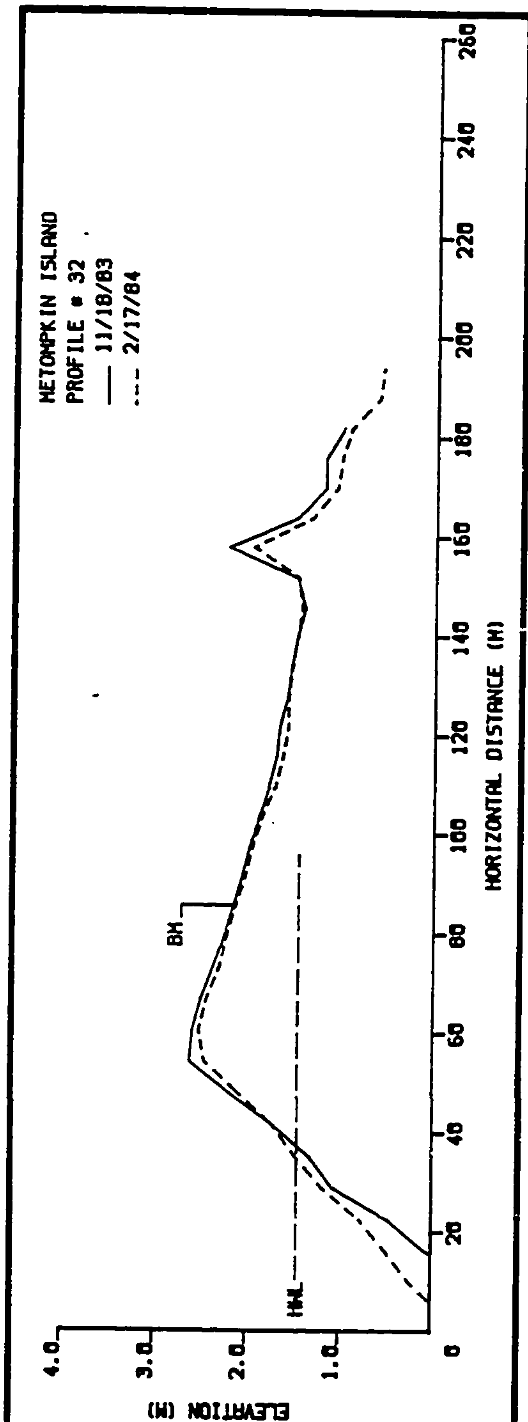


METOMPKIN ISLAND
PROFILE # 30
2/17/84
6/12/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 30
11/18/83
6/12/84
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

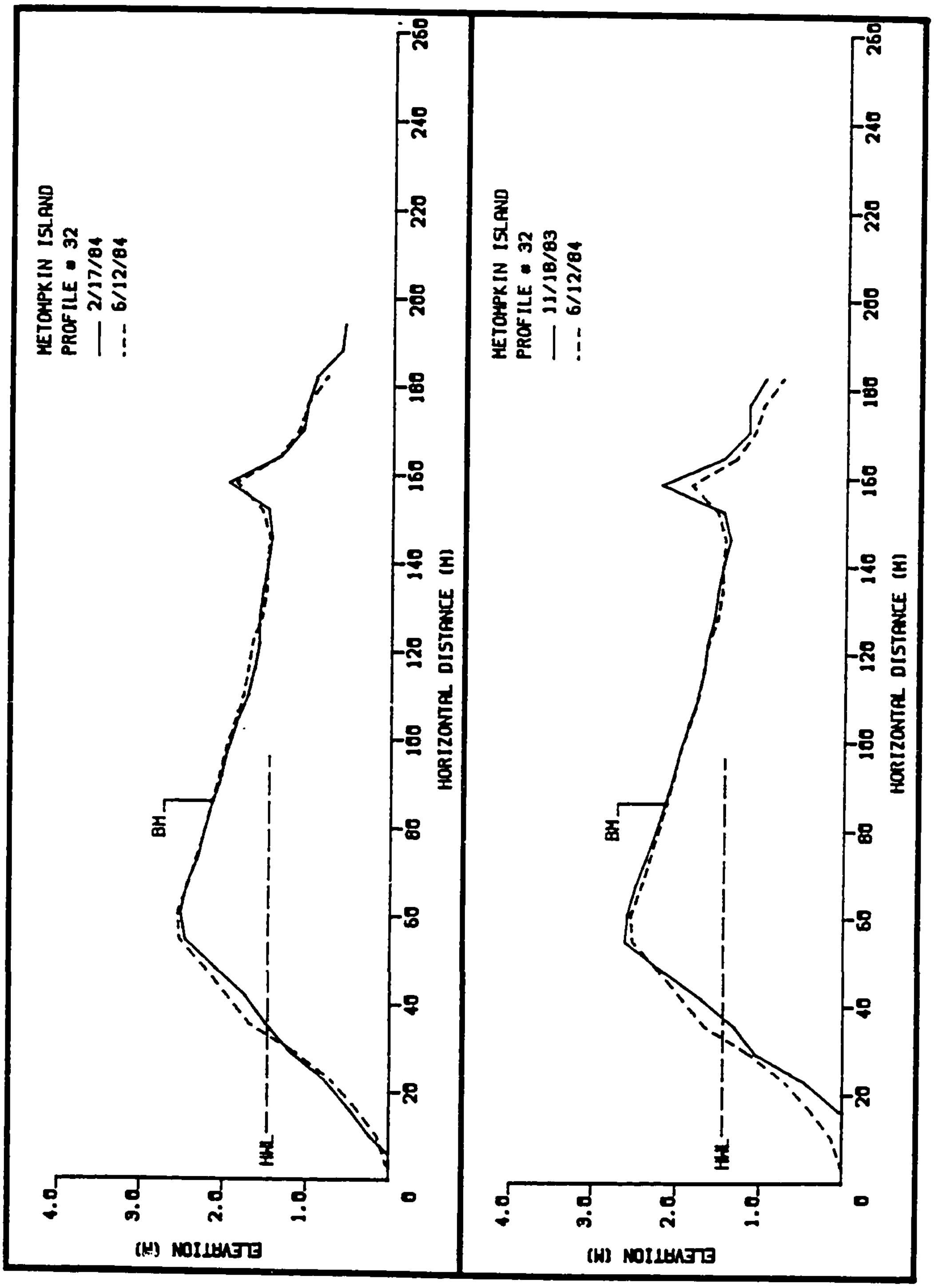

METOMPKIN ISLAND
PROFILE # 30
6/12/84
9/25/84
BM
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)
METOMPKIN ISLAND
PROFILE # 30
11/10/83
9/25/84
BM
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)

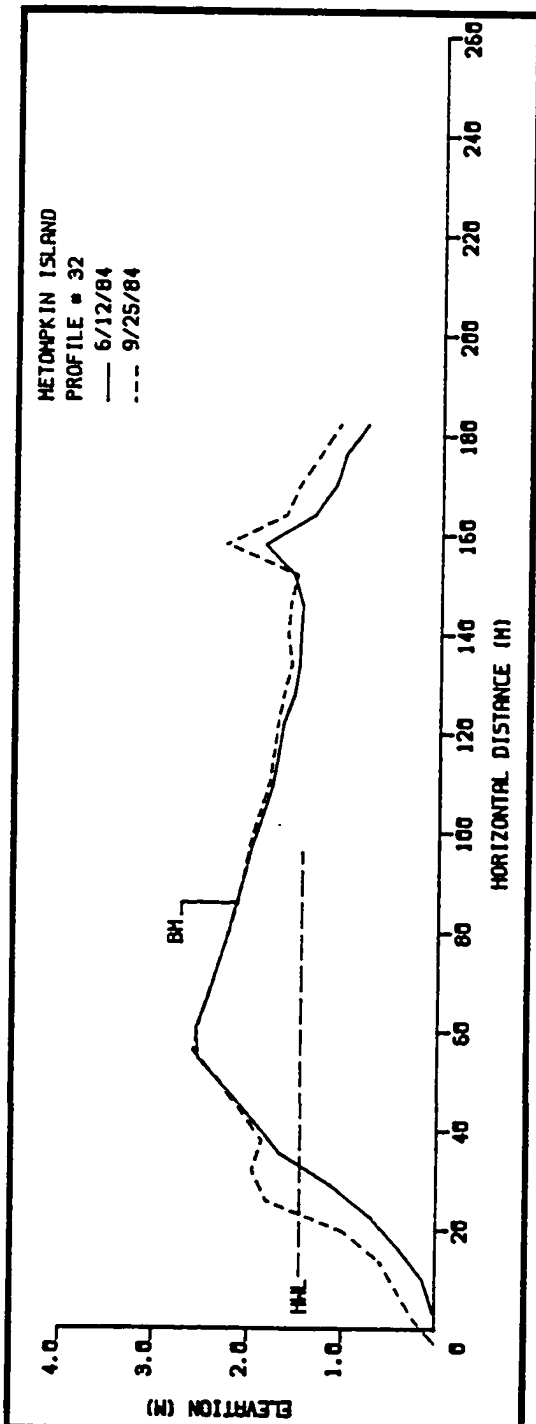

METOMPKIN ISLAND
PROFILE # 30
9/25/84
5/5/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 30
11/18/83
5/5/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

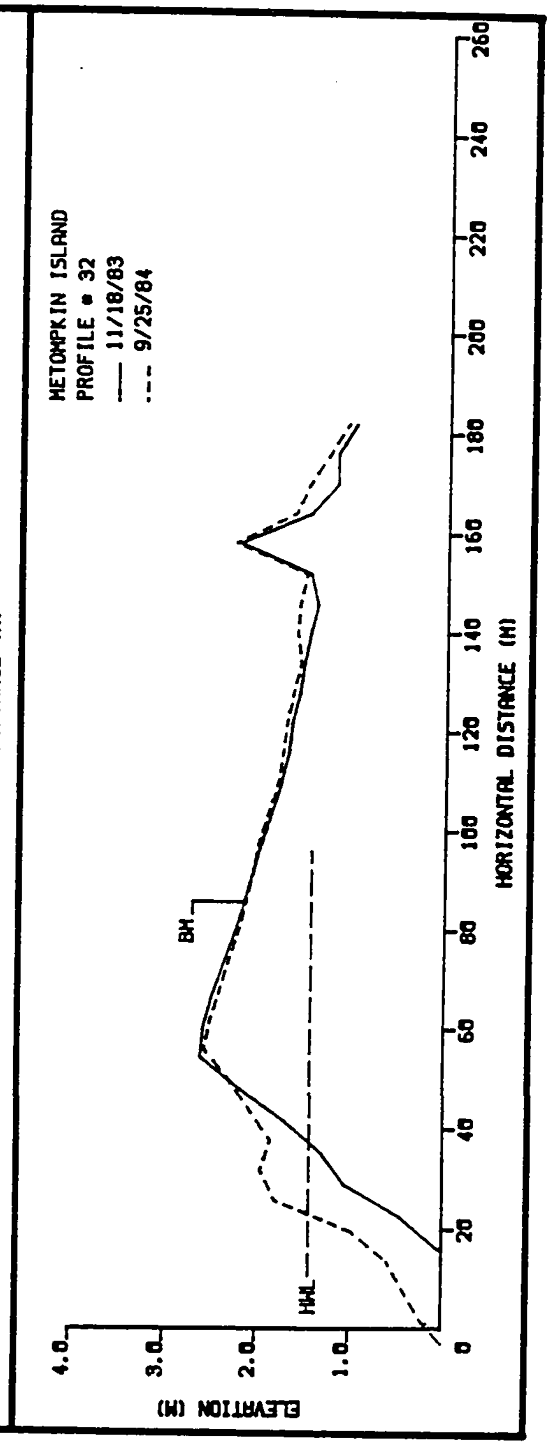

METOMPKIN ISLAND
PROFILE # 30
5/5/85
11/10/85
BM
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)
METOMPKIN ISLAND
PROFILE # 30
11/18/83
11/10/85
BM
MHL
HORIZONTAL DISTANCE (M)
ELEVATION (M)

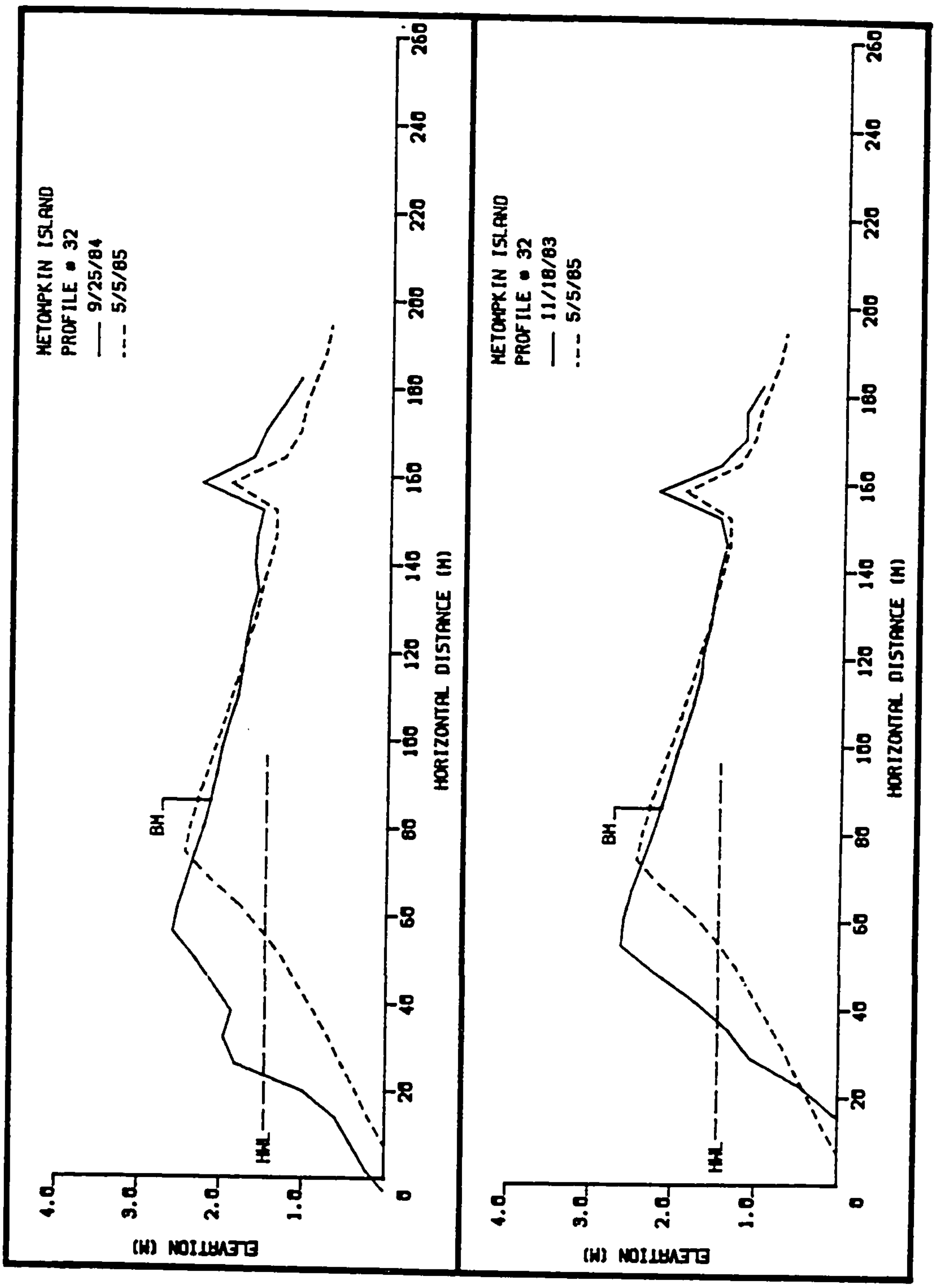


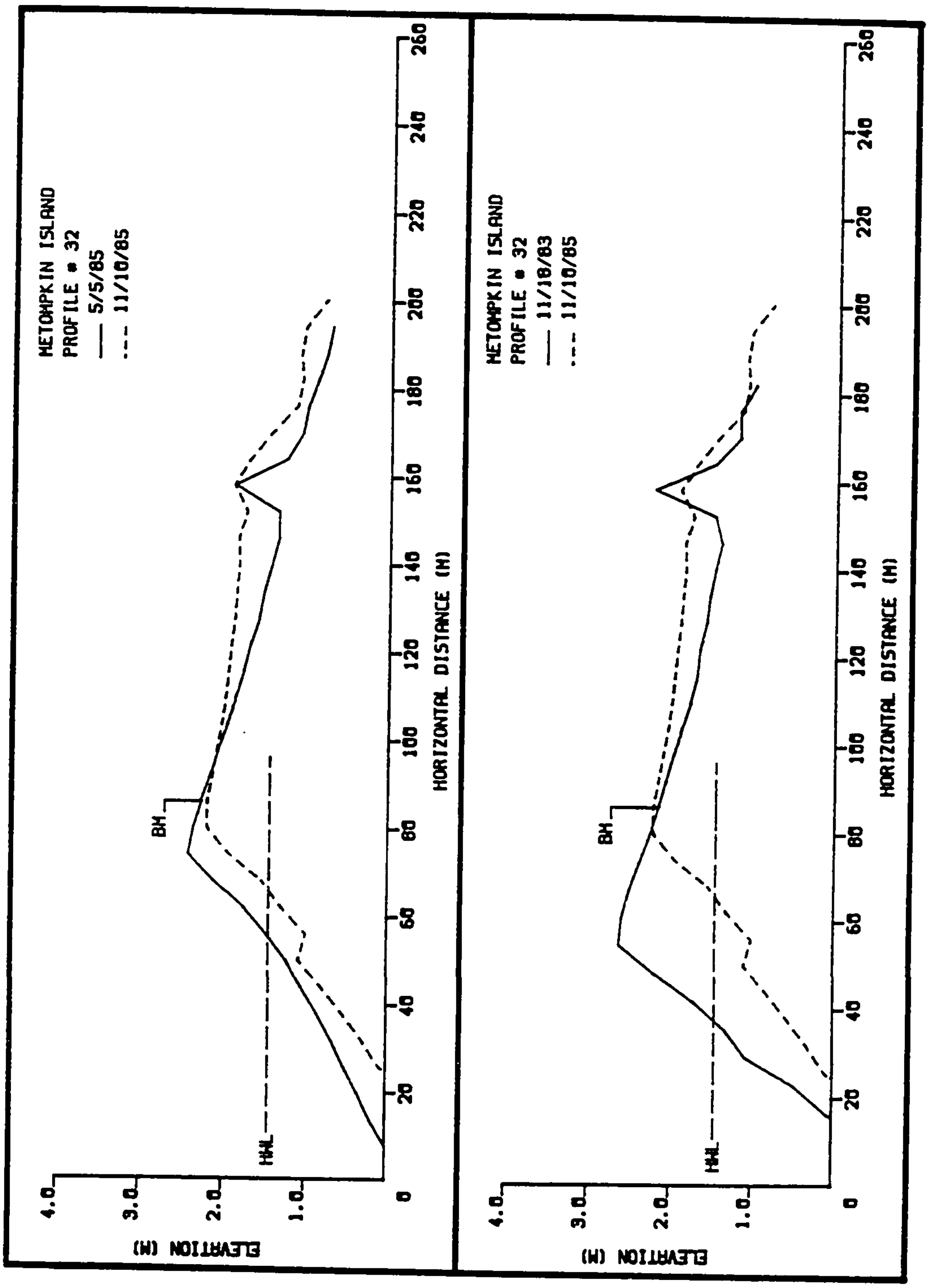
same as above


METOMPKIN ISLAND
PROFILE # 32
2/17/84
6/12/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 32
11/18/83
6/12/84
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 32
—— 6/12/84
- - - 9/25/84
BM
HWL
ELEVATION (M)
4.0
3.0
2.0
1.0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 32
—— 11/18/83
- - - 9/25/84
BM
HWL
ELEVATION (M)
4.0
3.0
2.0
1.0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 32
— 9/25/84
--- 5/5/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 32
— 11/18/83
--- 5/5/85
BM
MHL
ELEVATION (M)
HORIZONTAL DISTANCE (M)


METOMPKIN ISLAND
PROFILE # 32
5/5/85
11/10/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)
METOMPKIN ISLAND
PROFILE # 32
11/10/83
11/10/85
BM
HWL
ELEVATION (M)
HORIZONTAL DISTANCE (M)

APPENDIX B

VIBRACORE LOGS

CORE: M1

DATE: 6-23-83

LOCATION: 37°41'40"N, 75°35'00"W, Transect 1

ELEVATION (MSL): 1.40 m

CORE LENGTH: 7.30 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Barrier Island/ Beach	0-1.39	tan to lt. brownish-grey to grey, mod. well sorted, M-F qtz. sand; some heavy mins.; some horiz. to sub-horiz. laminae
Marsh	1.39-1.88	brown to v. dk. grey, v. poorly sorted, clayey silt; extensive root bioturbation (*Spartina alterniflora*)
Sandy Tidal Flat	1.88-2.87	grey to dk. grey, mod. well sorted, F-VF qtz. sand; highly bioturbated due to microlocomotion features (amphipods(?)); faint ripple laminations and planar cross-bedding
Mixed Tidal Flat	2.87-7.30	grey to dk. grey, v. poorly sorted, sandy silt to clayey silt; lenticular bedding and pockets of sand; unit thoroughly disturbed by polychaete burrows and macrolocomotion features creating swirling textural contrasts

CORE: M2

DATE: 6-24-83

LOCATION: 37°41'44"N, 75°35'11"W, Transect 1

ELEVATION (MSL): 0.29 m

CORE LENGTH: 4.38 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Sandy Tidal Flat	0-0.54	grey, well sorted, M-F sand with heavy mins.; v. faint horiz. to sub-horiz. and thin ripple laminae accented by heavy mins.; micro-locomotion bioturbation evident
Marsh	0.54-1.00	organic rich, grey to dk. grey, v. poorly sorted, clayey silt to silty sand; faint horiz. layers of mud and sand; extensive root bio-turbation; locomotion bioturbation
Sandy Tidal Flat	1.00-4.38	grey to lt. grey, mod. to poorly sorted, F-VF qtz. sand; horiz. to sub-horiz. laminae; faint ripple laminations and planar cross-bedding; few flasers of muds and organics (*Spartina* wrack); microlocomotion bioturbation with few polychaete burrows; whole *Ensis directus* shell towards base of unit

CORE: M3

DATE: 8-6-83

LOCATION: 37°41'52"N, 75°35'43"W, Transect 1

ELEVATION (MSL): 0.15 m

CORE LENGTH: 8.40 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Sandy Tidal Flat	0-1.40	lt. brownish-grey, well to poorly sorted, VF-F qtz. sand; horiz. to sub-horiz. laminae occasionally outlined by heavy mins.; v. thin ripple laminae; stringers and pockets of organic material; micro-locomotion bioturbation evident
Mixed Tidal Flat	1.40-4.55	dk. grey to v. dk. grey, poorly to v. poorly sorted, silty sand to clayey silt; horiz. to sub-horiz. layers disturbed by macrolocomotion bioturbation; numerous whole and fragmented *Littorina irrorata* shells
Lagoon/Muddy Tidal Flat	4.55-8.40	greyish-brown to grey, v. poorly sorted, clayey silt; microlocomotion bioturbation throughout creating massive appearance; numerous *Crassostrea virginica* shells and shell fragments; *Littorina irrorata* shells present

CORE: M4

DATE: 10-8-83

LOCATION: 37°46'26"N, 75°32'31"W, Transect 4

ELEVATION (MSL): 0.78

CORE LENGTH: 7.31 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.19	organic-rich, dk. grey, v. poorly sorted, clayey silt; extensive root bioturbation (*S. patens* and *S. alterniflora*)
Tidal Channel	0.19-7.31	grey to dk. grey, mod. well to v. poorly sorted; interbedded sand and mud layers of varying thickness; some organic flasers and lenticular bedding; few horiz. to sub-horiz. and faint ripple laminae; microlocomotion bioturbation; some macrolocomotion structures and few polychaete burrows; *Crassostrea virginica* and *Spartina sp*. stems at 2.55 m

CORE: M5

DATE: 10-9-83

LOCATION: 37°46'33"N, 75°33'13"W, Transect 4

ELEVATION (MSL): 0.82

CORE LENGTH: 5.09 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-2.00	organic-rich, grey to dk. grey, v. poorly sorted, sandy silt to silty clay; extensive root bioturbation by *S. patens* and *S. alterniflora*
Lagoon/Muddy Tidal Flat	2.00-3.42	grey to dk. grey, v. poorly sorted, clayey silt to silty clay; faint horiz. to sub-horiz. laminae outlined by heavy mins.; polychaete burrows; microlocomotion bioturbation
Basal Peat	3.42-3.62	blk. organic layer
Pre-Holocene Lagoon(?)	3.62-4.20	blk. to grey, v. poorly sorted, silty sand to clayey sand; structureless; polychaete burrows/roots (?) with mineralized walls
Pre-Holocene Marine(?)	4.20-5.09	yellowish-brown, poorly sorted, C-F qtz. sand; completely bioturbated; few polychaete burrows/roots(?) with mineralized walls

CORE: M6

DATE: 10-29-83

LOCATION: 37°46'44"N, 75°33'40"W, Transect 4

ELEVATION (MSL): 0.56

CORE LENGTH: 3.71 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.92	organic-rich, dk. grey, v. poorly sorted, silty clay; extensive root bioturbation (*Spartina alterniflora)*
Lagoon/Muddy Tidal Flat	0.92-1.21	dk. grey, v. poorly sorted, clayey silt; microlocomotion bioturbation dominant; few polychaete burrows; large *Crassostrea virginica* shell at base of unit
Transition Zone	1.21-1.52	dk. grey, v. poorly sorted, clayey sand; structureless
Pre-Holocene Marine/Fluvial (?)	1.52-3.71	dk. brown to tan, well to poorly sorted, VC-F qtz. sand; root bioturbation; v. faint horiz. to sub-horiz. laminae; small ripple laminae; dewatered; subaerial soil development; granules and pebbles present; organic layers throughout

CORE: M7

DATE: 5-26-84

LOCATION: 37°42'04"N, 75°36'27"W, Transect 1

ELEVATION (MSL): -0.23 m

CORE LENGTH: 4.21 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Sandy Tidal Flat	0-1.58	grey to v. dk. grey, v. poorly to mod. well sorted, F-M qtz. sand; horiz. to sub-horiz. laminae, some flasers; macrolocomotion bioturbation common; *Littorina* shells and shell frags.; structureless at base of unit
Transition Zone	1.58-2.28	lt. brownish-grey to greyish-brown, v. poorly sorted, F-M qtz. sand; structureless; thin vertical burrows or rootlets common
Pre-Holocene Marine (?)	2.28-4.21	lt. grey to lt. brownish-grey, mod. to mod. well sorted, med. qtz. sand; horiz. to sub-horiz. bedding; some planar cross-bedding

CORE: M8

DATE: 5-26-84

LOCATION: 37°46'18"N, 75°32'20"W, Transect 4

ELEVATION (MSL): 0.29

CORE LENGTH: 8.73 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.88	grey to dk. grey, v. poorly sorted, silty sand; dense mat of roots to 0.25 m; interbedded mud and sand; root bioturbation decreasing with depth; mostly mud below 0.65 m
Lagoon/Muddy Tidal Flat	0.88-8.73	dk. grey, v. poorly sorted, clayey silt to silty clay; intermittent *S. alterniflora* stems and roots from 2.41-3.46 m, root bioturbation present, organic content decreasing with depth, few thin sand layers present; *Littorina* shells and large *Crassostrea* frags.; small polychaete burrows and microlocomotion bioturbation

CORE: M9

DATE: 5-27-84

LOCATION: 37°05'45"N, 75°33'27"W, Transect 3

ELEVATION (MSL): 0.72

CORE LENGTH: 8.32 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.85	dk grey to dk greyish-brown, v. poorly sorted, clayey silt; extensive root bioturbation (*Spartina alterniflora* and *patens*); structureless; *Crassostrea* frags.
Lagoon/Muddy Tidal Flat	0.85-7.52	dk. grey to dk. greyish-brown, v. poorly sorted, clayey silt to silty clay; minor *Spartina* root bioturbation from 0.85-1.31 m; two zones of intermittent *Spartina stems and* roots from 1.31-2.10 m and 3.07-4.96 m, deeper layer slightly more decomposed; faint sand and mud laminae; few polychaete burrows; microlocomotion bioturbation dominant; *Crassostrea* shell layer at pre-Holocene contact
Pre-Holocene Lagoon (?)	7.52-8.32	grey to lt. blue-grey, v. poorly sorted, highly dewatered clayey silt; extensive bioturbation creating homogenous appearance

CORE: M10

DATE: 6-8-84

LOCATION: 37°45'13"N, 75°33'55"W, Transect 3

ELEVATION (MSL): 0.73

CORE LENGTH: 8.21 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.64	organic-rich, grey to dk. grey, v. poorly sorted, clayey silt; extensive root bioturbation (*Spartina sp.*); structureless
Lagoon/Muddy Tidal Flat	0.64-5.37	dk. grey to grey, v. poorly sorted, clayey silt; faint horiz. to sub-horiz. laminae; *Littorina* shells and few scattered *Crassostrea* shell frags.; few pockets of organic material; mostly microlocomotion bioturbation with some polychaete burrows; nearly structureless
Transition Zone	5.37-5.66	grey to dk. brown organic rich mud
Basal Peat	5.66-6.15	dk. brown to blk. organic layer
Pre-Holocene Marine(?)	6.15-7.16	blk. to blue-grey to yellowish-tan, poorly to v. poorly sorted, C-M sand to silty sand; stuctureless; root and polychaete burrow bioturbation
Pre-Holocene Lagoon(?)	7.16-7.77	blue-grey to grey, poorly to v. poorly sorted, silty clay; finely laminated sand and mud; mineralized root traces/worm burrows(?)
Pre-Holocene Marine(?)	7.77-8.21	grey to blk., v. poorly to mod. sorted, M-C sand to silty sand; re-worked sand and mud with organic layers; peat at base of unit

CORE: M11

DATE: 6-8-84

LOCATION: 37°45'02"N, 75°33'05"W, Transect 3

ELEVATION (MSL): 0.67

CORE LENGTH: 7.74 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.61	organic-rich, dk. grey, v. poorly sorted, clayey silt; dense *Spartina sp.* roots and stems; structureless
Lagoon/Muddy Tidal Flat	0.61-1.45	dk. grey, v. poorly sorted, clayey silt; microlocomotion bioturbation extensive; some macrolocomotion bioturbation; structureless
Tidal Channel	1.45-6.12	tan to grey, v. poorly to well sorted, clayey silt to F-VF qtz. sand; interbedded sand and mud of varying thicknesses with organic layers; some flasers; some ripple laminae outlined by heavy mins.; bioturbation; pre-Holocene clay inclusion at 5.73-5.75 m; *Crassostrea sp.* shell at base of unit
Lagoon	6.12-7.74	grey to dk. grey, v. poorly sorted, clayey silt to silty clay; microlocomotion bioturbation throughout, some v. fine laminae

CORE: M12

DATE: 6-23-84

LOCATION: 37°45'26"N, 75°34'18"W, Transect 3

ELEVATION (MSL): 0.73

CORE LENGTH: 6.58 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.62	organic-rich, dk. grey, v. poorly sorted, clayey silt; extensive root bioturbation (*Spartina sp.*); structureless
Lagoon/Muddy Tidal Flat	0.62-3.91	grey to dk. grey, v. poorly sorted, clayey silt; microlocomotion bioturbation throughout; polychaete burrows; some small sand pockets; *Littorina* and *Crassostrea* shells present
Transition Zone	3.91-4.50	grey, v. poorly sorted, clayey sand; extensive macrolocomotion bioturbation; mottled; structureless; *Crassostrea* and *Ensis* shells present
Basal Peat	4.50-5.19	blk. to v. dk. brown organic layers; some wood chips; some sand layers; possibly transported
Pre-Holocene Fluvial/Marine(?)	5.19-6.15	lt. grey to white, well to poorly sorted, VC-F qtz. sand; alternating tabular layers of gravel and F-M sand; some horiz. to near horiz. laminae
Pre-Holocene Lagoon(?)	6.15-6.58	dk. grey to grey, mod. to v. poorly sorted, silty sand to clayey silt; horiz. to sub-horiz. laminae; ripple laminations; some planar cross-bedding

CORE: M13

DATE: 6-23-84

LOCATION: 37°43'27"N, 75°34'12"W, Transect 2

ELEVATION (MSL): 0.85

CORE LENGTH: 3.70 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Inlet/Washover	0-2.61	tan to greyish-brown to grey, v. well to poorly sorted, C-F qtz. sand to silty sand; v. distinct horiz. to sub-horiz. laminae outlined by heavy mins. and shells (*Donax*, *Mulinia*); ripple foresets and trough cross-bedding; megaripple(?) foresets; numerous microripple laminations; 3 distinct fining upward sequences
Mixed Tidal Flat	2.61-3.11	dk. grey, v. poorly sorted, silty sand; extensive macrolocomotion bioturbation; *Littorina* shells; structureless
Lagoon/Muddy Tidal Flat	3.11-3.70	dk. grey, v. poorly sorted, clayey silt; extensive microlocomotion bioturbation; some worm burrows, root and stem frags.; structureless

CORE: M14

DATE: 8-20-84

LOCATION: 37°43'30"N, 75°34'12"W, Transect 2

ELEVATION (MSL): 0.85

CORE LENGTH: 3.02 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Inlet/Washover	0-1.58	tan to pale brown, mod. to mod. well sorted, F-M qtz. sand; numerous fragments of *Crassostrea*, *Mercenaria*, and *Spissula*; v. few horiz. to sub-horiz. laminae; v. little bioturbation or persistent primary structures
Lagoon/Muddy Tidal Flat	1.58-3.02	dk. grey, v. poorly sorted, clayey silt; v. faint traces of horiz. to sub-horiz. laminae; extensive micro-locomotion bioturbation; few organics (roots and stems) and *Crassostrea* shell frags. at top of unit

CORE: M15

DATE: 8-21-84

LOCATION: 37°43'51"N, 75°35'23"W, Transect 2

ELEVATION (MSL): 0.18

CORE LENGTH: 3.16 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Marsh	0-0.40	dk. grey, v. poorly sorted, clayey sand; extensive *Spartina* root bioturbation; structureless
Transition Zone	0.40-0.85	greyish-brown to dk. grey, mod. well sorted, M-F qtz. sand; structureless
Pre-Holocene Marine(?)	0.85-3.16	lt. grey to pale brown to yellow brown, mod. to well sorted, C-F qtz. sand; some pebbles; few bedding structures; horiz. to sub-horiz. laminae outlined by heavy mins. at base of unit

CORE: M16

DATE: 8-22-84

LOCATION: 37°43'34"N, 75°34'48"W, Transect 2

ELEVATION (MSL): 0.15

CORE LENGTH: 7.38 m

ENVIRONMENT	DEPTH (m)	DESCRIPTION
Oyster Flat	0-0.40	man-made oyster mound
Mixed Tidal Flat	0.40-2.50	grey to dk. grey, well to v. poorly sorted, silty sand to clayey silt; extensive polychaete bioturbation; macrolocomotion structures; abundant *Crassostrea* and *Littorina* shell frags.; pockets and lenses of v. fine sand in a mud matrix; some horiz. to sub-horiz. laminae
Lagoon/Muddy Tidal Flat	2.50-4.81	dk. grey, v. poorly sorted, clayey silt; completely bioturbated; some small shell frags. (*Crassostrea*(?)); some organic frags. interspersed; structureless; *Crassostrea* shell at base of unit
Transition Zone	4.81-4.96	dk. grey mud with med. sand
Pre-Holocene Marine/Fluvial (?)	4.96-7.38	dk. grey to white, mod. well to v. poorly sorted, C-F qtz. sand to silty sand; v. few structures; massive unit; mineralized polychaete burrows/roots(?); VC white sand and pebbles towards base of unit

APPENDIX C

GRAIN SIZE STATISTICS

Folk Inclusive Graphic Statistics

Sample	Mean	Median	Sorting	Skewness	Kurtosis	Depth (m)
M1-1	2.55	2.60	0.50	-0.11	1.18	0.33-0.37
M1-2	2.37	2.37	0.51	0.03	0.95	1.12-1.16
M1-3	7.90	7.49	2.43	0.20	0.68	1.49-1.53
M1-4	3.16	3.12	0.54	0.35	1.80	2.70-2.73
M1-5	6.83	5.90	2.79	0.43	0.67	3.33-3.36
M1-6	4.84	3.73	2.37	0.77	1.64	4.44-4.47
M1-7	6.64	5.36	2.77	0.58	0.72	5.54-5.57
M1-8	6.39	4.87	2.83	0.67	0.76	6.60-6.63
M1-9	5.57	4.43	2.38	0.72	1.73	7.25-7.28
M2-1	2.46	2.52	0.49	-0.21	1.21	0.43-0.46
M2-2	6.21	4.82	2.99	0.59	0.87	0.67-0.69
M2-3	6.71	5.65	3.05	0.43	0.59	0.77-0.80
M2-4	3.60	3.43	1.40	0.65	4.69	1.09-1.11
M2-5	3.22	3.15	1.14	0.53	4.98	1.25-1.28
M2-6	3.51	3.37	1.32	0.57	4.06	2.21-2.24
M2-7	3.09	3.05	0.56	0.24	1.43	2.77-2.80
M2-8	2.92	2.83	1.19	0.51	3.39	4.25-4.28
M3-1	2.81	2.80	0.40	0.09	0.93	0.40-0.43
M3-2	3.44	3.27	1.40	0.60	4.37	1.12-1.15
M3-3	4.80	4.07	2.12	0.67	1.82	1.70-1.73
M3-4	7.08	6.42	2.89	0.29	0.59	2.96-2.99
M3-5	5.03	4.38	1.94	0.68	2.12	4.41-4.44
M3-6	7.31	6.68	2.75	0.30	0.59	4.85-4.88
M3-7	6.90	5.87	2.78	0.47	0.63	6.25-6.28
M3-8	7.88	7.64	2.69	0.08	0.64	8.20-8.23
M4-1	7.28	6.66	2.86	0.24	0.68	0.07-0.10
M4-2	2.60	2.51	1.08	0.50	3.64	0.83-0.86
M4-3	6.91	6.68	3.18	0.01	0.65	1.34-1.37
M4-4	2.59	2.53	0.54	0.25	1.27	2.25-2.28
M4-5	6.59	5.71	2.97	0.38	0.73	3.50-3.53
M4-6	5.67	4.25	2.88	0.66	0.91	4.50-4.53
M4-7	4.60	3.49	2.40	0.76	1.55	5.80-5.83
M4-8	5.04	3.88	2.58	0.69	1.28	7.23-7.26
M5-1	5.98	4.53	2.92	0.64	1.14	0.31-0.33
M5-2	8.47	8.47	2.40	-0.04	0.69	1.20-1.22
M5-3	7.39	6.63	2.79	0.34	0.56	2.40-2.42
M5-4	7.37	7.11	3.38	-0.03	0.85	3.15-3.18
M5-5*	9.09	9.59	2.20	-0.30	0.65	3.50-3.52
M5-6*	5.20	4.66	3.73	0.22	0.70	3.70-3.73
M5-7*	5.06	4.68	3.61	0.19	0.72	4.00-4.03
M5-8*	3.99	2.00	3.55	0.76	0.84	4.21-4.24
M5-9*	1.75	1.65	1.85	0.47	3.48	4.43-4.46
M5-10*	1.69	1.67	1.08	0.23	1.66	4.77-4.80
M5-11*	1.43	1.43	1.40	0.15	2.16	4.97-5.00

M6-1	8.71	8.77	2.23	-0.06	0.67	0.12-0.14
M6-2	7.96	7.66	2.60	0.11	0.66	0.90-0.92
M6-3*	2.92	1.62	3.20	0.65	2.82	1.34-1.37
M6-4*	2.09	2.13	1.86	0.30	4.21	1.70-1.73
M6-5*	1.25	1.77	1.52	-0.42	1.42	1.96-1.99
M6-6*	1.63	1.79	1.08	-0.23	1.79	2.16-2.19
M6-7*	0.16	0.27	1.86	-0.01	0.74	2.33-2.36
M6-8*	1.02	1.18	1.20	-0.16	0.94	2.42-2.45
M6-9*	-0.16	-0.25	1.85	0.06	0.70	2.48-2.51
M6-10*	0.42	0.84	1.64	-0.34	0.80	2.57-2.60
M6-11*	1.74	1.69	0.53	0.17	1.32	2.70-2.73
M6-12*	1.87	1.84	0.60	0.12	1.24	3.05-3.08
M6-13*	2.27	2.25	0.45	0.14	1.01	3.47-3.50
M7-1	2.73	2.02	2.08	0.72	3.64	0.13-0.16
M7-2	1.68	1.76	0.55	-0.22	1.08	0.37-0.40
M7-3	2.00	2.04	0.69	0.08	2.28	0.62-0.65
M7-4	3.55	2.26	2.66	0.78	4.63	1.22-1.25
M7-5*	2.80	1.89	2.60	0.68	3.90	1.93-1.96
M7-6*	1.65	1.74	0.73	-0.19	1.05	2.55-2.58
M7-7*	1.85	1.90	0.96	0.10	1.70	2.87-2.90
M7-8*	1.86	1.88	0.57	-0.11	0.91	3.35-3.38
M8-1	4.73	3.85	2.45	0.62	1.46	0.21-0.24
M8-2	6.40	5.59	3.05	0.36	0.67	1.17-1.20
M8-3	8.31	8.05	2.33	0.11	0.69	2.60-2.63
M8-4	8.33	8.22	2.38	0.05	0.65	2.90-2.93
M8-5	7.55	6.81	2.49	0.36	0.66	3.60-3.63
M8-6	7.46	6.75	2.61	0.34	0.62	4.70-4.73
M8-7	6.72	5.72	2.80	0.47	0.66	6.10-6.13
M8-8	7.74	7.30	2.56	0.21	0.64	7.36-7.39
M8-9	7.67	7.16	2.57	0.24	0.65	8.61-8.64
M9-1	7.82	7.65	2.65	0.07	0.65	0.30-0.33
M9-2	7.31	6.77	2.71	0.25	0.68	1.26-1.29
M9-3	6.64	5.50	2.66	0.56	0.79	1.76-1.79
M9-4	8.01	7.53	2.31	0.26	0.64	2.84-2.87
M9-5	8.49	8.36	2.27	0.05	0.65	3.60-3.63
M9-6	8.39	8.38	2.37	-0.01	0.65	5.32-5.35
M9-7	8.44	8.37	2.34	0.01	0.69	7.30-7.33
M9-8*	7.72	7.17	2.57	0.25	0.64	7.78-7.81
M9-9*	7.36	6.52	2.46	0.45	0.69	8.20-8.23
M10-1	7.88	7.51	2.35	0.19	0.72	0.60-0.63
M10-2	7.68	7.53	2.76	0.04	0.71	2.30-2.33
M10-3	7.92	7.37	2.30	0.30	0.66	4.60-4.63
M10-4*	3.22	1.62	3.03	0.80	0.93	6.27-6.30
M10-5*	0.81	0.76	1.09	0.06	1.12	6.86-6.89
M10-6*	1.42	1.35	1.44	0.49	4.46	7.00-7.03
M10-7*	8.23	8.07	2.49	0.05	0.66	7.49-7.51
M10-8*	2.29	1.40	2.60	0.60	2.30	8.02-8.05
M10-9*	0.99	0.98	0.71	-0.02	1.27	8.15-8.18

M11-1	7.74	7.32	2.52	0.20	0.68	0.70-0.73
M11-2	3.37	3.13	1.52	0.58	3.88	1.60-1.63
M11-3	6.68	6.46	3.22	0.11	0.61	2.29-2.31
M11-4	2.73	2.68	0.40	0.17	0.94	2.98-3.01
M11-5	6.88	6.57	3.06	0.14	0.74	4.68-4.70
M11-6	2.53	2.48	0.39	0.21	1.12	5.23-5.26
M11-7	8.29	8.11	2.32	0.09	0.67	6.40-6.43
M11-8	8.22	7.94	2.27	0.14	0.69	7.55-7.58
M12-1	8.27	7.94	2.29	0.17	0.65	0.43-0.46
M12-2	7.65	7.11	2.53	0.25	0.67	1.82-1.85
M12-3	7.12	6.74	3.21	0.06	0.81	3.70-3.73
M12-4*	2.89	1.78	3.04	0.61	2.72	4.30-4.33
M12-5*	1.63	1.67	0.97	-0.03	1.04	5.09-5.12
M12-6*	1.89	1.93	0.58	-0.07	1.07	5.43-5.46
M12-7*	0.02	0.21	1.44	-0.21	1.42	5.78-5.81
M12-8*	3.83	3.58	0.85	0.50	1.12	6.25-6.28
M12-9*	7.67	7.28	2.62	0.18	0.63	6.30-6.33
M13-1	1.98	1.98	0.55	0.06	1.22	0.10-0.13
M13-2	1.44	1.56	0.96	-0.34	1.53	0.53-0.56
M13-3	2.06	2.08	0.49	-0.03	1.28	1.32-1.35
M13-4	1.62	1.66	0.55	-0.14	1.06	1.76-1.79
M13-5	3.92	3.58	1.71	0.56	2.06	2.10-2.13
M13-6	2.30	2.29	0.31	0.10	1.17	2.49-2.52
M13-7	5.19	3.82	2.54	0.80	1.18	2.72-2.75
M13-8	8.48	8.37	2.29	0.03	0.68	3.60-3.63
M14-1	1.82	1.84	0.59	-0.03	1.19	0.09-0.12
M14-2	1.57	1.66	0.97	-0.39	2.05	0.71-0.74
M14-3	1.69	1.69	0.55	0.03	1.14	1.15-1.18
M14-4	8.17	7.99	2.47	0.07	0.65	1.77-1.80
M14-5	7.28	6.50	2.65	0.38	0.62	1.90-1.93
M15-1	4.71	2.74	3.62	0.65	0.90	0.19-0.22
M15-2*	1.84	1.88	0.64	-0.09	1.20	0.60-0.63
M15-3*	2.06	1.95	1.59	0.43	3.27	0.78-0.81
M15-4*	1.83	1.90	0.70	-0.14	1.24	1.10-1.13
M15-5*	0.93	0.80	0.83	0.26	0.92	1.53-1.56
M15-6*	2.24	2.22	0.47	0.06	1.22	2.30-2.33
M15-7*	1.97	2.03	0.67	-0.17	1.23	2.87-2.91
M16-1	7.71	7.50	2.84	0.04	0.74	0.58-0.61
M16-2	3.47	3.40	0.44	0.33	1.28	1.09-1.12
M16-3	6.13	4.89	2.70	0.62	0.95	1.73-1.76
M16-4	7.83	7.53	2.95	0.01	0.80	3.06-3.09
M16-5	7.91	7.36	2.38	0.28	0.64	4.30-4.33
M16-6*	3.48	2.20	2.86	0.68	0.96	5.25-5.28
M16-7*	2.06	2.09	1.90	0.30	4.14	5.80-5.83
M16-8*	2.15	2.17	0.53	-0.05	1.38	6.35-6.38
M16-9*	0.94	0.89	0.67	0.17	1.11	6.84-6.87

MF-1	2.05	2.05	0.48	0.02	1.22	surface
MF-2	2.09	2.09	0.49	0.04	1.15	surface
MB-3	2.65	2.60	0.43	0.13	0.87	surface
MB-10	2.27	2.23	0.47	0.14	1.01	surface
MB-13	2.22	2.20	0.45	0.10	1.28	surface
MB-16	1.99	2.03	0.54	-0.07	1.28	surface
MB-20	1.75	1.80	0.52	-0.13	0.94	surface
MB-24	2.01	2.01	0.44	0.02	1.25	surface
MB-27	1.71	1.75	0.58	-0.09	0.93	surface
MB-30	1.72	1.68	0.44	0.15	0.99	surface
MB-33	1.95	2.04	0.59	-0.23	1.08	surface

Sample	Moment Statistics First	Second	Third	Fourth	Percent Composition Gravel	Sand	Silt	Clay
M1-1	2.78	1.45	4.18	21.23	0	96.39	0.13	3.48
M1-2	2.58	1.43	4.37	23.24	0.12	96.63	0.10	3.15
M1-3	7.86	2.37	0.03	1.82	0	2.43	53.20	44.37
M1-4	3.47	1.55	4.14	19.92	0	90.82	5.41	3.77
M1-5	6.75	2.70	0.49	1.77	0	10.83	57.58	31.59
M1-6	4.95	2.59	1.51	3.84	0	55.91	29.11	14.98
M1-7	6.51	2.69	0.71	1.95	0	10.31	61.38	28.31
M1-8	6.24	2.77	0.80	2.06	0	17.46	56.27	26.27
M1-9	5.49	2.50	1.26	3.57	0.20	21.79	60.80	17.21
M2-1	2.62	1.31	4.57	26.54	0.03	97.21	0.13	2.63
M2-2	6.00	2.85	0.77	2.20	0	24.86	50.09	25.05
M2-3	6.69	2.95	0.45	1.65	0	19.76	48.21	32.03
M2-4	4.01	1.88	2.10	11.17	0	78.60	15.03	6.39
M2-5	3.64	1.82	3.29	13.31	0.02	87.58	7.13	5.27
M2-6	3.86	1.79	3.24	12.86	0	80.59	13.83	5.58
M2-7	3.38	1.57	4.15	20.15	0	91.70	4.52	3.78
M2-8	3.32	1.87	3.31	13.66	0	88.27	6.68	5.05
M3-1	2.97	1.12	5.29	33.45	0	97.21	0.68	2.11
M3-2	3.84	1.90	2.85	10.62	0	82.20	11.67	6.13
M3-3	4.10	2.40	1.58	4.34	0	47.55	38.93	13.52
M3-4	7.05	2.81	0.26	1.59	0	13.29	49.98	36.73
M3-5	5.26	2.24	1.70	4.65	0	30.34	56.28	13.38
M3-6	7.34	2.68	0.25	1.54	0	4.21	56.94	38.85
M3-7	6.87	2.70	0.50	1.73	0	9.59	57.86	32.55
M3-8	7.90	2.62	-0.07	1.55	0	5.23	48.20	46.57
M4-1	7.23	2.75	0.14	1.73	0	9.64	52.51	37.85
M4-2	2.98	1.84	3.52	14.92	0	92.40	2.96	4.64
M4-3	6.94	3.00	0.05	1.64	0	22.69	38.76	38.55
M4-4	2.85	1.57	4.30	21.88	0	95.30	1.43	3.27
M4-5	6.52	2.83	0.42	1.86	0	21.00	48.68	30.32
M4-6	5.53	2.82	0.94	2.46	0	45.23	33.19	21.58
M4-7	4.68	2.59	1.46	3.89	0	62.16	23.76	14.08
M4-8	5.03	2.67	1.28	3.30	0	52.48	30.88	16.64
M5-1	5.69	2.70	1.04	2.73	0	30.82	49.54	19.64
M5-2	8.47	2.31	-0.26	1.73	0	1.41	43.81	54.78
M5-3	7.46	2.82	0.15	1.53	0	4.09	55.16	40.75
M5-4	7.10	3.41	-0.48	2.26	0.54	15.16	43.09	41.21
M5-5*	8.10	2.13	-0.43	1.64	0	0	37.45	62.55
M5-6*	4.91	3.68	0.40	1.72	0	48.84	27.35	23.81
M5-7*	4.84	3.60	0.41	1.79	0.23	48.05	29.75	21.97
M5-8*	3.90	3.60	1.02	2.48	0	67.04	14.65	18.31
M5-9*	2.35	2.46	2.58	8.86	0	89.03	4.33	6.64
M5-10*	1.99	1.89	3.44	16.33	0.18	94.22	2.26	3.34
M5-11*	1.70	2.17	2.71	12.62	4.34	89.80	1.98	3.88

M6-1	8.70	2.14	-0.23	1.57	0	0	42.46	57.54
M6-2	7.92	2.62	-0.23	2.06	0	3.58	49.78	46.64
M6-3*	2.81	3.36	1.42	3.95	2.80	75.86	8.91	12.43
M6-4*	2.61	2.40	2.64	9.69	0.53	90.91	1.81	6.75
M6-5*	1.63	2.31	2.12	10.49	11.11	84.30	0.73	3.86
M6-6*	1.86	1.91	2.60	12.68	2.81	92.79	0.80	3.60
M6-7*	0.37	2.36	1.55	7.97	30.43	66.58	0.43	2.56
M6-8*	1.21	1.95	2.62	13.15	5.39	90.97	0.57	3.07
M6-9*	0.07	2.41	1.79	8.51	38.11	58.86	0.26	2.77
M6-10*	0.61	2.23	1.77	9.37	24.48	72.41	0.37	2.74
M6-11*	1.94	1.52	4.43	23.98	0.19	96.59	0.21	3.01
M6-12*	2.06	1.49	4.15	22.88	0.33	96.52	0.39	2.76
M6-13*	2.54	1.53	4.29	21.04	0	95.96	0.31	3.73
M7-1	2.96	2.43	2.11	6.71	0	79.62	13.48	6.90
M7-2	1.82	1.32	4.71	29.42	0	97.20	0.89	1.91
M7-3	2.28	1.62	4.07	20.91	0	94.99	2.16	2.85
M7-4	3.45	2.88	1.66	4.41	0	77.71	10.71	11.58
M7-5*	2.83	2.83	1.95	5.62	0	83.03	7.56	9.41
M7-6*	1.67	0.93	2.77	26.79	0	99.16	0.47	0.37
M7-7*	2.09	1.50	3.16	15.93	0	94.12	4.00	1.78
M7-8*	1.85	0.73	4.01	48.65	0	99.58	0.11	0.31
M8-1	4.84	2.57	1.38	3.73	0	53.74	31.74	14.52
M8-2	6.34	2.91	0.43	1.78	0	30.44	39.13	30.43
M8-3	8.32	2.24	-0.11	1.76	0	1.09	48.35	50.56
M8-4	8.36	2.27	-0.08	1.52	0	0	47.82	52.18
M8-5	7.51	2.38	0.38	1.70	0	0.84	62.65	36.51
M8-6	7.48	2.53	0.30	1.55	0	11.76	59.22	39.02
M8-7	6.67	2.73	0.50	1.79	0	15.23	52.99	31.78
M8-8	7.74	2.46	0.15	1.56	0	1.10	55.78	43.12
M8-9	7.64	2.52	0.08	1.78	0	3.09	55.24	41.67
M9-1	7.82	2.54	-0.04	1.62	0	3.26	50.34	46.40
M9-2	7.27	2.58	0.24	1.72	0	7.00	55.95	37.05
M9-3	6.54	2.55	0.71	2.01	0	8.23	64.26	27.51
M9-4	8.01	2.21	0.21	1.57	0	0.17	55.85	43.98
M9-5	8.51	2.18	-0.08	1.49	0	0	46.47	53.53
M9-6	8.39	2.28	-0.14	1.55	0	0.31	46.28	53.41
M9-7	8.42	2.28	-0.28	1.10	0	1.28	44.85	53.87
M9-8*	7.70	2.53	0.06	1.83	0	2.22	56.12	41.66
M9-9*	7.30	2.36	0.53	1.82	0	0.72	65.68	33.60
M10-1	7.87	2.22	0.15	1.70	0	0.47	56.05	43.48
M10-2	7.66	2.62	-0.01	1.78	0	8.23	46.98	44.79
M10-3	7.90	2.21	0.26	1.64	0	0.25	57.19	42.56
M10-4*	3.30	3.26	1.22	3.16	0.57	69.31	17.75	12.37
M10-5*	0.95	1.73	2.92	15.96	5.03	91.72	1.29	1.95
M10-6*	2.07	2.32	2.67	9.29	0	88.36	6.26	5.38
M10-7*	8.11	2.66	-0.54	2.69	0	4.37	45.03	50.60
M10-8*	2.35	2.77	1.68	5.25	1.95	78.52	13.08	6.44
M10-9*	1.01	1.22	3.49	29.82	3.34	95.41	0.33	0.92

M11-1	7.71	2.41	0.12	1.71	0	2.06	55.24	42.70
M11-2	3.75	1.10	2.58	9.04	0	81.47	11.75	6.78
M11-3	6.67	3.04	0.13	1.63	0	28.23	36.12	35.65
M11-4	2.88	1.12	5.30	33.45	0	96.99	1.00	2.01
M11-5	6.92	2.81	0.15	1.76	0	18.95	45.56	35.49
M11-6	2.62	0.93	6.43	50.61	0	98.19	0.53	1.28
M11-7	8.30	2.22	-0.04	1.59	0	0.48	48.49	51.03
M11-8	8.21	2.17	0	1.74	0	0.59	50.24	49.17
M12-1	8.32	2.20	0.02	1.51	0	0.07	50.72	49.21
M12-2	7.62	2.41	0.22	1.65	0	1.06	58.42	40.52
M12-3	6.92	3.12	-0.25	2.23	0.54	15.72	45.14	38.60
M12-4*	2.84	3.15	1.51	4.20	1.11	77.53	10.04	11.32
M12-5*	1.81	1.60	2.78	14.59	0.65	94.86	2.66	1.83
M12-6*	2.04	1.20	4.42	28.62	0	97.09	1.58	1.33
M12-7*	0.01	1.76	1.54	12.37	19.78	78.82	0.36	1.04
M12-8*	3.10	1.31	3.00	15.37	0	62.01	35.64	2.35
M12-9*	7.65	2.53	0.12	1.59	0	2.81	54.48	42.71
M13-1	2.08	0.95	4.94	39.94	0	98.39	0.86	0.75
M13-2	1.38	1.36	0.48	14.16	5.47	93.32	0.63	0.58
M13-3	2.25	1.30	4.53	26.45	0.02	96.17	1.80	2.01
M13-4	1.67	1.05	4.63	40.09	0.71	98.01	0.34	0.94
M13-5	4.26	2.04	2.03	6.77	0	61.12	31.06	7.82
M13-6	2.40	0.92	6.97	56.67	0	98.39	0.40	1.21
M13-7	5.15	2.63	1.28	3.24	0	54.56	28.09	17.35
M13-8	8.45	2.24	-0.23	1.86	0	1.04	45.70	53.26
M14-1	1.94	1.27	4.63	30.84	0.21	97.77	0.15	1.87
M14-2	1.48	1.49	1.06	16.34	5.80	92.76	0.24	1.20
M14-3	1.87	1.45	4.56	26.40	0.33	96.95	0.09	2.63
M14-4	8.18	2.39	-0.10	1.68	0	1.25	48.88	49.87
M14-5	7.28	2.58	0.34	1.65	0	2.30	60.04	37.66
M15-1	4.68	3.51	0.66	2.01	0	56.95	21.47	21.58
M15-2*	1.10	1.39	3.87	22.60	0.29	96.19	1.61	1.91
M15-3*	2.56	2.23	2.47	8.90	0.08	86.14	8.39	5.39
M15-4*	2.02	1.52	3.92	21.33	0.04	96.75	0.42	2.79
M15-5*	0.99	1.06	3.53	28.01	0	99.19	0.31	0.50
M15-6*	2.27	0.64	3.18	29.37	0	98.98	0.95	0.07
M15-7*	1.96	0.71	-0.24	5.24	0	99.34	0.66	0
M16-1	7.66	2.72	-0.15	1.79	0	12.49	42.92	44.59
M16-2	3.62	1.01	4.37	25.76	0	87.59	10.86	1.55
M16-3	5.99	2.60	0.94	2.48	0	23.53	54.03	22.44
M16-4	7.70	2.85	-0.37	2.27	0	7.52	46.91	45.57
M16-5	7.90	2.30	0.20	1.58	0	0.49	56.54	42.97
M16-6*	3.57	2.95	1.16	3.21	0	68.22	21.11	10.67
M16-7*	2.56	2.37	2.57	9.49	0.31	90.33	2.94	6.42
M16-8*	2.24	1.07	4.71	34.63	0	97.73	1.08	1.19
M16-9*	1.01	0.99	4.70	41.43	0.11	99.05	0.28	0.56

MF-1	2.06	0.49	0.05	3.67	0	99.97	0	0.03
MF-2	2.10	0.48	0.19	3.25	0	99.99	0	0.01
MB-3	2.64	0.42	0.09	2.59	0	100	0	0
MB-10	2.28	0.47	0.34	3.07	0	100	0	0
MB-13	2.22	0.45	0.24	3.69	0	100	0	0
MB-16	2.01	0.54	-0.01	3.24	0	100	0	0
MB-20	1.75	0.52	-0.16	3.23	0	100	0	0
MB-24	2.02	0.46	-0.02	4.71	0	100	0	0
MB-27	1.70	0.59	-0.02	3.09	0	100	0	0
MB-30	1.73	0.45	0.65	3.53	0	100	0	0
MB-33	1.95	0.60	-0.59	3.49	0	100	0	0

Note: * = pre-Holocene sample
- where appropriate, phi units apply
- depths are relative to core surface

APPENDIX D

STATISTICAL ANALYSIS OF CLUSTER DATA

CLUSTER FACIES 1

Sample #	Mean	Sorting	Skewness	% Gravel	% Sand	% Silt	% Clay
M1-6	4.84	2.37	0.77	----	55.91	29.11	14.98
M13-7	5.19	2.54	0.80	----	54.56	28.09	17.35
M4-6	5.67	2.88	0.66	----	45.23	33.19	21.58
M3-3	4.80	2.12	0.67	----	47.55	38.93	13.52
M8-1	4.73	2.45	0.62	----	53.74	31.74	14.52
M13-5	3.92	1.71	0.56	----	61.12	31.06	7.82
M4-7	4.60	2.40	0.76	----	62.16	23.76	14.08
M4-8	5.04	2.58	0.69	----	52.48	30.88	16.64
M2-4	3.60	1.40	0.65	----	78.60	15.03	6.37
M16-2	3.47	0.44	0.33	----	87.59	10.86	1.55
M2-6	3.51	1.32	0.57	----	80.59	13.83	5.58
M12-8*	3.83	0.85	0.50	----	62.01	35.64	2.35
M1-4	3.16	0.54	0.35	----	90.82	5.41	3.77
M2-5	3.22	1.14	0.53	0.02	87.58	7.13	5.27
M3-2	3.44	1.40	0.60	----	82.20	11.67	6.13
M2-7	3.09	0.56	0.24	----	91.70	4.52	3.78
M11-2	3.37	1.52	0.58	----	81.47	11.75	6.78
M1-9	5.57	2.38	0.72	0.20	21.79	60.80	17.21
M3-5	5.03	1.94	0.68	----	30.34	56.28	13.38
Average (M1-6 to M11-2)	4.09 0.83	1.66 0.80	0.58 0.16	---- ----	69.14 15.92	21.33 11.35	9.53 5.92
Average (M1-9 to M3-5)	5.30 0.38	2.16 0.31	0.70 0.03	0.10 0.10	26.06 4.28	58.54 2.26	15.30 1.92
TOTAL	4.21 0.87	1.71 0.77	0.59 0.15	0.01 0.04	64.60 20.08	25.25 15.69	10.14 5.90

CLUSTER FACIES 2

Sample #	Mean	Sorting	Skewness	% Gravel	% Sand	% Silt	% Clay
M2-3	6.71	3.05	0.43	----	19.76	48.21	32.03
M4-5	6.59	2.97	0.38	----	21.00	48.68	30.32
M8-2	6.40	3.05	0.36	----	30.44	39.13	30.43
M4-3	6.91	3.18	0.01	----	22.69	38.76	38.55
M11-5	6.88	3.06	0.14	----	18.95	45.56	35.49
M11-3	6.68	3.22	0.11	----	28.23	36.12	35.65
M3-7	6.90	2.78	0.47	----	9.59	57.86	32.55
M8-7	6.72	2.80	0.47	----	15.23	52.99	31.78
M1-5	6.83	2.79	0.43	----	10.83	57.58	31.59
M1-7	6.64	2.77	0.58	----	10.31	61.38	28.31
M9-3	6.64	2.66	0.56	----	8.23	64.26	27.51
M3-4	7.08	2.89	0.29	----	13.29	49.98	36.73
M1-8	6.39	2.83	0.67	----	17.46	56.27	26.27
M16-3	6.13	2.70	0.62	----	23.53	54.03	22.44
M2-2	6.21	2.99	0.59	----	24.86	50.09	25.05
M5-1	5.98	2.92	0.64	----	30.82	49.54	19.64
Average	6.61	2.92	0.42	----	19.08	50.65	30.27
	0.31	0.17	0.20	----	7.18	7.79	5.05

* pre-Holocene samples

CLUSTER FACIES 3

Sample #	Mean	Sorting	Skewness	% Gravel	% Sand	% Silt	% Clay
M3-8	7.88	2.69	0.08	----	5.23	48.20	46.57
M6-2	7.96	2.60	0.11	----	3.58	49.78	46.24
M16-4	7.83	2.95	0.01	----	7.52	46.91	45.57
M9-1	7.82	2.65	0.07	----	3.26	50.34	46.40
M12-9*	7.67	2.62	0.18	----	2.81	54.48	42.71
M10-2	7.68	2.76	0.04	----	8.23	46.98	44.79
M8-8	7.74	2.56	0.21	----	1.10	55.78	43.12
M8-9	7.67	2.57	0.24	----	3.09	55.24	41.67
M9-8	7.72	2.57	0.25	----	2.22	56.12	41.66
M11-1	7.74	2.52	0.20	----	2.06	55.24	42.70
M12-2	7.65	2.53	0.25	----	1.06	58.42	40.52
M8-5	7.55	2.49	0.36	----	0.84	62.65	36.51
M8-6	7.46	2.61	0.34	----	1.76	59.22	39.02
M14-5	7.28	2.65	0.38	----	2.30	60.04	37.66
M3-6	7.31	2.75	0.30	----	4.21	56.94	38.85
M4-1	7.28	2.86	0.24	----	9.64	52.51	37.85
M9-2	7.31	2.71	0.25	----	7.00	55.95	37.05
M9-9*	7.36	2.46	0.45	----	0.72	65.68	33.60
M5-4	7.37	3.38	-0.03	0.54	15.16	43.09	41.21
M12-3	7.12	3.21	0.06	0.54	15.72	45.14	38.60
M8-4	8.33	2.38	0.05	----	0.00	47.82	52.18
M9-6	8.39	2.37	-0.01	----	0.31	46.28	53.41
M9-7	8.44	2.34	0.01	----	1.28	44.85	53.87
M13-8	8.48	2.29	0.03	----	1.04	45.70	53.26
M8-3	8.31	2.33	0.11	----	1.09	48.35	50.56
M9-5	8.49	2.27	0.05	----	0.00	46.47	53.53
M12-1	8.27	2.29	0.17	----	0.07	50.72	49.21
M11-7	8.29	2.32	0.09	----	0.48	48.49	51.03
M11-8	8.22	2.27	0.14	----	0.59	50.24	49.17
M14-4	8.17	2.47	0.07	----	1.25	48.88	49.87
M10-7*	8.23	2.49	0.05	----	4.37	45.03	50.60
M5-2	8.47	2.40	-0.04	----	1.41	43.81	54.78
M6-1	8.71	2.23	-0.06	----	0.00	42.46	57.54
M9-4	8.01	2.31	0.26	----	0.17	55.85	43.98
M10-3	7.92	2.30	0.30	----	0.25	57.19	42.56
M16-5	7.91	2.38	0.28	----	0.49	56.54	42.97
M1-3	7.90	2.43	0.20	----	2.43	53.20	44.37
M10-1	7.88	2.35	0.19	----	0.47	56.05	43.48
M16-1	7.71	2.84	0.04	----	12.49	42.92	44.59

(continued)

M5-5*	9.09	2.20	-0.30	----	0.00	37.45	62.55
M5-3	7.39	2.79	0.34	----	4.09	55.16	44.75
Average (M3-8 to M12-3)	7.57 0.24	2.71 0.24	0.20 0.13	0.06 0.16	4.88 4.33	53.94 5.84	41.12 3.61
Average (M8-4 to M5-5*)	8.22 0.37	2.38 0.16	0.09 0.15	---- ----	1.41 2.74	48.41 5.18	50.18 5.19
TOTAL	7.90 0.45	2.54 0.26	0.15 0.15	0.03 0.12	3.17 3.97	51.27 6.12	45.63 6.29

* pre-Holocene samples

CLUSTER FACIES 4

Sample #	Mean	Sorting	Skewness	% Gravel	% Sand	% Silt	% Clay
M6-3*	2.92	3.20	0.65	2.80	75.86	8.91	12.43
M12-4*	2.89	3.04	0.61	1.11	77.53	10.04	11.32
M5-8*	3.99	3.55	0.76	----	67.04	14.65	18.31
M10-8*	2.29	2.60	0.60	1.96	78.52	13.08	6.44
M5-9*	1.75	1.85	0.47	----	89.03	4.33	6.64
M5-10*	1.69	1.08	0.23	0.18	94.22	2.26	3.34
M5-11*	1.43	1.40	0.15	4.34	89.80	1.98	3.88
M12-5*	1.63	0.97	-0.03	0.65	94.86	2.66	1.83
M10-4*	3.22	3.03	0.80	0.57	69.31	17.75	12.37
M10-6*	1.42	1.44	0.49	----	88.36	6.26	5.38
M5-6*	5.20	3.73	0.22	----	48.84	27.35	23.81
M5-7*	5.06	3.61	0.19	0.23	48.05	29.75	21.97
M16-6*	3.48	2.86	0.68	----	68.22	21.11	10.67
M15-1	4.71	3.62	0.65	----	56.95	21.47	21.58
Average	2.98 1.36	2.57 1.01	0.46 0.26	0.84 1.27	74.76 15.25	12.97 9.02	11.43 7.15

* pre-Holocene samples

CLUSTER FACIES 5

Sample #	Mean	Sorting	Skewness	% Gravel	% Sand	% Silt	% Clay
M7-7*	1.85	0.96	0.10	----	94.12	4.00	1.78
M15-3*	2.06	1.59	0.43	0.08	86.14	8.39	5.39
M7-6*	1.65	0.73	-0.19	----	99.16	0.47	0.37
M7-5*	2.80	2.60	0.68	----	83.03	7.56	9.41
M6-4*	2.09	1.86	0.30	0.53	90.91	1.81	6.75
M16-7*	2.06	1.90	0.30	0.31	90.33	2.94	6.42
M6-5*	1.25	1.52	-0.42	11.11	84.30	0.73	3.86
M6-6*	1.63	1.08	-0.23	2.81	92.79	0.80	3.60
M7-2	1.68	0.55	-0.22	----	97.20	0.89	1.91
M13-4	1.62	0.55	-0.14	0.71	98.01	0.34	0.94
M14-3	1.69	0.55	0.03	0.33	96.95	0.09	2.63
M14-1	1.82	0.59	-0.03	0.21	97.77	0.15	1.87
MB-20	1.75	0.52	-0.13	----	100	----	----
MB-27	1.71	0.58	-0.09	----	100	----	----
M13-2	1.44	0.96	-0.34	5.47	93.32	0.63	0.58
M14-2	1.57	0.97	-0.39	5.80	92.76	0.24	1.20
MB-30	1.72	0.44	0.15	----	100	----	----
M6-11*	1.74	0.53	0.17	0.19	96.59	0.21	3.01
M6-12*	1.87	0.60	0.12	0.33	96.52	0.39	2.76
M7-1	2.73	2.08	0.72	----	79.62	13.48	6.90
MB-13	2.22	0.45	0.10	----	100	----	----
M15-6*	2.27	0.47	0.14	----	98.98	0.95	0.07
MB-10	2.27	0.47	0.14	----	100	----	----
M16-8*	2.15	0.53	-0.05	----	97.73	1.08	1.19
M6-13*	2.27	0.45	0.14	----	95.96	0.31	3.73
M1-2	2.37	0.51	0.03	0.12	96.63	0.10	3.15
M15-2*	1.84	0.64	-0.09	0.29	96.19	1.61	1.91
M15-4*	1.83	0.70	-0.14	0.04	96.75	0.42	2.79
M12-6*	1.89	0.58	-0.07	----	97.09	1.58	1.33
M7-8*	1.86	0.57	-0.11	----	99.58	0.11	0.31
MB-33	1.95	0.59	-0.23	----	100	----	----
M15-7*	1.97	0.67	-0.17	----	99.34	0.66	----
MF-1	2.05	0.48	0.02	----	99.97	----	0.03
MF-2	2.09	0.49	0.04	----	99.99	----	0.01
MB-16	1.99	0.54	-0.07	----	100	----	----
M13-1	1.98	0.55	0.06	----	98.39	0.86	0.75
MB-24	2.01	0.44	0.02	----	100	----	----
M7-3	2.00	0.69	0.08	----	94.99	2.16	2.85

(continued)

M13-3	2.06	0.49	-0.03	0.02	96.17	1.80	2.01
M7-4	3.55	2.66	0.78	----	77.71	10.71	11.58
Average (M7-7* to M7-1)	1.84 0.38	1.06 0.64	0.04 0.33	1.39 2.80	93.48 5.92	2.16 3.52	2.97 2.65
Average (MB-13 to M7-4)	2.13 0.37	0.65 0.48	0.03 0.21	0.02 0.07	97.27 4.79	1.12 2.31	1.59 2.60
TOTAL	1.98 0.40	0.85 0.60	0.04 0.27	0.71 2.10	95.37 5.71	1.64 3.02	2.28 2.71

* pre-Holocene samples

CLUSTER FACIES 6

Sample #	Mean	Sorting	Skewness	% Gravel	% Sand	% Silt	% Clay
M6-7*	0.16	1.86	-0.01	30.43	66.58	0.43	2.56
M6-9*	-0.16	1.85	0.06	38.11	58.86	0.26	2.77
M6-10*	0.42	1.64	-0.34	24.48	72.41	0.37	2.74
M6-8*	1.02	1.20	-0.16	5.39	90.97	0.57	3.07
M12-7*	0.02	1.44	-0.21	19.78	78.82	0.36	1.04
M10-5*	0.81	1.09	0.06	5.03	91.73	1.29	1.95
M15-5*	0.93	0.83	0.26	----	99.19	0.31	0.50
M10-9*	0.99	0.71	-0.02	3.34	95.41	0.33	0.92
M16-9*	0.94	0.67	0.17	0.11	99.05	0.28	0.56
Average	0.57 0.46	1.25 0.47	-0.02 0.19	14.07 13.55	83.67 14.11	0.47 0.30	1.79 0.98

* pre-Holocene samples

CLUSTER FACIES 7

Sample #	Mean	Sorting	Skewness	% Gravel	% Sand	% Silt	% Clay
M4-2	2.60	1.08	0.50	----	92.40	2.96	4.64
M4-4	2.59	0.54	0.25	----	95.30	1.43	3.27
M11-6	2.53	0.39	0.21	----	98.19	0.53	1.28
MB-3	2.65	0.43	0.13	----	100	----	----
M1-1	2.55	0.50	-0.11	----	96.39	0.13	3.48
M2-1	2.46	0.49	-0.21	0.03	97.21	0.13	2.63
M3-1	2.81	0.40	0.09	----	97.21	0.68	2.11
M11-4	2.73	0.40	0.17	----	96.99	1.00	2.01
M2-8	2.92	1.19	0.51	----	88.27	6.68	5.05
M13-6	2.30	0.31	0.10	----	98.39	0.40	1.21
Average	2.61	0.57	0.16	0.00	96.04	1.39	2.57
	0.18	0.30	0.23	0.00	3.22	1.95	1.50

*pre-Holocene samples

APPENDIX E

FORAMINIFERA SPECIES OF THE METOMPKIN ISLAND SYSTEM

Genus AMMOBACULITES Cushman, 1910

AMMOBACULITES DILITATUS Cushman and Bronnimann, 1948

Ammobaculites dilitatus CUSHMAN and BRONNIMANN, 1948, p. 39, pl. 7, figs. 10-11; PARKER, PHLEGER, and PIERSON, 1953, p. 5, pl. 1, figs. 13-15; RONAI, 1955, p. 142, pl. 20, fig. 2; TODD and LOW, 1961, p. 14, pl. 1, fig. 1; GROSSMAN and BENSON, 1967, p. 48, pl. 1, figs. 14, 18; SCOTT and MEDIOLI, 1980, p. 35, pl. 1, figs. 9-10.

Ammobaculites sp. cf. *A. dilitatus* Cushman and Bronnimann. PARKER, 1952, p. 443, pl. 1, fig. 23; PHLEGER, 1954, p. 633, pl. 1, fig. 4.

Material. 51 tests.

Occurrence. Found in brackish bays of the Louisiana coast (Parker, Phleger, and Pierson, 1953), in near-normal to normal marine waters of Buzzards Bay and Martha's Vineyard, MA (Todd and Low, 1961), and in the western portion of Pamlico Sound and the estuary landward of Beaufort Inlet, NC (Grossman and Benson, 1967). Generally found in salinities ranging from 15 to 30 ^{o}/oo, mainly 25 to 30 ^{o}/oo, and at depths to 10 feet on sandy silt and mud bottoms (Grossman and Benson, 1967). Found in the study area in substrates associated with marsh and lagoon backbarrier environments.

Genus AMMONIA Brunnich, 1772

AMMONIA PARKINSONIANA (d'Orbigny, 1839) forma TEPIDA Cushman, 1926

Rotalia beccarii (Linne, 1758) forma *tepida* CUSHMAN, 1926, p. 79, pl. 1.

"*Rotalia*" *beccarii* (Linne) forma *tepida* Cushman, PHLEGER and PARKER, 1951, p. 23, pl. 12, figs. 7a, b.

"*Rotalia*" *beccarii* (Linne) variants PHLEGER, 1954, p. 645, pl. 10, figs. 7-10.

Ammonia tepida (Cushman, 1926). GROSSMAN and BENSON, 1967, p. 56, pl. 9, figs. 5, 9; HAYNES, 1973, p. 191, pl. 18, fig. 17, pl. 30, fig. 7.

Ammonia parkinsoniana (d'Orbigny) forma *tepida* Cushman. POAG, 1978, p. 397, pl. 1, figs. 1-4; MECHLER and GRADY, 1984, p. 388, pl. 1, figs. 1-3.

Material. 154 tests.

Remarks. Forma *tepida* is the relatively small, thin-walled ecophenotype of *A. parkinsoniana*. Its morphologic expression depends upon variations in environmental parameters such as salinity and temperature (Poag, 1978).

Occurrence. Described from the Recent of the Gulf of Paria, Trinidad, and noted by Todd and Bronnimann (1957) as being abundant in the intertidal, nearshore, and offshore zones of that region. Reported by Parker (1952) from the Long Island Sound-Buzzards Bay area. Found by Grossman and Benson (1967) in the Neuse River estuary and Core and Pamlico Sounds. Found in San Antonio Bay, Texas and St. Andrews Bay, Florida associated with areas of maximum salinity and temperature (Poag, 1978; Mechler and Grady, 1984). Found in the study area associated with sandy silt to muddy bottoms of the backbarrier region. Generally associated with high diversity samples.

AMMONIA PARKINSONIANA (d'Orbigny, 1839) forma TYPICA

Rotalia parkinsoniana D'ORBIGNY, 1839, p. 99, pl. 4, figs. 25-27.
Rotalia beccarii (Linne, 1758) forma *parkinsonianna* (d'Orbigny, 1839). PHLEGER and PARKER, 1951, p. 23, pl. 12, figs. 6a, b.
"*Rotalia*" *beccarii* (Linne, 1878) variants PHLEGER, 1954, p. 645, pl. 10, figs. 4-6.
Ammonia sobrina (Shupack, 1934). GROSSMAN and BENSON, 1967, p. 56, pl. 9, figs. 10-11.
Ammonia parkinsoniana (d'Orbigny) forma *typica*. POAG, 1978, p. 397, pl. 1, figs. 5-9, 13-16, 19-21; MECHLER and GRADY, 1984, p. 388, pl. 1, figs. 4-6.

Material. 227 tests.

Remarks. Forma *typica* is the relatively large, thicker walled ecophenotype of *A. parkinsoniana*. Its morphologic expression differs from forma *tepida* primarily by possessing a prominent umbilical plug.

Occurrence. Reported in shallow waters of New York Harbor (Shupack, 1934), the nearshore regions of the Gulf of Mexico (Phleger and Parker, 1951), and from tidal and nearshore zones of the Gulf of Paria, Trinidad. Present in sediments in Core Sound, North Carolina (Grossman and Benson, 1967). Found in San Antonio Bay, Texas and St. Andrews Bay, Florida associated with areas of minimum salinity and temperature in central bay waters (Poag, 1978; Mechler and Grady, 1984). Found in the study area associated with silty to muddy sediment in the backbarrier environment behind Metompkin Island. Generally associated with high diversity samples.

Genus AMMOTIUM Loeblich and Tappan, 1953

AMMOTIUM SALSUM (Cushman and Bronnimann, 1948)

Ammobaculites salsus CUSHMAN and BRONNIMANN, 1948, p. 16, pl. 3, figs. 1-7; PARKER, PHLEGER, and PIERSON, 1953, p. 5, pl. 1, figs. 17-25; TODD and BRONNIMANN, 1957, p. 24, pl. 2, figs. 8-10.
Ammotium salsum (Cushman and Bronnimann). PARKER and ATHERN, 1959, p. 340, pl. 50, figs. 6, 13; TODD and LOW, 1961, p. 14, pl. 1, figs. 2, 3; GROSSMAN and BENSON, 1967, p. 49, pl. 2, figs. 1, 2, 8; SCOTT and MEDIOLI, 1980, p. 35, pl. 1, figs. 11-13.

Material. Nine tests.

Remarks. Recognized by its moderately compressed, coarsely arenaceous test and by a decrease in size of the last chamber from preceding ones.

Occurrence. Found in marsh and bay areas of the Gulf coast (Parker, Phleger, and Pierson, 1953), in the marshes of Cape Cod and Nantucket Sound, MA (Parker and Athern, 1959), in the Neuse and Pamlico River estuaries of North Carolina, and in the coastal marshes and bays of Nova Scotia. Salinity ranges from 1 to 25 °/oo and depth from surface to 10 feet. Typically associated with organic mud or muddy bottoms (Grossman and Benson, 1967; Scott and Medioli, 1980). Found in the study area associated with muddy substrates.

Genus ASTERIGERINA d'Orbigny, 1839

ASTERIGERINA CARINATA d'Orbigny, 1839

Asterigerina carinata D'ORBIGNY, 1839, p. 118, pl. 5, fig. 25, pl. 6, figs., 1, 2; PHLEGER and PARKER, 1951, p. 26, pl. 14, figs. 2a, b; PHLEGER, 1954, p. 636, pl. 1, figs. 15a, b; POAG, 1981, p. 42, pl. 47, fig. 1, pl. 48, figs. 1a, b; LOEBLICH and TAPPAN, 1988, pt. II, pl. 676, figs. 10-13.

Material. Three tests.

Occurrence. Present on the outside of the islands in the Mississippi Sound area (Phleger, 1954). One of the predominant forms on the central West Florida Shelf. Found in the study area associated with sand and silty sand substrates related to deposition near channels.

Genus BRIZALINA Costa, 1856

BRIZALINA LOWMANI (Phleger and Parker, 1951)

Bolivina lowmani PHLEGER and PARKER, 1951, p. 13, pl. 6, figs. 20a, b, 21; PARKER, 1954, p. 637, pl. 1, figs. 18-19; PHLEGER, 1954, p. 515, pl. 7, fig. 21.

Brizalina lowmani (Phleger and Parker). POAG, 1981, p. 46, pl. 25, fig. 3, pl. 26, figs. 3a, b, c; MECHLER and GRADY, 1984, p. 390, pl. 1, figs. 15-16.

Material. Two tests.

Occurrence. Abundant on the Texas and Campeche outer shelf and upper slope (Poag, 1981). Moderate numbers have been found on the inner shelf and in bays and estuaries of the Gulf coast (Phleger, 1954). Large numbers have been recorded in plankton tows and suggest that pelagic transport may account for its ubiquity (Leavesly et al., 1978). Found in the study area associated with the sandy flood-tidal delta of Metompkin Inlet.

Genus BUCCELLA Anderson, 1952

BUCCELLA FRIGIDA (Cushman, 1931)

Pulvinulina frigida CUSHMAN, 1922, p. 12.

Eponides frigida CUSHMAN, 1931, p. 45.; PARKER, 1952a, p. 418, pl. 6, figs. 12a, b; PARKER, 1952b, p. 449, pl. 5, figs. 2a, b.

Buccella frigida (Cushman). ANDERSON, 1952, p. 144, figs., 4a-c, 5, 6a-c; TODD and LOW, 1961, p. 18, pl. 1, figs. 24, 25; HAYNES, 1973, p. 193, pl. 18, fig. 13; MILLER, MUDIE, and SCOTT, 1982, p. 2364, pl. 2, figs. 9-10; MEDIOLI, SCHAFER, and SCOTT, 1986, p. 995.

Material. 159 tests.

Occurrence. Found on the inner shelf off Portsmouth, NH, in marine and brackish environments of Martha's Vineyard, MA, in Block Island Sound, NY, in Cardigan Bay in the British Isles, and on the shelf off Nova Scotia. It occurs widely in cool temperate waters of the Western Atlantic. Found in the study area associated with sandy silt to silty sand substrates.

Genus BULIMINELLA Cushman, 1911

BULIMINELLA ELEGANTISSIMA (d'Orbigny, 1839)

Bulimina elegantissima D'ORBIGNY, 1839, p. 51, pl. 7, figs. 13, 14.
Buliminella elegantissima (d'Orbigny). PHLEGER and PARKER, 1951, p. 17, pl. 8, figs. 3-4; MILLER, 1953, p. 57, pl. 8, fig. 11; PHLEGER, 1954, p. 637, pl. 1, figs. 24-25; FEYLING-HANSSEN ET AL., 1971, p. 234, pl. 6, fig. 13; POAG, 1981, p. 50, pl. 33, fig. 2, pl. 34, figs. 2a, b.

Material. Four tests.

Occurrence. Common in open-Gulf stations in the Mississippi Sound area on the inner and middle shelf (Phleger, 1954). Reported in low numbers in bays and estuaries. Cushman (1944) recorded it from Nonamesset Island to Vineyard Sound, Massachusetts. Parker (1948) reported it from depths of 15 m to 90 m on the continental shelf off Maryland. Miller (1953) found it in abundance in the Passage Channel, just landward of Mason Inlet, North Carolina. Found in the study area associated with sandy flood-tidal delta deposits of Metompkin Inlet.

Genus CRIBROSTOMOIDES Cushman, 1910

CRIBROSTOMOIDES CRASSIMARGO (Norman, 1892)

Haplophragmium crassimargo NORMAN, 1892, p. 17.

Cribrostomoides crassimargo (Norman). TODD and LOW, 1981, p. 16; MILLER, MUDIE, and SCOTT, 1982, p. 2362, pl. 1, fig. 15.

Material. Eight tests.

Occurrence. Barbieri and Medioli (1969) found this species to be particularly frequent in coarse sediment of the Nova Scotia Shelf. Williamson (1983) reported it as being a main component in sediment west of the Sable Island Bank, Nova Scotia in 90-200 m of water. It was also found in inner shelf waters. Medioli et al. (1986) found the species near Sable Island in water depths shallower than 50 m. Found in the study area associated with silty sand deposits of a flood-tidal delta from an ephemeral inlet breach.

Genus EGGERELLA Cushman, 1935

EGGERELLA ADVENA (Cushman, 1921)

Verneuilina advena CUSHMAN, 1921, p. 141.
Eggerella advena (Cushman). PARKER, 1952a, p. 404, pl. 3, figs. 12-13; PARKER, 1952b, p. 447, pl. 2, fig. 3; TODD and LOW, 1961, p. 14, pl. 1, fig. 4; SCOTT and MEDIOLI, 1980, p. 40, pl. 2, fig. 7.

Material. 21 tests.
Occurrence. This species was reported in coastal waters off Portsmouth, NH, in bay areas around Martha's Vineyard, MA, and on the continental shelf south of Cape Cod at depths less than 90 m (Parker, 1952a; Todd and Low, 1961). Recorded in abundance at some stations in Long Island Sound and Buzzards Bay (Parker, 1952b). Generally associated with samples where mud is present. Found in relatively low numbers on sandy silt to muddy substrates in the backbarrier region of Metompkin Island, VA.

Genus ELPHIDIUM de Monfort, 1808

ELPHIDIUM ARTICULATUM (d'Orbigny, 1839)

Polystomella articulata D'ORBIGNY, 1839, p. 30, pl. 3, figs. 9-10.
Nonion obiculare CUSHMAN, 1944, p. 24, pl. 3, fig. 24.
Elphidium articulatum (d'Orbigny). CUSHMAN, 1930, p. 26, pl. 10, figs. 6-8; CUSHMAN, 1944, p. 26, pl. 3, fig. 41; PARKER, 1952a, p. 411, pl. 5, figs. 5-7; GROSSMAN and BENSON, 1967, p. 57, pl. 6, figs. 13-14.

Material. One test.
Remarks. This species appears to be closely related to *E. bartletti* except the adult form of *E. articulatum* has only 9 to 10 chambers in the last whorl as compared to 12 for *E. bartletti*. Parker (1952a) stated that *E. articulatum* may represent the more southern development of the Arctic form of *E. bartletti*.
Occurrence. This species has been found off the Atlantic coasts of North and South America. Recorded in nearshore and offshore sand deposits off Portsmouth, NH (Parker, 1952a), and at salinities greater than 30 $^{o}/oo$ on silty sand substrates on the sound and ocean deltas of Ocracoke Inlet, Core Sound, and Cape Lookout Bight, NC (Grossman and Benson, 1967). Found in the study area associated with mud substrate near an active tidal channel along north Metompkin Island.

ELPHIDIUM EXCAVATUM (Terquem, 1875)

Polystomella excavata TERQUEM, 1875, p. 20, pl. 2, figs. 2a, b.
Elphidium clavatum CUSHMAN, 1930, p. 20, pl. 7, figs. 10a, b; LOEBLICH and TAPPAN, 1953, p. 98, pl. 19, figs. 8-10; GROSSMAN and BENSON, 1967, p. 58, pl. 8, figs. 13-14; KRAFT and MARGULES, 1971, p. 246, fig. 17.
Elphidium excavatum (Terquem). PARKER, 1952a, p. 412, pl. 5, figs. 8, 10, 11; PARKER, 1952b, p. 448, pl. 3, fig. 13; TODD and LOW, 1961, p. 19, pl. 2, fig. 5; LEVY ET AL., 1975, p. 176, pl. 3, figs. 5-6; BUZAS, CULVER, and ISHAM, 1985, p. 1083, figs. 6.7-6.10, 7.1, 7.2.

Material. 2884 tests.

Remarks. Buzas et al. (1985) stated that this abundant, worldwide species has probably been misidentified more than any other foraminiferal species, mostly under the name *E. clavatum*.

Occurrence. Reported in shallow waters from north of Cape Cod to the Long Island Sound-Buzzards Bay area (Parker, 1952b). Found in Indian River Bay, DE associated with lagoonal silts at the edge of the intruding sandy flood-tidal delta (Kraft and Margules, 1971). The most abundant species in the southern Pamlico Sound region, NC; associated with all sediment types. Found in abundance in the study area at most sample locations. Highest counts were recorded in sand to silty sand facies.

ELPHIDIUM GALVESTONENSE Kornfield, 1931

Elphidium gunteri Cole, 1931 forma *galvestonense* KORNFIELD, 1931, p. 87, pl. 15, figs. 1a, b; PHLEGER and PARKER, 1951, p.10, pl. 5, figs. 13-14; MILLER, 1953, p. 55, pl. 9, fig. 7.
Elphidium galvestonense (Kornfield). PARKER, PHLEGER, and PIERSON, 1953, p. 7, pl. 3, figs. 15-16; TODD and LOW, 1961, p. 19, pl. 2, fig. 9; GROSSMAN and BENSON, 1967, p. 60, pl. 7, figs. 1-2; ELLISON and NICHOLS, 1970, p. 15, fig. 9.3.

Material. 20 tests.

Occurrence. This species has been reported as common in shallow waters of the Gulf of Mexico along the coast of Texas, Louisiana, and Florida (Kornfield, 1931; Phleger and Parker, 1951; Mechler and Grady, 1984). Found on the ebb-tidal delta of Ocracoke Inlet and in Core Sound, NC. Generally associated with sand or silty sand substrate in 25 to 30 $^{o}/oo$ salinity. Found in the study area associated with sand to silty sand sediment near tidal channels and inlets.

ELPHIDIUM GALVESTONENSE Kornfield, 1931 forma MEXICANUM Kornfield, 1931

Elphidium incertum (Williamson, 1858) forma *mexicanum* KORNFIELD, 1931, p. 89, pl. 16, figs. 1-2; PHLEGER and PARKER, 1951, p. 10, pl. 5, figs. 15-16.

Elphidium galvestonense Kornfield forma *mexicanum* (Kornfield). POAG, 1978, p. 403, pl. 3; MECHLER and GRADY, 1984, p. 389, pl. 1, figs. 9-10.

Material. Eight tests.

Remarks. Poag (1978) reported that although forma *mexicanum* was originally described as a variety of *E. incertum* (Williamson), it was not a member of that species.

Occurrence. Found at shallow depths in the Gulf of Mexico. Abundant in cooler, low salinity waters of central San Antonio Bay, Texas (Poag, 1978) and a prominent component of intertidal and central bay facies of St. Andrew Bay, Florida (Mechler and Grady, 1984). Reported as predominant in a brackish water pond with direct connection to Nantucket Sound, MA (Todd and Low, 1961). Present in a sandy channel deposit behind northern Metompkin Island.

ELPHIDIUM GUNTERI Cole, 1931

Elphidium gunteri COLE, 1931, p. 34, pl. 4, figs. 9-10; PARKER, PHLEGER, and PIERSON, 1953, p. 8, pl. 3, figs. 18-19; TODD and LOW, 1961, p. 19, pl. 2, fig. 10; GROSSMAN and BENSON, 1967, p. 59, pl. 8, figs. 1-4; BUZAS, CULVER, and ISHAM, 1985, p. 1084, figs. 7.4, 7.5.

Material. Four tests.

Remarks. Can be confused with *E. excavatum*. Typically shows better development of umbilical bosses than *E. excavatum* and has coarser pores.

Occurrence. Present in the shallow waters of the Gulf of Mexico. Found in large numbers in Texas bays. Present in low numbers in Pamlico Sound, NC. Reported in Core Sound, NC in large numbers associated with sand to silty sand substrates in 5 to 20 feet of water near 30 $^{o}/oo$ salinity (Grossman and Benson, 1967). Present in the study area in low numbers associated with sand and silty sand substrate.

ELPHIDIUM INCERTUM (Williamson, 1858)

Polystomella umbilicata (Walker and Jacob, 1798) forma *incerta* WILLIAMSON, 1858, p. 44, pl. 3, fig. 82a.

Elphidium incertum (Williamson). CUSHMAN, 1930, p. 18, pl. 7, figs. 4-9; CUSHMAN, 1944, p. 25, pl. 3, figs. 28-31; PARKER, 1952b, p. 448, pl. 3, figs. 14, 16, 17; MILLER, 1953, p. 56, pl. 9, fig. 4; GROSSMAN and BENSON, 1967, p. 59, pl. 8, figs. 5-6; HAYNES, 1973, p. 199, 200, pl. 22, fig. 6, pl. 24, figs. 14-16, pl. 28, figs. 8-9.

Material. Eight tests.

Remarks. This species has been confused with a number of other species, particularly *E. excavatum*. Unless optically granular, specimens may be associated with the latter designation.

Occurrence. Common to waters of the North Atlantic; has been recorded from off the coasts of Norway and Great Britain and on the Atlantic coast of the United States as far south as Mason Inlet, NC

(Miller, 1953). Found in abundance in Core and Pamlico Sounds (Grossman and Benson, 1967) and in the Long Island Sound-Buzzards Bay area (Parker, 1952b). It is typically a shallow-water, mesohaline to normal marine species, and has been found on bottoms ranging from mud to sand. Specimens found in the study area were associated with a silty sand facies.

ELPHIDIUM MARGARITACEUM (Cushman, 1930)

Elphidium advenum (Cushman) forma *margaritaceum* CUSHMAN, 1930, p. 25, pl. 10, figs. 3a, b; PARKER, 1952b, p. 447, pl. 3, fig. 10.
Elphidium margaritaceum (Cushman). TODD and LOW, 1961, p. 19, pl. 2, fig. 3; HAYNES, 1973, p. 203, pl. 24, figs. 12-13, pl. 29, fig. 8; BUZAS, CULVER, and ISHAM, 1985, p. 1087, figs. 7.7, 7.8.

Material. One test.

Occurrence. Species was first described from beach sand in Rhode Island. Associated with sandy deposits of coastal New Hampshire and Long Island-Buzzards Bay area (Parker, 1952b). Todd and Low (1961) described it as the most widely distributed species of *Elphidium* around Martha's Vineyard, MA. Found in the study area associated with sandy flood-tidal delta deposits of Metompkin Inlet.

ELPHIDIUM POEYANUM (d'Orbigny, 1839)

Polystomella poeyana D'ORBIGNY, 1839, p. 55, pl. 6, figs. 25, 26.
Elphidium poeyanum (d'Orbigny). PARKER, PHLEGER, PIERSON, 1953, p. 9, pl. 3, fig. 26; PHLEGER, 1954, p. 639, pl. 2, figs. 8-9; PARKER, 1954, p. 509, pl. 6, fig. 17; TODD and LOW, 1961, p. 20, pl. 2, fig. 17; POAG, 1981, p. 62, pl. 39, fig. 3, pl. 40, figs. 3a, b; MECHLER and GRADY, 1984, p. 389, pl. 1, figs. 11-12.

Material. 46 tests.

Occurrence. Common on the inner shelf and in coastal bays and estuaries of northeast Gulf of Mexico (Phleger, 1954). Found in St. Andrews Bay, FL, Vineyard Sound, MA, and San Antonio Bay, TX (Poag, 1981; Mechler and Grady, 1984). All specimens in the study area were associated with silty sand inlet shoal and channel deposits.

ELPHIDIUM TUMIDUM Natland, 1938

Elphidium tumidum NATLAND, 1938, p. 144, pl. 5, figs. 5-6; TODD and BRONNIMANN, 1957, p. 39, pl. 7, figs. 7-9; GROSSMAN and BENSON, 1967, p. 60, pl. 8, figs. 11-12, 15.

Material. 21 tests.

Remarks. Recognized by its somewhat compressed, smooth to slightly lobulate perforate test, and by its slightly roughened umbilical region.

Occurrence. Found in bay areas of the Gulf coast and in shallow waters of the Gulf of Paria, Trinidad. Reported in Core Sound, NC on sand to silty sand substrate in 5 to 10 feet of water (30 $^{o}/oo$ salinity) (Grossman and Benson, 1967). Found in the study area associated with silty sediment near an active tidal channel.

Genus EOEPONIDELLA Wickenden, 1949

EOEPONIDELLA PULCHELLA (Parker, 1952)

Pninaella (?) *pulchella* PARKER, 1952a, p. 420, pl. 6, figs. 18a, b, 19, 20; PARKER, 1952b, p. 453, pl. 5, figs. 9a, b.
Eoeponidella pulchella (Parker). TODD and LOW, 1981, p. 40.

Material. One test.
Occurrence. Found at only a few stations in depths less than 50 m along the coast of Portsmouth, NH. Reported by Parker (1952a) near Fishers Island, at the entrance to Long Island Sound. Recorded in the study area associated with sand deposits of the flood-tidal delta of Metompkin Inlet.

Genus FISCHERINA Terqueum, 1878

FISCHERINA RHODIENSIS Terqueum, 1878

Fischerina rhodiensis TERQUEUM, 1878, p. 80; GALLOWAY, 1933, p. 111, pl. 9, fig. 6.

Material. Four tests.
Remarks. Test discoidal and symmetrical; wall calcareous, thin and imperforate. First occurrence of this species in the western North Atlantic (Culver and Buzas, 1980).
Occurrence. Reported in the Mediterranean Sea as a normal marine inner shelf species. Present at one location in the study area associated with a silty sand facies related to deposition at Metompkin Inlet.

Genus FISSURINA Reuss, 1850

FISSURINA LAEVIGATA Reuss, 1850

Fissurina laevigata REUSS, 1850, p. 366; WEISS, 1954, p. 161, pl. 33, fig. 8; MURRAY, 1968, p. 438; FEYLING-HANSSEN ET AL., 1971, p. 229.

Material. Two tests.
Occurrence. Associated with inner shelf sediment from the North Sea area and with silty sediment of the Long Island, NY area (Weiss, 1954; Feyling-Hanssen et al., 1971). Reported in silt and sand sediment of Buzzards Bay, MA. Found in the study area in a silty sand flood-tidal delta deposit at Metompkin Inlet.

Genus FURSENKOINA Loeblich and Tappan, 1961

FURSENKOINA FUSIFORMIS (Williamson, 1858)

Bulimina pupoides d'Orbigny, 1839 forma *fusiformis* WILLIAMSON, 1858, p. 63, pl. 5, figs. 129-130.
Fursenkoina fusiformis (Williamson). MURRAY, 1968, p. 438; MURRAY 1973, p. 127, pl. 6, fig. 3, pl. 8, fig, 7; TODD and LOW, 1981, p. 30; MILLER, MUDIE, and SCOTT, 1982, p. 2362, pl. 2, fig. 19; MEDIOLI, SCHAFER, and SCOTT, 1986, p. 996.

Material. One test.

Occurrence. Associated with silty sand along a shelf traverse off Long Island, NY. Found on the upper slope and in the central basins of the Scotian Shelf, and at stations near Sable Island, Nova Scotia in water depths 20 m or less (Miller, Mudie and Scott, 1982; Medioli, Schafer, and Scott, 1986). Found in fine to coarse sand in Bristol Channel and the Celtic Sea at depths between 60 and 130 m (Murray, 1973). Present in the study area associated with a silty sand deposit of the flood-tidal delta of Metompkin Inlet.

Genus GLABRATELLA Dorreen, 1948

GLABRATELLA WRIGHTII (Brady, 1881)

Discorbina wrightii BRADY, 1881, p. 413, pl. 21, fig. 6.
Eponides wrightii (Brady). PARKER, 1952a, p. 420, pl. 6, figs. 14-15; PARKER, 1952b, p. 450, pl. 5, figs. 4a, b; MILLER, 1953, p. 59, pl. 10, fig. 3.
Glabratella wrightii (Brady). COLE and FERGUSON, 1975, p. 35, pl. 8, figs. 10-11; TODD and LOW, 1981, p. 40.

Material. Three tests.

Occurrence. Reported in coastal and shelf waters around Nova Scotia, including Canso Strait and Chedabucto Bay (Cole and Ferguson, 1975). Found in sandy sediment in the North Sea area (Feyling-Hanssen et al., 1971) and at Mason Inlet, NC. Abundant in shallow water samples of the Long Island Sound area. Found in the study area associated with silty sand deposits of the Metompkin Inlet flood-tidal delta.

Genus GUTTULINA d'Orbigny, 1839

GUTTULINA LACTEA (Walker and Jacob, 1798)

Serpula lactea WALKER and JACOB, 1798, p. 634, pl. 14, fig. 4.
Guttulina lactea (Walker and Jacob). CUSHMAN and OZAWA, 1930, p. 43, pl. 10, fig. 1; CUSHMAN, 1944, p. 22, pl. 3, figs. 110-11; FEYLING-HANSSEN ET AL., 1971, p. 214, pl. 4, figs. 14-18.

Material. One test.

Occurrence. Reported on the inner continental shelf off New England, New Jersey, Virginia, and North Carolina (Cushman, 1944; Parker, 1948, Ellison, 1977; Schnitker, 1971). Also present in nearshore sediment of the North Sea (Feyling-Hanssen et al., 1971). Found in the study area associated with a sandy silt facies related to deposition at Metompkin Inlet.

Genus HAYNESINA Banner and Culver, 1978

HAYNESINA GERMANICA (Ehrenberg, 1840)

Nonionina germanica EHRENBERG, 1840, p. 23.
Nonion germanicum (Ehrenberg). CUSHMAN, 1930, p. 8, pl. 3, figs. 5a, b.
Protoelphidium anglicum MURRAY, 1965, p. 149-150, pl. 26, figs. 1-6.
Haynesina germanica (Ehrenberg). BANNER and CULVER, 1978, p. 191-195, pl. 4, figs. 1-6, pl. 5, figs. 1-8, pl. 6, fig. 1-7, pl. 7, figs. 1-6, pl. 8, figs. 1-10, pl. 9, figs. 1-11, 15, 18; BUZAS, CULVER, and ISHAM, 1985, p. 1089, pl. 8, figs. 4-5.

Material. 440 tests.

Remarks. Initially distinguished from *Elphidium* by the lack of sutural bridges, presence of a broadly rounded periphery, and distinctly depressed umbilici.

Occurrence. The specimens studied by Banner and Culver (1978) and Buzas et al. (1985) were from muddy marsh and bay deposits of Swansea Bay, South Wales, U.K. Found in the study area mainly associated with silty sand deposits throughout the backbarrier region of Metompkin Island. Recorded in greatest abundance in a muddy marsh deposit near an active tidal channel.

Genus HELENINA Saunders, 1957

HELENINA ANDERSENI (Warren, 1957)

Pseudoeponides anderseni WARREN, 1957, p. 39, pl.4, figs. 12-15; PARKER and ATHEARN, 1959, p. 341, pl. 50, figs. 28-31.
Helenina anderseni (Warren). SAUNDERS, 1957, p. 373, pl. 1, figs. 1, 2; TODD and LOW, 1961, p. 18, fig. 2; SCOTT and MEDIOLI, 1980, p. 40, pl. 5, figs. 10-11.

Material. One test.

Occurrence. Recorded occurrences of this species are from marshy areas in Poponesset Bay and Martha's Vineyard, MA, Southampton, Long Island, and Nova Scotia (Parker and Athearn, 1959; Todd and Low, 1961; Lee et al., 1969; Scott and Medioli, 1981). Found near the southern end of Metompkin Island in a silty sand facies associated with sedimentation at Metompkin Inlet.

Genus MILIAMMINA Heron-Allen and Earland, 1930

MILIAMMINA FUSCA (Brady, 1870)

Quinqueloculina fusca BRADY, 1870, p. 47, pl. 11, figs. 2, 3.
Miliammina fusca (Brady). PARKER, 1952a, p. 404, pl. 3, figs. 15, 16; PARKER, 1952b, p. 452, pl. 2, figs. 6a, b; PARKER and ATHEARN, 1959, p. 340, pl. 50, figs. 11, 12; TODD and LOW, 1961, p. 14, pl. 1, fig. 6; GROSSMAN and BENSON, 1967, p. 46, pl. 2, figs. 3-5; ELLISON and NICHOLS, 1970, p. 16, pl. 1, fig. 3; COLE and FERGUSON, 1975, p. 37, pl. 4, figs. 1, 2; SCOTT and MEDIOLI, 1980, p. 40, pl. 2, figs. 1-3.

Material. 19 tests.
Remarks. Recognized by its elliptical, arenaceous, quinqueloculine test, and by its rounded periphery.
Occurrence. This species was reported abundant in brackish tidal channels draining marshes and small ponds in Nantucket Sound, MA (Todd and Low, 1961), and from brackish water areas of the Gulf and Atlantic coasts of the United States. Found most abundant on a muddy substrate in 2 to 15 feet of water (1-10 ^{o}/oo salinity). Generally associated with other arenaceous foraminiferida such as *Ammobaculites* and *Trochammina* (Scott and Medioli, 1980). Found in the study area associated with silty clay to clayey silt marsh and lagoon sediment.

Genus QUINQUELOCULINA d'Orbigny, 1826

QUINQUELOCULINA SEMINULA (Linne, 1758)

Serpula seminulum LINNE, 1758, p. 786.
Quinqueloculina seminulum (Linne). WEISS, 1954, p. 161, pl. 33, fig. 11; TODD and LOW, 1961, p. 15, pl. 1, fig. 14; HAYNES, 1973, p. 74-75, pl. 7, figs. 14, 19, pl. 8, fig. 3, pl. 32, figs. 1-3.
Quinqueloculina sp. cf. *Q. seminulum* (Linne). MILLER, 1953, p. 52, pl. 8, fig. 1.
Quinqueloculina seminula (Linne). CUSHMAN, 1944, p. 13, pl. 2, fig. 14; PARKER, 1952a, p. 406, pl. 3, figs. 21a, b, 22a, b, pl. 4, figs. 1-2; PARKER, 1952b, p. 456, pl. 2, figs. 7a, b; GROSSMAN and BENSON, 1967, p. 53, pl. 4, figs. 13, 14, 18.

Material. Nire tests.
Occurrence. This species is known from European waters and is found along both coasts of the United States. It is present in shallow waters of the Gulf of Mexico, Martha's Vineyard, MA, and Mason Inlet, NC (Todd and Low, 1961; Miller, 1953). It has also been reported in the vicinity of Drum Inlet and on both the ebb-and flood-tidal deltas of Ocracoke Inlet, NC (Grossman and Benson, 1967). Found in the study area in a sandy silt facies associated with deposition at Metompkin Inlet.

Genus REOPHAX Montfort, 1808

REOPHAX NANA Rhumbler, 1911

Reophax nana RHUMBLER, 1911, p. 182, pl. 8, figs. 6-12; PARKER, 1952b, p. 457, pl. 1, figs. 14-15; KRAFT and MARGULES, 1971, p. 246, fig. 17; SCOTT and MEDIOLI, 1980, p. 43, pl. 2, fig. 6.

Material. Six tests.

Occurrence. This species was associated with marsh environments in Nova Scotia. It was reported persistent in shallow water in Gardiners Bay, NY and Buzzards Bay, MA (Parker, 1952b). Kraft and Margules (1971) found this species confined to protected shoreline areas of muddy sand in the eastern periphery of Indian River Bay, DE. It was recorded in low numbers and associated with muddy sand deposits in the backbarrier region of Metompkin Island.

Genus ROSALINA d'Orbigny, 1826

ROSALINA FLORIDANA (Cushman, 1922)

Discorbis floridana CUSHMAN, 1922, p. 39, pl. 5, figs. 11-12; PHLEGER and PARKER, 1951, p. 20, pl. 10, figs. 4a, b.

Rosalina floridana (Cushman). PARKER, 1954, p. 524-525, pl. 8, figs. 19-20; GROSSMAN and BENSON, 1967, p. 55, pl. 9, figs. 1-2; COLE and FERGUSON, 1975, p. 22, pl. 8, figs. 3-4.

Material. Two tests.

Occurrence. This species has been reported mainly from the Gulf of Mexico but Parker (1948) recorded it off the coast of Maryland and Cole and Ferguson (1975) found specimens in sediment of Chedabucto Bay, Nova Scotia. It is a rare species and generally found at depths less than 30 meters. Grossman and Benson (1967) found it at one station on the ocean delta of Ocracoke Inlet, NC. It was associated with sand and sandy silt deposits related to inlet shoal sedimentation at the southern end of Metompkin Island.

Genus TEXTULARIA Defrance, 1824

TEXTULARIA CANDEIANA d'Orbigny, 1839

Textularia candeiana D'ORBIGNY, 1839, p. 143, pl. 1, figs. 25-27; PARKER, 1954, p. 490, pl. 2, figs. 16-17; WILCOXON, 1964, p. 23.

Material. One test.

Occurrence. Found in low percentages associated with continental shelf deposits in northeastern Gulf of Mexico (Parker, 1954). Reported off the coast of Georgia and Florida at depths between 15 and 52 meters. Ellison (1977) also recorded this species in samples from the Virginia inner continental shelf. Found in the study area in a sample from a flood-tidal shoal of Metompkin Inlet.

TEXTULARIA EARLANDI Parker, 1952

Textularia teuissima EARLAND, 1933 (not Hausler, 1881), p. 95. pl. 3, figs. 21-30.
Textularia earlandi PARKER, 1952b, p. 458, pl. 2, figs. 4-5; PARKER, 1954, p. 490, pl. 2, fig. 12; TODD and LOW, 1961, p. 14; LIDZ, 1965, p. 399, fig. 11; KRAFT and MARGULES, 1971, p. 246, fig. 17; COLE and FERGUSON, 1975, p. 12, pl. 3, fig. 1.

Material. 12 tests.
Occurrence. Recorded in low numbers in Buzzards Bay, MA and in the northeastern Gulf of Mexico. Phleger (1954) reported this species to a depth of 1000 m but highest frequencies were associated with depths shallower than 80 m. This species has also been found in Martha's Vineyard and Nantucket Bay, MA, Indian River Bay, DE, and Chedabucto Bay, Nova Scotia (Todd and Low, 1961; Kraft and Margules, 1971; Cole and Ferguson, 1975). Found in clayey silt deposits behind Metompkin Island.

Genus TROCHAMMINA Parker and Jones, 1859

TROCHAMMINA INFLATA (Montagu, 1808)

Nautlis inflatus MONTAGU, 1808, p. 81, pl. 18, fig. 3.
Trochammina inflata (Montagu) PARKER, 1952a, p. 407, pl. 4, figs, 6, 10; PARKER, 1952b, p.459, pl. 3, figs. 2a, b; TODD and LOW, 1961, p. 15, pl. 1, figs. 22-23; MILLER, 1953, p. 54, pl. 8, fig. 9; LIDZ, 1965, p. 399, fig. 11; GROSSMAN and BENSON, 1967, p. 50, pl. 5, figs. 9-12; ELLISON and NICHOLS, 1970, p. 16; COLE and FERGUSON, 1975, p. 43, pl. 4, figs. 3-4; SCOTT and MEDIOLI, 1980, p. 44, pl. 3, figs. 12-14, pl. 4, figs. 1-3; MEDIOLI, SCHAFER, and SCOTT, 1986, p. 996.

Material. 266 tests.
Occurrence. This is a very common and widespread species from shallow water environments. From most occurrence records, this species appears to be characteristic of brackish waters and marshes (Parker et al., 1953). Todd and Low (1961) found greatest abundances where the open waters of Nantucket Sound wash over submerged bog deposits. Grossman and Benson (1967) found highest populations of this species next to marsh deposits along the western fringe of Core Sound, NC. Scott and Medioli (1980) also reported this species as being abundant in the lower part of coastal marshes and upper estuarine areas in Nova Scotia. In the study area, this species was recorded at most backbarrier locations. However, abundance was greatest in clayey silt marsh deposits and in lagoonal sediment very near these deposits.

TROCHAMMINA MACRESCENS Brady, 1870

Trochammina inflata (Montagu) forma *macrescens* BRADY, 1870, p. 290, pl. 11, figs. 3a-c.

Trochammina macrescens Brady. PARKER, 1952a, p. 408, pl. 4, figs. 8a, b; PARKER, 1952b, p. 460, pl. 3, figs. 3a, b; TODD and LOW, 1961, p. 16, pl. 1, fig. 16; GROSSMAN and BENSON, 1967, p. 50, pl. 5, fig. 8; ELLISON and NICHOLS, 1970, p. 16; HAYNES, 1973, p. 41-42, pl. 1, fig. 5, pl. 2, figs. 14-16; COLE and FERGUSON, 1975, p. 43, pl.4, figs. 6, 7; SCOTT and MEDIOLI, 1980, p. 44, pl. 3, figs. 1-8.

Material. Eight tests.

Remarks. Recognized by its partially evolute, planispiral, compressed, arenaceous test. The test is flexible and thus most specimens have concave chambers due to deformation during drying.

Occurrence. This species has been found in shallow brackish-water regions of Europe and in brackish waters of the Gulf and Atlantic coasts of the United States. It commonly occurs in association with *T. inflata* but is usually less abundant. Ellison and Nichols (1970) found it in brackish-water environments of Chesapeake Bay, Grossman and Benson (1967) recorded it in organic mud deposits along the western margin of Core Sound, NC, and Cole and Ferguson (1975) and Scott and Medioli (1980) recognized it in marsh deposits in Nova Scotia. Found in the Metompkin barrier island system associated with backbarrier mud deposits.

TROCHAMINA OCHRACEA (Williamson, 1858)

Rotalina ochracea WILLIAMSON, 1858, p. 55, pl.4, fig. 112, pl. 5, fig. 113.

Trochammina ochracea (Williamson) TODD and LOW, 1961, p. 16, pl. 1, fig. 18; HAYNES, 1973, p. 40, pl. 5, figs. 15-18; COLE and FERGUSON, 1975, p. 43, pl. 4, figs. 9-10; SCOTT and MEDIOLI, 1980, p. 45, pl. 4, figs. 4-5.

Material. 43 tests.

Remarks. A minute, scale-like, concavo-convex species of *Trochammina* with eight to nine chambers visible on the ventral side. Dark brown in color.

Occurrence. This species was originally described from the British Isles and has been recorded in brackish waters of New England (Cushman, 1944), including Martha's Vineyard, MA (Todd and Low, 1961). It has been reported on marshes and in brackish water around Nova Scotia. In the study area, specimens were generally associated with clayey silt backbarrier deposits but sand deposits at Metompkin Inlet also contained low numbers of this species.

TROCHAMMINA SQUAMATA Parker and Jones, 1865

Trochammina squamata PARKER and JONES, 1865, p. 407, pl. 15, figs. 30, 31a-c; PARKER, 1952a, p. 408, pl. 4, figs. 11-16; PARKER, 1952b, p. 460, pl. 3, figs. 3a, b; ELLISON and NICHOLS, 1970, p. 16; KRAFT and MARGULES, 1971, p. 246, fig. 17; COLE and FERGUSON, 1975, p. 43, pl. 4, figs. 11-12; SCOTT and MEDIOLI, 1980, p. 45, pl. 4, figs. 6-7.

Material. 95 tests.

Occurrence. Recorded in brackish-water areas along the east coast of the United States from North Carolina to Nova Scotia (Cole and Ferguson, 1975; Scott and Medioli, 1980). Representatives of this species are generally found in small quantities at all locations. In the study area, greatest abundance was always associated with clayey silt deposits but specimens were present in low numbers in sandy sediment. The presence or absence of specimens was very similar to that of *T. ochracea*.

AUTOBIOGRAPHICAL STATEMENT

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