THE GEOMORPHOLOGY OF HOG ISLAND, VIRGINIA: A MID-ATLANTIC COAST BARRIER

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ABSTRACT

Recent shoreline changes along the Virginia barrier islands indicate that these islands are the most dynamic along the mid-Atlantic coast. Hog Island, Virginia, has been rotating in a clockwise direction for the last 122 years; the shoreline has transgressed over 2.5 km along its southern shoreline and regressed over 1.5 km in the north. Prior to 1871, the island was rotating in a counter-clockwise direction. Between 1949 and 1989, high erosion rates (13 m/year) to the south and high accretion rates (13 m/year) to the north have led to reworking of approximately 50 percent of the island. There is, however, at least one feature on the island which is at least 300 years old.

The geomorphic history of Hog Island was deciphered by analyzing historical shoreline charts and aerial photography, juxtaposition of landforms, and the physical characteristics of the island along transects. On the modern landscape, five physiographic regions have been identified: 1) Overwash Flat and Dune Ridge; 2) Transitional; 3) Continuous Dune; 4) Overwash Fan and Terrace; and 5) Spit Complex. Sediment samples were collected from seven landform types (beach, berm, dune, overwash, relic overwash, runnel, and threshold) in each region and found to be homogeneous in mean grain size. By comparing the older landform morphologies and island configurations to the more recent island characteristics, it has been found that Hog Island has acted as a drumstick barrier throughout the history of visible landforms. It has also been found that at least three changes in the rotation of the island have occurred: 1) late 1600's; 2) middle 1700's; and 3) the most recent, around 1871.

Study of historical chart data reveals that the entire Virginia barrier chain has undergone major morphological change around 1871: Fishing Point was created as an extension of Assateague Island and Parramore and Cobb Islands switched from counter-clockwise to clockwise rotation. Comparison of these islands to Hog Island implies that there has been a change in a regional scale coastal agent.

The storm climate on the Eastern Shore of Virginia changed gradually from a few, continental track, storms in the late 1800's to frequent, offshore storms, in the the mid-1900's, peaking in the early 1960's. These climatological variations may be affecting the mid-Atlantic coast at intervals of 100 to 120 years (peak to peak). These climatological data coincide with a change along the Virginia barrier islands in the late 1800's, a decrease in the area of Hog Island from 1871 to the 1960's, and a shift in the ebb delta position and channel southward from the late 1800's to the 1970's. By projecting the 60 year climate variation to a 120 year cycle of peak to peak (a contemporaneous maximum clockwise rotation of Hog Island), the geomorphic data are independently fitted into a climate dominated system. Maximum clockwise rotation (with intervening maximum counter-clockwise rotation) occurred in the mid to late 1900's, early to mid 1800's, early 1700's, and around 1600.

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INTRODUCTION

The thirteen barrier islands located along the seaward margin of the Virginia coast are Holocene in age (Figure 1). Short- and long-term variations in marine processes have caused these islands to undergo rapid morphologic changes. Sea level change, tides, storms, waves, wind, and biota control the evolution of these islands and their morphology by creating, altering, and destroying barrier island landforms through the redistribution of sediments. These processes vary on daily, monthly, seasonal, and secular time scales. Although the Virginia barrier islands retain some evidence of their Holocene history, significant changes in shoreline position and island morphology have occurred in relatively recent times and obscure much of their older structure.

The goals of this study are to identify and map the different physiographic regions on Hog Island, reconstruct the island's geomorphic evolution, and determine those variations in short- and long-term changes which have influenced the island's development. Landform characteristics and landform juxtaposition are mapped and quantified using aerial photographs, shoreline charts, landform relationships, and field studies. Study of the juxtaposition of distinct landforms, the evolution of landforms, and the physical characteristics of the island, are the bases of a conceptual model of the Late Holocene history of Hog Island. More specifically, this study: 1) identifies the different landform patterns on Hog Island and describes the physical characteristics of each; 2) documents and describes the evolution of Hog Island; 3) relates differences in shoreline change along the island's

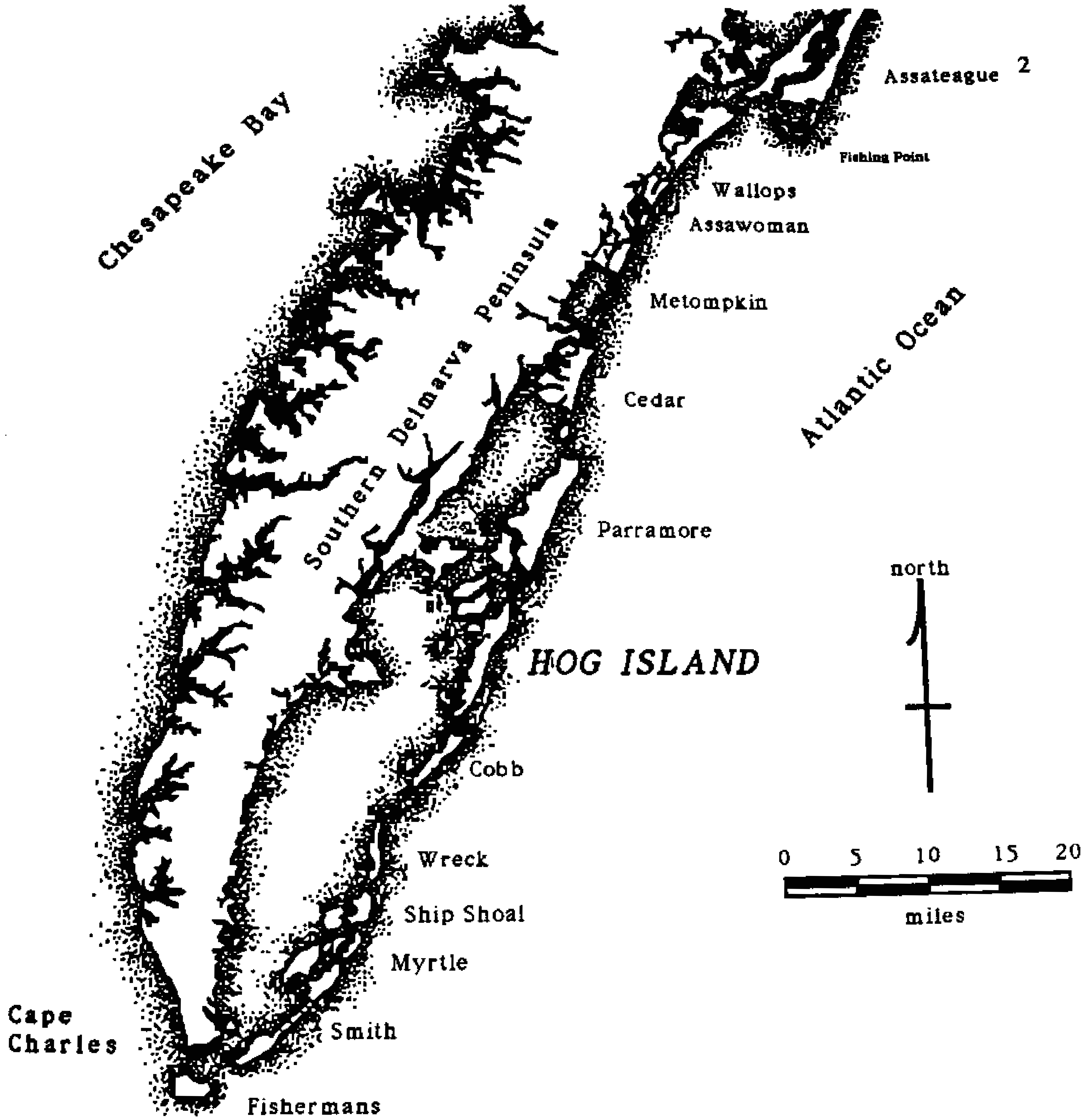


Figure 1. The Virginia barrier chain is located along the eastern margin of the southern Delmarva peninsula and is comprised of 13 major islands.

reach to the landforms and the evolution of the island; 4) develops a model of evolution for Hog Island; and 5) applies this model of development to other barrier islands along Virginia's coastal margin.

A detailed geomorphologic study of Hog Island has not been conducted in the past primarily because of its remote location. Recently, a National Science Foundation grant provided the support to establish a Long Term Ecological Research site along the Virginia coast. The University of Virginia Department of Environmental Sciences has been conducting meteorologic, ecologic, and geologic study of the central Virginia barriers as a part of this program.

Hog Island was chosen for my study because: 1) access and logistical and financial support were provided by the National Science Foundation; 2) it is similar to many drumstick barriers throughout the world which have been studied in detail; and 3) the island provides a study site in an area which has not been changed significantly by human activities.

Moreover, an aerial photographic record of the island is available from 1942 to the present. This, along with historic shoreline charts of the island from 1852, documents the island's rapidly changing shoreline (up to 13 m/year erosion and 13 m/year accretion along the island since 1949). In addition, Hog Island is similar to other Virginia barrier islands with regard to its orientation, general morphology, and overall configuration.

GEOMORPHOLOGY

Sediment deposition, erosion, and storage in the coastal zone by large scale processes contributes to regional-scale shoreline configurations (roughly 10-200 km). In contrast, local variations in island morphology (0.5-10 km) are governed by shorter-term variations in the waves, tides, storm surges and washovers, and vegetative colonization. These regional and local variations create island morphology and give rise to landform distributions.

Classification Systems: The dynamic agents involved in coastal change create a static morphology, albeit long- or short-lived. Researchers have analyzed coasts according to the dynamics of shorelines (Goldsmith, *et al.*, 1975; Rice and Leatherman,1982), resultant static morphologies (Fisher, 1967), and a combination of dynamic and static variables (Kochel, *et al.*, 1985).

Fisher (1967) used large-scale morphologic patterns to divide the Delmarva Peninsula barrier islands into four groups (Figure 2), whereas Kochel *et al.* (1985) concluded from analysis of 15 variables (dynamic and static) that three groups of islands exist along this stretch of coast (Figure 2). Both investigations agree that the *Barrier Island Chain* (Fisher, 1967) is a region of *short, discontinuous* (Kochel *et al.*, 1985) barrier islands separated by many inlets; however, there is disagreement on the characteristics of regions to the north. The difference between group divisions in the north may be due to a lag in the expression of long-term, regional morphologic change as a response to more recent changes in the dynamic variables. Also, the superposition of similar variables onto varied stratigraphic and paleotopographic remnants in the geologic record may institute substantial

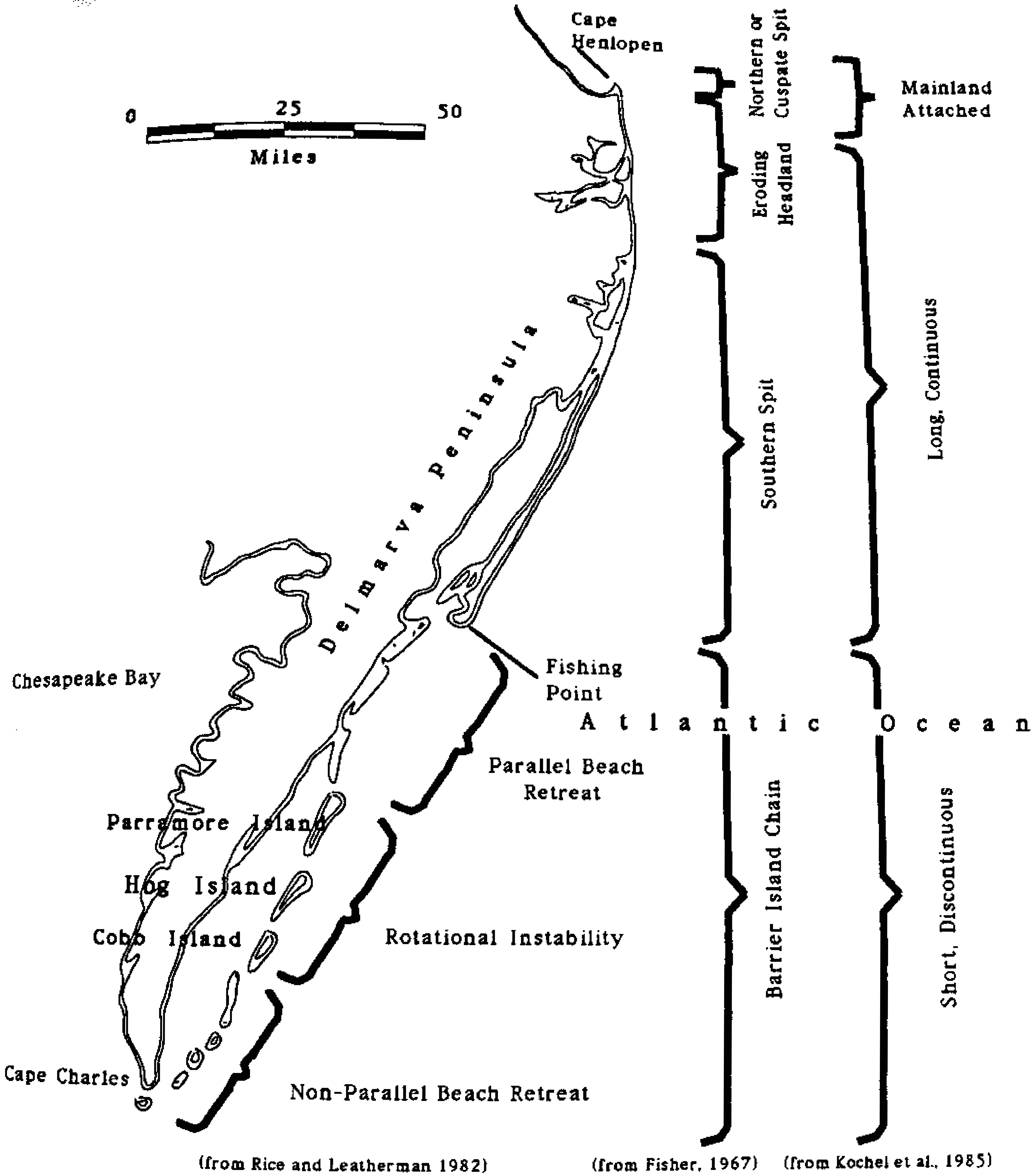


Figure 2. The mid-Atlantic coast has been divided into compartments based on coastal morphology (Fisher, 1967), on shoreline erosion rates and configuration (Dolan et al., 1979; Kochel et al., 1985; Rice and Leatherman, 1982), and on their physical environment (Hayes, 1979; Kochel et al, 1985).

differences in regional morphology. Halsey (1978, 1979) refers to paleotopographic influences as a cause for regional scale influences on the Virginia barriers (see section on Evolution of Hog Island).

Kochel, *et al.*, (1985) subdivided the Virginia portion of the Delmarva Peninsula barrier islands into a northern section and a southern section. The northern section extends from just south of Cape Henlopen, Delaware, to Fishing Point, Virginia, and is part of the *long, continuous* barrier (Kochel, *et al.*, 1985). The southern section of *short, discontinuous* barriers, extends from Fishing Point to Fishermans Island (Kochel *et al.*, 1985). Hog Island, Virginia, is located in the *Barrier Island Chain* as classified by Fisher (1967) and the *short, discontinuous* barrier of Kochel, *et al.* (1985). Rice and Leatherman (1982) divide the southern section of *short, discontinuous* barriers into a northern group characterized by *Parallel Beach Retreat*, a middle group characterized by *Rotational Instability*, and a southern group characterized by *Non-Parallel Beach Retreat* (Figure 2), reflecting regional-scale variations in the physical environment (e.g. wave climate, tides, sediment supply). The three barrier islands contained within the middle group (Cobb, Hog, and Parramore) have been "rotating" in a clockwise direction since the late 1800's, have exhibited reversal in offsets of the inlets (Rice and Leatherman, 1982), and display one of the most dynamic coastlines along the Atlantic seaboard (Dolan, *et al.*, 1979; Dolan, *et al.*, 1988).

Rotation of an island is the result of net shoreline erosion at one end (sediment translation landward or island transgression), and net shoreline accretion (regression) at the opposite end. During rotation, sediment accreting to the regressive section of an island is stored in landforms, creating the geomorphic features which document a portion of the islands history.

Sediment Redistribution: Coastal processes alter shoreline positions by redistributing sediment from a source to either short- or long-term storage and finally to a sediment sink (Field and Duane, 1976). The sediment sink may either be temporary, to be later reworked into the same transgression as it was deposited (e.g. a back-barrier sequence overridden by the island transgression), or the sediment sink may be stranded during a eustatic regression and abandoned as a terrace deposit on the Coastal Plain.

Washover deposits, dune ridges, spits, and welded bars are landforms which store sediment and outline former shoreline positions (Halsey, 1978). Halsey (1979) has stated that the differences between the *long, continuous* barrier, extending from Cape Henlopen to Fishing Point and the *short, discontinuous* barriers south to Cape Charles (Figure 2) are due to sediment availability; as more sediment becomes available to the longshore currents due to the erosion of the Delaware headlands, inlets between the *short, discontinuous* barriers to the south will be filled and one *long, continuous* barrier with few inlets will be created. However, studies of drumstick, and *short, discontinuous* barrier island systems along the mid-Atlantic coast of North America, Alaska, the Netherlands, and the German Bight (Hayes, 1979), indicate that the difference between *long, continuous* and *short, discontinuous* barriers can be better explained by the ratio of tide dominance to wave dominance.

Tides: Low mesotidal (1-2 m) and microtidal (0-1 m) tidal range in areas of low to moderate wave energy are associated with the formation of drumstick barriers (Hayes, 1979). This drumstick morphology is recognizable in the *rotational instability* section of Virginia's *short, discontinuous* barriers. According to Hayes (1979), the Virginia barriers consist of low mesotidal, short (3 to 20 km in length) drumstick barriers, with numerous tidal inlets. Tidal range and wave climate jointly results in the formation of large ebb dominated deltas with strong wave refraction effects.

Tidal Inlets: The tidal inlets of the Virginia barriers are ebb dominated with large ebb deltas that extend up to 6 km eastward from the barriers. The importance of ebb deltas and inlets in barrier island morphology and evolution is that the longshore currents, wave climate, and sediment flux in the littoral drift are greatly influenced by the ebb delta and ebb jet (Newman and Rusnak, 1965; Davis, *et al.*, 1972; Goldsmith, *et al.*, 1975; and Hayes, 1979). Reversal of longshore currents downdrift of the ebb deltas results in zones of deposition, offshore bar accretion, and a local surplus of sediment (Hayes, 1979; Davis *et al.*, 1972). In contrast, interruption of the littoral drift by discharge forces of the ebb jet and sediment storage in the large sediment sink of the deltas have been shown to create sediment deficiencies down-drift and create up-drift offset of barriers (Hayes, 1979). To compare these two seemingly contradictory ideas, reversal of the longshore currents and interference of the littoral drift by the ebb jet have both been cited as reasons for the existence of different offsets, or overlap, at inlets (Figure 3). Researchers often have discussed offsets at inlets; Boothroyd (in Davis, *ed.*, 1985) has listed five "documented" causes for barrier island offset at inlets:

1. large sediment supply from updrift creates updrift offset (earlier workers)

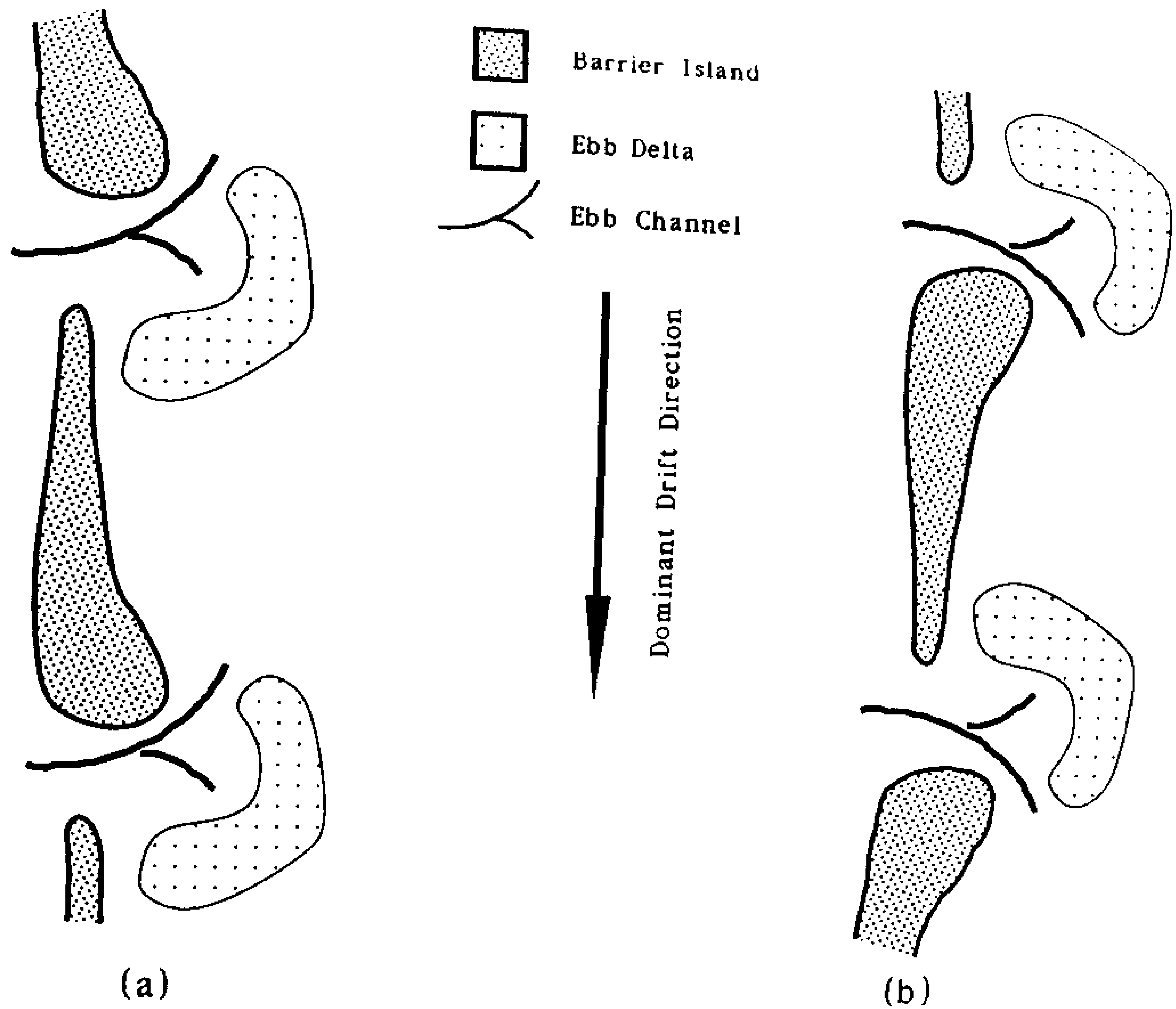


Figure 3. The origin of barrier island offsets at inlets has been disputed.

a. Updrift offsets have been described as forming when 1) a large sediment supply from updrift collects at the downdrift end of the island, and 2) a strong ebb tidal flow along the downdrift side of an island inhibits sediment transport downdrift.

b. Downdrift offsets have been described as forming when 1) wave refaaction and bar welding on the downdrift island, and 2) the main ebb channel erodes into a cohesive mud.

2. wave refraction and subsequent drift reversal and deposition creates downdrift offset,

3. downcutting of the main ebb channel into a cohesive mud creates a downdrift offset,

4. asymmetry of tidal velocities (flood vs. ebb) and position of tidal flushing paths creates an updrift overlap, and

5. large availability of sediment creates updrift overlap.

Large sediment supply (1) and drift reversal around the ebb delta (2) have been documented to be the most frequent reason for barrier island offset. In relation to sediment distribution on barrier islands, Boothroyd (in Davis *ed.*, 1985) states that an updrift offset "is usually a supratidal part of the barrier itself," implying a strong relationship between the barrier and the attachment of the ebb delta sediment mass to an island.

Hog Island is presently offset downdrift, and may presently be described by wave refraction effects (2) and downcutting into a cohesive mud (3). Variations and changes in sediment supply may cause the system to be reversed. The position of the ebb delta in the *Rotational Instability Section* of the Virginia barrier islands has shifted slightly southward over the last 140 years (Goldsmith *et al.*, 1982). However, the position of the dominant ebb channel has changed from a northeast to a southeast orientation from the late 1800's to the middle 1900's, contemporaneous with the major morphologic changes in the island (Figure 4) and changes in island rotation.

Storms: Tropical and extratropical cyclones provide the energy in the form of waves and surges which drives barrier islands inland, changes island orientation, and maintains active sand regions on the island (Dolan, *et al.*, 1978; Hayden, 1975). Northeasters (extratropical cyclones) are more

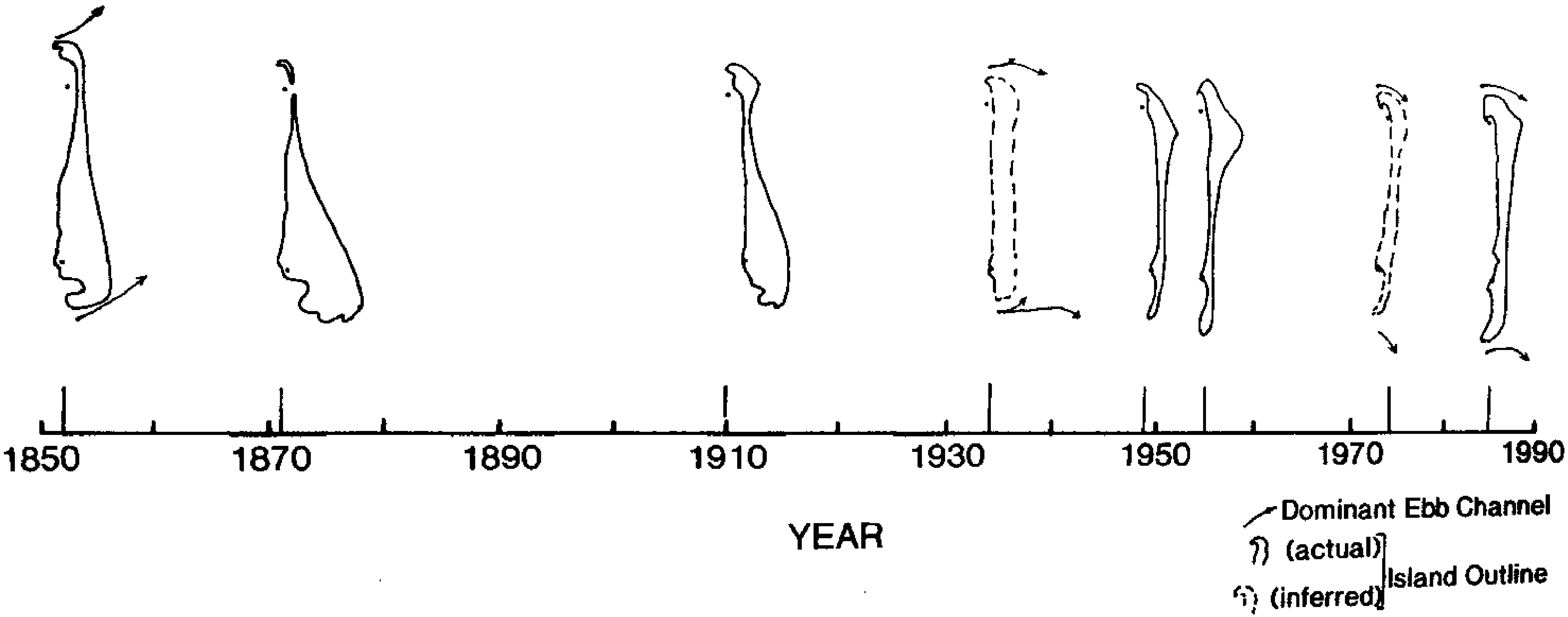


Figure 4. The position of the dominant ebb channel in the inlets to the north and south of Hog Island changed position from 1852 to 1986. In 1852, the inlet was situated to the north side of the inlet and trended in a more northerly direction. In 1934 the ebb channel has shifted southward, and in 1974, the channel shifted further south. Between 1974 and 1986, the dominant ebb channel shifted slightly northward. Each of these changes in ebb channel position corresponds with major changes in island morphology.

important than tropical cyclones because they occur more frequently along the mid-Atlantic coast than tropical cyclones (Dolan *et al.*, 1978). Over 1300 northeasters, producing waves of 1.6 meters or more, occurred along the mid-Atlantic coast during the 42 year period from 1942 to 1984 (Wayland and Hayden, 1975), with an average of 33 storms each year producing waves (>1.6 m) which are capable of eroding the beach (Hayden, 1975). Northeasters, with a wave climate dominant from the northeast, erode the beach and move sediments offshore (Davis, *et al.*, 1972); the otherwise southeast climate (in response to dominant high pressure near the coast) drives sediment onshore during calm periods (Davis, *et al.*, 1972).

Waves reaching the beach are directly related to the storm track, storm duration (Hayden, 1975), and offshore bathymmetry (Goldsmith, *et al.*, 1975). It has been suggested that if storm tracks or storm intensities change, that the result along the active coastline will be recognizable in shoreline configuration and orientation with time (Hayden, 1975; Wayland and Hayden, 1975; Dolan, *et al.*, 1988). Along the Atlantic coast of North America, Hayden (1981) analyzed spatial and temporal variations in storm frequencies occurring from 1885 to 1978. His first two eigenvectors represent the tracks of cyclones along the coast (E1, 28% of variance) and cyclogenesis (E2, 17.3% of variance; Figure 5). In the early 1900's, cyclones had a greater tendency to track to the west of the east coast (continental track: $E_1<0$); in the early 1960's, the dominant storm track was over the ocean (marine track: $E_1>0$). There tends to be a positive correlation with the number of storms and the marine track (Figure 5). The total increase of storms from the low to high over this 60 year variation was four-fold along Virginia's Eastern Shore (Figure 6).

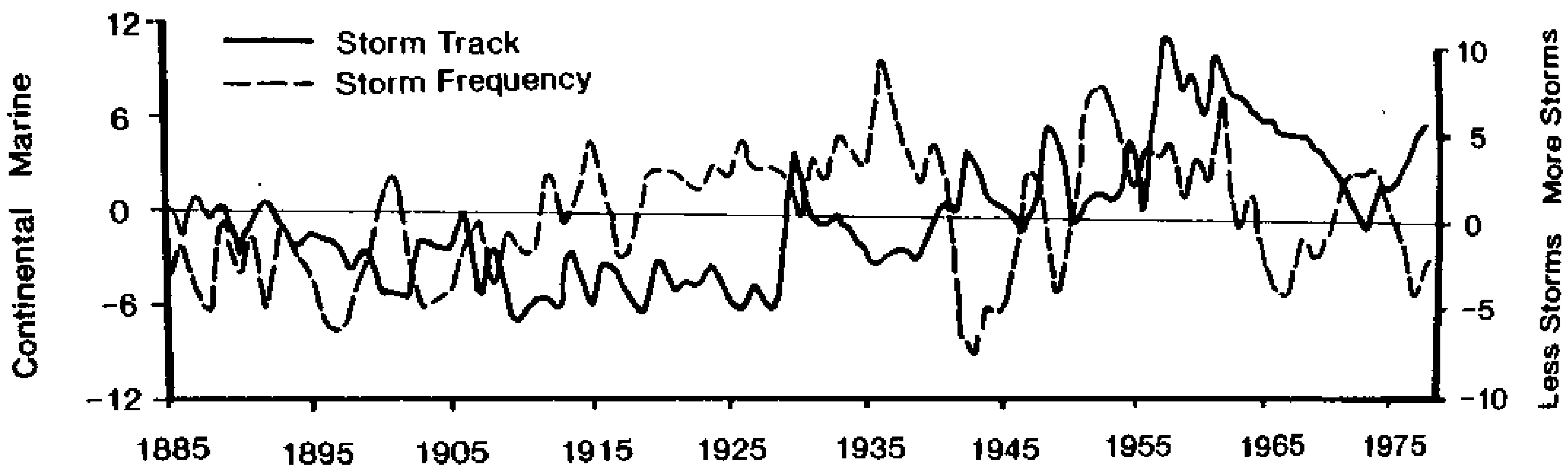


Figure 5. Storm track and storm frequency have varied along the mid-Atlantic coast. In the late 1800's and in the early 1900's, storms tracked mainly to the west of the eastern shore and storms were infrequent (value <0). In the middle 1900's, the storm tracks changed to a more easterly, maritime, position, and storms were more frequent. The dominant storm track was farthest east and the number of storms occurring along the coast was greatest around 1960 (modified from Hayden, 1980).

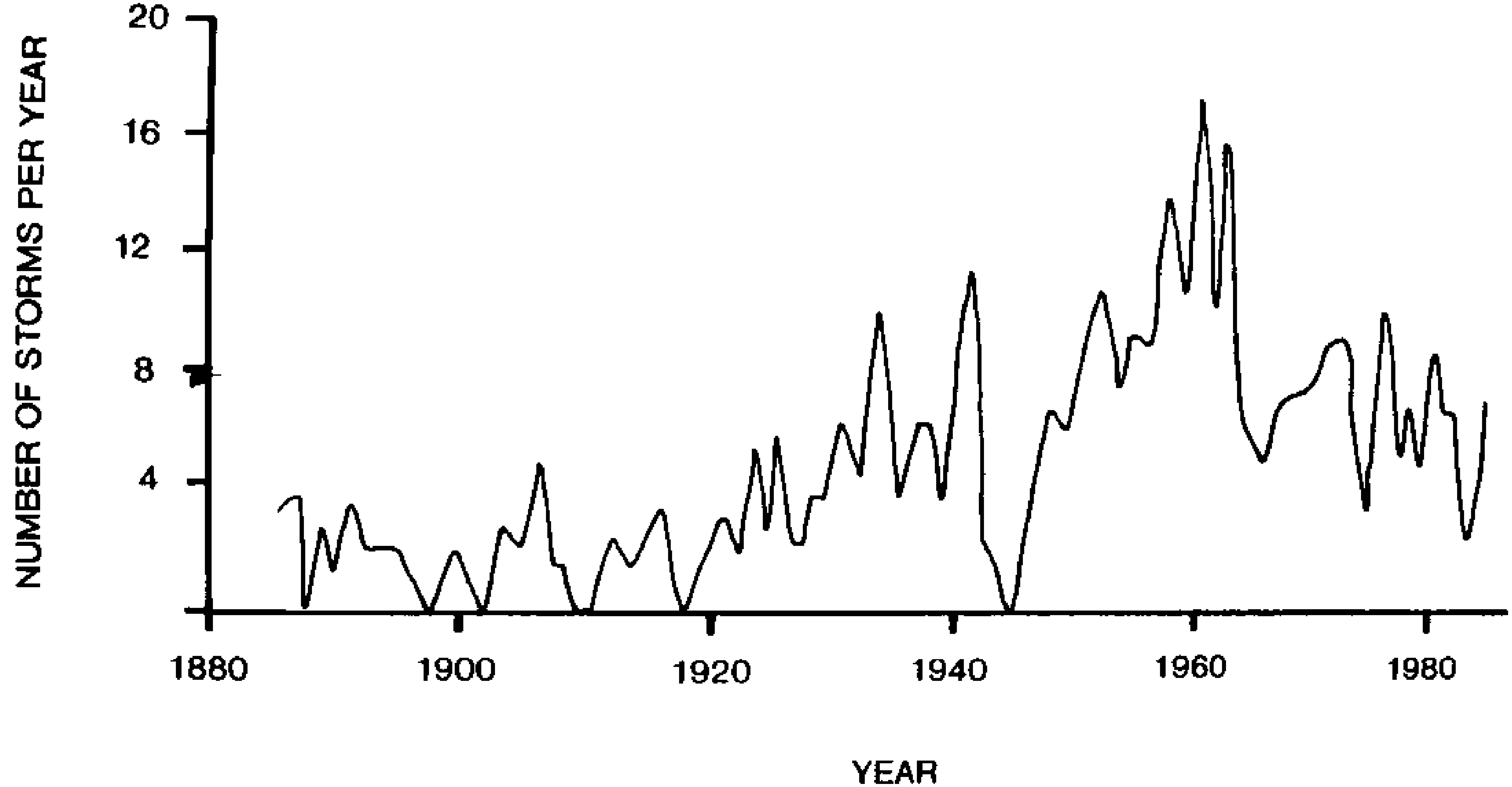


Figure 6. A detailed inspection of storm frequency along the southern Delmarva Peninsula clearly shows that few storms passed through the area around the turn of the century, and a peak in storm frequency occurred around 1960 (from Bruce P. Hayden).

Waves: Waves and storm surges commonly combine to overtop the threshold of the beach and spread across the island, depositing sediment and translating the island landward. As waves approach the coast, they are reflected and refracted by the bottom features offshore. Goldsmith *et al.* (1975) have studied the effect of offshore bathymmetry on waves approaching the Virginia coast. Their study showed that the ebb deltas of the middle Virginia barrier islands generally cause the accretionary southeast waves, as well as the erosional northeast waves, to be concentrated at the southern ends of the islands. Most sediments would then tend to be either eroded from or deposited on the shoreface along the south ends of the islands, depending upon storm (high energy, erosional, northeast) or calm (low energy, accretional, southeast) conditions.

During a storm in March 1989, visual observations on Hog Island were made from the beach regarding the relative intensity of waves breaking in the surf zone, directly on the beach, and across the ebb delta. I began observations one day before the storm peak at the south end of the island at mid-tide and walked north as the tide rose, ending at the north end of the island just after high tide. It was apparent from the large number of breakers outlining the ebb delta northeast of Hog Island that a large amount of the wave energy coming from the north-northeast was released on the ebb delta. The ebb delta visibly reduced wave heights reaching the north end of the island. Wave energy reaching the shore increased south of the ebb delta where waves were breaking directly on the beach. There appeared to be a slight difference in wave energy at the extreme southern part of the island, and this may be due to the large ebb delta extending east of Machipongo Inlet or to the difference in tidal elevation. The dominant northeast wave climate and refraction in and around the ebb delta have caused erosion on the updrift sides of the inlets and deposition on the down drift sides since the late 1800's (Figure 4).

EVOLUTION OF HOG ISLAND

The Virginia barriers are now transgressing across an irregular Pleistocene topography which has a local relief of at least 20 m. Based on this coring evidence (Finkelstein and Kearney, 1988; Halsey, 1979; Newman and Munsart, 1968), the pre-Holocene landscape along the seaward margin of Virginia's Eastern Shore consists of an incised trellis drainage pattern on a coarse grained substrate of a regressive Pleistocene sequence (Figure 7). Low areas between and through the regressive beach ridges provided a natural, geomorphically induced, stream pattern when the sea level dropped during glacial periods.

Sea level curves indicate a rapid rise in sea level before 2,500 B.P. (years before present) which was followed by a reduction in the rate of sea level rise to its current rate (Figure 8). Extrapolation of the long-term sea level curves over the last few hundred years indicate that sea level rise has occurred at a rate of 1 mm to 2 mm per year (Van de Plassche, 1990). More recently, Emery and Aubrey (1991) have used tide-level data from 1920 to 1986 to estimate relative rise in sea level along the coast. By regression analysis of the entire record for the Chesapeake and Delaware Bay region, they determined a rate of 3 mm to 4 mm/year; using eigenanlysis of the tide data, they determined a rate of 2 mm to 3 mm/year (2.3 mm/year at Cape Charles, Virginia, and 2.5 mm/year at Cape Henlopen, Delaware). Due to the nature and time spans of Van de Plassche (1990) and Emery and Aubrey (1991) data, the more recent, tidally derived rates (2 mm to 3 mm) will be used as an estimate for the Virginia barriers in this report.

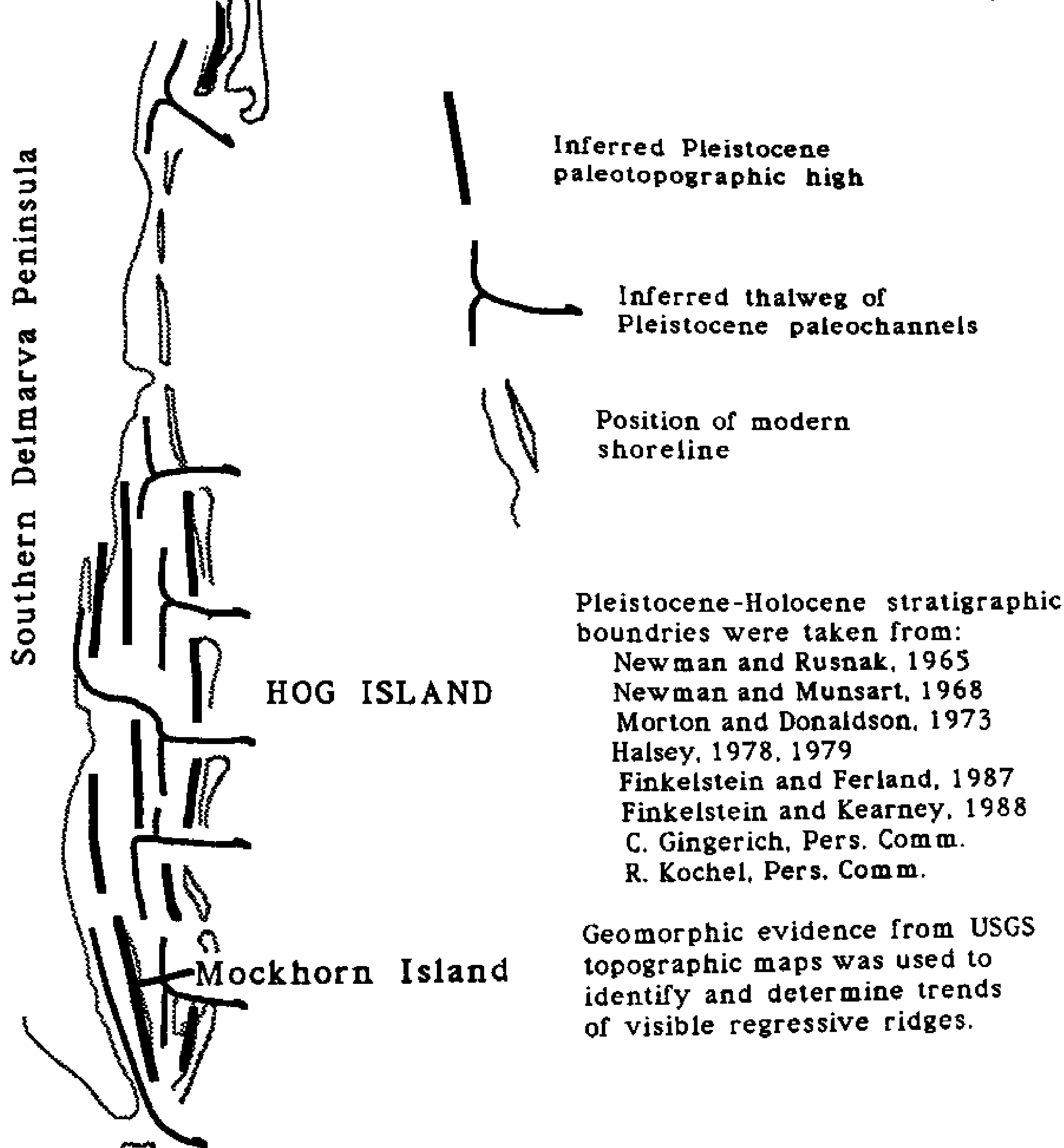
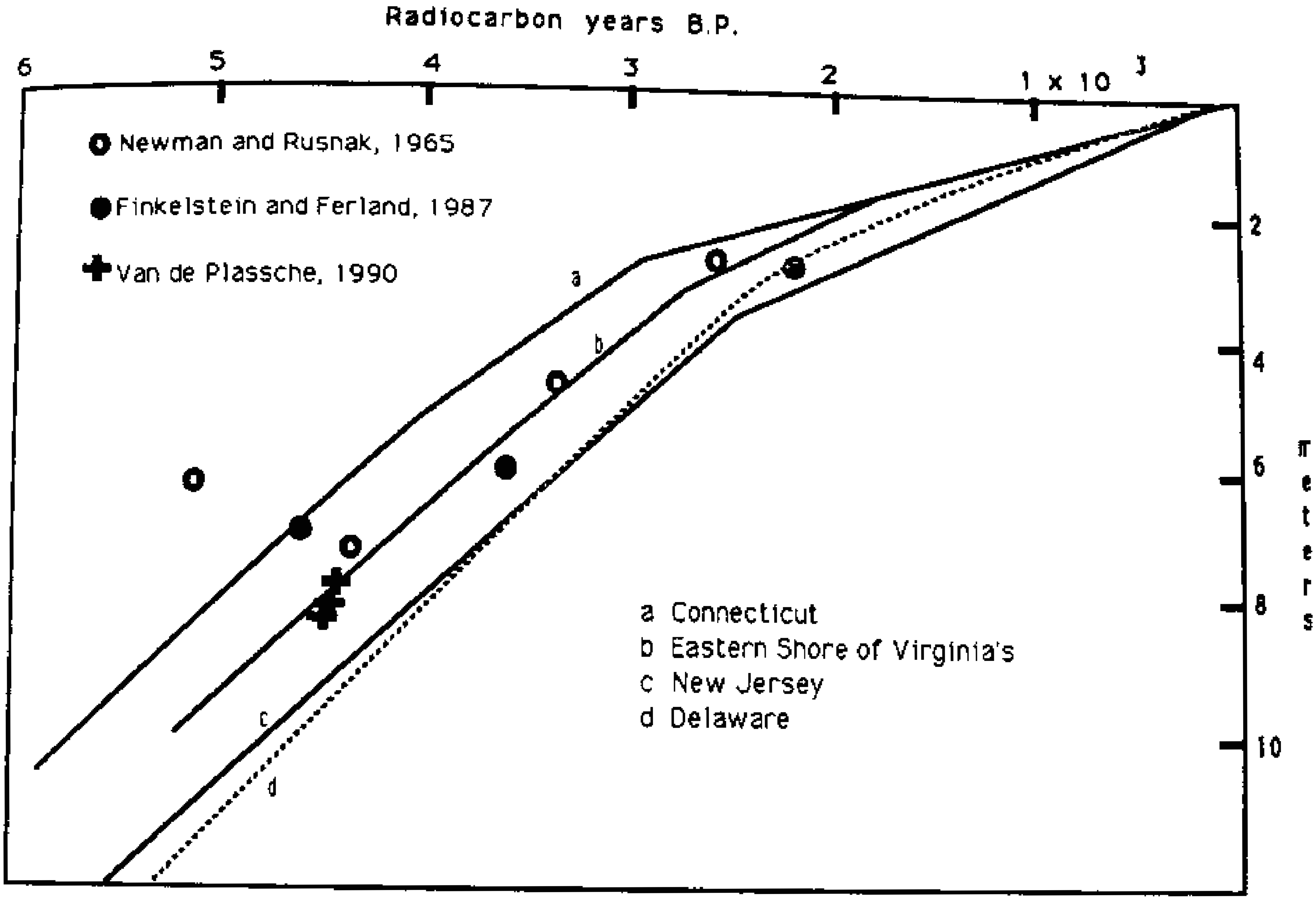


Figure 7. During the last lowstand of sea level, an incised trellis drainage pattern formed on the exposed Pleistocene surface. This surface is composed of fine and coarse grained sediments. As a regressive phase of sea level fall, shore parallel ridges were left behind. Mockhorn Island is one of these stranded barrier ridges (Finkelstein and Kearney, 1988). Note the location of paleochannels associated with modern inlets, and the relative position of Parramore, Hog, and Cobb Islands with the inferred Pleistocene paleotopographic highs.



from Van de Plassche, 1990

Figure 8. Sea level curves for the East Coast of the U.S. indicate that sea level was rising rapidly until about 2,500 B.P. Since that time, sea levels have been rising at a rate of 1 mm to 2 mm per year. More recent studies, using tide gague data, have been used to calculate an accurate recent rise in sea level of 2 mm to 3 mm per year.

Due to changes in sea level rise and sediment distributions, the depositional environments behind the Virginia barrier islands have varied through time. Deposition of high-energy (fine sand), open lagoonal sediments on the Pleistocene surface occurred from at least 5,100 B.P. to 1000 B.P., coming to within 1 m of the present marsh surface. However, Oertel, *et al.*, (1989), through the use of pollen studies, argue that the open lagoonal sediments are a Pleistocene facies below the modern marsh sediments. Holocene radiocarbon dates from comparable facies behind the islands from Parramore Island to Smith Island (Newman and Rusnak, 1965; Finkelstein and Ferland, 1987) suggest that Oertel, *et al.*, (1989) may have cored a local Pleistocene marsh platform. Since 1,000 B.P., up to 2.5 m of marsh sediments have been deposited on top of the high energy, Holocene, lagoonal sediments behind the Virginia barriers (Newman and Rusnak, 1965; Newman and Munsart, 1968; Morton and Donaldson, 1973; Halsey, 1978).

Behind Hog Island, Finkelstein and Ferland (1987) identified 4 m to 5 m of open lagoonal sediments below 1 m to 2 m of back-barrier marsh sediments. No radiocarbon dates are available on the cores but, given stratigraphic relationships behind the Virginia barriers, the change in depositional environments probably occurred around 1,000 B.P. Pleistocene lithologies have been found 7 m below sea level (Craig Kochel, *personal communication*) at the northern end of Hog Island, directly behind the most landward dune ridge. About 6 m of lagoonal sands and muds, and 1.0 m to 2.0 m of marsh and overwash overlie the Pleistocene unconformity. A probe at MHW (mean high water), just north of Bowen's Cabin (refer to Figure 11), indicates that there is 0.64 m of thickly matted, spongy, organic material

(*Spartina patens* roots) on top of 1.5 m of very fine sand, and at least 1.3 m of soft mud below the sand (Figure 9). By comparing a sea level rise rate of 2 mm to 3 mm/year, and the accumulation of 0.64 m of high marsh sediments behind these older portions of Hog Island (Figure 9), the older landforms are estimated to be 230 to 320 years old. This date is comparable to Fitch (1991), who estimated the age of the island to be 264 years using overwash sedimentation rates and erosion rates for Hog Island.

On the south end of Parramore Island, the Pleistocene is encountered at about 5.0 m below sea level and is covered with an ephemeral inlet sequence (Katherine Gingerich, *personal communication*, 1990). In the marsh at the northern end of Parramore, Pleistocene sediments have been recovered 1.2 meters below sea level (Newman and Munsart, 1968). Here, as below the marsh behind Hog Island, a Pleistocene high or ridge is situated between two former thalwegs, which are now the location of inlets (Halsey, 1978).

Covering the Pleistocene lithologies, the Late Holocene (modern) surface units of the active barriers are composed of two main lithofacies: a fine grained (mud) low energy marsh substrate being overridden by a relatively coarse grained sand barrier (overwash, dune, and beach environments). Some fringing marsh substrates on Hog Island are composed of fine sands (Tanya Furman, *personal communication*), however for discussion in this paper, the coarse fraction of the island will refer to the areas of the island not covered by fringing marsh. The development and evolution of the coarse sediment fraction of Hog Island can be documented based on evidence from historical charts of the shoreline (1852, 1871, 1910, 1975, 1982) and aerial photographs (1949, 1955, 1962, 1985). Oblique

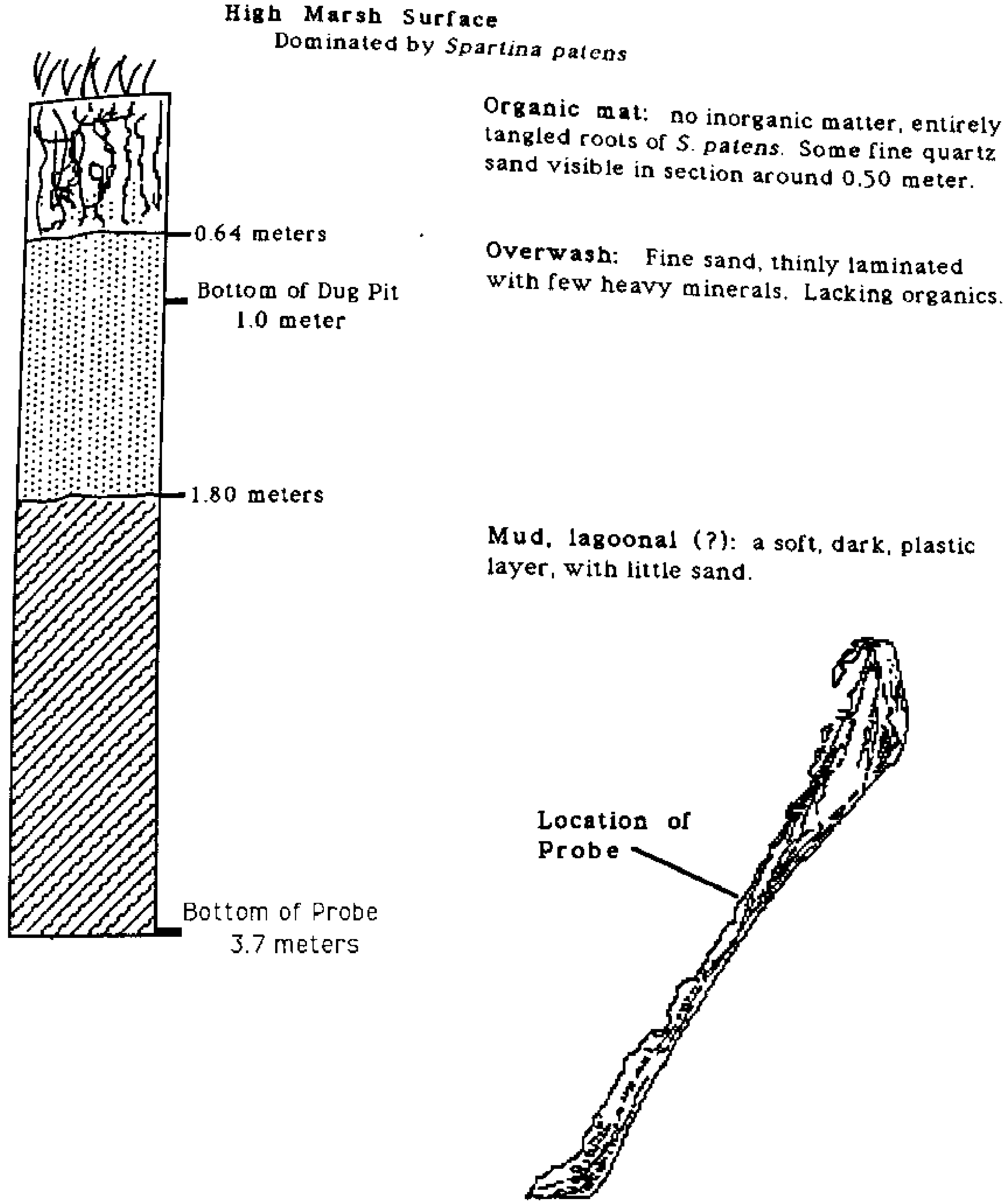


Figure 9. A stratigraphic column from a probe behind Hog Island, north of Broadwater Tower and Bowen's Cabin. The organic mat is composed entirely of Spartina patens root material, representative of a high marsh area.

photographs taken in the late 1800's and early 1900's from the Broadwater Lighthouse (Badger and Kellam, 1989) depict the existence of large regressive dune features at the south end of the island during that time period.

Prior to the availability of historical photographs and shoreline data, the only available portrait of the evolution of Hog Island is the mosaic of landforms. Aerial photographs from 1985 and 1949 were used for preliminary interpretations of the landform relationships; landform positions were field checked through extensive visits to the island in the summer of 1989.

Shoreline positions (Figure 10) were superimposed onto a 1985 rectified outline and landform map of the island in order to delineate the age of each portion of the island (Figure 11). The portion of the island which is identified as an "ancient" barrier by Rice *et al.* (1976) and referred to here as "the oldest portion" or "the oldest landforms," has not been absolutely dated. However, the existence of Native American artifacts on this segment of the island (John Hall and Barry Truitt, *personal communication*) suggests that these oldest portions formed prior to the elimination of Native Americans from the Delmarva Peninsula, sometime between 1670 and 1700 (McCary, 1957; Middleton, 1989).

The 1949 aerial photographs are extremely useful in mapping the oldest portions of the island because increased overwash in 1955, and the severe northeaster in March 1962, obliterated surficial evidence of the connection between the oldest landforms. Observation of the island's oldest features reveals the existence of two ages and forms of island physiography west of the 1871 dune ridge (Figure 12). From the juxtaposition of these landforms, other episodes of island orientation and movement may be inferred (Figure 13).

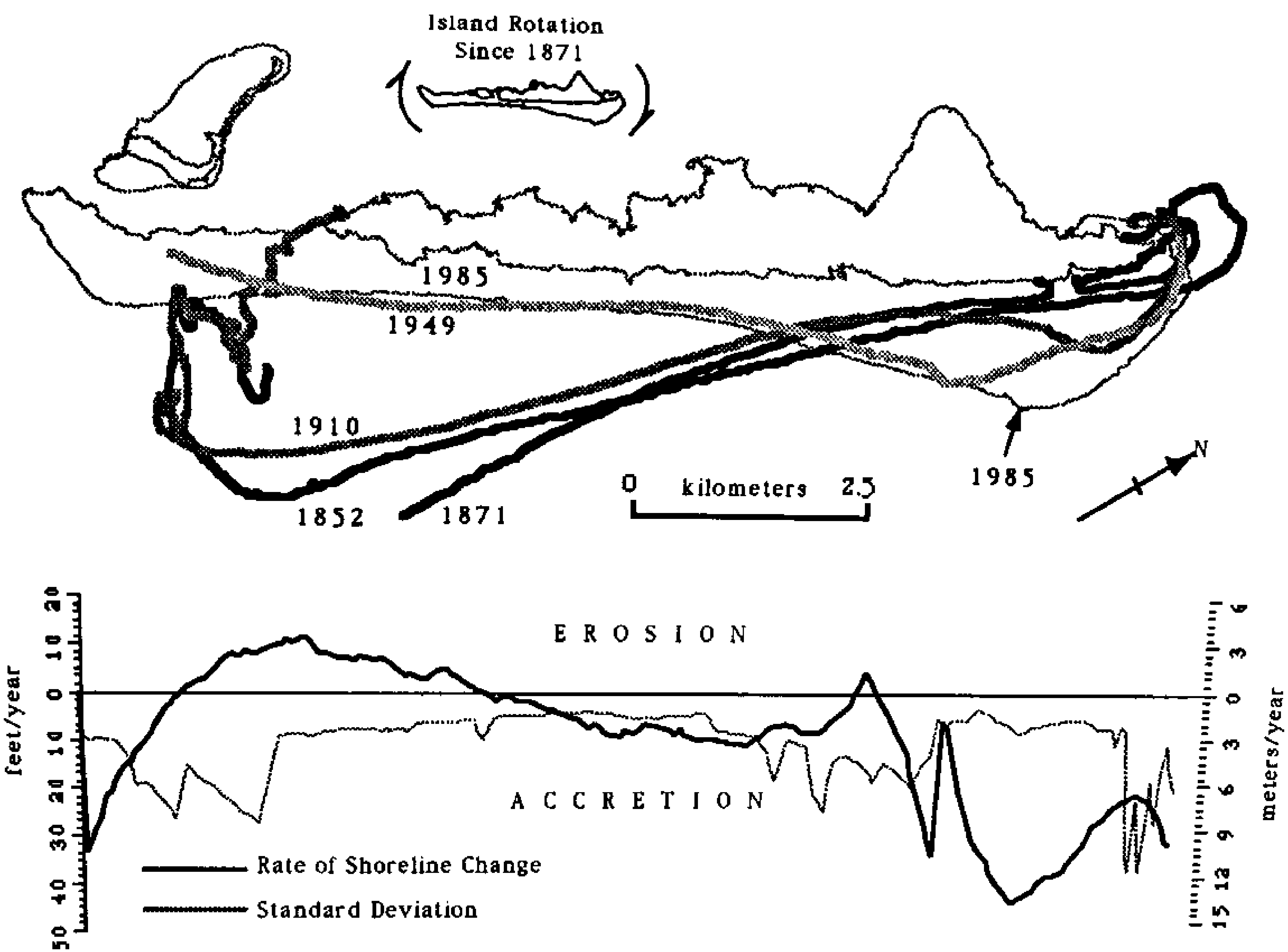


Figure 10. Shoreline positions are shown for Hog Island since 1852. The shoreline erosion data cover the period from 1949 to 1989. Shoreline positions prior to 1949 were digitized from Knowles et al. (in prep.); 1949 and 1985 shorelines were digitized from rectified aerial photographs

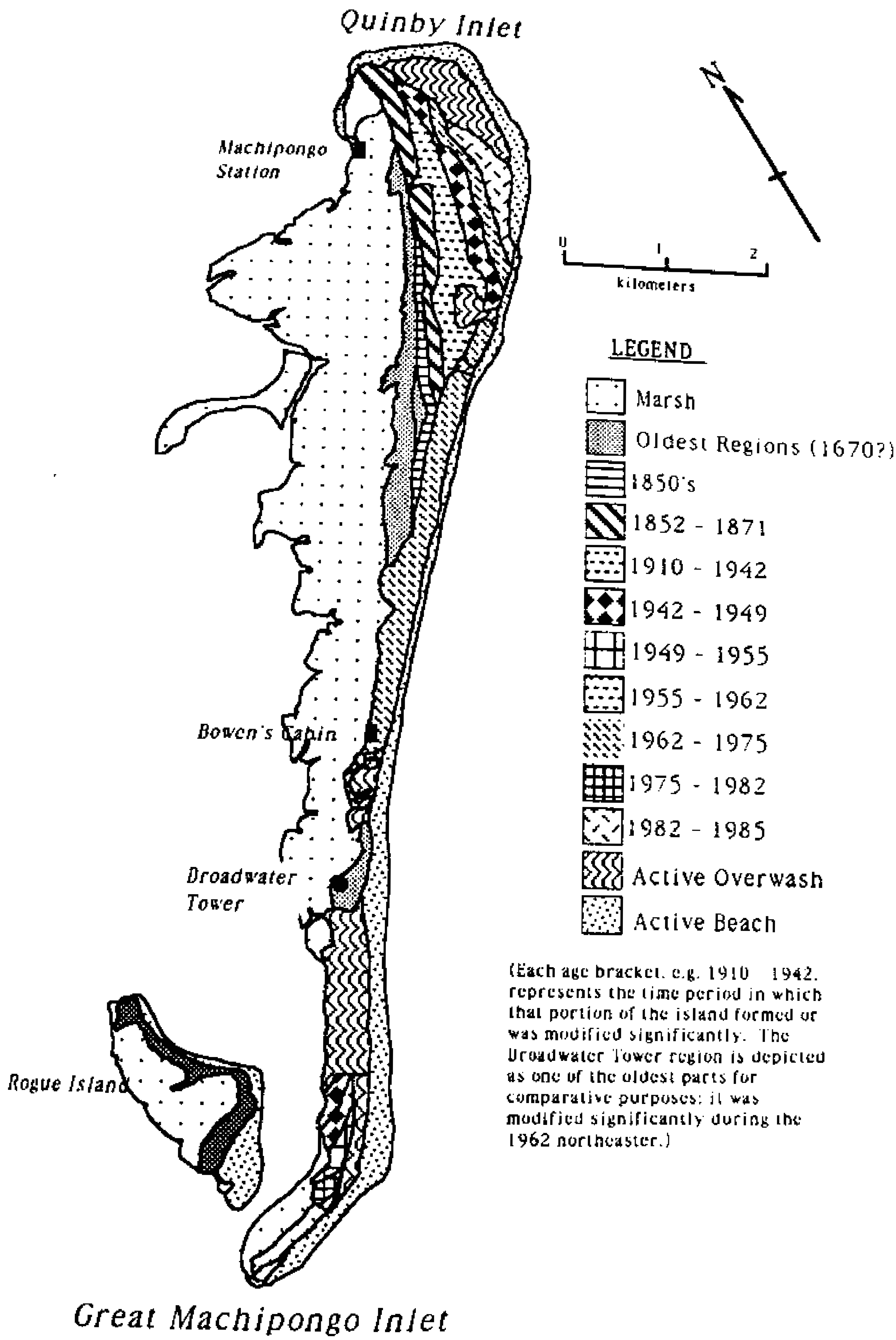


Figure 11. The age of each region on the island was determined by superimposing shoreline charts and aerial photographs onto a 1985 base map. The resulting overlay shows the oldest section of island near the marsh. The oldest portions at *Broadwater Tower* were covered by the 1962 storm.

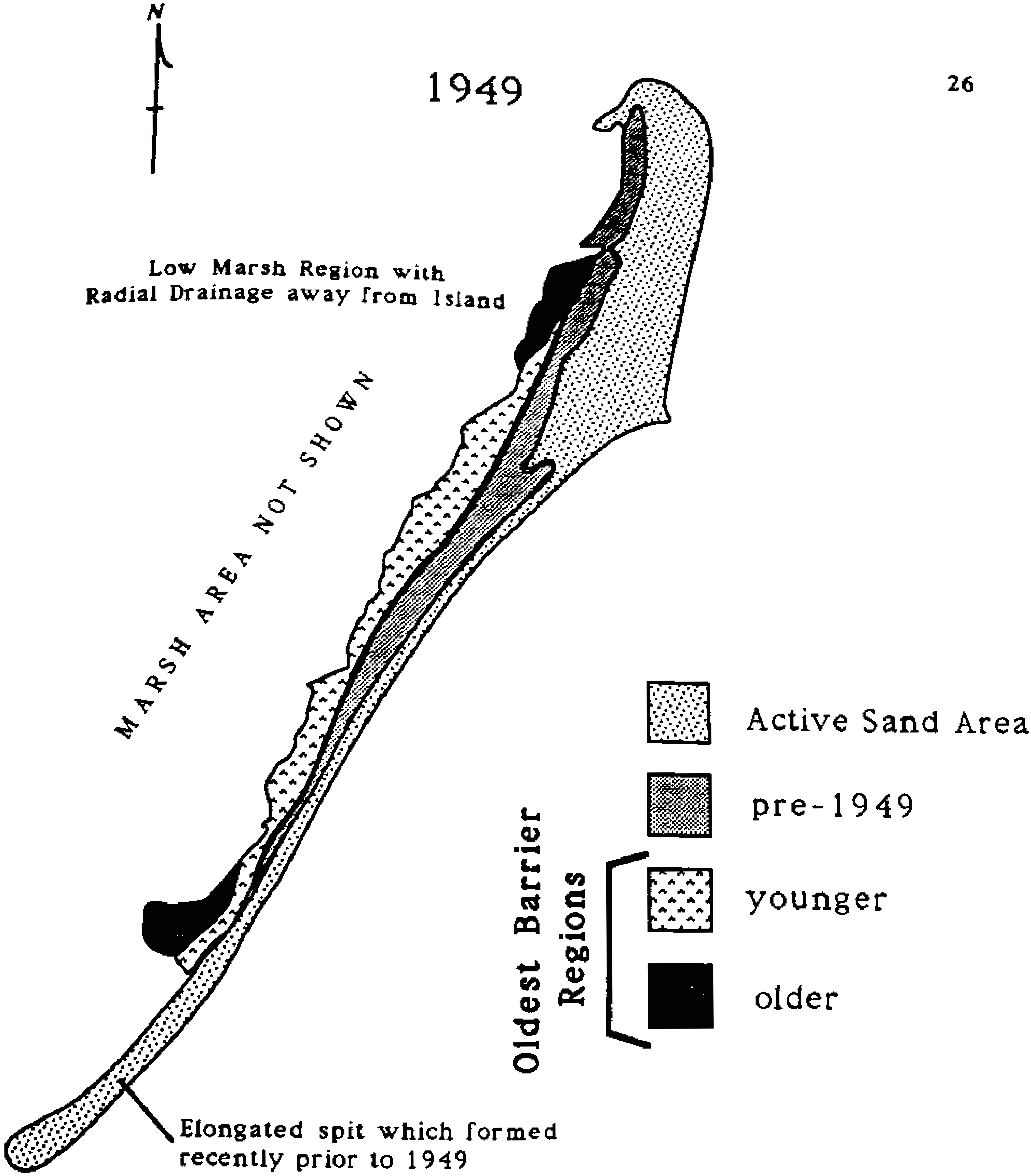


Figure 12. Two ages of oldest barrier features are visible in 1949 photographs of Hog Island. The oldest portions are to the north and south, while the younger portions have migrated across them.

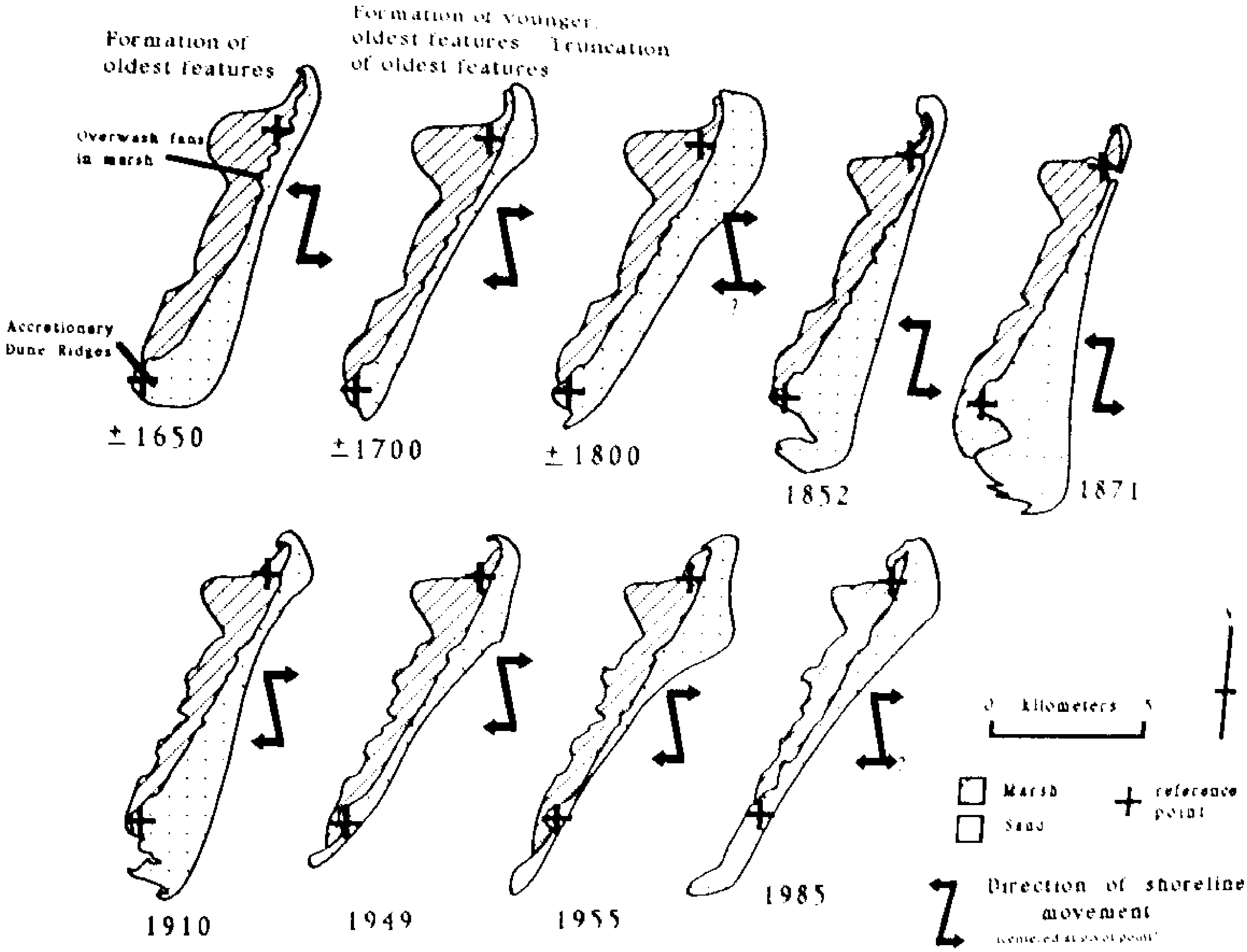


Figure 13. Hog Island has changed direction of shoreline change several times in the last 200 to 300 years. Shorelines from 1852 to 1985 were digitized from rectified chart data and aerial photographs. The marsh regions are correct from 1949 to 1985. Prior to 1949, the marsh region is schematic, and prior to 1852, the island positions are based on visible landforms and extrapolation.

Early History: he landforms along the marsh side of Hog Island make up the oldest portion of the island and represent two different periods of island evolution. In the marsh along the north end of the island, landforms, radial drainage patterns, and vegetation patterns indicate that at one time this was an area of common overwash. Imbricate dune ridges, which appear to have been connected to the overwash, are visible in the 1949 photographs near Broadwater Tower (Figure 14). These ridges indicate that the shoreline was prograding slightly southward while simultaneously accreting seaward. From these landforms, their relative positions, and their probable connection, it is evident that the island was rotating counter clockwise during the mid- to late-1600's. A schematic diagram, representing the earliest visible landform on Hog Island, depicts a drumstick barrier that is experiencing erosion to the north and accretion to the south (Figure 13).

Like some of the older portions of the oldest landforms, most of the younger portions of the oldest landforms consists of low dune ridges and overwash. These younger features truncate the older overwash fans to the north and the imbricate ridges to the south (Figure 12). They are oriented to the southwest, indicating a southerly longshore current. The island during the 1700 configuration (Figure 13) portrays a situation in which the thin, landward migrating barrier has changed rotation and breached the center portion of the island. Here, high dunes do not create a threshold which the storm climate could not overcome. Between the time of Native American habitation and 1871, no landforms are visible. The island extended seaward of the 1852 shore between the late 1600's and the mid-1800's. This period of

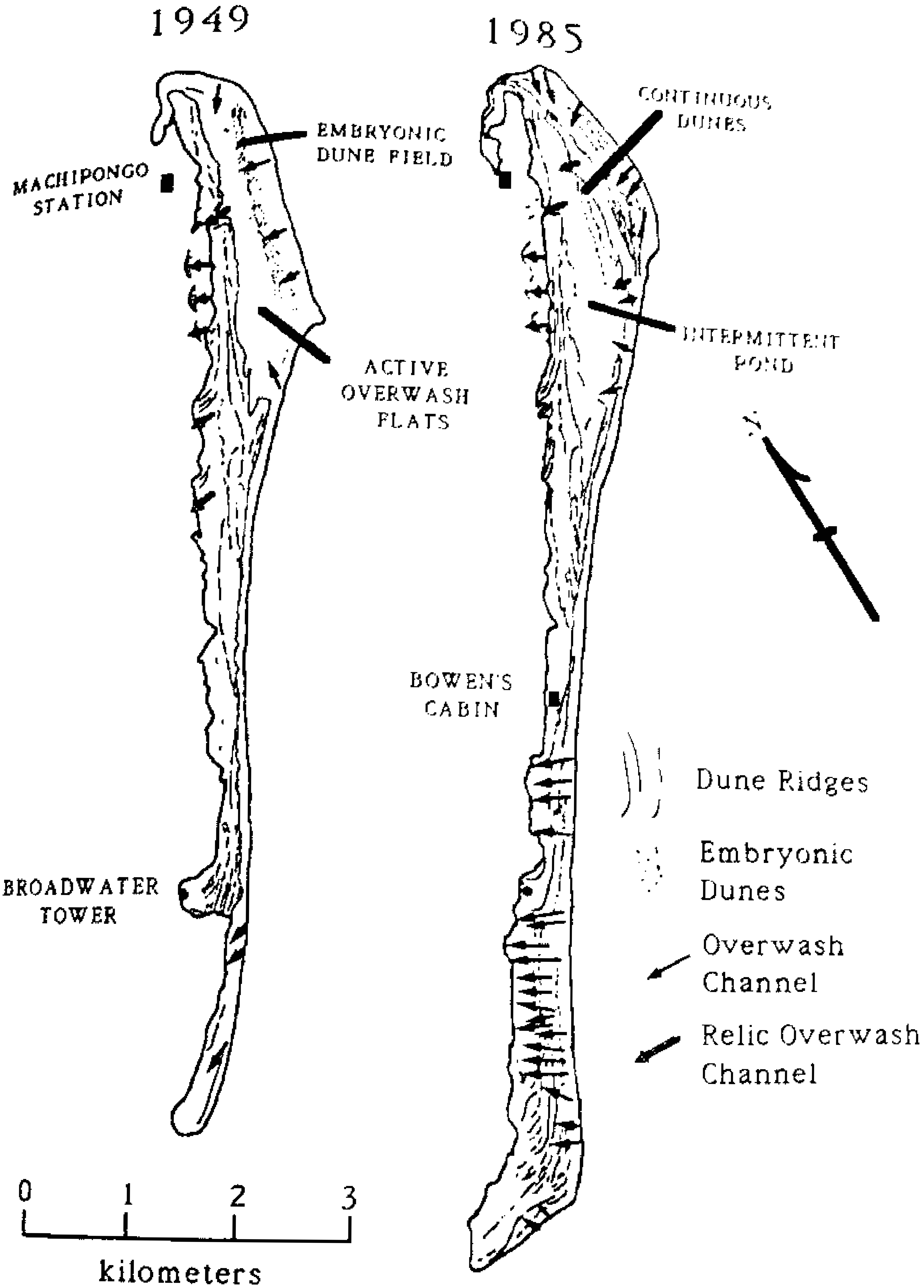


Figure 14. Crests of dune ridges and directions of major overwash penetration were traced from unrectified 1949 and 1985 aerial photography. Notice that the embryonic dunes in 1949 (represented by small dots along the northeastern shoreline) coalesced into a continuous dune ridge separating the overwash flat from the shore.

[illegible] is identified as a clockwise rotating vortex and is portrayed for [illegible] (Figure 13).

1852 to 1871: Shoreline chart data (Knowles et al., in preparation) show that Hog Island was being modified with an apparent counter clockwise rotation between 1852 and 1871. The area of the coarse grass portion of the island covered approximately 15 km^2 in 1852 and decreased to almost 12 km^2 in 1871 (Figure 15). Landforms created during this period at the south end of the island are documented in historical photographs taken from the former Broadwater Lighthouse near the present location of Broadwater Tower. Large dunes and dune ridges were present at the south end of the island and overwash flats were present at the north end. The sediment volume was much larger, given the dominance of large dune features over a much greater area of island. Presently, the features at the north end of the island truncate the older regions created before the late 1700's. Thus the shoreline was seaward of this area and moved across the oldest features between 1852 and 1871.

1871 to 1949: From 1871 to 1949, shoreline chart data indicate that extensive erosion occurred at the south end of the island, and that accretion occurred at the northern end. Most erosion at the south end occurred between 1910 and 1949 (Figure 10) and resulted in a nearly 50% decrease in island area (Figure 15). In fact, the extreme southern tip of the island, south of Broadwater Tower was completely removed. The dominant ebb channel migrated to the south during this time period (Figure 4). Also, the 1949 photographs reveal a newly formed spit extending southward in the direction of longshore drift (Figure 12). Small, imbricate ridges, predecessors to the

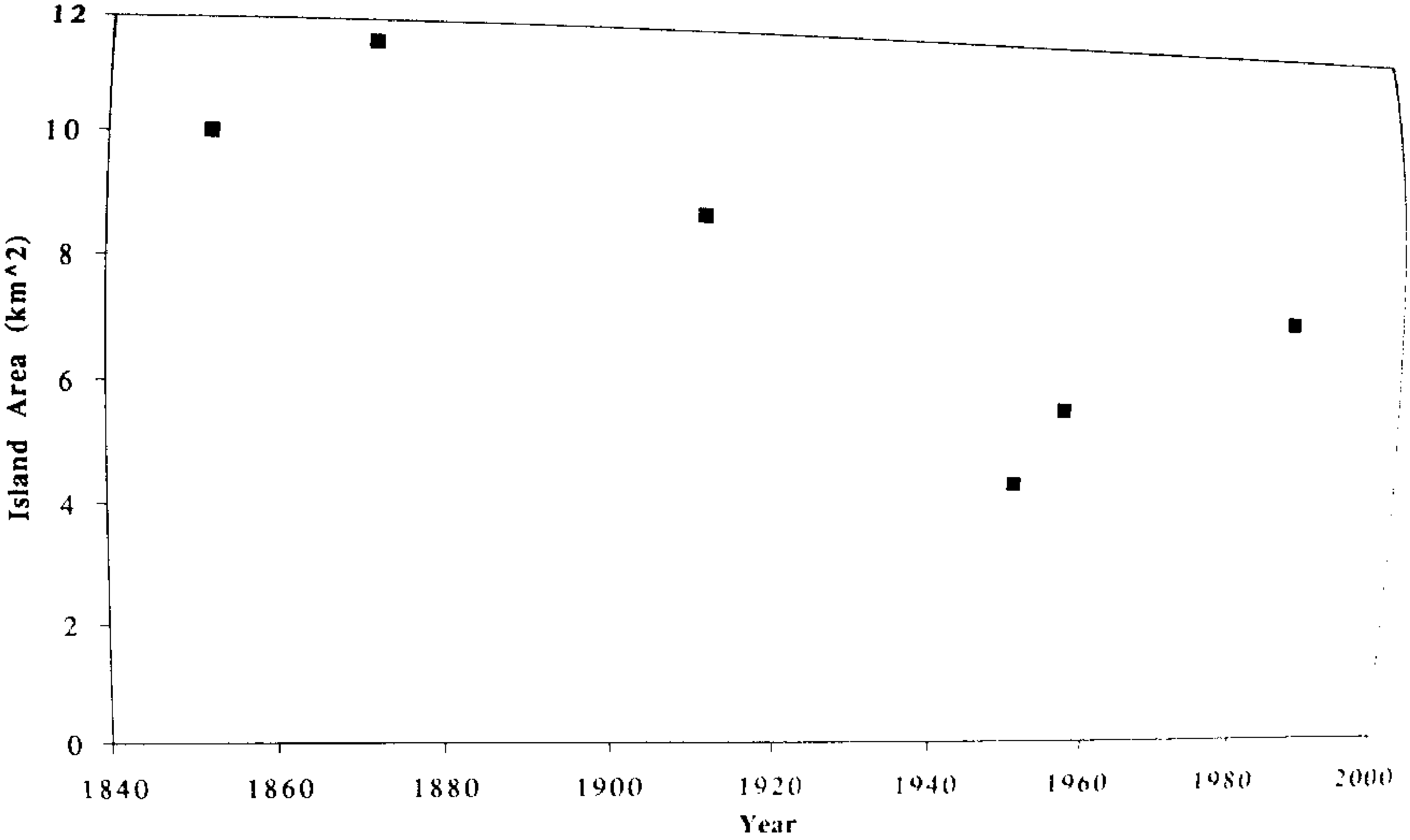


Figure 15. The area of Hog Island has changed considerably from 1852 to 1985. The loss in sediment mass from 1871 to 1949 has been even greater due to the loss of the large dune features which used to dominate the south end of the island in the late 1800's.

larger spit-parallel ridges now visible, are present along this spit in 1949 (Figure 14).

1949 to present: From 1949 to the present, the southern spit has continued to migrate southward under the influence of the dominant longshore currents, and island area has increased from 4.5 km^2 in 1949 to 7.5 km^2 in 1985 (Figure 15). The dominant ebb channel simultaneously migrated north from 1974 to 1985 (Figure 4).

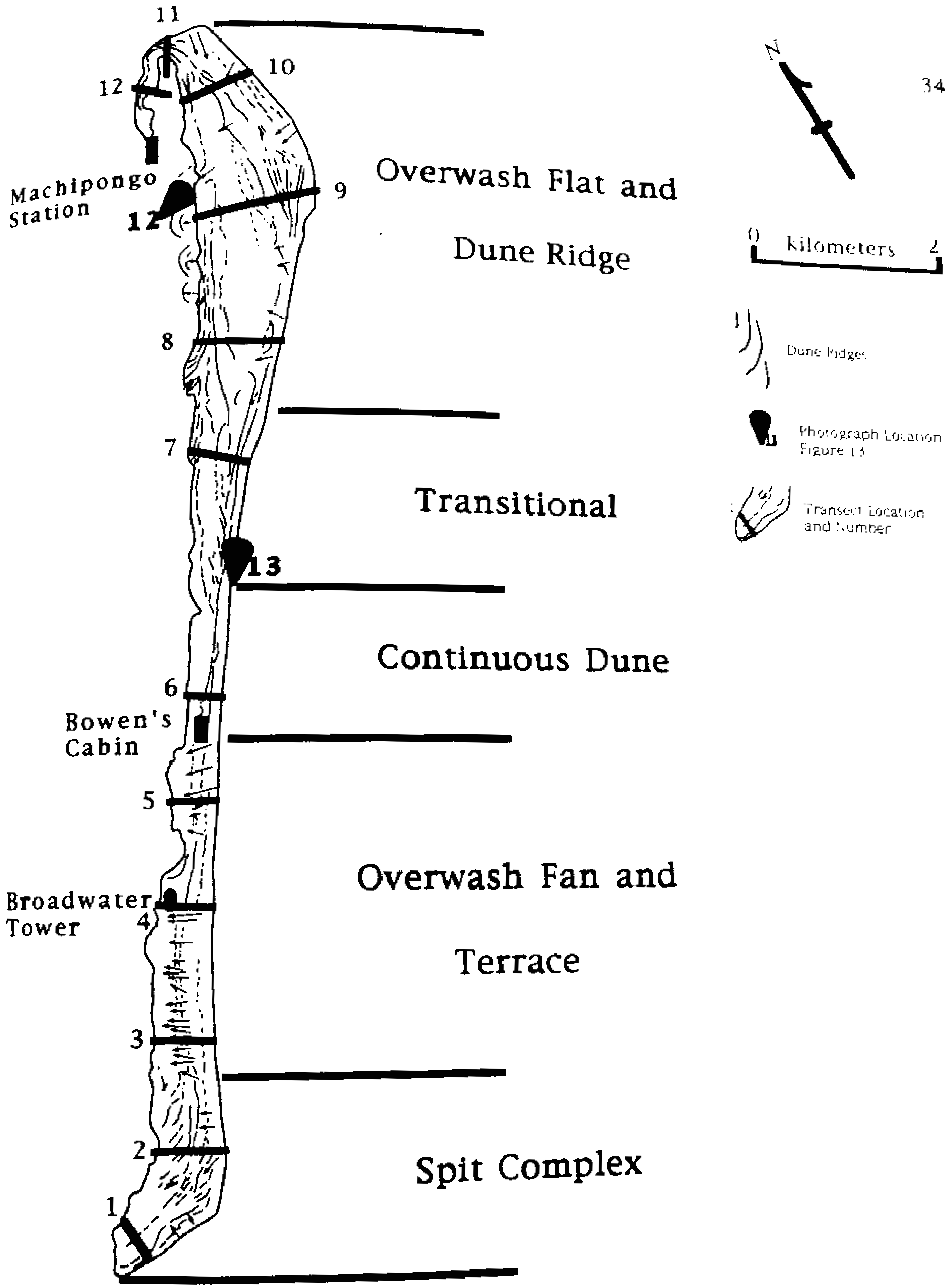
Overwash regions north of the spit complex at the southern end of the island have migrated progressively northward, and between 1949 and 1955, two large overwash throats penetrated the continuous dune 200 m north of Broadwater Tower and created two large fans which spread across the marshes. This breach occurred because the dunes eroded to such an extent that a storm exceeded the overwash threshold of the island in that area.

At present, the northern part of the island, comprised of accretionary overwash flats and dunes, continues to accrete; the active flat behind the largest unstabilized dune is slowly being stabilized by vegetation. Meanwhile, a new embryonic dune ridge continues to coalesce and form another barrier against storm surge to the flats. Despite the fact that the south end of the island has behaved in an erosional manner since the late 1800's, most areas near Broadwater Tower have accreted since 1985 (Jimmy Kelly, *personal communication*, 1989).

PHYSIOGRAPHIC REGIONS

Approximately 90% of the landforms presently visible on Hog Island have formed or have been modified since the period of clockwise rotation began around 1871. Based on the relative age, dune and overwash patterns, and shoreline erosion rates, the island can be divided into five physiographic regions. From north to south they are: 1) Overwash Flat and Dune Region; 2) Transition Region; 3) Continuous Dune Region; 4) Overwash Fan and Terrace Region; and 5) Spit Complex Region (Figure 16). Each of these regions closely corresponds with different shoreline erosion rates for the last 40 years (Figure 10), and each has developed a different physical character.

The physiographic regions have been studied through the use of charts, aerial photographs, and by data collected along 12 transects (Figure 16). Definitions of the variables are presented in Table 1 and data for each of the transects are presented in Table 2. One to five transects are situated within each physiographic region. General descriptions, vegetation cover, shoreline changes, geomorphic history, transect data, region variability, and relationships to the adjacent regions are discussed in the following pages. The regional characteristics and the landforms present within each region are used to compare modern coastal influences with known landforms to the historical landforms preserved on the island or in historical aerial photography.



igure 16. Hog Island can be divided into five major physiogaphic regions based on relative age, dune and overwash patterns, shoreline erosion rates, and physical characteristics.

Variable	Definition	Measurement Method
Decennial to Centennial		
Sand Width	The width of the coarse grained portion of the island along the transect.	Measurements made from 1989 photographs.
Marsh Width	The width of the fine grained portion of the island along the transect.	Measurements made from 1989 photographs.
Maximum Altitude	The highest point along the entire transect. May be presently active dune or older stabilized dune.	Elevation above MHW as measured by transit and stadia or hand level and stadia.
Annual to Decennial		
Active Width	The width of the region of island which was influenced by storm surge associated with the March 1989 northeaster.	Distances measured by pace and compass.
Trend	Shoreline orientation relative to north.	Azimuth of tangent to shoreline.
Percent Overwash	The approximate amount of identifiable overwash which covers the transect region. Where the active beach is backed by a continuous foredune, zero overwash is used.	Qualitative visual measurement.
Diurnal to Annual		
Beach Width	Width of active region including area from approximately mean sea level to the berm.	Field surveys
Beach Slope	Angle from horizontal to the beach surface 2 m below the high water berm.	Brunton Compass
Beach Sediment Size	Mean grainsize for surficial beach sand from midway between high and low water.	Channel sample collected to 15 cm below surface and run through RSA.
Dune Sediment Size	Mean grainsize for dune ridge along active beach from the crest of the dune.	Channel sample collected to 15 cm below surface and run through RSA.
Erosion Rate	Average rate of shoreline change between 1949 and 1989.	COASTS shoreline erosion program developed at the University of Virginia.

Table 1. Data were collected along each of the twelve transects.

Transect	Trend	Maximum Altitude (m)	Beach Slope (degrees)	Beach (phi)	Dune (phi)	Beach Width (m)	Percent Overwash	Erosion Rate (m/yr.)	Sand Width (m)	Marsh Width (m)	Active Width (m)
1	82	1.3	4 (0)	2.28 (0.057)	2.43 (*)	60	20	7.9 (3.0)	400	0	180
2	19	1.0	4 (0)	2.40 (0.034)	2.23 (*)	60	25	4.0 (3.9)	460	60	245
3	21	1.6	3 (0)	2.28 (*)	2.21 (*)	75	35	-3.0 (2.8)	490	0	490
4	24	1.8	2 (0)	2.45 (0.013)	2.32 (*)	90	70	0.6 (1.8)	425	275	90
5	26	1.6	2 (0)	2.42 (0.053)	2.27 (*)	60	15	2.4 (1.2)	370	300	370
6	28	2.1	5 (0.6)	2.48 (0.023)	2.33 (*)	70	0	3.0 (2.6)	300	490	90
7	40	3.9	4 (0.6)	2.29 (0.030)	2.44 (*)	50	0	-0.9 (4.6)	370	640	60
8	36	3.3	5 (0)	2.34 (*)	2.21 (*)	65	0	3.7 (5.8)	700	880	30
9	16	2.4	5 (0.6)	2.11 (0.010)	2.15 (*)	25	85	12.8 (2.1)	950	1430	210
10	18	2.8	3 (0.6)	2.18 (*)	no sample	30	100	7.3 (7.5)	460	150	370
11	90	4.5	5 (0)	2.21 (*)	2.22 (*)	75	100	NA	120	NA	60
12	207	1.4	7 (0.6)	2.05 (*)	2.09 (*)	20	0	NA	75	NA	30

Trend - measured as degrees from north of tangent to shoreline.
Beach and Dune - mean sediment size of beach and dune sediments.
Erosion Rate - positive values are accretion, negative values are erosion.
NA-indicates not applicable due to the measurement relative to the trend of the island.
* - only one sample analyzed for mean grainsize.
( ) - standard deviation

Table 2. Data collected for eleven variables along the twelve transects.

Overwash Flat and Dune Ridge Region

The Overwash Flat and Dune Ridge Region (Figure 16) is characterized by large overwash flats separated by one or more shore parallel dune ridges. The four dominant overwash flats, ranging from approximately 50 m to 500 m wide and 750 m to 2500 m long, trend approximately north-northeast on the least active parts of the island and to the north-northwest along the presently active shoreline (Figure 14). Two of the overwash flats are inactive; the others are periodically influenced by storm surges or wind and as stated earlier, are being stabilized as beach ridges form larger barriers against storm surge. Five dominant dune ridges, and four to seven minor dune ridges, approximate the trend of the overwash flats. The dominant ridges range from 600 m to 3,600 m long, 5 m to 50 m wide, and 1 m to 5 m high. A low break through the western most dune ridge (formed prior to 1871), and leading into the marsh, is a remnant overwash channel over the location of the 1871 inlet (Figure 17), marking the transition from an erosional to an accretionary shoreline during the late 1800's. The changes in shoreline position have resulted in the large accumulation of sediment on the north end of the island.

Because of the differences in shoreline location since 1871, many dune ridges have been truncated by active ocean and inlet parallel shores (e.g. along the northern end of the island). Truncation of stable dune ridges by the actively migrating shore occurs mainly in the southern part of the Overwash Flat and Dune Ridge Region, but also to some degree along Quinby Inlet. Shoreline changes and truncation have also resulted in the reactivation of the intermittent pond (Figure 14). Overwash commonly crosses the storm surge threshold at the south end of the intermittent pond, creating a fan on

Figure 17. This photograph, looking northeast, shows an inactive overwash channel in the location of the 1871 ephemeral inlet. The dune ridge formend parallel to shore as the island began to rotate clockwise in the late 1800's.

Figure 18. This photograph (view to the north) shows where the eroding shoreline has truncated a former shore parallel dune ridge and exposed *Myrica* spp. to the active shore processes.

the former overwash flat. To the north, dune ridges have been truncated by the southerly migrating inlet (approximately 1.0 m/year). Some of the coarse grained sediments have migrated to the bayside, creating an inlet parallel ridge which extends to Machipongo Station. Because of the truncated dune ridges and overwash areas, characteristics of this region are highly variable.

Physical data along five transects located in this region (Figure 16) represent the geomorphic expression and variability of the dune and overwash areas. The primary features of this region are: high relief (up to 5.0 m), steep beach slope (5 to 7 degrees), high accretion rates (up to 13 m/year), a coarser beach (2.05 phi to 2.34 phi) and dune (2.09 to 2.21 phi) mean grain size, small beach width (20 m to 75 m), large sand width (75 m to 950 m), and large marsh width (150 to 1,430 m).

Three subregions, distinguished by their active features and more recent evolution, are recognized in this part of the island. Transect 11 and Transect 12 are located along a small spit complex associated with flood tides; Transect 10 and Transect 9 are in the large overwash flat area; Transect 8 is located where dune ridge truncation has been dominant and overwash is less common. The area in the vicinity, and to the south, of Transect 8 grades into the Transitional Region with more closely spaced dune ridges and a smaller percentage of overwash.

Transitional Region

The Transitional Region has characteristics similar to both the Overwash Flat and Dune Ridge Region and the Continuous Dune Region. Seven to ten dune ridges converge in the Transitional Region and are truncated by the active shore parallel dune ridge. Very little to no overwash is present. The dune ridges of this section are from 300 m to 1,200 m long, from 10 m to 75 m wide, and 3.0 m to 4.0 m high; only in a few isolated places, is there an area below 1.0 m or 2.0 m above MHW. One exception exists on the marsh-side of the island where the oldest dune ridges typically have only 0.5 m to 1.5 m height above MHW.

Vegetative cover on the landforms ranges from sparse and thick grassy areas to thickets, bushes, and dense stands of myrtle. Scattered pine trees stand above the myrtle and thickets in a few isolated spots. Because of the shoreline's tendency to erode and truncate older dune ridges, some dead and dying myrtle have been exposed on the beach *in situ* (Figure 18).

The Transitional Region, located about two thirds the distance between Great Machipongo Inlet and Quinby Inlet, has undergone both accretionary and erosional stages over the last 150 years. The rotational pivot point (where the net change in shoreline updrift [north] is opposite that of downdrift [south]) is located in this area of the island. Most recently, the northern part of the island has been accretionary, and the southern part has been erosional, although, as mentioned before, the shoreline has accreted along most of the island since 1985. The net change of the shoreline position (erosional) over the past 120 years has been from approximately -4.0 m/year to +5.0 m/year in the Transitional Region. As a result, the oldest portions of the island (e.g., the island's marsh-side) have not been destroyed, and the primary landform remains a shore parallel dune ridge. This region exhibits little variability.

Transect 7 is located in this region. The primary difference between the Transitional Region and the other regions is the lack of low lying areas and its small beach width (20 m). The beach slope (4 degrees) is somewhat less than regions to the north and south and the mean grain size for the beach sediments (2.29 phi) is more coarse. The maximum altitude (4.0 m) marks the change from higher dunes to the north and lower dunes to the south.

Continuous Dune Region

The Continuous Dune Region is composed of two major shore parallel dune ridges separated by a small terrace. The dune ridges range from 1,000 m to 1,200 m long, from 3.0 m to 10.0 m wide, and from 1.0 m to 3.0 m above MHW. The higher dune ridge is adjacent to the marsh; the lower dune ridge, adjacent to the active beach, is itself active. The lower dune ridge is the same shore parallel dune that is located in the Transitional Region; it grades in relief from about 2.0 m in the north (compared with 4.0 m in the Transitional Region) to less than 1.0 m in the south where the Overwash Fan and Terrace Region begins. The small terrace separating the two dune ridges was active in the 1962 Ash Wednesday storm but, based on aerial photographs, vegetation, and trenching, it does not appear to have been active since. This terrace decreases in width northward where the younger, seaward, dune ridge converges and truncates the older, marsh-side, ridge in the Transitional Region.

Vegetation cover ranges from sparsely to thickly grassed areas, and from bushes (*Baccharis* spp.) to scattered myrtle (*Myrica* spp.). Myrtle is only able to grow in the protection of a large dune on the marsh side of the island. In addition, a high marsh system, dominated by *Spartina patens* and *Distichilis* spp., has formed directly behind the dune ridge. Dense grasses cover the overwash terrace.

According to aerial photographs, the Continuous Dune Region was eroded to within a few tens of meters of its present position by the early 1940's. In the 1940's, this region reached south to Broadwater Tower, but sometime between 1949 and 1955 was breached by overwash which now penetrates the dune ridges just south of Bowen's Cabin. The 1962 Ash Wednesday storm extended the breach northward with the addition of several overwash fans and channels, decreasing the extent of the Continuous Dune Region and extending the Overwash Fan and Terrace Region northward.

Because of the low variability in the Continuous Dune Region, only one transect represents this area of the island. This area has the smallest mean grain-size on the island for the beach sediments (2.48 phi), a small beach width (25 m), a thin sand width (300 m), and little to no currently active overwash. The Continuous Dune Region is the narrowest part of the island, and because of the 3.0 m high dunes, overwash only penetrates the first dune during extreme storm events (such as the 1962 northeaster). This region has a relatively low, narrow, foredune, an elevated terrace (which has been modified by overwash in the last 30 years), and a large marsh side dune with the high marsh adjacent to it. The higher, marsh-side dune is fairly consistent in height and has several blow outs. The marsh itself is growing on a thick organic mat (0.64 m) which is composed entirely of *Spartina patens* root material with some sand below 0.50 m. At the extreme southern part of the Continuous Dune Region, overwash from the northern part of the Overwash Fan and Terrace Region thins northward over the organic mat.

Overwash Fan and Terrace Region

Extensive overwash fans dominate the Overwash Fan and Terrace Region. These fans are fed from the beach between low dunes through anastomosing overwash channels. In this region, two major areas of overwash are defined by truncated dune ridges to the north and south, by the bay and marsh to the west, and by the beach threshold to the east. These two overwash fan and terrace areas vary in size from 600 m to 1,500 m along the beach front (where the overwash channels penetrate the dunes) and from 750 m to 1,600 m along the bay and marsh (where the fans spread laterally along the island). The overwash channels range in width from 1.0 m to 50 m wide and extend across the island for 100 m to 300 m, commonly intermingling with other channels. Several episodes of storm surge can be recognized in some of these channels by the existence of small, channel parallel, scarps. In addition, some of the channels intersect the ground water table where storm surge scoured the channel to that depth.

In contrast to the extensive overwash channels, small terraces and dunes mark the boundaries between channels. The dunes in the areas of major overwash range from 0.5 m to 2.0 m in relief, and consist of a lower, discontinuous foredune area and a higher, discontinuous dune ridge which is separated from the marsh and bay by the coalesced overwash fans. A large continuous dune ridge separates the two overwash regions with dunes of up to 2.5 m above the high water line; this ridge was most recently overwashed during the 1962 northeaster.

Prior to the dominance of overwash fans and terraces in the Overwash Fan and Terrace Region in the 1940's, the shoreline here was accretionary;

dunes of up to 12 m in height (Badger and Kellam, 1989) dominated the southern section of the island in the late 1800's and early 1900's. This southern section formerly extended into the ocean nearly 3 km, where the town of Broadwater was located with over 350 inhabitants. During the late 1800's and early 1900's, the area around and to the east of Broadwater Tower supported a dense maritime forest with large pines and live oak (Badger and Kellam, 1989). A series of storms in the 1930's eroded the island greatly, forcing most of the inhabitants to move themselves and their houses to the town of Willis Wharf on the mainland of the Delmarva Peninsula (Badger and Kellam, 1989). Between 1949 and 1989, the average erosion rate of this entire region is 6.0 m/year, however, since 1985, the shore has prograded over 30 m (Jimmy Kelly, *personal communication*). At present, only a mixture of sparse grass, dense grass, and small bushes (*Baccharis* spp.) can grow in the two major overwash regions. A few pines and a more extensive array of bushes inhabit the dune ridge area surrounding Broadwater Tower which separates the two overwash areas described above. *Salicornea* spp. and *Spartina alternaflora* cover some of the less active overwash flats, and *Spartina patens* inhabits some of the dunes and overwash channels.

As mentioned previously, an elongated spit emerged adjacent to and south of the older portions of the barrier, thereby creating the platform on which the southern part of the Overwash Fan and Terrace Region has formed. The Continuous Dune Region did extend to Broadwater Tower in the early 1950's, however, overwash eventually penetrated the oldest dune ridges to the north of the tower and as the Overwash Fan and Terrace Region expanded to the north. Seven to nine shore and inlet parallel dune ridges are visible at

Broadwater Tower in the 1949 aerial photographs (Figure 14), but these were destroyed when the storm surge associated with the 1962 northeaster overtopped the south end of Hog Island. An ephemeral inlet was also cut across the spit south of the Broadwater Tower during this 1962 northeaster; it closed within five years of its creation.

In order to describe the Overwash Fan and Terrace Region, Transects 3, 4, and 5 are used. The Overwash Fan and Terrace Region trends N.21E. to N.26E.; has a very low beach slope (2 to 3 degrees); a moderate beach (2.42 phi to 2.28 phi) and dune (2.32 phi to 2.21 phi) mean grain size; a large beach width (60 m to 90 m); and, moderate overwash cover (15 percent to 70 percent). This region is also active across its entire width in places (up to 500 m). There are differences between each of the transect areas due to the fact that the two northerly transects (4 and 5) cross the island at a point which, until the 1950's, would have been considered a part of the Continuous Dune Region. The southern transect (3) bears some resemblance to the Spit Complex Region, but due to the 1962 inlet, many similarities have been removed. The differences between these three subregions are primarily due to their evolutionary history.

Spit Complex Region

Five imbricate dune ridges of varied ages (Figure 11), separated by overwash filled runnels and overwash flats, dominate the Spit Complex Region. Each of the five ridges ranges from 150 m to 600 m in length, from 10 m to 25 m in width, and from 1.0 m to 2.0 m in height. The dunes trend from north by northeast to almost directly east as they wrap around a shore which has been modified by former inlet positions. The runnels and overwash flats are up to 250 m in length and up to 100 m wide. Near the extreme southern point of the island, overwash fans spread into the swales between dunes. Overwash enters these swales through breaches in the discontinuous dune ridges and through openings between *en echelon* dune ridges.

As in the other physiographic regions, variations in topography and the differences in ages of the dune ridges creates many different environments for vegetation growth. The vegetation cover on the landforms varies depending upon its location with respect to the dunes, runnels, overwash flats, and beach. Most of the area is covered with sparse grasses, but dense grass if found on older, isolated dune ridges. The areas between the dunes on active overwash flats have little vegetation. Southern areas have collected large amounts of rack, which provides a better habitat for vegetation growth. Historical aerial photographs document that as the dune ridges are isolated by southward and slightly eastward progradation of the shoreline, the dunes are stabilized by grasses.

Since the 1940's, the Spit Complex Region has been migrating southward under the influence of the dominant longshore current. As stated earlier, the extension of the island has built up the entire length of Hog Island south of Broadwater Tower. In the locations where offshore bars welded to the beach and wrapped around the southern end of the island, the most dominant dune ridges were formed. The collection of rack, colonization by vegetation, and subsequent dune formation on this arcuate ridge and runnel contributed to the development of dune ridges.

Transects 1 and 2 represent the inlet shore normal and the ocean shore normal transects, respectively. The shore at Transect 1 faces south (82 degree azimuth). At Transect 2, the shore faces east by southeast (19 degree azimuth). The distinguishing characteristics of the Spit Complex Region include the imbricate relation of the dune ridges and overwash, the beach slope (4 degrees), and the lack of marsh (0 m to 60 m width).

LARGE AND SMALL SCALE MORPHOLOGIC TRENDS

Small-scale gradients in island morphology within any of the physiographic regions tend to occur in active areas, whereas large-scale gradients in island morphology are generally retained in stable portions of the island. Long-, moderate-, and short-term trends in the morphologic characteristics of Hog Island have been analyzed according to variables and landforms which may be influenced over similar time spans. Island morphology can be described and distinguished using three different temporal scales: centennial to decennial (decades to centuries), decennial to annual (years to decades), and annual to diurnal (days to years).

Transect variables and the morphology of landforms described as centennial to decennial were selected to represent characteristics of the island which varied greatly over a period of decades to a century. These variables were identified through the use of charts, oblique photographs, and stereoscopic analysis of aerial photographs, and observed to vary within longer time spans. Larger, stable dune ridges and regions with similar, stable landform trends, help in distinguishing long-term morphologic trends.

Decennial to annual variables and landforms were selected because overwash, active beach width, and trend of the island are related to larger scale storm events which occur over years or decades (Dolan and Hayden, 1980; Dolan, *et al.*, 1988). Landforms visible in aerial photographs which have been active within the last few decades (e.g. 1962 northeaster), are generally used to help distinguish trends and relationships.

The variables and landforms identified at varying scales (in Table) were chosen as measurements of short-term variations in active regions of a barrier. They have been suggested to vary due to seasonal variations in wave climate (Davis, et al., 1972), and differential energy gradients along a reach of shore (Hennigar, 1974; Jones and Cameron, 1977). Small active features along the beach and foredune areas aid in differentiation between areas which may change on the order of days to years.

Sediment Analyses: Sediments on the island consist mainly of quartz with minor shell material and heavy minerals (ilmenite, rutile, garnet, magnetite). Some shell lag was present in overwash areas and heavy minerals were commonly present in dune sands (< 5%) and in overwash sequences (up to 20%). Sediments collected for analysis generally contained minor amounts (<10%) of heavy minerals and little (<1%) shell material. Analyses of the sediments were conducted using a Rapid Sediment Analyzer (RSA). The benefit of using a RSA, rather than typical sieving methods, is that this method provides a comparison in hydraulic characteristics between samples; factors of size, shape, grain texture, density, and overall sample character are incorporated into an empirical settling velocity formula (Baba and Komar, 1981). The RSA method was chosen over sieving because the hydraulic characteristics of the sediments were desired and sieving tends to give false modal representations in hydraulic interpretations (Reed, et al., 1975).

Initially, sediments collected for this study were to be used as an indicator of energy gradients along the island. Other sedimentologic studies along the East Coast have shown that sediment analysis provides useful information regarding energy gradients along an island (Jones and Cameroon, 1977; Heinsius, 1974). However, analysis of sediment samples on Hog Island show no variation between the mean grain size (calculated from hydraulic settling velocities with a density of 2.65 gm/cm^3) for seven different environments (Table 3 and Table 4). There is, however, a significant difference between the skewness of dune sediments to all other environments sampled and between the sorting and kurtosis of the Relic Overwash and all other environments sampled but the beach. The dune sediments are more positively skewed; the relic overwash is more negatively sorted and more platykurtic. Hog Island is homogeneous in mean grain size, and given that there are strong energy gradients acting on different portions of the island (Goldsmith, *et al.*, 1975; this report), the sediments are possibly derived from a shoreface exposure of a fine grained, Pleistocene barrier island complex (regressive Joynes Neck Sand ?) as described by Mixon (1985)

Centennial to Decennial Over 90 percent of the island has formed or been modified since the island's rotation changed in the late 1800's (Figure 11). Analysis of historical charts and aerial photographs allows documentation of similar landforms and physiographic regions along the island over the centennial to decennial time spans. By analyzing three of the eleven variables described in Table 2, maximum altitude, marsh width, and sand width, and by identifying through historical aerial photographs the distribution of larger, stable dunes and dune trends, large scale variations in the island may be determined. These infrequently disturbed landforms along the island include the long, linear, sand dunes, interdune swales, overwash terraces, and prograding spit ridges which are generally in the stable portions of the island. The island can be subdivided into four areas based on

	Beach n=41	Berm n=15	Dune n=27	Overwash n=6	Relic Overwash n=5	Runnel n=10	Threshold n=5
Mean grainsize (phi units)	2.2872 (0.2022)	2.2799 (0.1184)	2.2697 (0.1151)	2.3124 (0.1129)	2.2252 (0.0996)	2.3018 (0.1170)	2.2812 (0.1170)
Mean Sorting	0.3350 (0.1604)	0.2952 (0.0275)	0.2914 (0.0245)	0.3028 (0.0250)	0.3492 (0.0165)	0.3035 (0.0294)	0.2963 (0.0228)
Mean Skewness	-0.1665 (0.1058)	-0.1136 (0.0649)	-0.0612 (0.0544)	-0.1378 (0.0735)	-0.1128 (0.0399)	-0.1235 (0.0495)	-0.1080 (0.0424)
Mean Kurtosis	0.2684 (0.0405)	0.2552 (0.0173)	0.2528 (0.0231)	0.2577 (0.0097)	0.2952 (0.0210)	0.2578 (0.0183)	0.2547 (0.0091)

Table 3. Statistical parameters and their mean values and standard deviations for all samples and each environment. Standard deviations are in parenthesis. Refer to Table 4 for statistical comparison between each of the environments. There are no significant differences in mean grain size between any of the environments sampled on the island (see Table 4).

Pooled estimate for δ^2

$\alpha = 0.05$

$H_o: \mu_1 - \mu_2 = 0$

$H_a: \mu_1 - \mu_2 \neq 0$

	Mean Grainsize	Sorting	Skewness	Kurtosis
Beach vs. Berm	F	F	F	F
Beach vs. Dune	F	F	R	F
Beach vs. Overwash	F	F	F	F
Beach vs. Relic Overwash	F	F	F	F
Beach vs. Runnel	F	F	F	F
Beach vs. Threshold	F	F	F	F
Berm vs. Dune	F	F	R	F
Berm vs. Overwash	F	F	F	F
Berm vs. Relic Overwash	F	R	F	R
Berm vs. Runnel	F	F	F	F
Berm vs. Threshold	F	F	F	F
Dune vs. Overwash	F	F	R	F
Dune vs. Relic Overwash	F	R	F	R
Dune vs. Runnel	F	F	R	F
Dune vs. Threshold	F	F	F	F
Overwash vs. Relic Overwash	F	R	F	R
Overwash vs. Runnel	F	F	F	F
Overwash vs. Threshold	F	F	F	F
Relic Overwash vs. Runnel	F	R	F	R
Relic Overwash vs. Threshold	F	R	F	R
Runnel vs. Threshold	F	F	F	F

Table 4. Results of t-tests comparing the mean values of grainsize, sorting, skewness, and kurtosis for combinations of environments. A boldface "R" (**R**) indicates a significant difference between environments. An "F" indicates a Failure to Reject H_O.

these variables and landforms (Figure 19). Each of the four areas are related directly with the position of the island in relation to the ebb delta and the evolution of the island since the change in rotation in the late 1800's.

Decennial to Annual: Approximately 50 percent of the island has been modified or changed since 1949. Due to frequent storms along the east coast and the shoreline changes that these storms subsequently cause, the variables of shoreline trend, percent overwash, and active width exhibit significant variability over decennial to annual time spans (Dolan and Hayden, 1980; Dolan *et al.*, 1988). As stated before, landforms modified over these time periods are generally located close to the shore and only modified during large-scale storms (e.g. 1962 Ash Wednesday storm). These landforms are generally covered with vegetation and tend to be low dunes and younger overwash terraces. Through analysis of the three variables and the landforms, five areas can be subdivided along the island (Figure 19). These areas are similar, with some changes in boundary location, to the five dominant physiographic regions in Figure 16, and represent the trend in evolution of the island with relation to the ebb delta position since the 1940's.

Annual to Diurnal: Approximately 25 percent of the island is influenced and modified during the average year. These variations in the island landforms from year to year represent small-scale, local changes in shoreline position and beachface activization. The five variables described in Table 2, shoreline rate of change, beach width, beach slope, mean beach grain size, and mean dune grain size, are influenced daily to yearly, depending upon energization by winds or storms. Small-scale landforms, typically associated with the active beach and active overwash areas, are also used to distinguish separate regions. As stated earlier, the use of sediment analyses did not prove useful for distinction of areas on Hog Island, so the slight variations in mean grain size provide little information for differentiation along the coast.

From analysis of the five variables and the small-scale landforms, the island is subdivided into six areas (Figure 19). Each of these areas represents a place along the island's active (or easily activated) zone which has distinct morphologic and physical characteristics as a result of the recent variations in processes and variability in antecedent topography along the coast.

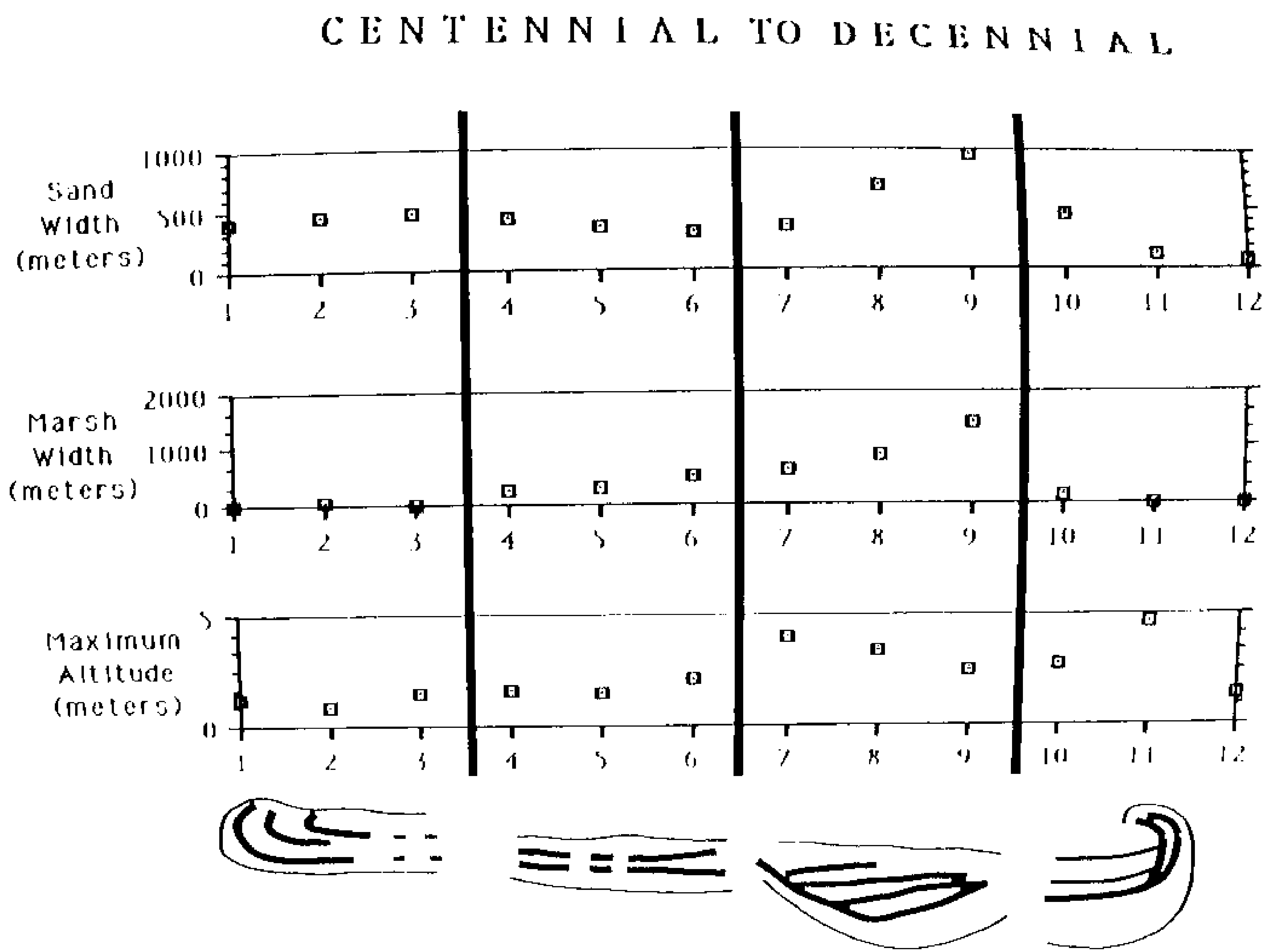


Figure 14. a) By identifying trends in variables which change significantly over time spans from decades to centuries, four gradational areas may be identified on Hog Island

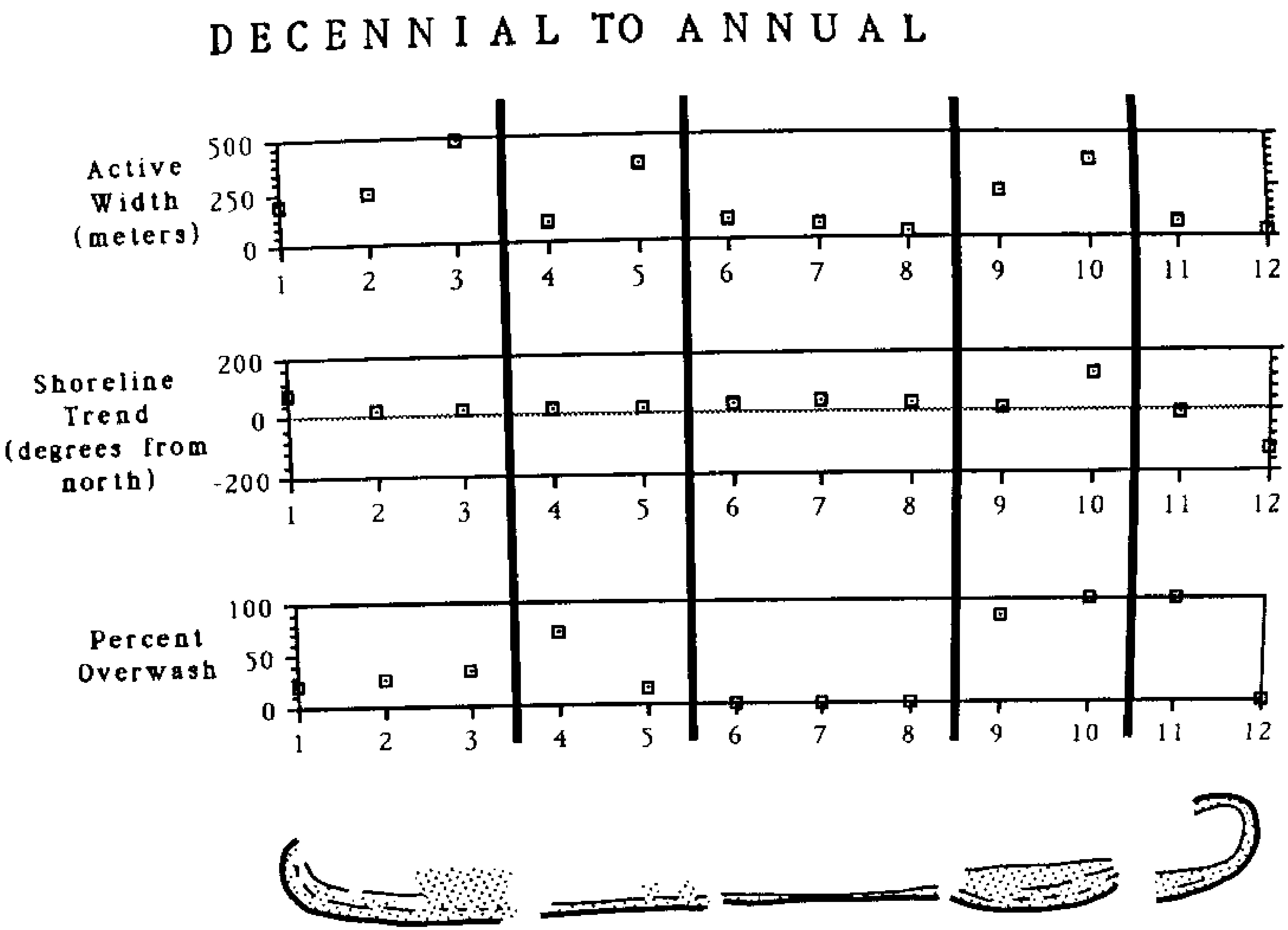


Figure 14. b) Five gradational areas are identified by using variables which change significantly over time spans from years to decades.

ANNUAL TO DIURNAL

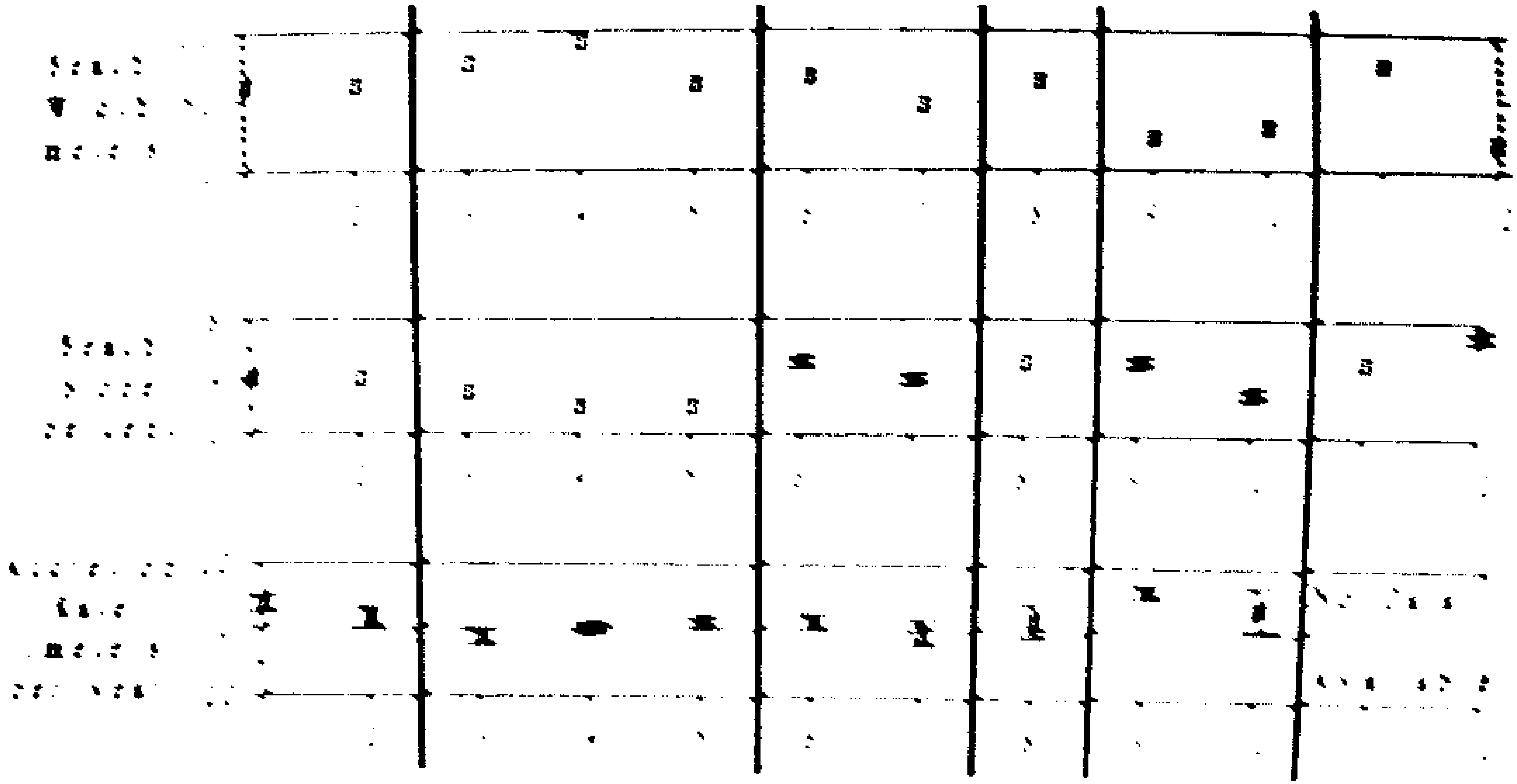


Figure 14

COASTAL CHANGE AND PHYSICAL CHARACTERISTICS

The landforms in each of the five physiographic regions (Figure 16) can be attributed to the balance between the dominant processes and sediment supply. Storms in the fall and winter months generate large, powerful waves from the northeast; the spring and summer seasons produce accretionary waves from the southeast (Goldsmith, *et al.*, 1975). As the waves refract across the ebb tidal deltas, different sections of the island erode or accrete depending on their location relative to the ebb deltas (Davis, *et al.*, 1972; Hayes, 1979).

The Overwash Flat and Dune Ridge Region is strongly influenced by the refraction of waves around and across the ebb delta of Quinby Inlet. Presently, storm waves from the northeast refract around the ebb delta, which causes a divergence of littoral currents and a reduction in wave energy reaching the beach. Sediment is carried across the ebb delta to the south by the dominant longshore drift; sediment that is not carried south is transported to the north under reversed longshore currents (Figure 3). Wave energy to the north of the divergence zone will be slightly higher during storm events at high tides. At low tide, a line of breakers forms along the ebb delta shoals; at high tide, more swells pass over the ebb delta through minor flood and ebb channels. The resulting surge of water from the northeast during flood tide causes a local elevation of the water, which submerges the large open sand flats and deposits overwash on the north end of the island. Offshore bars weld to the shore in the Overwash Fan and Dune Ridge Region during calm periods and form subaerial shore-parallel ridges and runnels. Typically, the ridges build up and collect deposits of rack, creating an environment favorable for floral pioneer species. As vegetation collects blowing sands, from either the overwash flats or the exposed beach, embryonic dunes form (Figure 14 [1949]). Once established, the dunes may coalesce, creating a long dune ridge which will, in turn, protect the overwash flats from further overwash events (Figure 14 [1985]).

In contrast to the partial exposure of the Overwash Flat and Dune Ridge Region to the dominant northeast wave climate, the Transitional Region typically lies in the wave shadow of the ebb delta. Wave orthogonals bend to the north or continue to the southwest, therefore excluding this area from direct wave attack. The point marking the transition between accretion to the north and erosion to the south has been located in this region since the end of the 1800's. The landforms in the northern section of the Transitional Region are generally typical of those found in the Overwash Flat an Dune Ridge Region, whereas those to the south are typical to the Continuous Dune Region. Erosion in the southern part of the of the Transitional Region may be attributed to sediment bypassing as well as beachface energization caused by occasional direct wave influence during varied climatic regimes or slight variations in offshore bathymmetric configurations.

South of the wave shadow zone created by the ebb delta, the Continuous Dune Region is exposed directly to waves and storm surge. However, overwash is not common in this high energy region. The higher dunes characteristic of this region have retarded breaching. This region will become smaller as the Overwash Fan and Terrace Region expands northward. The processes which dominate the Continuous Dune Region are only slightly different than those in the Overwash Fan and Terrace Region, mainly due to existing topography and to the differences in the island orientation relative to the prevalent wave climate.

The more northerly orientation of the shoreline exposes the Overwash Fan and Terrace Region to the highest waves and storm surge on Hog Island. South of Broadwater Tower, at the location of the ephemeral inlet created during the 1962 northeaster, the landforms are relatively stable. The high dune ridges in this region deter overwash. To the north, where the continuous dunes have been breached, the landforms are adjusting to increased overwash. The abrupt change in landform types between the Overwash Fan and Terrace Region and the Spit Complex Region may be topographically controlled, rather than a product of processes. The higher dune ridges formed on the spit during the middle part of this century have created a topographic barrier to overwash; however, the Spit Complex Region may be partially protected by the ebb delta of Great Machipongo Inlet to the south. Overwash occurs in the Spit Complex Region due to the low elevations within interdune areas.

LONG TERM DYNAMICS AND ISLAND ROTATION

Long-term variations in island morphology are related to the movement of the island: either counter-clockwise or clockwise rotation. The present configuration and direction of shoreline movement is the opposite of that of the late 1800's. The well developed ebb deltas were prevalent then (Goldsmith *et al.*, 1975) and the large sediment mass associated with them was situated slightly farther north than in 1934 or 1972 (Figure 4).

Barrier Island Evolution Model: Comparison of dominant ebb channel position (Figure 4), island area (Figure 15), storm track and frequency (Figure 5), and number of storms occurring along the coast of Virginia (Figure 6) reveals a close relationship of storm track and frequency to the morphology of the island and ebb channel position. During the late 1800's, a low frequency of inland storms and the prevailing Atlantic high pressure, created a dominant, accretionary, southeast wave climate. Major northeasters passing to the west of the island would also tend to generate a southerly wave climate. As more storms began to occur over maritime areas during the early 1900's (Figure 5), the wave climate became more northeasterly and erosional, peaking around 1960 (Figure 6).

The variation in storm track and frequency caused several morphologic changes recognizable in the historic record. During accretionary periods (dominant southeast wave climate) sediment is welded to the shore from the southeast: a net northerly littoral transport. The large sediment mass associated with Great Machipongo Inlet served as a source of sediment for the south end of the island, which accreted seaward from 1852 to 1871. Sediment, moving northward along the barrier chain, caused a northward shift in the ebb tidal channel as the channel was driven away from the sediment load and sought a steeper gradient. Also, the island area increased from approximately 10 km^2 to nearly 12 km^2 from 1852 to 1871. This corresponds to a southeast, accretionary, wave climate, increasing the sediment transport from offshore sources to the island and increasing the area of the island.

During the early part of the 1900's, storm frequency increase and an offshore (maritime) storm track created an erosional, northeast wave climate. The exposed south end of Hog Island was eroded severely, especially during the 1930's (Badger and Kellam, 1989), and the sediment was transported south into the ebb delta. The surplus of sediment tended to shift the dominant ebb channel southward (Figure 4). Sediment transported into the ebb deltas was deposited at the divergence of littoral currents and at the loss in hydraulic competency along the north end of Hog Island (Figure 3). During the less frequent southeast wave climate, bar welding occurred where the abundance of sediment occurred in the transport (divergence) zone at the north end of the island. Since the 1960's and 1970's, the island area has increased (Figure 15), and the dominant ebb channel has shifted slightly northward (Figure 4), correlative to the change in the peak of storm frequency and offshore storm track.

Long-term trends in island rotation appear to be affected by the 60 year variation in storm track and frequency identified by Hayden (1981). This pattern may be longer from the low to high peak, however data are not available for a longer period of time. Using 60 years as a low to high peak, a 120 year peak to peak climate pattern is inferred.

The 120 year variation in the climate exhibits close correlation to the geomorphic evidence. At the end of the 1800's, the climatic regime began to change considerably (Figures 5 and 6), as did the erosion rates on Hog Island (Figure 13). The actual position of the island has not changed much since the early 1960's, and has accreted along most of its shore since that time.

Extrapolating the 120 year variation into the geomorphic record, several changes in island rotation can be correlated with the storm track and frequency. A peak in storm track and frequency would have occurred in approximately 1840, 1720, and 1600 (each of these dates assumes that the variation in climate occurs with a constant period and that storm frequency and storm track occur contemporaneously). This peak corresponds with the maximum progression in clockwise rotation of the island, after which the island would rotate counter-clockwise.

The independent geomorphic analysis (Figure 13) closely corresponds with these predicted dates. In the early 1600's, the island had reached a maximum peak, and in about 1650 was reaching the maximum in counter-clockwise rotation (one half of the variation). From the mid-1600's, the island rotated in a clockwise direction and peaked in the early 1700's, again coincident with the predicted peak (1720) in storm frequency and track. No geomorphic evidence was found to be preserved on the island which is representative of the late 1700's low (maximum counter-clockwise rotation) nor of the predicted 1840 maximum. The 1852 island position indicates a counter-clockwise rotation (initiated after a clockwise maximum) which has progressed such that the predicted 1840 maximum must have occurred earlier in the 1800's.

VIRGINIA BARRIER ISLANDS

Two of the Virginia barriers, Parramore and Cobb Islands, exhibit similar characteristics in shoreline change, and in geomorphic features, as Hog Island: wide northern ends (formerly narrower) with a prograding shoreline, a pivot region, a region of extensive fan overwash, and a southward migrating spit. These islands are being influenced by the same ebb delta location (Rice and Leatherman, 1972), relative to the respective inlets, and wave energies (Goldsmith, *et al.*, 1975) at similar positions along each of the islands. From 1871 to 1910, the entire hook of Fishing Point was formed at the south end of Assateague Island (refer to Figure 1). At least three previous phases of hook (spit) formation are recognized at the south end of Assateague island (Goettle, 1978), and probably correlate with the major changes in the rotation to Hog Island. Also during that time, both Cobb and Parramore Island switched from counter-clockwise to clockwise rotation.

The fact that changes along the entire chain of the Virginia barriers are contemporaneous suggests that a regional influence is responsible for both the changes on Hog Island and the other Virginia barriers. Sediment flux from the north in littoral currents does not explain these changes because they occurred over tens of years from Assateague Island in the north to Myrtle Island in the south. The documented variations in storm frequency and track (Figures 5 and 6) may be the cause of the rapid changes and modifications along the Virginia *Barrier Island Chain*, and the known pulses of spit growth of south Assateague Island may also related to the change in storm climate.

CONCLUSIONS

About 90 percent of the coarse grained fraction of Hog Island is less than 150 years old, whereas the remaining 10 percent, based on Native American artifacts, may be 300 years old. Since the changes in the direction of shoreline movement on Hog Island occurred in the late 1800's, resulting in a reversal of the shoreline erosion rates of the island, most of the coarse grained sediments have been reworked and stored in dunes and overwash deposits. Sediment analyses and comparison of mean grainsize indicates a homogeneous source of sediments for Hog Island.

Hog Island can be divided into 5 major physiographic regions. From north to south, they are: 1) Overwash Flat and Dune Ridge Region, 2) Transitional Region, 3) Continuous Dune Region, 4) Overwash Fan and Terrace Region, and 5) Spit Complex Region. These regions may be lumped together or subdivided further, depending upon the time scale of disturbance analyzed. Identification of variables and landforms which tend to vary over periods of centuries or decades (centennial to decennial), the island may be divided into four areas. This subdivision is controlled by variation in large-scale processes modified by ebb delta location. They represent changes which have occurred on the island since the last change in rotation in the late 1800's.

Analyzing variables and landforms which vary over periods of decades to years, the island may be divided into five regions which closely correspond to the five physiographic regions. These regions represent changes in the island attributable to large, infrequent storms and demonstrate the general relationship to slight variations in local ebb delta position. Yearly to daily changing variables and landforms were analyzed, and based on the resulting trends, the island can be subdivided into six areas. These areas are a result of recent variations in processes along the coast and commonly depend on antecedent topography as a controlling factor.

Longer term variations in island morphology are a result of changes of rotation in the island. Prior to 1871, Hog island rotated counter-clockwise, with shoreline erosion along the north and shoreline accretion to the south. Stratigraphic evidence suggests that a remnant regressive Pleistocene ridge is causing the landward motion of the barrier to stall, thus the geomorphic history of the island has not been obliterated by typical barrier island transgression. The estimate of 250 to 320 years for the age of the fringing high marsh roughly approximates the 264 years calculated from overwash data (Fitch, 1991). These estimates, combined with the stratigraphic evidence, indicate a stalled drumstick barrier island, which has been pivoting back and forth in the same location for several hundred years. Four periods of northerly offsets (maximum clockwise rotation) have been documented from geomorphic evidence on Hog Island: 1) around 1600, 2) early 1700's, 3) early to mid-1800's, and 4) mid- to late 1900's. The most recent change in rotation on Hog Island (around 1871) occurred throughout the Virginia barriers and supports a regional, rather than local, variation in the driving processes. Independent climatic data exhibit a cycle or variation in storm frequency and track along the Virginia barrier islands occurring with a period of approximately 120 years, peaking in the 1960's. By extrapolation of the 120 year cycle and comparison to the geomorphic data, the maximum clockwise rotation of the island occurs in about 1840, 1720, and 1600. Extrapolation into [illegible] future suggests that the [illegible] and [illegible] [illegible]

[illegible] in 2020

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